

Investigating the impact of spellcheck on writing for students with and without dyslexia

Lynsey O'Rourke

Degree awarded by Oxford Brookes University

This thesis is submitted in partial fulfilment of the requirements of the award of Doctor of
Philosophy

August 2019

[blank page]

Acknowledgements.

This thesis would not have been possible without the combined efforts of so many people. I would like to acknowledge everyone who, at some point or other, persuaded me to continue.

I would like to thank my supervisors, Vince, Anna and Olivia for their expertise, patience and support over the years. I would also like to express my gratitude to Alberto for salvaging lost data; Sarah H for proofreading early drafts; and Sarah C for guidance in statistics and general PhD survival.

Special thanks to Alfred and Georgia who have shared the ~~rae~~ journey through the PhD and who have always made themselves available for support in the form of tea breaks or Google-excursions. Thank you to the writing retreaters for always sending positive energy and good writing vibes, it definitely helped.

I would like to acknowledge the generosity of the John Henry Brookes Studentship, Santander, and the European Literacy Network for their financial support, the generosity of everyone who gave their time to participate in my studies, and the generosity of all the researchers who made their work freely accessible.

Finally, I would like to thank Gregg for always cheering me on, and my family for pretending to be interested in what I do, while patiently waiting for graduation day.

[blank page]

Abstract.

Background. Writers with dyslexia have difficulty with spelling, which may also restrict their written lexical diversity. Thus spellcheck could be particularly useful to these writers. However, writers with dyslexia also have difficulties with executive functioning required to prevent distraction, and so the automatic underlining of spellcheck could be disruptive for this group. Little empirical evidence for effects of spellcheck exists in the literature. Furthermore, functions within word processing programs, such as spellcheck, are not accounted for in theoretical frameworks of writing.

Method. Three studies were conducted to address three research questions. First a survey was used to explore how and why writers use word processing programs, and spellcheck in particular ($n=30$ with dyslexia, $n=177$ without dyslexia). The second study comprised of two experiments that used keystroke logging to monitor writing behaviour to find out whether spellcheck disrupts writing and what this means in terms of cognitive processing, particularly for writers with dyslexia (experiment one, $n=18$ with dyslexia, $n=18$ control group; experiment two, $n=10$ with dyslexia, $n=10$ control group). In the third study, essays written with and without spellcheck, ($n=18$ with dyslexia, control group $n=18$), were measured to find out whether spellcheck improves spelling accuracy and lexical diversity more for writers with dyslexia than for writers without dyslexia.

Results. Findings make original contributions to knowledge. Survey results indicated that groups differ in their motivations for using word processing programs but both groups report that they always use spellcheck in its default settings. Writing behaviour showed that spellcheck disrupts writing. Furthermore, when writers were disrupted, they were more likely to forget what they were going to write next. Writers with dyslexia were affected more than writers in the control groups. Text measures demonstrated that, for both groups, spellcheck reduced the number of spelling errors to near zero and, for writers with dyslexia, spellcheck also increased the lexical diversity of essays. Lexical diversity was not increased for the control group.

Conclusions. Findings have practical implications regarding advice for best practice when writing with spellcheck, which differs per group. The fact that each group was affected by spellcheck differently relates to theories of dyslexia and has implications concerning cognitive processing during writing. It is proposed that writing models are expanded to account for effects of spellcheck on writing.

[blank page]

Contents

Investigating the impact of spellcheck on writing for students with and without dyslexia.....	i
Section One: Introduction.....	17
Thesis Introduction.....	19
1 Chapter One: Cognitive Processes in Writing.....	25
1.1 The Components of Writing.....	25
1.2 Writing Processes.....	28
1.2.1 Conceptualisation.....	28
1.2.2 Translation.....	28
1.2.3 Spelling.....	28
1.2.4 Spelling models.....	29
1.2.5 Spelling in writing models.....	31
1.2.6 Graphomotor planning and execution (transcription).....	32
1.2.7 Planning, goal setting and evaluation.....	33
1.2.8 Revision.....	34
1.3 Cognitive Resources.....	37
1.3.1 Long-term memory.....	37
1.3.2 Working memory.....	37
1.3.3 The central executive.....	39
1.3.4 Attention.....	39
1.4 Organising Cognitive Writing Processes.....	40
1.4.1 Parallel and sequential processing.....	40
1.4.2 Development of writing processing and management.....	41
1.4.3 Cascading organisation.....	42
1.4.4 Writing bursts.....	43
1.5 Revision interrupts text production.....	44
1.6 Conclusions.....	46
2 Chapter Two: Dyslexia and Writing.....	47
2.1 Chapter Introduction.....	47
2.2 Defining Dyslexia.....	47

2.2.1	Characteristics.....	48
2.2.2	Cognitive abilities.....	48
2.2.3	Severity.....	49
2.2.4	Prevalence of dyslexia in the UK.....	49
2.2.5	Secondary consequences and co-occurring difficulties.....	50
2.2.6	Dyslexia in adulthood.....	52
2.3	Adults with Dyslexia and Writing.....	53
2.3.1	Phonological processing.....	55
2.3.2	Phonemic awareness.....	55
2.3.3	Working memory.....	56
2.3.4	Central executive functioning.....	57
2.4	Dyslexia and Spelling Error Revision.....	60
2.4.1	Revising spelling errors.....	60
2.4.2	Revision during text production.....	61
2.5	Word-Level Focus.....	61
2.6	Conclusions.....	66
3	Chapter Three: Writing with Spellcheck.....	67
3.1	Description of Spellcheck.....	67
3.2	Spellcheck and the writing environment.....	67
3.2.1	A brief history of spellcheck.....	68
3.3	How Spellcheck Works.....	69
3.3.1	Identifying spelling errors.....	69
3.3.2	Spelling error revision.....	69
3.3.3	Selecting candidates for word replacement.....	70
3.3.4	Ranking the candidates.....	71
3.3.5	Other spelling aids.....	74
3.4	Key Research Papers.....	74
3.4.1	Spellcheck used by writers with spelling difficulties.....	75
3.4.2	Spellcheck in proofreading.....	79
3.4.3	Spellcheck and transcription, writers with dyslexia.....	80
3.5	Conclusions from the introductory chapters.....	82

Section Two: Empirical Studies.....	85
4 Chapter Four: A Survey Study Exploring the Use and Perceptions of Spellcheck.....	87
4.1 Introduction.....	87
4.1.1 Common features in the virtual writing environment.....	87
4.1.2 Why use a word processing program?.....	89
4.1.3 Do writers feel that spellcheck impacts writing?.....	92
4.1.4 The current study.....	93
4.2 Method.....	94
4.2.1 Survey design and development.....	94
4.2.2 Recruitment.....	101
4.2.3 Participants.....	101
4.2.4 Data analysis	103
4.3 Results.....	103
4.3.1 Common features in the virtual writing environment.....	103
4.3.2 Why use a word processing program?.....	106
4.3.3 Do writers feel that spellcheck impacts writing?.....	111
4.4 Discussion.....	115
4.4.1 Common features in the virtual writing environment.....	115
4.4.2 Why use a word processing program?.....	116
4.4.3 Do writers feel that spellcheck impacts writing?.....	119
4.4.4 Limitations.....	120
4.4.5 Conclusion.....	123
5 Chapter Five: The Impact of Spellcheck During Writing.....	125
5.1 Introduction.....	125
5.1.1 Sentence completion tasks.....	127
5.2 Experiment One.....	129
5.3 Predictions.....	129
5.4 Experiment One Method.....	130
5.4.1 Participants.....	130
5.4.2 Design.....	137

5.4.3	Procedure.....	137
5.4.4	Materials.....	139
5.4.5	Measures.....	141
5.5	Experiment One Results.....	142
5.5.1	Analysis.....	142
5.5.2	Initial response.....	144
5.5.3	Lexical representation.....	145
5.5.4	Latency.....	145
5.5.5	Writing time.....	146
5.6	Experiment One Discussion.....	147
5.6.1	Conclusions.....	148
5.7	Improvements to the Experimental Design.....	149
5.8	Experiment Two.....	150
5.8.1	Predictions.....	151
5.9	Experiment Two Method.....	151
5.9.1	Participants.....	151
5.9.2	Design.....	155
5.9.3	Materials.....	155
5.9.4	Procedure.....	156
5.9.5	Measures.....	157
5.10	Experiment Two Results.....	158
5.10.1	Analysis.....	158
5.10.2	Initial response.....	159
5.10.3	Lexical representation.....	160
5.10.4	Latencies.....	161
5.10.5	Writing time.....	162
5.10.6	Typing speed	163
5.10.7	When revisions are made.....	164
5.10.8	Spelling errors.....	165
5.10.9	Questions post task.....	165
5.11	Overall Discussion.....	166

5.12	Limitations.....	171
5.13	Conclusions.....	173
6	Chapter Six: The Impact of Spellcheck on Spelling Accuracy and Lexical Diversity in Essay texts.....	175
6.1	Introduction.....	175
6.1.1	Spelling.....	175
6.1.2	Lexical diversity.....	178
6.1.3	Spellcheck.....	181
6.1.4	The current study: spellcheck and text product.....	182
6.1.5	Predictions.....	182
6.2	Participants.....	183
6.3	Procedure: Written Composition Task.....	183
6.3.1	Task instructions.....	184
6.4	Measures.....	185
6.4.1	Spelling accuracy.....	185
6.4.2	Real-word errors.....	185
6.4.3	Lexical diversity.....	185
6.4.4	Word frequency.....	186
6.4.5	Quality.....	186
6.4.6	Essay length.....	186
6.5	Analysis.....	187
6.6	Results.....	187
6.6.1	Spelling accuracy.....	187
6.6.2	Lexical diversity.....	189
6.6.3	Word frequency.....	191
6.6.4	Quality.....	191
6.7	Discussion.....	193
6.7.1	Limitations.....	198
6.7.2	Conclusions.....	200

Section three: Discussion.....	201
7 Chapter Seven: General Discussion.....	203
7.1 Introduction.....	203
7.2 Overall Findings.....	203
7.2.1 Findings from the survey.....	203
7.2.2 Findings from sentence completion and essay writing experiments.....	204
7.3 Theoretical Implications.....	206
7.3.1 How and why do writers use word processing programs and spellcheck in particular?.....	206
7.3.2 Does spellcheck disrupt writing, and what does this means in terms of cognitive processing, particularly for writers with dyslexia?.....	207
7.3.3 Does spellcheck improve spelling accuracy and lexical diversity, and does this only impact writers with dyslexia?.....	211
7.4 Practical Implications.....	214
7.5 Practical Recommendations.....	216
7.6 General Limitations.....	217
7.7 Suggestions for Future Research.....	218
7.7.1 Research on other writing tools.....	220
7.8 Concluding Remarks.....	221
8 References.....	223
9 Appendices.....	240

List of appendices

Appendix A: Part of the marking criteria used at Oxford Brookes University.....	241
Appendix B: The full questionnaire.....	242
Appendix C: UREC approval letter.....	257
Appendix D: Participant information text for the questionnaire study.....	258
Appendix E: Participant information sheet for study one in chapter 5 and chapter 6.....	261
Appendix F: Consent form for studies 1 and 2 in chapter 5 and for chapter 6.....	264
Appendix G: The writing prompt from YAA-R.....	265
Appendix H: Common spelling error sources (websites).....	267

Appendix I: Tables of misspellings and difficult to spell words for studies in Chapter 5.....	268
Appendix J: Participant information sheet for study 2 chapter 5.....	269
Appendix K: Essay scoring rubric.....	272

List of Tables and Figures

Tables

Table 3.1 Examples of Levenshtien distance.....	70
Table 4.1 List of questions from the survey.....	95
Table 4.2. Description of participant groups with and without dyslexia.....	102
Table 4.3 Ratings of how often writers use each word processing program.....	104
Table 4.4 Median ratings, per group, regarding the use of spellcheck settings.....	104
Table 4.5 The amount of writers, per group, who have altered the spellcheck settings.....	105
Table 4.6 The amount of writers, per group, who switch autocorrect off.....	105
Table 4.7 The amount of writers, per group, who add words into the spelling dictionary.....	105
Table 4.8 The amount of writers, per group, who add words to autocorrect.....	106
Table 4.9 The amount of writers, per group, who use specialised writing software.....	106
Table 4.10 Reasons that participants use a word processor (median ranks, 1= most important) compared between groups.	107
Table 4.11 The amount of writers that find each tool useful and chi-square tests for independence between groups.....	109
Table 4.12 Spearman Correlations between responses to questions about drafting, $N=$ 207.....	110
Table 4.13 Spearman Correlations between responses to questions about planning, $N=$ 207.....	110
Table 4.14 The amount of writers, per group, that report spellcheck causes them to stop writing.....	111
Table 4.15 The amount of writers per group that report the notification of a spelling error disrupts their thoughts.....	112

Table 4.16 Median ratings, (1= <i>never</i> , 5= <i>always</i>), for frequency of error detection and correction behaviours, per group.....	113
Table 4.17 The amount of writers, per group, that selected each revision behaviour response option.....	114
Table 4.18 Amount of writers who selected each response regarding revision behaviour. consolidated categories.....	115
Table 4.19 Amount of student and non-students who selected each response regarding revision behaviour, consolidated responses.....	115
Table 4.20 Amount of students who selected each response regarding revision behaviour, consolidated responses.....	115
Table 5.1 Performance on participant measures across groups, experiment one.....	134
Table 5.2 A comparison of participant measures from the YAA-R.....	136
Table 5.3 The amount of trials showing signs of revision per group, experiment one.....	142
Table 5.4 The amount of trials included in analyses, per group and condition.....	142
Table 5.5 The amount of trials per initial response, group, and condition.....	144
Table 5.6 The amount of trials per presence of content words and per initial response.....	145
Table 5.7 Latency, per group and initial response, in seconds.....	146
Table 5.8 Writing time, per group and initial response, in seconds.....	146
Table 5.9 Performance on participant measures across groups, experiment two.....	154
Table 5.10 Examples of stimuli texts.....	155
Table 5.11 The amount of trials showing signs of revision per group and condition, experiment two.....	158
Table 5.12 The amount of trials included in analyses per first action, group and condition.....	159
Table 5.13 The amount of trials per presence of content words and first action.....	161
Table 5.14 The amount of trials per presence of content words and group.....	161
Table 5.15 The amount of trials with and without the difficult-to-spell word, per group.....	161
Table 5.16 The amount of trials per presence of content words and condition.....	161

Table 5.17 Time spent typing, per group and condition, in seconds.....	163
Table 5.18 Typing speed per group and condition, in keys per minute.....	163
Table 5.19 The number of characters typed before revision, per group and condition.....	164
Table 5.20 The amount of trials per category indicating when writers revised text.....	164
Table 5.21 The mean number of spelling errors per trial, per group and condition.....	165
Table 5.22 The number of participants who selected each statement.....	166
Table 6.1 Examples of real-word errors.....	185
Table 6.2 ANOVA results for spelling accuracy and real-word errors.....	188
Table 6.3 ANOVA results for lexical diversity (MTLD) of essays.....	190
Table 6.4 Mean lexical diversity MTLD of essays with corrected spellings.....	190
Table 6.5 Means lexical diversity (MTLD) of essays with misspelled words removed.....	191
Table 6.6 ANOVA results for essay quality scores and text length.....	192

Figures

Figure 1.1 Hayes and Berninger's (2014) framework of cognitive writing processes.....	26
Figure 1.2 Visual representation of the cognitive processes and storage in writing.....	27
Figure 1.3 The cascading organisation of writing from Olive (2014).....	43
Figure 2.1 A representation of the relationship between dyslexia and SLI from Bishop and Snowling (2004).....	52
Figure 3.1 Image of a spelling error underlined by spellcheck.....	69
Figure 3.2 Replacement list in Microsoft Word 2016 spellcheck	77
Figure 5.1 Details of procedure in experiment one.....	138
Figure 5.2 Details of procedure in experiment two.....	156

[blank page]

Section One: Introduction

Chapter 1: Cognitive processes in writing

Chapter 2: Dyslexia and Writing

Chapter 3: Writing with Spellcheck

[blank page]

Thesis Introduction

Writing research

To gather information about writing, researchers design experiments for the observation and measurement of the writing process, often using technology such as digitizing tablets and keystroke logging programs to accurately measure movements in writing and provide behavioural data. In addition, some assumptions about the cognitive processes involved in writing can be made when aspects of text differ in response to specified conditions. Thus measuring the product of writing (the text) can also provide data for research. Findings, from rigorous empirical research, are brought together to conceptualise the writing process, which can be represented in writing models. These models can be used to elicit theories and provide a framework against which these theories can be tested. Models change and develop in reaction to generalisable and replicable findings. The well-cited writing model by Flower and Hayes (1981), for example, illustrates the many components involved in writing and has been modified many times to become the most recent version by Hayes and Berninger (2014) and is built on a strong evidence base gathered over 30+ years.

In this thesis, writing is investigated in the context of word processing programs (such as Microsoft Word). Unfortunately, Hayes and Berninger's (2014) writing model only includes environmental factors that are physically present. Thus affordances of word processing programs, including spellcheck, are not currently accounted for by this model. This thesis considers how spellcheck could fit into this writing model. The impact of spellcheck on spelling revision is of particular interest.

Generally, in writing research, revision has been seen as a writing activity in and of itself, separate from initial text production (Hayes & Berninger, 2014). However, even without spellcheck automatically underlining spelling errors, the need to revise can occur whilst producing text, in which case revision tends to interrupt text production (Chenoweth & Hayes, 2001, 2003; Hayes & Chenoweth, 2007). When the writer, who is in the midst of text production, notices a spelling error, they are challenged with addressing this error while causing as little disruption to text production as possible (Leijten, Ridder, Ransdell, & Waes, 2007; van Waes, Leijten, & Quinlan, 2010).

To some extent, writers can process multiple pieces of information in parallel (Olive, 2014; Olive & Kellogg, 2002). Thus can potentially process information about the spelling error and the text they plan to write at the same time. However, cognitive resources for processing and storing information are limited and so if one process requires more resources then there are less available for other processes (McCutchen, 1996; Olive & Kellogg, 2002), in which case writers must prioritise either text production or revision. For writers with dyslexia, the cognitive requirement

of spelling is high. Text production and spelling error revision are therefore cognitively demanding tasks and writers with dyslexia are likely to struggle to process the necessary information in parallel. How writers orchestrate cognitive processes can be interpreted from behaviour.

Models of revision indicate that reading is essential to detect the presence of a spelling error (Alamargot & Chanquoy, 2001; Bereiter & Scardamalia, 1987; Flower, Hayes, Carey, Schriver, & Stratan, 1986; Hayes, Flower, Schriver, Stratman, & Carey, 1987), this is supported by research investigating the role of reading in revision (Chenoweth & Hayes, 2003; Torrance, Rønneberg, Johansson, & Uppstad, 2016). No revision model, or empirical research into revision, has considered the possibility of noticing the presence of a spelling error because of the appearance of an eye-catching red underline from spellcheck, yet the idea that spellcheck draws attention to spelling errors has caused several researchers to suggest that spellcheck is disruptive and causes writers to focus on spelling error revision at the cost of other writing processes (Hiscox, Leonavičiute, & Humby, 2014; MacArthur, Graham, Haynes, & DeLaPaz, 1996; Rønneberg, Johansson, Mossige, Torrance, & Uppstad, 2018). There is currently a lack of empirical evidence to support this suggestion. However, if this is the case then, writers with dyslexia are likely to be particularly vulnerable to disruption due to difficulties inhibiting distraction (Brosnan et al., 2002; Krause, 2015; Smith-Spark, Henry, Messer, Edvardsdottir, & Ziecik, 2016; Valdois, Bosse, & Tainturier, 2004).

Research into revision, including spelling revision, has focussed on what knowledge is necessary for the detection and correction of spelling errors (Hacker, Plumb, Butterfield, Quathamier, & Heineken, 1994; Hayes, 2004; Hayes et al., 1987). Such research has not included the possibility of using spellcheck as a means of providing the information, or knowledge, necessary for revision, yet this is what could make spellcheck so useful to writers with dyslexia, whose spelling knowledge tends to be poor (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008; Elliot & Grigorenko, 2014; Snowling, 2012).

Empirical investigations into the writing process do not typically include spellcheck. Even when investigating writing within word processing programs (as opposed to handwriting) most researchers use programs designed for writing research which do not include spellcheck or, when using more widely used word processing programs (such as Microsoft Word), choose to deactivate spellcheck. Excluding spellcheck provides more controlled conditions which may be particularly desirable, for example, if researchers plan to investigate spelling in the context of text production (as opposed to single word spelling). However, if writers usually use word processing programs with spellcheck active, then not allowing them to use it is distancing the experience of the writing task from their usual writing experience, which limits the ecological validity and generalisability of any findings from such research.

Writing and dyslexia

Due to a phonological deficit, writers with dyslexia struggle to create store or recall representations of spellings and therefore exhibit poor spelling accuracy (Berninger, Nielsen, et al., 2008; Snowling, 2012; Tops, Callens, Lammertyn, van Hees, & Brysbaert, 2012; Warmington, Stothard, & Snowling, 2012). Spellcheck is designed to support revision of spelling errors. Thus it could be assumed that writers with dyslexia would especially benefit from using it; however, research published in the mid-1990s has indicated that, while spellcheck did help teenage writers with dyslexia to reduce the amount of spelling errors in their text, they used spellcheck with limited effectiveness (MacArthur, Graham, Haynes, & DeLaPaz, 1996). However, undergraduates today are likely to be a lot more familiar with using spellcheck. In addition, spellcheck has been updated multiple times, changing the user experience, yet there has been no recent research to investigate how well up to date versions of spellcheck improve spelling accuracy in texts.

The spellcheck used in MacArthur et al.'s (1996) study was not active during text production, it needed to be activated by the user and opened in a window separate from their text. Today, spellcheck, in its default settings, automatically underlines spelling errors as they are made. As described, writers may be distracted by the automatic underlining. It may be particularly difficult for writers with dyslexia to ignore the red underline due to difficulties with some executive functioning. In addition, managing multiple tasks in writing (spelling error revision and text production) with limited working memory is likely to be more effortful for writers with dyslexia.

Interestingly, for writers with dyslexia, poor spelling ability has been found to relate to lower lexical diversity in texts (Sumner, Connelly, & Barnett, 2016; Wengelin, 2007), yet a greater number of spelling errors in text relates to higher lexical diversity (Connelly, Campbell, MacLean, & Barnes, 2006; Sumner & Connelly, 2020). Lexical diversity is a measure of word variety. When words are repeated, they reduce lexical diversity. The relationship between spelling and lexical diversity has only been found for writers with dyslexia and not for control groups and is therefore most likely related to spelling difficulties, but the precise nature of the relationship is unclear. Furthermore, the relationship could be changed when writers receive support with spelling error revision from spellcheck. Previous research into spelling and lexical diversity has not involved spellcheck, however spellcheck may well be a part of everyday writing for some people, particularly for those who have trouble with spelling. Thus, it is important to understand the relationship between spelling and lexical diversity when writing with spellcheck.

Low lexical diversity is related to poor text quality (Connelly et al., 2006; Olinghouse & Wilson, 2013; Sumner et al., 2016; Wengelin, 2007). Poor spelling has a negative influence on judgements of text quality (Marshall & Powers, 1969; Rezaei & Lovorn, 2010) and is sometimes included in marking criteria for university coursework. Thus if spellcheck has a positive impact on spelling accuracy and lexical diversity it may improve judgements of text quality. Students in

higher education (HE) are regularly expected to produce texts in digital formats and are likely to use word programs with spellcheck active by default. Students in HE do not generally receive support or guidance specific to writing strategies with word processing programs but are assumed to be well-practised at writing, to be competent at typing, and at using word processing programs. However, if students are not benefiting from using word processing programs and spellcheck then this could restrict their writing and potentially limit their grades. Therefore, understanding the impact of spellcheck on writing is particularly important for the student population.

Structure of the thesis

This thesis is divided into three sections: an introduction; empirical studies; and a final overall discussion. The first three chapters constitute a comprehensive review of the literature, establish the research questions for the empirical studies of the thesis, and provide support for predictions. Chapter 1 is a detailed exploration of the cognitive processes, cognitive resources and management of these, that concludes with an examination of how these are active during spelling revision. Chapter 2 begins by defining dyslexia, then examines how dyslexia impacts writing, and ends with an exploration of how dyslexia is likely to impact spelling revision in text production, referring to the cognitive components discussed in Chapter 1. Spellcheck is introduced in Chapter 3, the role of spellcheck in writing is reviewed using the few studies that have investigated spellcheck, and highlights the gaps in the literature concerning the use of spellcheck in writing are highlighted. The introductory section ends with conclusions drawn from the first three chapters and establishes the main research questions for the thesis.

The next three Chapters (4-6) describe three empirical studies on students with and without dyslexia. These provide a thorough investigation using different methodologies to meet gaps in the literature identified earlier. The first empirical study reported in Chapter 4, presents a survey study used to investigate writers' choices about the environment, including the use of spellcheck and to establish how spellcheck is used in the context of word processing programs (as opposed to spellcheck used in search engines or text messaging or on hand held spellcheckers). Furthermore, writers report whether they find spellcheck disruptive, which serves as an initial investigation into the assumption that spellcheck disrupts writing. Then, in Chapter 5, reports of disruption are followed up using keystroke logging to observe the disruption of spellcheck under the controlled conditions of a sentence completion task, and to investigate whether writers with dyslexia are more prone to disruption than their peers. The findings from keystroke logging also provide an indication of how spellcheck affects the orchestration of writing components.

The final empirical study, presented in Chapter 6, investigates the impact of spellcheck on texts using a naturalistic essay writing task. The purpose of this was to confirm the assumption that spellcheck supports spelling, and to investigate how supporting spelling affects text quality and lexical diversity.

Overall findings and implications are discussed in Chapter 7. Spellcheck impacts writers with and without dyslexia differently, which indicates differences in cognitive processing relating

to theories of dyslexia, especially concerning executive functioning. Results also contribute to an explanation of the relationship between spelling and lexical diversity, which is demonstrated by writers with dyslexia. Importantly, the effects of spellcheck on writing behaviour and on text produced indicates that spellcheck needs to be accounted for in writing models. How models could be expanded to include spellcheck is discussed. Findings also have implications for practice. Writers should be made aware of the impact that spellcheck has on their writing in order to make the most of it. Recommendations for use of spellcheck, for individuals with and without dyslexia, are made towards the end of the discussion chapter.

[blank page]

Cognitive Processes in Writing

Cognitive psychology has been a major research field since the 1950s. The term ‘cognitive’ relates to thoughts and the term ‘cognitive processes’ refers to thinking. Individuals are sometimes aware of cognitive processes (conscious processes) and sometimes not (subconscious processes). Two key concepts in cognitive psychology are: 1) the processes that are involved in thinking; and 2) a limited capacity for thinking. In writing research, these concepts are applied to the cognitive processes involved in writing and how a limited capacity impacts these processes. Writing is a complex activity involving many components for storing and processing information, these are displayed overleaf in Hayes and Berninger’s (2014) writing model Figure 1.1. The responsibilities of each component have been described in detail over the course of this chapter.

It should be acknowledged that the environment of the writer also impacts their writing. The key part of the writing environment under investigation in this thesis is spellcheck. Spellcheck is not currently accounted for in Hayes and Berninger’s (2014) writing model. The writing environment and how spellcheck might fit into this is discussed, but not until Chapter 3. The current chapter is focussed on introducing the cognitive processes in writing which transform ideas into text and the cognitive resources that manage and support these.

1.1 The Components of Writing

The components of writing include the processes that transform information into text as well as the mechanisms that support these processes and the storage of this information. The cognitive needs of processing and storing information during writing is met by a single limited pool of cognitive resources, often considered to be working memory (Hayes & Berninger, 2014; Hiscox et al., 2014; McCutchen, 1996). How information is transformed as it flows from one process to the next, and the relationships between processes and storage, are not specified by Hayes and Berninger’s (2014) model, therefore these have been illustrated in a separate model, Figure 1.2. Also included in Figure 1.2 is the central executive, which is responsible for monitoring and coordinating writing processes and the working memory mechanisms and revision which is the process of making changes in writing. As illustrated in Figure 1.2 revision that can occur at any point of the writing process which is a result of constantly occurring evaluation (Fitzgerald, 1987). While evaluation is one of the processes present in Hayes and Berninger’s (2014) model, revision is not.

Figures 1.1 and 1.2 are presented at the start of this chapter to be used as a guide for relationships between components in writing whenever necessary. For example, they are referred to throughout the remainder of this chapter when the details of each cognitive process and

working memory mechanism are described. Furthermore in Chapter 2, the impact of dyslexia on these writing components is explored. In fact, throughout the whole thesis, ideas about writing are described in the context of the cognitive writing components described in this chapter.

Figure 1.1. Hayes and Berninger’s (2014) framework of cognitive writing processes

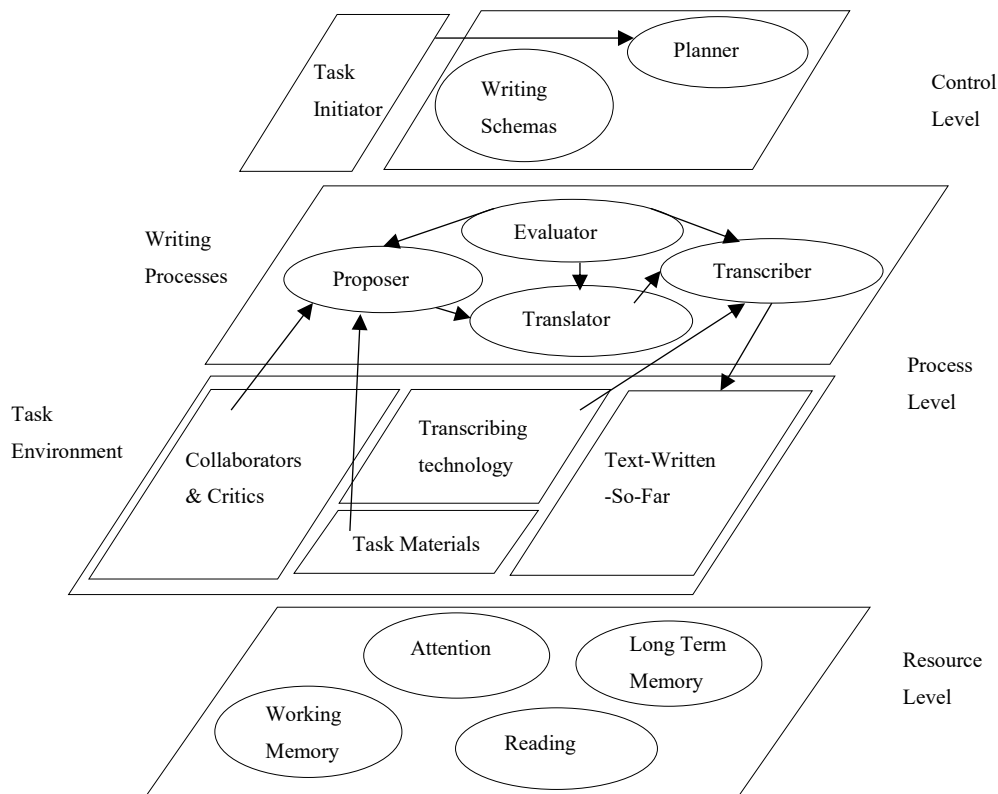


Figure 1.1 The ovals within this figure represent the cognitive components involved in writing, these are discussed in the current chapter. The arrows represent some of the relationships that exist between components. The rhombi within the task environment and the task initiator represent external factors that impact writing.

Figure 1.2 Visual representation of the cognitive processes and storage in writing

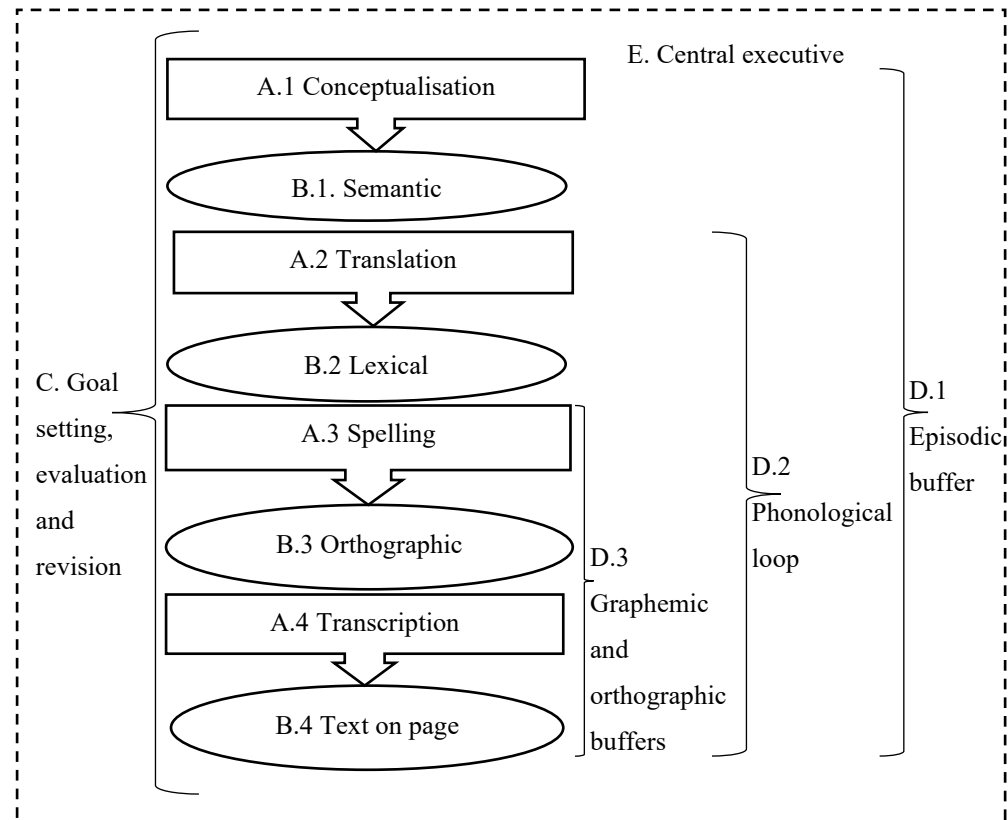


Figure 1.2 This figure depicts the flow of information in text production, the cognitive processes which transform it, the mechanisms of working memory used for processing and storage of the information, and the central executive which controls how working memory is used in the production of text.

A.1-4. Boxes with arrows represent the cognitive process used to transform the idea package.

A.1 Proposing a message to be conveyed.

A.2 Mapping thoughts to language, words, grammar so that they can be rehearsed using the inner voice via phonological loop.

A.3 Adding orthographic representations to words chosen as abstract graphemes with some visual representation.

A.4 Selecting motor patterns for mode, allographs, and size of text. Then executing movements to store information as text on the page.

B.1-4. Ovals represent the form that the idea package takes.

B.1 Semantic representation: Non-verbal.

B.2 Lexical representation: Verbal, non-visual.

B.3 Orthographic representation: Verbal and some visual information but abstract.

B.4 Text on the page.

C. The processes of goal setting, evaluation and revision are shown by the left curly bracket.

D.1-3. The right curly brackets represent mechanisms of working memory used to store the idea package. The overlap represents storing information in multiple formats as the idea package becomes more complex.

E. The box with a dashed line is the central executive, which coordinates writing processes and allocates working memory resources.

1.2 Writing Processes

1.2.1 Conceptualisation

Conceptualisation is the process of idea generation, the creation of conceptual messages to be conveyed to the reader. Conceptualisation is considered to be how the writing begins, it is where each ‘information package’, a representation of information, is created (Olive, 2014). Only after this information package is created can other processes add new dimensions to the existing representation. The mechanism involved in conceptualisation is referred to as the ‘proposer’ by Hayes and Berninger (2014). For consistency, the word ‘conceptualisation’ will be used throughout this thesis. The information in these idea packages may come from the writer's environment (such as the text written so far or task materials such as worksheets) or retrieved from long term memory (Hayes & Berninger, 2014, Figure 1.1). The conceptual message at this stage is in non-verbal form and is stored in memory buffers (Hayes, 2012) to be integrated with other pieces of information by the episodic buffer (Olive & Passerault, 2012). In this thesis, this non-verbal form of the information package will be referred to as the prelexical representation. See items A.1, B.1 and D.1 in Figure 1.2 for a visual representation of conceptualisation and the storage of the prelexical representation within the context of other writing processes.

1.2.2 Translation

Translation (A.2 in Figure 1.2) is the process of mapping back and forth between the prelexical representation and language, creating a linguistic structure to add to the information package (B.2 in Figure 1.2). The writer selects and orders words, choosing from their vocabulary and taking into account tense and grammar, to express the information package thus, producing a lexical representation (Fayol, Alamargot, & Berninger, 2012; Olive, 2014). It has been proposed that the lexical representation is held in the conscious mind as words with auditory format (Chenoweth & Hayes, 2003; Hayes, 2012) and is maintained using the phonological loop. The post-translation information package is described as having both auditory and visual forms by Hayes and Berninger, however to create a visual format of words also requires spelling processes. For the purpose of this thesis, spelling is considered separately from translation.

1.2.3 Spelling

Information about the spelling is added to the representation of information, resulting in an orthographic representation of the words that were selected in the translation process, creating a richer representation. The orthographic representation includes semantic (meaning) and phonemic (sound) information of words, and information about the spelling of the word. The representation of spelling is almost certainly visual, however it is somewhat fluid, as it is not in a particular case at this stage (capitals or lower case). This orthographic representation is held in the orthographic buffer, a short-term memory store (Afonso, Suárez-Coalla, & Cuetos, 2015; Tainturier & Rapp,

2003; van Galen, 1991). The precise nature of the spelling process varies across spelling models, some of these models are outlined in the following section.

1.2.4 Spelling models

Dual-routes

The dual-route cascade (DRC) model (Coltheart et al., 2001) is based on the dual-route theory of reading. Reading and spelling both depend heavily on one's knowledge of the phoneme-grapheme relationship (Mishra, 2015). During reading information is transformed from print into meaning and writing is the opposite direction, from meaning into print. In dual-route theories, spelling is achieved via two processing routes, the lexical route and sublexical route (both routes are described in the following section). The existence of both routes is almost undisputed (Afonso et al., 2015).

Lexical route

In the lexical route, the spellings of words are retrieved from the lexicon in long term memory. The lexical route gives access to the spelling of whole-words. The processing of high-frequency or well-known words is more likely to occur with the lexical route in comparison to low-frequency words. This is because individuals build stronger, more readily retrieved representations of familiar words due to repeated exposure. It is particularly useful for spelling familiar but irregular words. However, the lexical route does not lend itself as well to spelling unfamiliar words (words that individuals have not been exposed to enough to build strong representations).

Sub-lexical route

Less familiar words may require the building of spellings via the sub-lexical route. While the lexical route is a top-down approach to spelling, the sub-lexical route of spelling is a bottom-up approach. The sub-lexical route makes use of knowledge about how phonology (sound) and orthography (letters) are connected (mapping). Mapping letters and letter groups within a word is carried out by breaking a word into phonemes and sequentially converting phonemes to graphemes (to letters or letter groups) (Ellis, 2016). Using phoneme-orthography knowledge allows writers to build phonologically plausible spellings, this works particularly well for regular words. This route can be used when writers do not possess an orthographic representation in their lexicon, such as for non-words or low-frequency words (Tainturier & Rapp, 2001). However, relying on mapping rules does not support spelling of irregular words, thus many words in English cannot be spelled via the sub-lexical route alone.

Connectionist models

Although some words lend themselves to a particular route, for example, familiar words to the lexical route and words made of unfamiliar components to the sub-lexical route, it is also possible to use a combination of the two routes through simultaneous activation (Houghton &

Zorzi, 2003). For example, parts of words e.g. prefix, suffix or root might be recalled using the lexical route and the remainder of the word may rely on grapheme-phoneme spelling.

Both routes influence the final orthographic representation used for spelling. Units interact through excitation and inhibition within routes. Excitation is the activation of a unit, inhibition is the prevention of a unit being activated (Coltheart et al., 2001). The size of the units processed is debated. The spelling of a word might consist of a single large unit (a whole word), or smaller multiple units, such as individual letters or small clusters of letters, (Mishra, 2015). The units processed in the lexical route are the whole word, processed at the word level. The units processed in the sub-lexical route are phonemes and graphemes (or groups of graphemes), which is at the sub-word level. Using excitation and inhibition, both routes (lexical and sub-lexical) ‘vote’ on a candidate graphemic element, voting in either agreement or disagreement. When both routes activate the same grapheme, the selection is reinforced. The voting results in the chosen orthographic representation (Coltheart et al., 2001). As a result, both the strength of lexical representation (used in the lexical route) and phoneme-orthographic knowledge (used in the sub-lexical route) influences spelling. At this stage, the routes converge via the orthographic representation at the grapheme level (Afonso & Alvarez, 2011; Bosse, Chaves, Largy, & Valdois, 2015; Rapp, Epstein, & Tainturier, 2002; Tainturier & Rapp, 2003). The orthographic sequences computed by lexical or sub-lexical processes would be maintained by the graphemic buffer.

Parallel distributed processing (PDP)

Parallel distributed processing (PDP) is a general theory of how lexical knowledge is acquired and used (Seidenberg, 2005). PDP informs the connectionist model of spelling described above but does not in itself explain the process of spelling during writing. PDP models are considered computational models that act as an interface between the theory of learning and the physiology of learning (Seidenberg, 2005). As described in the connectionist model section, PDP models assume that information processing occurs via excitatory and inhibitory signals between units of information or knowledge in a similar way to the interaction of neurons (Rumelhart & McClelland, 1986). Rumelhart and McClelland's (1986) description of PDP modelling is somewhat reminiscent of a game of ‘guess who’ where there a set number of options available and in order to choose the most likely option, the possible options are activated while the impossible options are eliminated (inhibited), narrowing down the options until a choice is made.

According to PDP, in general learning, knowledge units form a flexible structure (Rumelhart & McClelland, 1986). To interpret learning in spelling using PDP, the units can be letters, clusters of letters, words or parts of words. As a spelling choice is made it is also reinforced. This reflects the physiology of learning in that pathways between information, like neural pathways, become stronger when repeatedly activated and are more likely to be activated in future leading to the same spelling choices. Thus we learn patterns and rules (Rumelhart & McClelland, 1986). In this way, both developing spelling knowledge and making spelling choices are statistical.

One critique of using PDP to explain the development of spelling knowledge is that while pattern and rule learning is explained, spelling rules are not always consistent (in English in particular) yet we manage to learn irregular words (Bullinaria, 1994). However, PDP is still applicable if the patterns we learn are the spelling of whole words and of word parts (knowledge for lexical route), and if the rules we learn are grapheme-phoneme conversion (knowledge for sub-lexical route). Furthermore, in support of PDP, it has been proposed that we learn quasiregularity of language rules (Seidenberg, 2005). The activation and inhibition is bidirectional, for example after activation there appears to be some form of evaluation that accounts for a writer's ability to apply rules to different degrees of consistency and take into account complex contingencies (e.g. to turn words that end in 'y' into plural forms, change 'y' to 'ies' unless the word ends in vowel+y, then add an 's'). Thus writers develop spelling knowledge using context and exposure (Treiman & Kessler, 2006). Thus according to PDP models, spelling is a learning process and what is learned via the spelling process also influences future spelling processes.

1.2.5 Spelling in writing models

How spelling is managed alongside other writing processes is investigated in this thesis. Thus, spelling must be considered as part of text production rather than on its own as single word spelling. In Figure 1.2 spelling is placed into the context of text production. Spelling is shown as a process that occurs before transcription, which in the figure refers only to graphomotor activities. In the context of writing models, this is unusual because spelling is usually included in writing models as part of translation (as in 'formulation' Olive, 2014), or as part of transcription (McCutchen, 1996; Berninger, 1992; Hayes & Berninger, 2014). It has been accepted by several researchers that transcription requires coordination of spelling and graphomotor execution (Berninger & Swanson, 1994; Connelly et al., 2006; Hayes & Berninger, 2014) and it is considered a single process in the well-known writing models such as 'the simple view of writing' (Berninger & Swanson, 1994) and Hayes and Berninger's writing model (2014).

It is clear that spelling processes influence motor activities, which is perhaps why spelling and motor activities are often considered as one process. For example, Sumner, Connelly, and Barnett, (2014) found that, for children aged 9 years with spelling difficulties (dyslexia), handwriting performance was predicted by spelling ability and children paused motor execution more in words that they struggled to spell. Similarly, several studies (Abbott, Berninger, & Fayol, 2010; Olive, Alves, & Castro, 2009; Olive, Favart, Beauvais, & Beauvais, 2009; Sumner, Connelly, & Barnett, 2012; Torrance et al., 2016; Wengelin, 2007) have all found that spelling ability influenced writing behaviour, shown through pen movements in handwriting experiments and key presses in typing experiments. However, that is not to say that spelling and transcription occur together, only that spelling influences motor activities. Spelling is not the only process which can influence motor activity. There is a knock-on effect on motor activity when writing activities impact any cognitive processes to the point that writers' working memory cannot meet

the demands of all writing processes (Olive & Kellogg, 2002). In fact, research by Chenoweth and Hayes (2001, 2003, 2007) suggests that, for adults, translation is the main bottleneck for the flow of information causing pauses in writing, yet translation is never paired with motor activity in the same way that spelling is.

Information cascades from spelling processes into movement production, thus while spelling influences motor execution it is a separate process (Kandel & Perret, 2015). That is to say, we cannot write words without first spelling them, but we can spell words without transferring the words to the page. We can spell words orally, speaking the letters without any graphomotor involvement or think about how we would spell a word without writing or speaking the letters. Furthermore, spelling has been separated from motor execution in some writing models. For example in Olive's (2014) cascading model of writing processes, spelling is included in the linguistic level ('formulation', similar to translation) while graphomotor execution is included at the separate level of execution (Olive, 2014). Thus, the separation of spelling from transcription in Figure 1.2 is justified. Spelling is considered separate from transcription, it is a process between the end of translation and the beginning of transcription (see Figure 1.2 for positions of transcription, translation and spelling within the writing process).

1.2.6 Graphomotor planning and execution (transcription)

Once the writer has selected the order of graphemes, as part of the spelling process, they need to transcribe this information onto the page using graphomotor planning and execution (A.4 in Figure 1.2). Figure 1.2 relates to typing and handwriting. In this thesis, the process of getting the lexical representation from working memory onto the page using graphomotor planning and graphomotor execution (but not spelling) will be referred to as transcription. Graphomotor planning requires allograph selection (upper case, lower case, print or script), and recall of the correct motor pattern for the mode (handwriting or typing). Graphomotor execution is the implementation of the motor pattern, the physical movements involved in writing. The specific motor processes required for transcription differ in handwriting and typewriting. For handwriting, motor pattern selection includes controlling for the size of allographs and requires muscular adjustment for the strokes which make up each allograph (Van Galen, 1991). For typing, the selection of allographs is controlled through additional key presses (such as shift or caps lock). Therefore, while, in typing, the selection of allographs involves adjusting the motor pattern for the order and number of keypresses, a whole letter is produced by a single keypress thus there is no muscular adjustment for each stroke, instead the motor pattern is adjusted for the number and location of keypresses, possibly involving the use of different fingers. In addition, for handwriting, text size is adjusted during initial transcription and concerns each pen stroke, but for typing the size of text is adjusted via menus in the software and can be carried out after the initial transcription of words onto the page, as can other factors such as italicisation, bold or underlining. These motor patterns are then executed in order to produce text on the page (van Galen, 1991). Graphomotor execution involves subtle and complex finger movements for pen control in

handwriting and for key presses in typing. Graphomotor execution is the writing behaviour used to investigate the writing process in many studies (Olive & Kellogg, 2002; Prunty et al., 2014; Sumner et al., 2013; Torrance, Rønneberg, Johansson, & Uppstad, 2016; Wengelin, 2007). Transcription is impacted by familiarity with ‘transcribing technology’ (Hayes & Berninger, 2014) such as the use of a keyboard for typing or a pen for handwriting, as writers become more familiar with a particular transcription method it becomes less costly, allowing writers to devote cognitive resources to other writing processes which has a positive impact on text quality (Connelly, Gee, & Walsh, 2007).

1.2.7 Planning, goal setting and evaluation

Planning and goal setting

Planning is part of Flower and Hayes’ (1981) model and ‘the planner’ remains part of the most recent version of that model (Hayes & Berninger, 2014, Figure 1.1). The planner is responsible for setting goals of topic, tone, and impact on audience. Setting such goals involves conceptualisation, translation, and spelling, using knowledge from writing schemas. Writing schemas hold knowledge and understanding of text production including genres, structures and formats, and strategies for text production. Writers can be given goals or assisted in setting goals by the task initiator (e.g. a teacher or the marking criteria of an assignment) and writers can set goals for themselves. Goals can be changed at any time.

The planner is active throughout the writing process (Hayes & Berninger, 2014). The act of goal setting ranges from subconscious to conscious and occurs in conceptual (before translation) and linguistic (post-translation) forms. Goal setting is important for problem analysis in revision, including spelling revision (Bereiter & Scardamalia, 1987). To spell words correctly is a writing goal. Writing processes are orchestrated to best meet writing goals (Beauvais, Olive, & Passerault, 2011). Clear goals enable the writer to monitor their writing and encourage the writer to attend to elements of text production that will help them to achieve their goals, which has a positive impact on writing performance (Ferretti & Fan, 2017; Fidalgo, Torrance, Rijlaarsdam, van den Bergh, & Lourdes Álvarez, 2015).

Evaluation

Evaluation is the process of comparing the information package (in any format) to the writer’s goals and making a decision as to whether this information could be improved to better meet those goals (Hayes & Berninger, 2014). Evaluation is a central process and occurs throughout the whole writing process (Olive, 2014). After conceptualisation, ideas are evaluated before being selected. After translation the lexical representation is compared to communicative goals, including spelling goals, before graphomotor processes turn the representation into text on the page (Hayes & Berninger, 2014). Once text is on the page it is still evaluated against the writer’s goals. To evaluate text on the page, writers need the ability to read and evaluate the text from the audience’s point of view (Kellogg, 2008; Myhill & Jones, 2007; Olive, 2014; Sommers,

1980). For undergraduates producing coursework, the reader is who marks the coursework against marking criteria.

Evaluation is cognitively costly, for example, in a proofreading task, undergraduates evaluated text for revision, without actually making revisions, and found that, even when evaluating for spelling errors, reading for evaluation is cognitively expensive (measured as reaction times as a secondary task), much more so than reading for meaning (Piolat, Roussey, Olive, & Amada, 2004). If during evaluation it is decided that the information package could be better at meeting the goals set, then evaluation can be followed by revision. The same information can be re-evaluated multiple times, particularly because writing goals can change.

1.2.8 Revision

When evaluation indicates that writing goals could be better met, the writer can implement revision (Alamargot & Chanquoy, 2001; Flower et al., 1986). Revision is a cognitive problem-solving process in that it involves decisions about how to best meet writing goals and then making the changes. Goal setting, evaluation and revision are characteristic of adult writing and is often absent in young writers (Bereiter & Scardamalia, 1987). More planning and revising leads to higher quality texts (Bereiter & Scardamalia, 1987; Berninger & Swanson, 1994).

Hayes and Berninger's (2014) writing model does not include details of revision. They write that revision is a writing task that makes use of the processes in their model to replace earlier text. However, the evaluator in their model examines the output of any process (conceptualisation, translation, spelling, transcription) and if found to be inadequate, can reject it and demand revision. Thus, within the model there is conflict between whether revision refers to changes made to text, or changes made at any point.

Over time, revision models have evolved around questions about whether revision occurs only to text on the page or at all levels of mental representation (Alamargot & Chanquoy, 2001; Flower et al., 1986; Hayes, 1996; Scardamalia & Bereiter, 2006). It is widely accepted that evaluation and revision occur at all levels (Alamargot & Chanquoy, 2001; Fitzgerald, 1987; Hayes, 2004). The following is a well-cited definition of revision by Fitzgerald (1987):

Revision means making any changes at any point in the writing process. It involves identifying discrepancies between intended and instantiated text, deciding what could or should be changed in the text and how to make desired changes, and operating, that is, making the desired changes. Changes may or may not affect meaning of the text, and they may be major or minor. Also, changes may be made in the writer's mind before being instantiated in written text, at the time text is first written, and/or after text is first written. (p.484)

Importantly, Fitzgerald clarifies that ““text” can refer to text in the writer's mind before setting pen to paper”(p.484). Thus not only does revision occur as a result of evaluation when writers notice dissonance between text written and intended text (Bereiter & Scardamalia, 1987) but also when they notice dissonance between information in working memory and writing goals.

Thus revision can occur at any point in the writing process (Fitzgerald, 1987; Hacker et al., 1994; Hayes, 2004). Models of revision tend to use evaluation as a starting point, which leads to detection, then diagnosis and ends with the writer making changes (Bereiter & Scardamalia, 1987; Flower et al., 1986; Hayes et al., 1987)¹.

At the final stages of revision, the writer could choose not to address the error (ignore the problem, delay revision, or search for more information to clarify it), or make changes (Hayes, 2004; Hayes et al., 1987). Revision of the prelexical or lexical representation is difficult to monitor, however, it is possible to tap into these by using think-aloud techniques (Flower & Hayes, 1980) or possibly via interviews or questionnaires (Sommers, 1980). Revision of text on the page is sometimes shown in finished products but is best revealed by monitoring writing behaviours. For example, when examining revision in handwritten texts, revisions in ink on paper leave a trace in the product but can be seen in real-time if handwriting is recorded on digitizing tablets. Revisions to texts on word processing programs cannot be seen from the product as they do not leave a trace, however these revisions can be monitored with keystroke logging.

Revision of text can occur alongside reading for evaluation as part of a proofreading activity but can also occur whenever the writer is struck by the need to make changes, sometimes interrupting their own text production (Chenoweth & Hayes, 2003). Information that has been revised will continue to be evaluated against writing goals and may be revised several more times, making the writing process cyclical. Revision can be surface changes that do not affect the message being conveyed, such as spelling revision, or deeper changes that do affect the meaning (Barkaoui, 2007; Faigley & Witte, 1981).

Revision models (in particular, Bereiter & Scardamalia, 1987; Flower et al., 1986; Hayes et al., 1987) have been critiqued for not specifying where different representations are built, stored or maintained during revision and not fully explaining how writers manage the revising process during the progress of the writing activity (Alamargot & Chanquoy, 2001). This chapter has combined research and models to offer detailed descriptions for the building, storage and maintenance of representations, however to investigate how revision processes are managed during the writing activity, empirical studies are required.

Revision of a spelling error

When it comes to revising a spelling error, spellings of words are evaluated as correct or incorrect in order to meet the writing goal of accurate spelling. For undergraduates accurate spelling can be part of marking criteria (see appendix A for an example of marking criteria) even

¹ Flower et al's (1986) three stage model consists of (a) detection, (b) diagnosis, and (c) revision; similarly, Scardamalia and Bereiter's (1987) three mental operations are (a) comparing intended and written texts to detect disagreement (b) identifying the nature of the disagreement (c) changing text and/or writing plan and goals; Hayes et al's (1987) model includes an additional first step a) task definition, followed by three steps similar to the other two models, (b) evaluation, (c) strategy selection, and (d) modification of the text.

if not specified, accurate spelling is important to the marker and poor spelling can lead to poorer grades (Golding, Sharmini, & Lazarovitch, 2014; Graham, Harris, & Hebert, 2011; Marshall & Powers, 1969; Rezaei & Lovorn, 2010).

Initial detection of a spelling error requires the writer to notice that the word is not spelled as they think it should be. It has been argued that in order to detect a spelling error it is necessary to have knowledge of how to correct the spelling error (Hacker et al., 1994) or at least to have partial knowledge of word patterns (Hayes, 2004). It is generally assumed that the spelling error in the text is noticed via reading (Alamargot & Chanquoy, 2001; Hacker et al., 1994; Hayes, 2004). Reading models indicate that words are recognised via visual analysis, where the visual input of the word is analysed in order to identify the abstract letter representations and consider whether the order of them is a familiar word (for detailed descriptions of models of word recognition in reading see Ellis, 2016). Thus if a word is not familiar it is identified as an error.

Spelling errors can also be quasi-automatically detected (Hayes et al., 1987; Piolat et al., 2004). Spelling errors can be detected just after transcription or while still producing the word and can be revised without being read. Chenoweth and Hayes (2003) found that, under usual writing conditions, writers typically made 3.01 revisions per sentence, yet when text was made invisible, thus errors could not have been detected via reading, writers still made 1.34 revisions, which is 45% of the amount of revisions made when text was visible. Similarly, Torrance et al. 2016 also showed a reduction in the amount of revision when text was masked, but revision was still present. The error could be detected from the lexical representation or, if it is a typing error, via feedback from the fingers and keyboard (Logan & Crump, 2010). The automatic underlining by spellcheck creates a visual cue designed to catch the writer's attention, that way even errors that were not detected automatically by the writer can be noticed without requiring knowledge of the spelling of the word, and possibly even without reading the word.

After the error is noticed, generally writing models indicate that the writer must figure out what is wrong so that it can be corrected. The writer can retrieve the intended word, providing that it exists in the writer's lexicon, for comparison between the intended word and the written word, thus knowledge of the word is required to correct an error (Hacker et al., 1994; Hayes, 2004). Because revision uses the same processes as text production, like spelling production, spelling revision uses both lexical and sublexical processing to decide on the correct spelling of the word (Coltheart et al., 2001; Seidenberg, 2007). The writer can revise the whole word, or parts of the word.

In some cases, the writer may not know how to correct the spelling error. They may leave the error in the text, revise it incorrectly, or decide not to use that word (Hayes et al., 1987; Wengelin, 2007). The writer might change the error to another word, or the text may be rephrased or even deleted (Wengelin, 2007). Similarly, if a lexical representation contains a spelling error, the writer may revise the spelling before that word is transcribed to the page or choose an alternative word or phrase in order to avoid writing that word (Fitzgerald, 1987; Sumner,

Connelly, & Barnett, 2014; Wengelin, 2007). Revision of a lexical representation is not visible in the text product, though potentially could cause a pause in transcription, particularly if rethinking word choice, which requires translation, a cognitive process considered to be a bottleneck to writing fluency (Hayes & Chenoweth, 2007; Sumner et al., 2016; Wengelin, 2007). Spending additional time on translation has been linked to production of poorer quality texts (Beauvais et al., 2011).

In reviewing revision models, Alamargot and Chanquoy (2001) write that, while models (Bereiter & Scardamalia, 1987; Flower et al., 1986; Hayes et al., 1987) describe stages of revision, they do not consider motivation for revision or situational factors. This means that the impact of spellcheck is not something revision models account for. Spellcheck changes the revision process, for example, spellcheck alerts the writer to the error, perhaps motivating the writer to address it, and it can change the writer's situation by providing spelling information the writer may not have and allows the writer to use reading knowledge (as opposed to spelling knowledge) to select the target word and use it to replace the error.

1.3 Cognitive Resources

1.3.1 Long-term memory

A writer's long-term memory stores their knowledge used for the topic of writing, knowledge of language and vocabulary, knowledge of spelling, and more. During writing, knowledge is extracted from long-term memory into working memory where the information can be used (Hayes & Berninger, 2014).

Lexicon

The words that an individual has learned are stored in the lexicon, a mental word bank (Margolin, 1984; Tainturier & Rapp, 2003). Words are retrieved from the lexicon when using the lexical route in spelling. This includes semantic, phonological and orthographic information. This information is sometimes considered to be stored in separate lexicons, a semantic lexicon, phonological output lexicon and orthographic output lexicon (Shelton & Weinrich, 1997).

1.3.2 Working memory

Working memory is a system for storing information while cognitive operations are performed (Bereiter & Scardamalia, 1987; Hayes & Berninger, 2014; McCutchen, 1996). The working memory includes the episodic buffer and two slave systems: the phonological loop and the visuospatial sketchpad (Baddeley, 2000); these are described in following subsections. All components in working memory are described as having temporary storage and the ability to problem-solve and synthesize information (Baddeley, 2000). These mechanisms use working memory resources to keep information available for immediate processing. Working memory

resources refer to the mental energy available at a given moment that cognitive processes require for storing and processing information (Piolat et al., 2004). There is a limit to how much can be processed and stored at once due to the limited working memory capacity (McCutchen, 1996). Working memory capacity corresponds to the maximal amount of working memory resources available to an individual (Piolat et al., 2004).

Episodic buffer

The episodic buffer acts as a temporary modelling space between long term memory and slave systems. Mental representations of written texts are multidimensional (Olive, 2012) and the episodic buffer is responsible for combining multidimensional information into coherent episodes which are consciously retrievable (Baddeley, 2000). Multiple representations of information include semantic prelexical, lexical and orthographic (built or retrieved spelling) (Olive & Passerault, 2012). When it comes to spelling for example, phonemes (sounds) and graphemes (letters) are thought to be stored in separate parts of the slave systems, then put together by the episodic buffer (Olive & Passerault, 2012; Tainturier & Rapp, 2003). As illustrated in Figure 1.2, the episodic buffer is used throughout the writing process, in problem-solving and information synthesis, for conceptualisation, for spelling, and for evaluation during the writing process.

Phonological loop

The phonological loop processes, stores and rehearses verbal and acoustic information (Baddeley & Hitch, 1972), it is sometimes referred to as verbal working memory (Kellogg et al., 2007). The two components of the phonological loop are the articulatory control process and phonological store. The articulatory control process refreshes the information in the phonological store. In reading it is also involved in converting written material into phonological code so that it can be registered by the phonological store. The phonological store holds the information for 1.5-2 seconds using a conscious sub vocal articulatory rehearsal system. Lexical information, such as the text to be written, is rehearsed by an inner voice (Chenoweth & Hayes 2003) which appears to be this subvocal articulatory rehearsal system. The phonological loop is important in storing the lexical representation being produced and in the translation process. The rehearsal of existing lexical representations allows any deterioration in the memory trace to be repaired. This reflects the concept of retranslation (Hayes, 2012). Suppression of articulatory rehearsal leads to deterioration and some loss of information (Chenoweth & Hayes 2003). Furthermore, lexical representations that are heard as an inner voice allow the writer to review and edit this, prior to committing to transcription of the text (Chenoweth & Hayes, 2003).

Visuospatial sketchpad and graphemic buffer

The visuospatial sketchpad stores and manipulates visual images. The role of visual working memory or the visuospatial sketchpad might be quite limited in text production. Olive and Passerault (2012) suggest that visuospatial dimension of writing is important for reading and reviewing texts. However, in terms of initial text production, Kellogg et al. (2007) proposed that

generating concrete ideas would invoke visual imagery but that without concrete visual representations of the words, visual working memory is of little use.

In spelling, although the graphemic and to some extent the orthographic representations are thought to have visual representations, rather than being stored and manipulated by the visuospatial sketchpad, such information is manipulated and stored by graphemic buffer (or graphemic output lexicon) (Afonso et al., 2015; Caramazza, Miceli, Villa, & Romani, 1987; Ellis, 2016; Tainturier & Rapp, 2003). The graphemic buffer is a dedicated working memory system. In spelling, it is responsible for temporarily storing and maintaining abstract letter sequences produced that are then used in transcription processes where abstract letter sequences are converted into specific letter shapes used to guide graphomotor processes for text production (Caramazza et al., 1987; Tainturier & Rapp, 2003). It has been proposed that damage to the graphemic buffer results in misspellings due to substitutions, insertions deletions or transpositions of letters (Caramazza et al., 1987).

1.3.3 The central executive

The central executive is the component of working memory responsible for allocating attention within the working memory system (see E in Figure 1.2). The central executive uses attention mechanisms to manage multiple processes with limited working memory capacity. This requires focusing, dividing and switching of attention between the writing processes by coordinating the working memory components that support each of the writing processes. It is thought that, in well-practised adults, graphomotor execution may operate with minimum or no executive attention, but all other processes rely on the central executive (Kellogg, Olive, & Piolat, 2007).

Executive functioning uses some working memory resources (Berninger, Rijlaarsdam, & Fayol, 2012). Higher-order executive functioning supports conceptualising, translating, planning, reviewing and revising. Lower order executive function supports the supervision of attention mechanisms. A well-developed central executive allows prioritisation of processes and storage for controlling working memory components whilst largely ignoring irrelevant information (Baddeley, 2000; Baddeley & Hitch, 1972; Hayes & Berninger, 2014). Kellogg et al. (2007) suggest that the central executive may be the most important component in writing due to its involvement in all writing processes.

1.3.4 Attention

Attention refers to mechanisms involved in controlling or filtering information being taken in from the environment. The word 'attention' is sometimes used interchangeably with the term 'cognitive resources' or 'cognitive capacity' when describing the distribution of resources (e.g. 'how much attention is given to a process'). For clarity, in this thesis when describing the distribution of cognitive resources, the term 'working memory resources' will be used rather than

‘attention’. The term ‘attention’ will be used when referring to attention mechanisms as described in this section.

In the writing model by Hayes and Berninger (2014) the resource labelled 'attention' is described as focused attention, the mechanism that allows the writer to maintain focus and ignore distraction, this is also known as selective attention. In writing, the writer must monitor internal processes involved in text production. The internal processes include the writing processes described earlier. Monitoring multiple processes simultaneously requires both selective and divided attention. Furthermore, these attentional mechanisms are used to take in information from the environment.

Selective and divided attention

Selective and divided attention are controlled by the central executive and supported by working memory resources. For selective attention, the central executive inhibits some processes and information in order to prioritise other information processing. Divided attention allows the writer to attend multiple processes simultaneously. Selective and divided attention are important for developing writing strategies.

Attention switching

Attention switching refers to flexible rapid changing of attention. Attention switching allows writers to switch between writing processes while continuing with transcription. For example, in translation the central executive manages processing by switching between the cognitive and linguistic systems to translate a prelexical representation (conceptual message) into a lexical format.

1.4 Organising Cognitive Writing Processes

1.4.1 Parallel and sequential processing

When processes are carried out, they require varying amounts of working memory resources. Providing that the total processing demands do not exceed writers' limited working memory capacity, writers can continue to transcribe while processing other information, thus with good executive skills, processes can be orchestrated in parallel (Kellogg, 1996; Hayes 2012; Hayes & Berninger, 2014; Olive, 2014). This means that writers can continue to produce text on the page whilst switching attention between other writing processes, resulting in a smooth flow of writing (Olive & Kellogg, 2002).

Working memory has a limited overall capacity for processing and storage, thus processes and storage compete for working memory (McCutchen, 1996). When one of the processes involved in writing draws upon large proportions of working memory then this leaves less available for other processes (Berninger & Swanson, 1994; Olive, 2014), and so the needs of other processes will not be met, and must be run sequentially (Bourdin & Fayol, 2002; Maggio et

al., 2015; Olive, Favart, et al., 2009; Olive & Kellogg, 2002). Writers carry out more or less parallel processing depending on the availability of resources (Olive, 2014).

Beginner writers need to devote large amounts of working memory resources to each process thus, for these writers, parallel processing is rarely possible and they need to resort to running processes sequentially. As described previously and shown in Figure 1.2, a writer cannot transcribe a piece of information until it has been conceptualised, translated and spelled. If only one piece of information can be processed at a time then it must be processed until it is ready for transcription, then only after transcribing that piece of information can the writer needs to begin processing another piece of information. Thus, when processing sequentially the writer cannot keep up a continuous flow of transcription and so beginner writers spend large proportions of time paused (Olive & Kellogg, 2002). However, typically, as writing skills develop these processes require smaller proportions of working memory resources (Berninger & Swanson, 1994). Eventually writing processes require so little working memory resources that multiple processes can operate in parallel without exceeding the limited working memory capacity.

1.4.2 Development of writing processing and management

Berninger and Swanson (1994) report that, in typically developing writers, while the amount of working memory resources required reduces, the amount by which it reduces and the speed at which it reduces varies per process and per person. At each of the three stages of writing development (described in the next two paragraphs) a different skill becomes the constraining factor, but as the skill slowly develops it requires less working memory resources until it is no longer the constraining factor. Thus, the amount of working memory resources required by processes reduces at different rates because the working memory capacity is limited.

Transcription, which in Berninger and Swanson's (1994) model includes spelling and graphomotor skills, is the first process to constrain writing for beginning writers, this is at ages six to ten. Motor skill and spelling predicted the length and quality of texts by children at this stage (Berninger et al., 1992). Furthermore, Berninger and Swanson (1994) report that while children struggle to transcribe texts, they are capable of conceptualising and translating the texts in their minds, and as a result, children can 'read' long, well-formed texts even when they have produced very few words on a page. Transcription depends on the development and coordination of spelling and graphomotor execution and the degree to which this coordination occurs automatically, without great effort. When this coordination reaches such a point, transcription takes less working memory resources. Thus more is available for composing. As children develop and practise transcription skills, the constraining factor in writing becomes translation. At 11-14 years, the strongest predictor of text quality is the ability to generate new sentences from given stimuli (Berninger et al., 1992).

The last process to constrain writing, at ages 15-18, is composition and structuring text. Composition and structuring involve ordering the content and considering how the message of the

text is conveyed by the intended audience, this requires planning. Writers begin to plan on a whole-text level, but executive functioning needed for planning lags behind the (still developing) skills in transcription and translation, hampering text quality. However, planning and revising skills slowly develop and the quality of texts produced increases. More planning and revising leads to higher quality texts (Swanson & Berninger, 1994; Berierter & Scardmalia 1987). Although the working memory resource requirements of individual writing processes decrease with practise, the overall working memory resources devoted to writing does not necessarily decrease. Rather, the resources which are no longer required for one process will be reassigned elsewhere (Kellogg, 1996).

Students in Higher Education (HE) are frequently used in general writing research and are assumed to be well-practised at writing, which has been evidenced by reductions in working memory resources required for transcription (Berninger et al., 2002) and, pause profiles that indicate parallel processing and practised coordination of writing processes (Olive, Alves, et al., 2009; Olive & Kellogg, 2002). Higher Education student writers are also assumed to be competent at typing and at using word processing programs. Typing ability is evidenced by typing speed and accuracy (Warmington et al., 2012), where fluent text production reflects reductions in working memory resources required and efficient coordination of these processes (Torrance et al., 2016; Wengelin, 2007). There is a lack of evidence for proficiency at using word processing programs beyond typing skills, for example, whether HE student writers are making the most of features that word processing programs offer, such as spellcheck.

1.4.3 Cascading organisation

The most advantageous position for a writer is to have low demands on working memory resources and high executive skills, to better coordinate processing as the information flows, or ‘cascades’, from process to process (Olive, 2014). In Olive's (2014) cascading model, information flows from conceptualisation to formulation (formulation roughly corresponds to a combination of translation and spelling), and then to execution (transcription). This flow of information is compatible with that shown in Figure 1.2. Figure 1.3(a) describes how multiple information packets can be processed simultaneously, demonstrating how the central executive orchestrates writing processes to run in parallel and promote smooth continuous transcription without a pause between transcribing information packets ‘N’ and ‘N+1’. Furthermore, not seen in the figure but described by Olive (2014), information not only cascades from process to process but also within each process. For example, within the transcription process, while the writer executes the movement of one letter the motor pattern of the following letter is being retrieved, thus enabling a smooth flow of text production.

Figure 1.3(b) illustrates sequential processing, as described earlier in subsection 1.4.1, with a pause in transcription between information packages ‘N’ and ‘N+1’. Olives original model

describes the orchestration of components in writing when transcription involves handwriting but is used in this thesis to describe writing when transcription involves typing.

Figure 1.3 The cascading organisation of writing from Olive (2014)

Figure 1.3 has been removed from this version of the thesis due to copyright restrictions

Figure 1.3 A schematic representation of the orchestration of writing processes when producing the sentence “*I am trying to explain what a cascade is*”. Parallel processing is illustrated in (a), while (b) represents the sequential coordination of the writing processes.

NB: The white ‘a’ box represents a period where buffering is necessary while the following processes get ready to operate. The white ‘b’ box indicates a pause in transcription, necessary to allow conceptualisation and formulation of segment $n+1$.

1.4.4 Writing bursts

The number of words produced between pauses in transcription is referred to as a writing burst. Although writing processes can be coordinated to achieve smooth continuous flow of text production, adult writers typically produce text continuously for 11 or so words at a time (Chenoweth & Hayes, 2003; 13 words according to Torrance, 2017). Bursts end at sentence and clause boundaries in around 40% of cases, which is more than expected by chance (Hayes, 2012). It is likely that writers make use of parallel processing to produce the long writing bursts that end at sentence and clause boundaries. When a writer pauses transcription after a writing burst, that previous writing burst is considered a 'pause-burst' (P-burst). It is widely accepted that a pause in transcription indicates a reduction in parallel processing (Bourdin & Fayol, 2002; Maggio, Lété, Chenu, Jisa, & Fayol, 2012; Olive, 2014; Olive & Kellogg, 2002). Thus the pause after a P-burst

is indicative of the writer stopping transcription to release working memory to other processes, which Hayes (2012) considers to be largely translation. Translation is assumed to be the bottleneck in this process following a series of studies by Hayes and Chenoweth (2003, 2006, 2007). In these studies, when writers copied text, they did not transcribe in bursts (Hayes & Chenoweth, 2006), thus bursts are not caused by transcription only. When writers rearranged sentences, meaning they had to use translation as well as transcription (but not conceptualisation), writers did write in bursts (Hayes & Chenoweth, 2007). Hayes (2012) concludes that translation processes are the prime source of language bursts.

1.5 Revision Interrupts Text Production

Writing bursts can be interrupted by the need to revise text produced so far, such as the need to revise a spelling error. A writing burst that comes before the revision is called a revision burst (R-burst). These bursts refer only to observable revisions made to text and not revisions made to mental representations. R-bursts make up 13% of writing bursts and are generally shorter (6.39 words) than P-bursts (11.10 words) (Chenoweth & Hayes, 2003). R-bursts are P-bursts that have been interrupted by revisions (Chenoweth & Hayes, 2003). It appears that, without revision, transcription would continue for another four or five words. In terms of cognitive processing, it seems that R-bursts end in order to release working memory for revision demonstrating the competition between revision and text production.

Chenoweth and Hayes (2003) describe that during text production, the lexical representation is being dictated by a perceived inner voice, a subvocal articulatory rehearsal process which appears to be the same articulatory rehearsal process as the phonological loop (Baddeley & Hitch, 1972). Chenoweth and Hayes (2003) demonstrated this by asking writers to produce written descriptions of stimuli (cartoons) and repeat the word 'tap' (articulatory suppression). This reduced P-bursts to 8.22 words compared to 11.10 without the articulatory suppression. Interrupting articulatory rehearsal (inner voice), or overloading the capacity of the phonological loop, reduced ability to write, though not to the same extent as revision did.

When revision processes compete with the processing and storage of the lexical representation (text to be written) the lexical representation is in danger of becoming lost or damaged. This reflects McCutchen's (1996) capacity theory which dictates that working memory resources are shared between processes and storage (McCutchen, 1996; Berninger et al, 2002). Thus, if revision processes take up a lot of working memory resources, then little is left for the maintenance and storage of the lexical representation and the lexical representation could become damaged or lost before it can be transcribed on to the page. Once the lexical representation is on the page, working memory resources can be released for other purposes such as spelling error revision (Wengelin et al., 2009)

Competition for working memory needs to be managed by the central executive, for example by employing selective attention to focus on either error revision or on the text to be written, and inhibiting processing the other. Thus, when a writer notices an error during text production, assuming that the writer does revise the error, they could either revise it straight away or defer revision (Hayes et al., 1987) in favour of continuing with text production first and transcribing the lexical representation safely onto the page. How writers respond to this dilemma has been investigated using a sentence completion task (Leijten et al., 2007; van Waes et al., 2010).

Leijten et al., (2007) created a sentence completion task to emulate situations where a writer notices an error during text production. Sixty Dutch-speaking university students were presented with a series of partial sentences that sometimes contained a semantic error (rather than a misspelling). The partial sentence represented the text-written-so-far. The writers were tasked with correcting the error and completing the sentence, in either order. Thus writers faced the dilemma of which action to carry out first. Writers were presented with the partial sentence either visually only, or aurally then visually. Eye movements and keystrokes were recorded to provide behavioural data.

Reading with auditory feedback has been found to improve the accuracy of error correction (Pilotti, Maxwell, & Chodorow, 2006), however, audio presentation did not encourage prioritisation of error revision, writers tend to continue writing the sentence before correcting the error. In visual-only conditions writers completed the sentence first in 66% of trials. Interestingly, this increased to 94% when the partial sentence was presented aurally then visually (Leijten et al., 2007). The authors concluded that, when uncertain of errors, writers focus on finding and revising errors, but audio presentation allowed easier identification of errors which helped writers to be more certain of errors, allowing them to focus on completing their sentences. However, it is also possible that while audio played, writers built a lexical representation of the sentence ending, which was then at risk if they edited the error first, thus by completing the sentence first writers may have been showing risk-averse behaviour.

Van Waes et al. (2010) expanded Leijten et al.'s (2007) task design to investigate the effect of sentence complexity on the coordination of error revision with sentence completion. Authors presented partial sentences to 32 Dutch-speaking undergraduates, using audio then visual stimuli. Visual stimuli contained a spelling error in 50% of trials. Writers were given either one or three content words to include in the sentence end to create low and high cognitive load conditions respectively. Each writer completed seven trials in each condition (one or three words, error or no error).

A combination of eye-tracking and keystroke logging revealed that, even though writers noticed the semantic error in 80% of cases before starting to type, they only began trials with error revision 10% of the time. Thus, in 90% of cases writers deferred error revision. Writers rarely started trials with revision, but when they did it tended to be in conditions with a lower

cognitive load when the lexical representation was less at risk. In addition, when writers began trials with revision, the longer writers spent reading during the initial latency (measured as sum of fixation time), the less likely they were to incorporate the given words in the sentence end (van Waes et al., 2010). This suggests that the longer it is before the lexical representation is transcribed, the more likely it is to become lost or damaged. The authors suggested that deferring revision in favour of sentence writing is a strategy to conserve the lexical representation. Inhibiting error revision in order to transcribe the lexical representation demonstrates effective management of cognitive resources. Whether writers respond in the same way to spelling errors, as opposed to semantic errors, has not been investigated. Furthermore, because Dutch has a more transparent orthography than English, spelling errors could be more difficult to identify and correct when writing in English.

1.6 Conclusions

Writing models provide general frameworks which can be used to illustrate possible ways in which one could manage multiple components with limited resources. As described in the thesis introduction, Hayes and Berningers (2014) writing model is well cited and based on a large accumulation of strong empirical evidence. However, while there is much literature available to describe cognitive components involved in writing, there is limited empirical evidence for how writers orchestrate processes in a complex writing situation, such as when experiencing competition between revision and text production. Managing writing processes in complex situations is likely to be even more difficult for writers with dyslexia who struggle with spelling (Lyon, Shaywitz, & Shaywitz, 2003; Nergård-nilssen & Hulme, 2014; Tops, Callens, van Cauwenberghe, Adriaens, & Brysbaert, 2013; Wengelin, 2002; World Health Organisation, 2013) and have difficulties with some executive functioning (Berninger, Nielsen, et al., 2008; Hari & Renvall, 2001; Krause, 2015; Pickering, 2006; Swanson, 2006; Valdois et al., 2004). Exactly how dyslexia impacts writing, and what this could mean for the competition between revision and text production, is explored in the next chapter.

Dyslexia and Writing

2.1 Chapter Introduction

This chapter begins with a broad introduction to dyslexia which narrows to focus on writing difficulties that individuals with dyslexia experience. The impact of dyslexia on writing is described at the cognitive level referring to the components of writing described in Chapter 1. Following the same format as Chapter 1, the final section of this chapter is devoted to spelling error revision during writing, this time focussing on how dyslexia is likely to affect this process.

2.2 Defining Dyslexia

Dyslexia is widely recognised as a specific difficulty in learning to read (Rose, 2009; World Health Organisation, 2013). It is generally accepted that the core feature of dyslexia is a problem with word decoding, which causes difficulties with reading accuracy and fluency (Lyon et al., 2003; Torrance et al., 2016). Word decoding is using knowledge of letter-sound relationships to understand the pronunciation of written words. Writing is also affected, and spelling in particular (Nergård-nilssen & Hulme, 2014; Tops et al., 2013; Wengelin, 2002; World Health Organisation, 2013).

However, precisely how dyslexia is defined in terms of a diagnostic category is unclear. The current Diagnostic and Statistical Manual of mental disorders (DSM 5 by the American Psychological Association, 2013), which is used widely in clinical diagnosis, does not provide diagnostic criteria for dyslexia. Under the DSM 5 criteria, the pattern of learning difficulties associated with dyslexia would be referred to as a Specific Learning Disability (SpLD) with impairment in reading and in written expression (DSM 5 by the American Psychological Association, 2013). However, while dyslexia can be encompassed by this category, SpLD with impairment in reading and written expression is not specific to dyslexia. For example, an individual presenting with comprehension difficulties alongside poor grammar and punctuation accuracy (a pattern of difficulties that does not reflect dyslexia) would also be diagnosed with SpLD with impairment in reading and written expression. Dyslexia is recognised in regards to a pattern of learning difficulties characterized by problems with accurate or fluent word recognition, poor decoding, and poor spelling abilities, and use of the term dyslexia to describe this pattern is not discouraged in the DSM 5 (American Psychological Association, 2013). Furthermore the term dyslexia is still commonly used in research (for example, see papers published in the last 12 months: Kearns, Roeland, Hoeft, Pugh, & Frost, 2019; Lindstrom, 2018; Perry, Zorzi, & Ziegler, 2019; Snowling, Nash, Gooch, Hayiou-Thomas, & Hulme, 2019).

While many definitions specific to dyslexia exist, for this thesis dyslexia will be defined using the definition from Rose (2009):

Dyslexia is a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling. Characteristic features of dyslexia are difficulties in phonological awareness, verbal memory and verbal processing speed. Dyslexia occurs across the range of intellectual abilities. It is best thought of as a continuum, not a distinct category, and there are no clear cut-off points. Co-occurring difficulties may be seen in aspects of language, motor co-ordination, mental calculation, concentration and personal organisation, but these are not, by themselves, markers of dyslexia. A good indication of the severity and persistence of dyslexic difficulties can be gained by examining how the individual responds or has responded to well-founded intervention. (pp.9-10)

This definition is broken down into its components and discussed over the next few pages.

2.2.1 Characteristics

“Dyslexia is a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling” (Rose, 2009; p.9).

It is widely agreed that the presence of difficulties with reading accuracy or reading fluency, poor decoding and poor spelling abilities are an indication of dyslexia (for example by the British Psychological Society: a Working Party of the Division of Educational and Child Psychology, 1999; Hatcher, Snowling, & Griffiths, 2002; Rose, 2009; Snowling, 2013). These difficulties can be considered as inclusion criteria. Furthermore, this definition goes on to address the cause for the difficulties specified, suggesting that they are *directly* influenced by a core deficit within the phonological component of language. While the presence of difficulties is important for identifying the presence of dyslexia, specifying the underlying reasons is important for researching precisely which deficits lead to which difficulties and how these can best be supported.

2.2.2 Cognitive abilities

“Characteristic features of dyslexia are difficulties in phonological awareness, verbal memory and verbal processing speed. Dyslexia occurs across the range of intellectual abilities” (Rose, 2009; p.9).

Individuals with a range of cognitive abilities are diagnosed with dyslexia, this is supported by evidence from a longitudinal study of US children (from grades 2 or 4 to grade 9 or 10) measuring IQ (intelligence quotient) and reading ability (Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010). While individuals without dyslexia typically showed a close coupling of cognitive ability and reading development, individuals with dyslexia did not and so, for individuals with dyslexia, difficulties in reading were unrelated to cognitive abilities and perhaps unexpected in regard to cognitive abilities.

It is important to recognise that while dyslexia presents in individuals across a range of intellectual abilities, poor general cognitive abilities indicate that a broader disability is likely to be present. In such cases, a broader disability may provide better explanation of poor reading and spelling abilities than dyslexia. This section of the definition has received praise from Hulme and Snowling (2009) in their chapter ‘developmental dyslexia’, in which they echo the importance of specificity when defining dyslexia and write that excluding more general learning problems maximises the chances of establishing the underlying cognitive deficits at the route of dyslexia.

However, it should be noted that the majority of individuals with dyslexia experience other difficulties alongside phonological difficulties and many individuals diagnosed with dyslexia are also diagnosed with comorbid disorders. The high prevalence of other difficulties and disorders that accompany a phonological deficit has led to wider acceptance of multiple deficit models, which acknowledge range of cognitive function, not only a phonological deficit (Pennington, 2006).

2.2.3 Severity

“It is best thought of as a continuum, not a distinct category, and there are no clear cut-off points. ... A good indication of the severity and persistence of dyslexic difficulties can be gained by examining how the individual responds or has responded to well-founded intervention” (Rose, 2009; p.9).

There is no clear, agreed-upon division between good readers/writers, poor readers/writers and readers/writers with dyslexia. However, as set out in the definition, difficulties with accurate and/or fluent word recognition and poor spelling and decoding abilities must be present in order to indicate the presence of dyslexia. Two ways to assess whether an individual is experiencing difficulties with reading accuracy, fluency and spelling are to consider whether their abilities in these areas are having a negative impact on their day-to-day life (for example, The Adult Reading History Questionnaire, Lefly & Pennington, 2000), or to measure these abilities and compare them to what is expected given their age and other factors (for example, the YAA-R uses norms, Warmington, Stothard, & Snowling, 2012). Measuring specific skills and diagnosing core difficulties is important for investigating precisely which deficits relate to one another and how. This level of specificity is important for moving research forward but also important for determining the most appropriate form of support and intervention. Measuring skills associated with dyslexia tends to include some thresholds, although they vary depending on purpose of the measures and definition being used.

2.2.4 Prevalence of dyslexia in the UK

The prevalence of dyslexia is determined by how it is defined and measured. When thresholds are used to identify the presence of dyslexia, stringent thresholds cause lower prevalence while more inclusive thresholds lead to higher prevalence. Multiple thresholds can be used to separate severity of difficulties measured, for example, the British Dyslexia Association

(BDA) separate mild and severe difficulties. The BDA suggest that 4% of the population have severe dyslexia while 10% show mild dyslexia (British Dyslexia Association, 2019) however the differences between mild and severe dyslexia, or any thresholds and measures used, are not described. Furthermore, it is assumed that the BDA include all ages in this estimate, but this is not specified on their website.

Other research, using a particularly large sample of (around 5000), considered children to have dyslexia if they performed 1.5 to 2 standard deviations below what was expected for their age, intelligence and education, and found proportions of dyslexia in UK primary and secondary schools are at 3-10% (Hulme & Snowling, 2009; Snowling, 2012) which is similar to the BDA estimate. The prevalence of dyslexia among adults is less documented than that of children. The APA estimate the prevalence of USA adults at 4% (APA, 2013). There does not appear to be an estimation specific to adults with dyslexia in the UK. However, some information about the percentages of UK HE students with a specific learning disorder is available from Higher Education Statistics Agency (HESA).

Of the students in UK HE institutions with registered disabilities in 2015/6, 44.23% have a specific learning disorder, this is 5.22% of students overall (HESA, 2016). Individuals with dyslexia make up some proportion of those with a specific learning disability. Unfortunately, the percentage of adults with a specific learning disability who have dyslexia is not reported, thus it is not clear what proportion of UK HE students have dyslexia. With all students with registered SLD at 5.22%, the proportion of HE students with dyslexia is likely to be equal to or less than the lower end of the prevalence estimates for the whole population (4-10% as suggested by the BDA, 3-10% suggested by Hulme & Snowling, 2009). It is possible that, as HE is not compulsory, smaller proportions of individuals with dyslexia attend university in comparison to the proportion in schools. Difficulties with reading and spelling impact academic performance (Richardson, 2009; Richardson & Wydell, 2003) and self-esteem (Riddick, Sterling, Farmer, & Morgan, 1999; Ridsdale, 2005) which may impact the opportunity and choice to attend HE.

2.2.5 Secondary consequences and co-occurring difficulties

“Co-occurring difficulties may be seen in aspects of language, motor co-ordination, mental calculation, concentration and personal organisation, but these are not, by themselves, markers of dyslexia” (Rose, 2009; p.10).

Vocabulary may tend to be poorer for individuals with dyslexia, but it is generally thought that this is a secondary consequence of dyslexia, due to poorer reading and less reading, rather than a direct consequence of dyslexia (Elliot & Grigorenko, 2014). Diverse vocabulary choices (lexical diversity) are important in writing because lexical diversity correlates with writing quality in compositions by adults with dyslexia (Connelly et al., 2006). Some studies have not found a difference in lexical diversity in texts by writers with and without dyslexia (Connelly et al., 2006; Tops et al., 2013; Sumner 2016). However, other research has found that while there tends to be

no difference between lexical diversity in spoken narratives between writers with and without dyslexia, texts by writers with dyslexia do show poorer lexical diversity than text by writers without dyslexia (Sumner, Connelly, & Barnett, 2016; Wengelin, 2007). Authors of those studies suggest that poor lexical diversity may be related to, a secondary consequence of, poor spelling ability (Sumner, Connelly, & Barnett, in press; Sumner et al., 2016; Wengelin, 2007). More detail of this relationship can be found in Chapter 3, page 61.

Poor word-reading ability contributes to sentence comprehension difficulties, even in high achieving adult students with dyslexia (Wiseheart & Altmann, 2018). Comprehension difficulties can occur as a secondary consequence of dyslexia because of poor reading accuracy and fluency but are not part of dyslexia (Snowling, 2012). In addition, poor comprehension can lead to poorer background knowledge if relying on reading. Although we gain background knowledge in ways other than reading, reading is a prominent method of developing background knowledge within education. A good reader can comprehend information beyond their current domain knowledge, increasing their knowledge beyond that of poor reader with good knowledge (Adams et al. 1995).

Secondary, or indirect, consequences of dyslexia should not be confused with co-occurring difficulties. Co-occurring difficulties can affect aspects of writing but such effects are not consequences of dyslexia. Disorders that commonly co-occur with dyslexia and can impact writing include: developmental coordination disorder, motor difficulties impact handwriting speed and neatness (Prunty & Barnett, 2017; Prunty et al., 2014) and typing abilities (Niles-campbell, Tam, Mays, & Skidmore, 2008); and attention deficit syndrome which impacts ability to focus on tasks such as producing long texts (Adi-Japha et al., 2007; Rosenblum, Epsztein, & Josman, 2008). Other language difficulties can cooccur with dyslexia, such as developmental language disorder (DLD, previously referred to as ‘specific language impairment’, or ‘SLI’). Individuals with DLD experience problems with the acquisition and processing of oral language skills (Dockrell, Lindsay, Connelly, & Mackie, 2007) and, then, written language as well (Connelly, Dockrell, Walter, & Critten, 2012). Like dyslexia, DLD involves phonological processing difficulties, but unlike dyslexia also involves broader language difficulties such as production and comprehension of spoken language (Bishop & Snowling, 2004). Thus difficulties associated with DLD and dyslexia overlap, but DLD is distinct from dyslexia (Catts, Adlof, Hogan, & Weismer, 2005). Bishop and Snowling (2004) describe the relationship between SLI (the terminology used at the time) and dyslexia using a two-dimensional continuum of phonological and non-phonological language skills, shown in Figure 2.1 (this figure also includes poor comprehenders, for more information on this group see Snowling, 2012 and Snowling, Hayiou-Thomas, Nash & Hulme, 2019).

In research specifically into dyslexia, it is important to account for co-occurring difficulties and the impact of these on the performance of abilities being measured or to use participants without co-occurring difficulties. Separating the consequences and underlying causes of dyslexia from other conditions allows for more accurate investigation into dyslexia.

Figure 2.1 A representation of the relationship between dyslexia and SLI from Bishop and Snowling (2004)

Figure 2.1 has been removed from this version of the thesis due to copyright restrictions

Figure 2.1 The typical phonological and non-phonological language abilities of each group are indicated by the arrows, with ‘+’ indicating expected and ‘-’ indicating less than expected.

2.2.6 Dyslexia in adulthood

Dyslexia is a lifelong condition (Hulme & Snowling, 2009; Maughan et al., 2009; Warmington et al., 2012). This thesis is focussed on adults with dyslexia, particularly those in UK HE. Most adults with dyslexia complain of slow reading, problems with spelling and difficulties with written expression (Snowling, 2012). Spelling problems are the most prominent indication of dyslexia in adults followed by text reading fluency and nonword decoding (Nergård-nilssen & Hulme, 2014). In a UK based survey, 80% of (n=42) adults with childhood dyslexia reported below average spelling, compared to 13% of comparison group (n=86) (Maughan et al., 2009). Furthermore, 80% of adults in the dyslexia group reported experiencing problems with day-to-day writing such as form filling, and 77% reported that they need help with these activities. In comparison, 17% of the group without dyslexia reported experiencing problems and 6% reported they require assistance. Thus, for adults with dyslexia, spelling problems impact their daily lives.

Undergraduates with dyslexia, who are considered ‘high-functioning’ and may have developed compensatory strategies (Coleman, Gregg, McLain, & Bellair, 2009; Mapou, 2008),

also demonstrate difficulty with spelling. In essays written by undergraduates with dyslexia, spelling errors constituted 4% of texts (Sumner & Connelly, 2020), which is only slightly lower than texts by children ($n=55$, ages 11-14) with dyslexia whose errors made up 5.93% of their essays (MacArthur et al., 1996), demonstrating persistence of poor spelling into adulthood. For UK students with dyslexia writing forms part of their day-to-day life and influences their academic achievement, and so writing skills are particularly important for these adults.

Graduates with dyslexia were less likely to obtain degrees with 1st or 2:1 than graduates with no known disability in 1995-1996 (Richardson & Wydell, 2003) and again for students graduating 2004-2005, where a higher proportion of students with dyslexia graduated, significantly smaller proportion of students with dyslexia obtained 1st or 2:1s (Richardson 2009). However, further investigation suggested that other factors, including age, prior qualifications and subject being studied explain a lot of the variance and led Richardson (2009) to conclude that, provided individuals with dyslexia receive appropriate support they are as likely to obtain a 1st or 2:1 as students with no known disability. Such support may include help with writing. Generally, adults in HE continue to struggle with writing and find writing more effortful than their peers without dyslexia do (Connelly et al., 2007; Elliot & Grigorenko, 2014; Mortimore & Crozier, 2006; Nergård-nilssen & Hulme, 2014; Sumner et al., in press; Torrance et al., 2016). Details of the impact that dyslexia has on writing performance is described in the next section.

2.3 Adults with Dyslexia and Writing

It is widely agreed that spelling problems are the most prominent difficulty in adults with dyslexia (Nergård-nilssen & Hulme, 2014; Tops et al., 2013). It is well established that individuals with dyslexia perform less well in spelling tests and that texts by writers with dyslexia contain more spelling errors than texts by their typically developing peers (Coleman et al., 2009; Connelly et al., 2006; Connelly & Dockrell, 2017; Sumner et al., in press; Tops et al., 2013). In typically developing writers, spelling, as part of transcription, acts as a constraint around ages six to ten, but as writers develop these skills, less working memory needs to be devoted to them and, eventually, spelling no longer constrains their writing (Berninger and Swanson, 1994, and as described in Chapter 1). However, for writers with dyslexia, spelling continues to constrain writing into adulthood, causing more pausing in transcription indicating that writers are less able to make use of parallel processing (Medimorec & Risko, 2017; Sumner et al., in press; Wengelin, 2007).

Poor spelling is not only problematic during text production, it also has a negative influence on judgements of text quality (Figueredo & Varnhagen, 2005; Johnson, Wilson, & Roscoe, 2017), even when texts with spelling errors are compared with the same word for word text with no spelling errors (Marshall & Powers, 1969; Rezaei & Lovorn, 2010). In addition, raters do not always know that they are being influenced by spelling accuracy, for example, raters indicated that essays without spelling errors were better than the same essays with spelling errors

due to better quality of ideas (Graham, Harris, Hebert, 2011). However, even with errors removed, texts by writers with dyslexia have been rated as generally poorer by teachers who were blind to conditions (Tops et al., 2013). Thus the poor quality of texts goes beyond spelling.

Using the WOLD to score six aspects of essay quality, Sumner and Connelly (2020) found that essays by UK undergraduates with dyslexia exhibited poorer sentence structure, organisation and coherence, grammar, capitalisation and punctuation (Sumner & Connelly, 2020) than essays by age-matched peers, but essays scored equally for vocabulary and for ideas and development. Encouragingly, groups with and without dyslexia also performed equally in ideas and development in a similar study by Connelly, Gee, and Walsh, (2007). This suggests that texts by adult writers (or at least writers attending university) do not show difficulties related to conceptualisation. Instead overall quality appears to be poorer in ways that make text less fluent to the reader, potentially indicating difficulties with processes that occur after initial conceptualisation. Tops et al., (2013) also found that texts by writers with dyslexia could not be read as fluently as texts by writers without dyslexia.

Exactly how text by writers with dyslexia is poorer is perhaps not captured accurately by WOLD measures of text quality or it varies across samples. For example, Connelly et al. (2007) also measured texts by undergraduates with and without dyslexia from the same university as Sumner and Connelly (2020) and using the same writing task. However, while measures of capitalisation and punctuation was poorer in essays by writers with dyslexia, as it was in Sumner and Connelly's (2020) study, the measures taken of other aspects were not reflected by Sumner and Connelly's (2020) findings. Thus while it is clear that writers with dyslexia tend to produce poorer quality texts, and that this goes beyond spelling accuracy, pin pointing exactly why quality is poorer has proven difficult.

A number of studies have found that texts by writers with dyslexia show poorer vocabulary and lexical diversity than texts by writers without dyslexia (Connelly et al., 2006; Sumner et al., 2016; Tops et al., 2013; Wengelin, 2007). Vocabulary is important in writing quality, it has been shown to account for variance in text quality more than any other aspect of text or other ability (such as working memory span and handwriting fluency) (Connelly et al., 2006; Sumner & Connelly, 2020). Comparisons of spoken and written texts have shown lexical diversity of texts by individuals with dyslexia is only poorer than that of peers when written but not when spoken, thus poorer lexical diversity is not related to translation but appears to be related to spelling and or transcription (Sumner et al., 2016; Wengelin, 2007). Difficulties with spelling appear to restrict word choice (Berninger, Nielsen, et al., 2008; Sumner et al., 2016; Wengelin, 2007). Spelling and vocabulary measures have an interesting relationship which requires further investigation. More on this relationship is written at the end of this chapter, in the section 'Word-Level Focus', furthermore, this relationship is investigated in Chapter 6.

Reading is part of writing (Hayes & Berninger, 2014; Shanahan, 2017), difficulties with reading cause individuals with dyslexia to be slower at extracting the required words, and limited

in their engagement with the text written so far (Connelly & Dockrell, 2017; O'Rourke, Connelly, & Barnett, 2018). Poor word recognition combined with poor spelling also has a long-term negative impact on vocabulary available for writing (O'Rourke, Connelly, Barnett, 2018), for details of this relationship between word recognition, spelling and written vocabulary, see the subsection on phonemic awareness (section 2.3.2).

In the subsections that follow, why dyslexia impacts writing is described using a popular cognitive explanation of dyslexia, a phonological deficit. The possibility that writers with dyslexia are affected by difficulties with central executive functioning is also explored.

2.3.1 Phonological processing

While there are many hypotheses regarding the cause of difficulties associated with dyslexia, one broadly accepted cognitive explanation is that individuals with dyslexia have a phonological deficit (Elliot & Grigorenko, 2014; Ellis, 2016; Snowling, 2012). A phonological deficit is where the individual possesses poor phonological knowledge or an inability to create clear lexical representations, an inability to store them without them becoming degraded or an inability to access them (Elliot and Grigorinko, 2014; Hulme and Snowling 2009). Hence a phonological deficit causes difficulties writing ideas onto the page as writers experience poor spelling, poorer written vocabulary and a word-level focus as writers struggle over words (Connelly & Dockrell, 2017; Wengelin, 2007). Difficulties with processing, storage and access of phonological information stem from poor phonemic awareness (described below).

2.3.2 Phonemic awareness

Phonemic awareness is the ability to identify and manipulate individual phonemes. It is a part of the larger umbrella of phonological knowledge which also includes understanding and manipulation of intonation, rhythm, rhyme and syllables. Phonemic awareness is needed for phonemic structuring, which is the selection and manipulation of individual phonemes (sounds which are independent of meaning). Poor phonemic awareness causes difficulties with phonemic structuring, which in turn makes it difficult to analyse, produce and manipulate phonological representations (Blachman, 2017). Phonological representations are mental representations of phonemes and phoneme combinations (Goswami, 2012). These exist at the cognitive level (consonant phonemes and vowel phonemes), the linguistic level (articulation), and the acoustic level (raw signals of pitch loudness and duration) (Goswami, 2012). Phonological representations are part of the orthographic component of lexical representations (see Chapter 1).

When defining dyslexia, Warmington et al. (2012) write that, in addition to Lyon et al.'s (2003) definition, for individuals with dyslexia, the phonological boundaries of words (and their constituent phonemes) represented in lexical memory are not well specified, therefore, lexical representations are poor/weaker and lexicons are less rich because of poor phonemic awareness. Well-specified representations of words can be recognised as whole words in reading and can be

spelled using the lexical route. A less rich lexicon leads to slow and inaccurate recognition and production of text via the lexical route.

Without clear representations of words, writers need to rely on decoding skills (phoneme-grapheme mapping) and the sub-lexical route. Writers with dyslexia have difficulties developing knowledge of the sounds and how they connect to different symbols, thus decoding skills are poor. Poor phoneme-grapheme knowledge leads to difficulties in creating and using lexical and orthographic representations (Mishra, 2015). Such difficulties hinder the development of strong lexical representations (as described in the spelling section, concerning connectionist and PDP models, of the previous chapter, without frequent use, strong pathways are not developed). Completing this cycle, poorly structured representations cause difficulties acquiring grapheme–phoneme correspondence rules for phoneme-grapheme mapping.

Because of poor phonemic awareness, individuals with dyslexia cannot use skills and knowledge of representations to develop grapheme-phoneme skills and knowledge or vice-versa, as effectively as their peers can. Poor phoneme awareness has been found to be a persistent weakness in adults, it correlates with literacy problems (measured from a battery of tests) in (Norwegian) adults with dyslexia ($n=26$, mean age 34 years) (Nergård-nilssen & Hulme, 2014). Poor phonemic awareness causes difficulties with reading and spelling and with the creation/strengthening of orthographic representations. Poor and effortful reading and limited exposure to printed words contributes to poorer development of orthographic representations. Snowling and Hulme (2002) review several studies involving naming and identifying tasks where children with dyslexia exhibit receptive vocabulary (understanding, semantic representations) as well developed and accessed as peers' but expressive vocabulary poorer than peers', even when spoken. Snowling and Hulme (2002) suggest that phonemic awareness causes weaker or less easily accessed representations, which causes poorer expressive vocabulary. However, while adults with dyslexia in HE produce texts with poorer written vocabulary, their spoken vocabulary is equal to their peers (Sumner et al., 2016; Wengelin, 2007). It is possible that adults in HE, who are somewhat of a subgroup of the wider population with dyslexia, have compensatory strategies which allow them to develop receptive and expressive vocabulary equal to peers when speaking but their skills and knowledge specific to writing words remains weak.

2.3.3 Working memory

How the various components of working memory contribute to text production was described in the previous chapter. While problems with working memory is not included in Lyon et al.'s (2003) definition of dyslexia, working memory is frequently reported to be poorer in individuals with dyslexia (Connelly et al., 2006; Smith-Spark, Henry, Messer, Edvardsson, & Ziecik, 2016; Snowling, 2012; Nergård-nilssen & Hulme, 2014). This section focusses on how having dyslexia might affect working memory and why this impacts writing.

Working memory problems are mostly found in situations where stimuli can be phonologically encoded (Jeffries & Everatt, 2004; Swanson, 2006) but importantly, tend to be absent when tasks do not involve phonological processing (Elliot & Grigorenko, 2014). For example, a large corpus of adults with dyslexia ($N=200$) underwent extensive screening for literacy and working memory related abilities, results indicate that deficits with phonological processing interfere with working memory (Berninger, Nielsen, et al., 2008). The working memory components in adults with dyslexia that were most affected were the phonological loop and executive functioning. Problems with working memory are likely a secondary consequence of dyslexia due to a phonological deficit as opposed to co-occurring problems with general working memory. When tasks do not involve language processing, individuals with dyslexia may have as large a working memory capacity as anyone else (for a review see Elliot & Grigorenko, 2014 or Swanson, 2006).

Phonological processing, and some executive functioning, requires more working memory resources for writers with dyslexia than for a typically developing writer (Swanson 2006; Berninger et al., 2006). Therefore, they leave less available for other forms of processing and storage, such as translation of ideas and storage of lexical representations (Berninger et al., 2002; McCutchen, 1996; Olive & Kellogg, 2002; Torrance 2016). Less available resources causes reductions in parallel processing (Olive, 2014), which may in turn lead to less efficient phonological and orthographic loop functioning, slowing or preventing a writer's ability to perform tasks (Berninger, Nielsen, et al., 2008).

Reductions in parallel processing in writers with dyslexia has been shown by increased frequency of spelling related pausing during text production, a task heavily reliant on phonological processing (Sumner et al., 2012; Wengelin, 2007). Competition for working memory due to phonological deficit supports the word-level focus hypothesis, where working memory is devoted at word-level due to a phonological deficit. Thus working memory restricted for other processes, which contributes to production of text poorer in quality (Connelly et al., 2006; Sumner et al., in press; Wengelin, 2007). The limited capacity hypothesis and word-level focus hypothesis are widely accepted and have been used to explain and predict behaviours in many writing studies (McCutchen, 1996; Olive & Kellogg, 2002) including dyslexia studies (Sumner et al., 2013; Torrance et al., 2016, Wengelin 2007).

2.3.4 Central executive functioning

Competition for working memory is managed by the central executive. As described in the previous section, writing involves a great deal of competition for working memory resources, especially for writers with dyslexia who experience a phonological deficit. Swanson and colleagues have amassed an extensive body of work investigating central executive functioning and reading difficulties (RD), often including individuals with dyslexia. Their investigations separate executive functioning from phonological processing (for a summary of Swanson's

studies see Swanson, 2006). In reviews of this work, it has been concluded that individuals with dyslexia experience deficits with executive functioning, independent of the difficulties experienced with the phonological loop (Pickering, 2006; Swanson, 2006). Swanson (2006) writes that:

‘attention problems in children with RD are related to their capacity to maintain and hold relevant information in the face of interference or distraction’ (p.78).

Thus, managing competition between writing demands, such as between text production and revision is challenging.

It has been argued that for the study of dyslexia, the central executive is particularly significant because deficits with executive functioning cause difficulties in a number of attentional mechanisms, causing problems with active processing of information in working memory (Pickering, 2006). Specifically, individuals with dyslexia appear to struggle with inhibition (in selective attention) and attention switching (Hari & Renvall, 2001; Pickering, 2006; Swanson, 2006; Valdois et al., 2004) which may interfere with the efficiency of working memory in processing written language (Berninger, Nielsen, et al., 2008) and would explain why Swanson's findings indicate difficulty ignoring distractors. Difficulties with attention mechanisms (alongside a phonological deficit) could cause a breakdown of fluent cascaded production, reduced parallel processing (Olive, 2014), which may look somewhat like the shortened writing bursts as found by Chenoweth and Hayes (2003, 2007). Difficulty with these mechanisms is described as sluggish attentional shifting (SAS) which causes two problems: processing sequential stimuli is less effective; disengaging selective attention in order to focus on other information processing is slow.

SAS or visuo-attentional deficit typically co-occur with phonological processing and phonological awareness deficits in developmental dyslexia and is considered a plausible second core deficit in developmental dyslexia (Krause, 2015; Valdois et al., 2004). In typical writing development, executive functioning is a constraining factor in writing for older teenagers (ages 15-18, according to Swanson and Berninger, 1994, as described in Chapter 1). However, individuals with dyslexia continue to experience difficulties with executive functioning in their adulthood (Brosnan et al., 2002; Hari & Renvall, 2001; Krause, 2015). Executive functioning is needed in revision. Poor executive functioning hampers a writer's ability to use revision to meet their writing goals. Thus difficulties with executive functioning, such as SAS, might hamper revision in writing. How SAS impacts attentional mechanisms is described in the next two subsections.

Sequential stimuli

In review of a series of behavioural experiments on rapid sequential processing studies, adults with and without dyslexia recalled information from rapid sequential visual and audio stimuli and identified items among a series of distractors. Response times and response accuracy revealed that adults with dyslexia perform poorly in comparison to peers (Hari & Renvall, 2001).

This was the case even when phonological processing was not required (e.g. listening to clicks that vary in pitch, or watching appearances of lines and dots) Poor performance in tasks involving auditory processing of sequential stimuli, separating and manipulating sounds in words may contribute to poor phonemic awareness (Krause, 2015). As described previously, poor phonemic awareness leads to a phonological deficit which has negative impacts on writing. The struggle to recall the order of stimuli presented is thought to contribute to the muddling of letter order within words that some individuals with dyslexia experience when reading (Hari & Renvall, 2001; Valdois et al., 2004).

The reason behind this poorer processing is that adults with dyslexia take longer to process information than their peers, creating a prolonged cognitive window. The cognitive window occurs after the initial processing of one piece of information. During this cognitive window, information is attended to but, due to the prolonged time, is not processed efficiently (Hari & Renvall, 2001). Writers with dyslexia appear to have difficulties narrowing their attentional focus (Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000) and inhibiting irrelevant information (Brosnan et al., 2002). Thus, the temporal order of successive items is easily confused. Thus, during writing, SAS may contribute to poor reading and spelling due to poor processing of sequential information, leading to slower phonological processing (reduced parallel) and word-level focus.

Attention switching and selective attention

Attention switching is important for managing writing processes but may be impaired in individuals with dyslexia according to the sluggish attentional shifting theory (SAS). Individuals with dyslexia tend to have difficulties with selective attention, once they have engaged their (selective) attention, it is difficult to disengage it and attention switch (Hari & Renvall, 2001; Krause, 2015). While continuing to process information during the prolonged cognitive window, the individual is 'blind' to other information. This period of 'blindness' is referred to as dwell time (Hari & Renvall, 2001; Hari, Valta, & Uutela, 1999). Like the cognitive window, dwell time is longer for individuals with dyslexia and once their attention is engaged being 'blind' to other stimuli makes it difficult to disengage (Hari et al., 1999) which slows or prevents shifting of selective attention (Krause, 2015; Valdois et al., 2004). Thus attention switching takes more time, it is sluggish.

Inhibition

In a study where university students ($N=61$) were required to switch between cognitive operations (manipulating numbers, which required no phonological processing), students with dyslexia ($n=31$) took longer to switch, demonstrating SAS (Smith-Spark et al., 2016). In a second task, the same students pressed keys in response to images (e.g. left key for image 1, right key for image 2). Writers with dyslexia overused the key for most popular image, demonstrating poorer inhibition than peers (Smith-Spark et al., 2016). If writers with dyslexia fail to efficiently disengage automatic attentional systems, it could cause difficulties inhibiting some processes

during writing, such as reading. Thus poor inhibition contributes to difficulties with selective attention.

Automatic processing in reading is best demonstrated by the Stroop test (Stroop, 1935). In the Stroop test readers are presented with a list of colour names (eg 'BLUE', 'YELLOW', 'RED') and these words are presented with incongruent font colours (eg the word 'BLUE' is presented in red font). Readers are asked to identify the colour of the font. However, the text interferes with naming the font colour, thus the meaning of the word has also been processed to a semantic level without the reader meaning to do so (Stroop, 1935). Readers with dyslexia perform poorly on Stroop tests, taking longer to answer, which has been linked to difficulties with inhibiting reading (Faccioli, 2008). As already described, reading tends to be slower in readers with dyslexia (Ellis, 2016).

2.4 Dyslexia and Spelling Error Revision

2.4.1 Revising spelling errors

During text production, spellings of words are evaluated for correct spelling (meeting writing goal) before and after transcription. Spellings of words are evaluated as part of the spelling process, even before the words are transcribed (see Chapter). Writers with dyslexia experience difficulties with this spelling process, due to a phonological deficit, as described earlier in this chapter (phonemic awareness section). Thus many spelling errors are transcribed onto the page.

Writers with dyslexia tend to be poorer at detecting and correcting spelling errors on the page, (Elliot & Grigorenko, 2014; Nergård-nilssen & Hulme, 2014; Morken and Helland 2013). Detecting and diagnosing a spelling error in text is likely to (but does not always) involve reading (Chenoweth and Hayes 2003; Torrance et al. 2016). Reading, as established earlier, is poorer for writers with dyslexia due to poor phonemic awareness, and executive functioning (Berninger, Raskind, Richards, Abbott, & Stock, 2008; Lyon et al., 2003; Nergård-nilssen & Hulme, 2014). Identifying and diagnosing an error by comparing the written word to the orthographic representation from the lexicon is difficult if the orthographic representation is weak, which is likely to be the case for writers with dyslexia leaving them unsure of spellings. Difficulties identifying errors can lead to missed errors and false identification (Morken & Helland, 2013; Torrance et al., 2016; Wengelin, 2007).

Revising written words involves spelling the word again. Due to weak orthographic representations and poor grapheme-phoneme mapping, writers with dyslexia are more likely to edit a spelling error but still not correct it, or even edit correctly spelled words into incorrectly spelled words than their peers are (Torrance et al., 2016; Wengelin, 2007).

2.4.2 Revision during text production

As described at the end of Chapter 1, how writers manage spelling error revision during writing has been investigated in a sentence completion study by van Waes et al. (2010). When university students without dyslexia noticed a spelling error they tended to start trials with production before revising the error (90% of cases), demonstrating efficient management of cognitive resources (van Waes et al., 2010). In the same situation, writers with dyslexia may be less likely to demonstrate such efficiency in writing. There are a number of reasons that this may be the case.

First, because writers with dyslexia experience difficulties with executive management, including attentional shifting and inhibition (Hari & Renvall, 2001; Valdois et al., 2004). Once a writer with dyslexia notices a spelling error it would be difficult for them to disengage from processing it and to shift their focus back to storing and processing the lexical representation (to continue transcribing it to the page). Thus, for writers with dyslexia, text production is particularly likely to be disrupted by spelling error revision.

Second, due to a phonological deficit, writers with dyslexia are likely to write with reduced parallel processing. When writing involves difficult spellings the competition between processing and storage (McCutchen, 1996) means that when writers devote large amounts of cognitive resources to spelling, very little working memory is available for processing or maintaining the lexical representation. Thus, for writers with dyslexia, the lexical representation is more likely to become damaged or lost when text production is interrupted by spelling error revision and writers with dyslexia are less likely to engage in efficient writing behaviours in comparison to their peers.

Furthermore, in natural text production, as opposed to controlled experimental conditions, writers with dyslexia are likely to make more spelling errors in their texts than writers without dyslexia. On the one hand, this could lead to a greater frequency of interruption, on the other hand, due to difficulty identifying spelling errors, more errors in text does not necessarily lead to more revision.

If writers tend to write using word processing programs with spellcheck in its default settings (to underline spelling errors as they are made), this can draw attention to spelling errors, which may or may not be helpful. Spellcheck also provides a short list of words that the writer can use to replace the spelling error, as long as the correct word is on the list and can be identified, this could save time and effort during revision, especially for writers with dyslexia.

2.5 Word-Level Focus

Writers with dyslexia experience difficulty with spelling, causing them to struggle over words (Connelly & Dockrell, 2017; Wengelin, 2007). In fact, it is thought that writers focus at the word level so much, that other areas of text lack attention and that this is what causes writers with dyslexia to produce poorer quality texts (Ronneberg et al., 2018; Torrance et al., 2016; Wengelin,

2007). Difficulty with spelling has been linked to restrictions in word choice and poorer lexical diversity (Berninger, Nielsen, et al., 2008; Sumner et al., 2016; Wengelin, 2007). Limitations on word choice also contribute to the word-level focus. This section of the chapter introduces some studies that are key to the word-level focus theory of writing for adults with dyslexia.

The word-level focus was suggested by Wengelin (2007) after writers with dyslexia demonstrated that awareness of spelling problems manifested in increased pausing and restricted use of vocabulary. Adults with and without dyslexia (Swedish, $n=11$ per group) wrote five texts each (personal narrative, picture elicited narrative, providing directions, an argumentative text and a job application). Keystrokes were recorded using a keystroke logging program (Scriptlog) which timestamped each keypress to provide typing profiles, including when writers revise text. Participants also produced three spoken texts (the two narratives and the directions mentioned earlier). Revision behaviour in typed texts, and lexical diversity of all texts, was measured.

Writers with and without dyslexia produced spoken texts with equal lexical diversity. This equal performance suggests that general vocabulary is not poorer for writers with dyslexia. For individuals without dyslexia, lexical diversity tends to be better in written than in oral productions (Johansson, 2009; Sommers, 1980; Strömquist et al., 2002). As expected, writers without dyslexia showed higher lexical diversity in written than spoken texts. Writers with dyslexia, however, showed no improvement of lexical diversity when texts were written. Thus, texts written by writers with dyslexia contained lower lexical diversity than texts written by the control group. Findings imply that the cause of poorer written lexical diversity in texts by writers with dyslexia is writing related.

For writers with dyslexia, but not for writers without dyslexia, revision frequency was a unique predictor of lexical diversity. Both groups made a similar number of revisions, however, while for writers without dyslexia less than 2% of their revisions were spelling related, on average, 28% of total revisions were spelling related for writers with dyslexia. Spelling related revisions were defined as revisions that change a spelling. Wengelin (2007) suggested that spelling revisions indicate awareness of spelling problems and large proportions of spelling related revisions indicate that writers with dyslexia focused on this more than revising other areas of text. Focussing on spelling appears to relate to poorer lexical diversity. Writers with dyslexia appear to focus on spelling revision because there were a lot of errors that required revision, their texts contained significantly more spelling errors at almost 8% of words, compared to almost 0% in texts by writers without dyslexia. Writers with dyslexia also appear to focus on spelling revision because it is difficult, they only 50% of revisions were successful.

Six of the eleven writers with dyslexia substituted words with synonyms or near-synonyms. Thus poor spelling may lead to avoidance of difficult-to-spell words, which in turn decreases lexical diversity. Wengelin (2007) suggests that pauses in transcription may be related to avoiding difficult to spell words before they are transcribed, limiting lexical diversity. As described in the previous chapter, words can be changed before reaching the page via evaluation and revision at

the translation stage, and when information takes longer to get passed the translation stage, it causes pausing in transcription (Chenoweth & Hayes, 2003; Hayes, 2012; Hayes & Chenoweth, 2007).

Avoidance may explain findings from other studies. For example, Tops et al. (2013) found that HE students with dyslexia ($N=100$) made more spelling errors when transcribing to dictation, when they were not in control of their word choice, and fewer spelling errors when writers decided what to write for themselves. Furthermore, Berninger, et al. (2008) write that: “Many participants in our research studies lament that they cannot write compositions that express their ideas without limiting those ideas to the words they think they can spell without embarrassment.” (p17).

Wengelin (2007) considered several possible explanations for the link between spelling and lexical diversity but her two main contenders were that (1) writers with dyslexia, consciously or subconsciously, use revision to avoid words that they find difficult to spell, thus limiting the vocabulary available for writing, or that (2) spelling problems cause a strain on limited working memory capacity reducing resources available to vocabulary choice. Both possibilities lead to poor lexical diversity and increase word-level focus.

While many studies indicate that writers with dyslexia are poorer at spelling (Berninger, Nielsen, et al., 2008; Snowling, 2012; Tops et al., 2012), few studies have investigated lexical diversity and the link it has to spelling accuracy for writers with dyslexia. The few that have, are explored over the remainder of this chapter.

Similarly to the adults in Wengelin’s study (2007), younger writers with dyslexia (UK schoolchildren, $n=31$ per group, mean age of 9 years) showed equal spoken lexical diversity to age-matched controls for spoken narratives, but poorer lexical diversity in handwritten narratives. For the writers with dyslexia, spelling was significantly, positively correlated with written lexical diversity, and was more related to lexical diversity than to vocabulary knowledge.

In two similar studies (Connelly et al., 2006; Sumner & Connelly 2020), UK undergraduates with dyslexia also appear to show a relationship between lexical diversity and spelling. However, in this case, writers with dyslexia produced written lexical diversity equal to that of their peers and it appears to be at the expense of spelling. In both studies, writers with dyslexia, aged-matched peers and spelling ability matched groups handwrote an essay to writing prompts from the Graduate Record Examinations (GRE) analytical writing measure (in Sumner & Connelly $n=32$ per group, mean age of 20 years, spelling ability matched group mean age of 13 years; in Connelly et al., $n=21$ per group, mean age 19 years, spelling ability matched group mean age of 18 years, range of 11-31). Several measures were taken, including spelling and lexical diversity.

As expected, in both studies, writers with dyslexia made a higher percentage of spelling errors than aged-matched groups (Sumner & Connelly’s, dyslexia group = 4%, age-matched group = 0.5%, Connelly et al.’s dyslexia group = 3%, age-matched group = 1%), but unexpectedly

they also made more spelling errors than the spelling ability matched groups (2% in Sumner & Connelly and between 1.5% and 2%² in Connelly et al.). This is especially surprising for writers in Connelly et al. (2006) because spelling ability matched group had an age range of 11-31 years, thus the group contained some adults with spelling ability matching the dyslexia group, which suggests that they may have had undeclared difficulties which affected spelling.

Interestingly, in both studies, the lexical diversity of texts was equal for writers with dyslexia and their age-matched peers. In Sumner and Connelly (2020) the texts by the younger, spelling ability matched writers had lower lexical diversity than the other groups. Connelly et al.'s (2006) spelling matched group wrote with lexical diversity equal to the other groups. Their spelling matched group may average equal lexical diversity because there were participants in this group who were close in age to the dyslexia group, which was not the case for the spelling matched group in Sumner and Connelly (2020). In Connelly et al., (2006) lexical diversity accounted for variance in text quality more than any other aspect of text or other ability (such as working memory span and handwriting fluency).

Sumner and Connelly (2020) found that lexical diversity was related to spelling and suggest that adult writers with dyslexia disregard whether or not they could correctly spell the words thus lexical diversity is not restricted. Sumner and Connelly (2020) suggest the ability to ignore spelling errors may be related to familiarity with spellcheck, which perhaps younger writers in their 2014 study were not as familiar with. However, this explanation does not explain why adult writers with dyslexia in Wengelin's (2007) study showed poor lexical diversity in written texts. The precise nature of the relationship between spelling and lexical diversity is unclear but seems to reflect some kind of trade off and in some cases vocabulary choices appear restricted by poor spelling.

The spelling of text already written, currently being written, and yet to be written can all be revised, and can all take up resources, causing writers to focus on the spellings of words. Torrance et al. (2016) hypothesised that if writers are focussing on words being written, or just about to be written, then text production would be interrupted by pauses (such as the P-bursts described in Hayes and Chenoweth, 2003), and that if writers are focussing at the word level because of the need to revise text on the page, then transcription would be interrupted by revision (R bursts, as described by Hayes and Chenoweth, 2003). Furthermore, it was reasoned that if interruptions were related to focussing on text already produced, then preventing reading would remove word-level focus.

Writers with and without dyslexia ($n=26$ per group, mean age 17 years, Norwegian writers, matched for maths skills as a proxy for general ability), produced two short essays in a simple

² This number is described in the article as an average of 7.21 errors per essay, the average length of which was described as not significantly different to dyslexia, which was 414 words, thus it is possible to estimate the percentage of spelling errors as between 1.5% and 2%

text editor (without spellcheck available). One essay was typed in a masked condition, where all letters were shown on screen as X's, and one with visible text. Pausing, text quality, lexical diversity, and spelling revision were recorded.

In masked and in visible text, writers with dyslexia paused more than controls, particularly before words. Masking text increased the number of spelling errors but did not impact lexical diversity for either group. The word-level focus did not appear to be related to revisiting words written earlier in the text. Torrance et al. (2016) initially interpreted pausing to mean that writers were focussed on words as they were transcribed. However, authors later suggested that, actually, writers were not focussing on what is being written but instead on what they planned to write next (Ronneberg et al., 2018).

It seems that both interpretations could be correct. As indicated in Chapter 1 (particularly in Olives, 2014, Cascading mode, Figure 1.3), writers need to manage the information package currently being written and the package that is to be written next. Thus there is competition for cognitive resources. Spelling and transcription of text currently being written compete with processing and storage of a lexical representation to write next. This explains why masking the text in Torrance et al. (2016) had no effect on quality. Masking the text did not increase or reduce this competition for cognitive resources.

Difficulties with spelling and spelling revision may be different in Norwegian, because Norwegian has a more transparent orthography than English. Torrance et al. (2016) explain that Norwegian students are used to typing their work and exams on a computer and that students with dyslexia are all provided with assistive technology. Presumably this is technology that assists with spelling error correction. No spelling technology (such as spellcheck or autocorrect) was available in the simple text editor used in Torrance et al.'s (2016) study. There were no significant effects for lexical diversity between groups, which supports Sumner and Connelly's (2020) idea that writers who are used to using spellcheck prioritise lexical diversity and therefore write with lexical diversity equal to their peers. It is possible that having spellcheck as part of the typical writing environment has long-term effects on writing.

Ronneberg et al. (2018) hypothesised that word processing programs, and spellcheck as part of them, could increase the word-level focus by drawing attention to the word level revisions. Yet spellcheck could also benefit writers, particularly writers with dyslexia, by providing the correct spellings so that writers only need to recognise the correct word rather than produce it, an easier task. It is possible that when writing with assistive technology, as would be their usual writing conditions, writers with dyslexia in Torrance et al.'s (2016) study would have been as successful as peers at correcting spelling errors. However, as writers struggle with, and focus on, initial production (Torrance, 2016) spellcheck, which is activated by the presence of an error on the screen, may not reduce word-level focus and only support revision after the errors have been made.

2.6 Conclusions

Very little is known about how writers use word processing programs, and what this means in terms of their typical writing environment, for example, it might be assumed that writers tend to use spellcheck in its default settings (to underline errors as they are made) but there is no evidence for this. The next chapter introduces spellcheck in detail and then reviews the few investigations about spellcheck and writing that have been conducted.

Writing with Spellcheck

3.1 Description of Spellcheck

Spellcheck is part of most word processing programs; it identifies potential spelling errors and, for each error identified, offers a list of candidate words that can be used to replace the error. In the default settings of word processing programs, spellcheck is typically active, monitoring words as they are typed, and could be a part of the writing environment for many writers.

3.2 Spellcheck and the writing environment

As illustrated by Hayes and Berninger's (2014) model, Figure 1.1, the writing environment influences other components in writing, and so it is an important factor to consider when investigating writing. The task environment accounts for factors in the physical presence of the writer and consists of four components, including other people (collaborators and critics), the tools writers physically touch and manipulate to transcribe text (transcribing technology) and physical items that contain information used for writing, such as dictionaries and worksheets (task materials). Interestingly, the presentation of the fourth component 'text-written-so-far', has not been specified. Thus it might be presented on paper but might also be presented via a computer screen if writers are using word processing programs such as Microsoft Word. While the text produced in word processing programs might be accounted for, the tools such as spellcheck, that are part of using word processing programs are not included in this model.

One might assume that word processing programs, including spellcheck, are part of 'transcribing technology' due to the word 'technology', however, Hayes and Berninger (2014) describe 'transcribing technology' as tools which affect transcription in terms of motor planning and execution, including a keyboard for typing or a pen for handwriting. One might interact with word processing programs via a keyboard (or sometimes speech), but there is more to them, they include digital pages, digital text and a host of writing tools, including spellcheck. Unfortunately, Hayes and Berninger's (2014) writing model fails to include environmental factors beyond those that are physically present, thus word processing programs, and therefore spellcheck, do not currently fit into this writing model.

As indicated previously, writing models develop and change in reaction to empirical evidence. Empirical studies are necessary to provide evidence of the impact of spellcheck on writing. Compelling evidence would give reason to modify the existing model. If the writing environment in this model were to be expanded to include factors beyond the physical environment, then word processing programs and spellcheck could be accounted for. Spellcheck would fit best as part of the component 'collaborators and critics'. Hayes and Berninger write

that, in their (2014) model, ‘collaborators and critics’ represent factors occurring in the physical environment of the writer such as the presence of a teacher. Interestingly, Sommers (1980), described that during revision (as proofreading activity), the writer revises text based on anticipated readers judgments and the imagined reader was described as a ‘critical and productive collaborator’ (p.384). In this case the, not physically present, critical collaborator is a cognitive mechanism for evaluation. Spellcheck, although not physically present, is an environmental factor that, arguably, anticipates readers judgements of spelling by alerting the writer to spelling errors (critic) and supports revision by suggesting how to correct the error (collaboration). Thus spellcheck acts as a collaborator and critic.

As described in Chapter 1, most revision models are based on three main processes: detection, diagnosis and revision (Bereiter & Scardamalia, 1987; Flower et al., 1986; Hayes et al., 1987). All of these processes are drastically impacted by using spellcheck. With spellcheck active, detection no longer requires reading because spelling errors are automatically underlined, diagnosis is carried out by spellcheck, and revision does not require the production of a word, only recognition of the target word from a short list of candidates provided by spellcheck.

3.2.1 A brief history of spellcheck

The technology for spellcheck has existed since the 1960s when Lester Ernest inadvertently created it. Ernest was developing a handwriting recogniser. It could recognise handwritten words if they were words from his preprogramed list of 10,000 words (Wolman, 2010). However, if a word was spelled incorrectly it would not be recognised. This was effectively the basis of the first spellcheckers. Ernest’s word list was relatively short in comparison to a full dictionary (the second edition of the Oxford English Dictionary contains 228,132 entries, published in 1989, the Collins English dictionary, published in 2014, contains over 700,000). The first dictionary to be compiled electronically was Houghton’s American Heritage dictionary in 1969, the number of entries is not specified. This dictionary was later licensed to multiple software companies, including Microsoft, to be used in combination with spellcheck technology.

The late 1970s and 1980s saw a rise in personal computers. Microsoft Word was created in 1981 and Simonyi is largely responsible for its creation and development from then until 2002. From 1990, Hachamovitch also helped to develop Microsoft Word’s spellcheck, he discovered that because English words are space-delimited, the space bar itself could be used as a trigger for autocorrect, this was also applied to spellcheck to automatically check each word as soon as the writer finished typing it. Microsoft Word integrated spelling and grammar checkers into Microsoft Word in 1992 (this was suggested in, Morphy & Graham, 2012). By the mid 90’s Microsoft bought the spellcheck technology and Houghton’s American dictionary outright. Since then the dictionaries used for spellchecking have continued to grow to incorporate new words (e.g. selfie), and company names (e.g. Instagram). These days rather than buy whole dictionaries, companies like Google, Microsoft, and Apple use in-house language experts to decide how to

modify dictionaries. Linguists work alongside programmers to decide how to recognise target words from spelling attempts.

Commercial companies tend not to publish details of how their spellcheck programs work, but there is enough information available on programming websites and self-published texts to gain a general idea of how some spellcheckers are likely to work.

3.3 How Spellcheck Works

3.3.1 Identifying spelling errors

For most word processing programs, in the default settings, spellcheck monitors text as it is produced comparing the words typed to words that are stored in the program's dictionary. If a word typed does not match any word stored in the dictionary, then spellcheck automatically underlines the word typed to alert the writer to it as a potential spelling error, as shown in Figure 3.1.

Figure 3.1 Image of a spelling error underlined by spellcheck

misspellled wrod

Figure 3.1. An image of the underlining function of spellcheck.

Spellcheck can over- or under-identify spelling errors. Over-identification can occur if writers produce correctly spelled words that are not stored in spellcheck's dictionary. Under-identification occurs when spellcheck fails to identify an error.

3.3.2 Spelling error revision

After identifying a potential spelling error, spellcheck provides a list of candidate words that can be used to replace the error. These candidates are words from the dictionary that are spelled similarly to the potential spelling error. Identifying whether a word typed matches words in the dictionary is relatively straightforward. However once a word is identified as a mismatch (a potential spelling error), deciding which words in the dictionary are most similar to the potential spelling error is a more complex task. Candidates for the target word are selected using algorithms.

There are variations between algorithms used, and the details are not generally provided by companies, thus it is not possible to be sure precisely how each spellcheck works. Nonetheless, it can be assumed that spellcheck uses a combination of rules, with some rules carrying more weight than others. Furthermore, it is likely that the exact nature of each spellchecker changes as programs are updated. Some methods for selecting and ranking candidate words are briefly

described in the next sections of this chapter. There are many more algorithms in existence than have been described here, however, the next part of this chapter will provide a general idea of how spellcheckers select and rank candidate words for the replacement of spelling errors.

3.3.3 Selecting candidates for word replacement

Levenshtien distance

After a word is identified as a spelling error, in order to find words that are similar to the spelling error, it must be compared to words in the dictionary and the difference between them must be measured. Words in the dictionary that have small differences from the spelling error are more likely to be the target word than words with large differences. A popular measure to compare words is Levenshtien distance, also called ‘edit distance’ (Levenshtein, 1966). Levenshtien distance is the number of deletions, transpositions, replacements or additions between two words, see Table 3.1 for examples.

Table 3.1 Examples of Levenshtien distance.

Typed word	Distance from target word ‘ <i>great</i> ’
Greate	1 Insertion
Grat	1 Deletion
Graat	1 Substitution
Gerat	1 Transposition (or 2 substitutions depending on algorithm)

Some spellcheckers search for candidates by creating all possible versions of the word identified as a spelling error up to two Levenshtien distances from the typed word. Starting with a Levenshtien distance of one, the words generated are compared to the words in the dictionary and matches are proposed as possible candidates for the target word. Then this search is repeated for a Levenshtien distance of two. Because insertion and deletion are included in the distance measure, the words proposed are usually similar in length to the typed word. It sometimes happens that the attempted spelling is more than two Levenshtien distances away from the target word, and so the target word is not always proposed as a candidate for replacement if relying only on this method. Using Levenshtien distance does not take into account whether the spelling attempt can be pronounced similarly to the target word, while a human reader might be likely to guess the target word from a phonetically similar attempt, the algorithm cannot. Furthermore it is possible that if the Levenshtien distance from the potential error to other words in the dictionary is greater than two, then no candidates will be presented. On the other hand, it is also possible for many candidates to be proposed at the same time, in which case the writer will need to select the correct target word from a list of similar words.

Phonetic similarity

Another method for identifying candidates is using phonetics to code the words. The SoundEx algorithm (Jacobs, 1982) is an example of a code designed to preserve the salient features of word pronunciation. The first letter is kept, the vowels are removed and the consonants are coded. Consonant letters that are likely to be substituted for each other are grouped, for example, an *s* may be written for a *c*, and so they would be in the same group, but an *x* is unlikely to be written for an *m* and so they would be in separate groups. Each group of letters is given a number. A word is coded with the first letter and three numbers. A list of possibilities of words can be generated from that.

As an example, the written word 'brelliunt' becomes 'B,6,4,5,' (R=6, L= 4 only one consonant is coded in the case of a double letter, n=5, T is not coded as the maximum of three numbers has already been reached). The proposed candidates for replacement using SoundEx include 'brilliant', 'burling' and 'barreling'. SoundEx, or similar algorithms, often propose candidates that would not be proposed if relying only on the Levenshtien distance. Using phonetic similarity should allow phonetically correct (or phonetically similar) spelling attempts to generate proposed candidate words that include the target. However, like using the Levenshtien distance, it is possible for many candidates to be proposed from phonetically matching typed words to words in the dictionary. Algorithms for proposing candidates do not necessarily account for how likely it is that each candidate is the target word.

3.3.4 Ranking the candidates

When spellcheck proposes a list of candidates likely to be the target word, the most likely candidate appears at the top of the list, with second most likely in second place and so on. Thus, in cases where there are several candidates, spellcheck must have some rules in place to rank the candidates on their likelihood of being the target word.

Distance ranking

The potential spelling error can be compared with all words in the dictionary and then the words with a small distance (Levenshtien, or others) are put forward as candidates for the target word, with the smallest distance being most likely (Hanov, 2018). For example, words with a Levenshtien distance of one are rated as more probable than words with a Levenshtien distance of two. However, it is possible for more than one word from the dictionary to be the same distance from the potential spelling error. Other factors can contribute to rating the candidates, these are described below.

Probability of mistyping

Whilst typing, as opposed to handwriting, always produces correctly formed legible letters, it comes with the added risk of producing a misspelled word through mistyping. While a spelling error is due to uncertainty of the correct spelling of a word, a typing error is considered a slip of the keyboard (Wengelin, 2007). The probability that the potential spelling error would be typed in

place of the candidates proposed is included in the decision to propose and rank candidates (Norvig, 2018). For example, when producing the target word *great*, *gerat* is a common typing error, with a single transposition of letters, the keys of which are side by side on a qwerty keyboard. *Grimp* however, is unlikely to be typed instead of *great* as the keys *i,m,p* are far from *e,a,t*. *Gerat*, in Word 2016 in default settings, autocorrects it to *great*, suggesting it is a common typing error, and spellcheck triggers only the word *great*. *Grimp*, on the other hand, is not autocorrected and triggers the words *grump*, *grim* and *grip* in spellcheck.

Weighting word beginning

H and F sit either side of the G on a qwerty keyboard and so one could be forgiven for thinking that *hreat* and *freat* are common typing errors of *great*, particularly *freat* because *g,f* and *r* tend to be typed with the same finger. However, it has been suggested that spelling errors are unlikely to occur at the beginning of a word, even in typos (Mitton, 1987; Pollock & Zamora, 1983). Analysis of spelling errors by writers with dyslexia suggests they are also less likely to make a spelling error by starting with the wrong letter (Pedler, 2001; Yannakoudakis & Fawthrop, 1983). With this in mind, some spellcheckers, accept the beginning of a word as correct or weight it as more likely to be correct than the remainder of the word. For example when *hreat* is typed into Word 2016, the spellcheck (which suggests a maximum of three candidate words at a time) suggests a candidate list of *Herat*, *heat* and *heart*, while *freat* triggers the list: *feat*, *fret* and *freak*. *Gfeat*, *grwat*, and *greaf* however, which each have a single substitution and the correct first letter, all of these words trigger *great* as the top candidate word in spellcheck.

Some methods also weight letters near the end of the word as more likely to be correct than those in the middle. In addition, some spellcheckers rate certain letters as more likely to be incorrect than others, such as vowels as being more likely to be incorrect than consonants (if using something like the SoundEx algorithm). However in another example, if relying on consonants and weighting the first letter then *rgeat* becomes *RGT*, coded as *R,2,3,0* (0 is added to make the code up to 3 numbers) and based on this code the words *raged*, *ragged* and *raced* are proposed as candidates. *Great* would not be proposed. However in practice, when *rgeat* is typed, *great* is the only candidate proposed (in Microsoft Word at least), thus spellcheck must also take into account other factors.

Word frequency

One factor that contributes to rating the probability of the candidates being the target word is word frequency. A more frequent word is more likely to be the target word than a less frequent word. Word frequency can be calculated using the number of times each word appears in a large text. Examples of these texts include a concentration of public domain book excerpts, lists of most frequent words from Wiktionary, or the British National Corpus. Some companies create their own texts, for example, Google uses a list of all of the words in all of the books in their books search feature.

Word frequency is also used to inform decisions around which words to include in dictionaries. Very low-frequency words are sometimes excluded if they are very close to other words. For example, the word *calender* refers to a machine used in textile manufacturing, but the word is used very rarely and is very close to the more frequently used word *calendar*. Thus *calender* is not in the standard Microsoft Word dictionary. The size and content of the dictionary impacts the effectiveness of error identification. Reducing the size of the dictionary reduces the risk of under-identification of errors because misspellings that result in very low-frequency words (such as *calender*) will become underlined. However, reducing the dictionary also increases the likelihood of overidentification of errors because spellcheck is more likely to identify low-frequency words as errors.

One solution is that users can add their own words to the dictionary to account for words that are generally low frequency but may be used often by particular writers. In addition, specialist word lists can be added to the dictionary. These word lists can often be added using settings on word processing programs but can also be downloaded separately. For example, the software ‘Medincle’ (Medincle Ltd.) adds medical words that, as low-frequency words, are not included in standard spellcheck dictionaries and would otherwise become underlined as errors and would not be suggested by spellcheck if the word was misspelled.

Phonetic rating

As described in the earlier *phonetic similarity* section, some spellcheck dictionaries contain information about pronunciation, and offer words that might sound like the potential spelling error without weighting the initial letter. Candidates can be ranked using phonetic similarity. Using phonetic information allows words with a large Levenshtien distance from the potential error to be proposed and rated as the most likely candidate for example when faced with the misspelling *newmoanya*, the phonetic candidate list would include *pneumonia* while lists obeying only Levenshtien ranking, weighted beginnings or word frequency would not.

This rule alone does not work well if the misspelling is phonetically irregular. For example, a writer may use knowledge of the irregular but frequent whole word *eight* to form the end of the word *great*, resulting in *greight*. *Greight*, while sounding like *great* is phonetically irregular and does not trigger *great* as a candidate word. The candidate words triggered are *freight*, *freights* and *Geraghty*.

Intelligent spellcheck

Newer versions of spellcheck cache (store) previously computed problems and reuse the same results. The mechanisms for this appears to be something similar to the PDP model of learning to spell described in chapter one, where the solution to frequently solved spelling problems become more likely to be ‘voted’ for. This ‘learning’ may occur per user whereby mistakes are stored on the user’s account. This may also occur on a larger scale, for example, Google’s “did you mean” suggestions are not based on a static dictionary but on algorithms that incorporate data from previous searches of any user.

3.3.5 Other spelling aids

In addition to spellcheck, other spelling aids such as autocorrect and grammar check are part of standard word processing programs such as Microsoft Word and are often active in default settings.

Autocorrect

Autocorrect replaces the misspelled word with the most likely candidate when the writer completes the word and presses spacebar (or punctuation keys). Autocorrect has been known to cause problems with the text produced by changing words identified as errors to unintended words, furthermore, because this occurs automatically, it can happen without the writer's knowledge. To reduce the chance of an error being replaced with a word that is not the target word, most forms of autocorrect only correct an error when it is very close to one candidate word and very far from other words. Like spellcheck, autocorrect uses similar rules as described already, for selecting and ranking candidate words. Autocorrect works well for very common errors that are unlikely to be attempts to spell other words (e.g., *seperate* for *separate*). In the example word *great* autocorrect works well for typing errors that involve letter switching, for example 'rgeat' and 'gerat' are autocorrected to *great*, however neither *graet* (which is close to *greet*) nor *greta* (which is a name) are autocorrected to *great*.

Grammar check

If a misspelling results in a real word then spellcheck will not recognise it as an error. However, often in these cases grammar check will recognise it as an error and alert the writer to it (Pedler, 2001), or some grammar errors may be changed by autocorrect. Grammar check attempts to analyse each sentence into its syntactic parts. If it fails, because the sentence is grammatically incorrect, it tries again, but relaxes some of its grammar rules. Grammar check reveals which rule or rules it relaxed and suggests what is grammatically wrong with the sentence. For example, grammar check will identify *grate* as an error if *great* is more appropriate. *Grate* and *great* may not be commonly confused, but *there*, *there* and *they're* are frequently confused, as are *affect* and *effect*. Grammar check not only suggests alternative words but also punctuation.

3.4 Key Research Papers

The general question under investigation in this thesis is: *How does spellcheck impact writing for undergraduate writers with and without dyslexia?* There are very few published investigations into the combination of writing, spellcheck and dyslexia. In this section of the chapter, the few papers that have investigated key elements of this research question are described. Together they offer insight into how spellcheck is likely to impact the text produced, and the process of writing, for students with and without dyslexia.

3.4.1 Spellcheck used by writers with spelling difficulties

This section of the chapter introduces a study by MacArthur et al. (1996) which considers the effectiveness of spellcheck when used by students with learning difficulties (dyslexia or suspected dyslexia) who struggle with spelling. MacArthur et al.'s (1996) study comprises of two investigations. First, authors reviewed the performance of 8 different handheld spellcheckers and 2 spellchecking programs, on the detection and correction of spelling errors from essays of writers with moderate to severe spelling problems ($N=55$, aged 11-14). The errors themselves were also analysed for error type and severity. Spelling errors from this collection of essays revealed that misspellings made up approximately 13% of the text; when duplicate words were removed spelling errors made up 5.93% of total words.

As described in the previous chapter, spelling difficulties persist into adulthood and so adults with dyslexia continue to demonstrate spelling difficulties. For example, adults with dyslexia ($n=11$) in Wenglelin's (2002) study wrote texts with 7.7% spelling errors, and even adults with dyslexia in HE, who are considered a subgroup (Coleman et al., 2009; Mapou, 2008; Tops et al., 2012) write texts with 4% (Sumner et al., in press, $n=32$) and 6.49% (Warmington et al., 2012, $n=20$) spelling errors. Reviewing spellcheckers showed that 50-65% of misspelled words (not including real-word errors) were flagged and caused the target word to appear in the top 10 candidates on the word replacement list.

In the second study, poor spellers ($n=27$, aged 11 to 14- years-old) wrote and edited their own essays with and without spellcheck. How successfully they corrected their misspellings was monitored. This study has been described multiple times in subsequent reviews of spellcheck by MacArthur (2006; 2009), it features as the core study in such reviews and remains one of the few studies to investigate how writers with spelling problems use spellcheck.

When students with learning difficulties corrected their own texts, using a word processing program with inbuilt spellcheck, only 37% of misspelled words were corrected (MacArthur et al., 1996). A correction rate of 37% may seem low considering that the investigation into spellcheckers indicates more than 37% of misspelled words would have been flagged and could have been corrected with spellcheck. MacArthur (2006) reported that low proportions of corrections made with spellcheck were due to real-word errors, which spellcheck programs do not recognise. Real word errors contributed to the high proportion, 63%, of misspelled words that were left uncorrected. However, when using spellcheck, poor spellers did correct significantly more misspellings than the 9% that were corrected when students corrected their print outs by hand. Thus, spellcheck does assist with spelling correction but users with learning difficulties appear not to use it to its full potential. Authors identified two main areas where spellcheck can either help, or fail to help, writers to correct errors. These areas are the identification of spelling errors and the candidate words proposed.

Identification of spelling errors

Because spellcheck generally performs single word recognition, spelling errors that result in other words, that are stored in spellcheck's dictionary, will not be recognised as errors. These are real-word errors and can be homophones (their/there/they're) malapropisms (close/clothes) or other words with similar spellings (feel/fell). In the collection of spelling errors from 55 essays, 26% of unique misspellings were real words. In the essay writing task, approximately one in three (37%) total misspellings were real-word errors, due to repeated errors. MacArthur et al. (1996) highlighted real-word errors as a cause for under-identification of misspelled words when using spellcheck. In the essay writing task, all unflagged spelling errors were real-word errors. This presents a problem for poor spellers when they rely on spellcheck to identify their spelling errors. MacArthur et al. (1996) suggest that the biggest limitation of spellcheck is that it is not designed to identify these errors.

Additional software may be required to combat this issue. As suggested previously, grammar check will sometimes identify real-word errors as words used incorrectly based on the surrounding text. To check real-word errors beyond capabilities of standard grammar check, writers can add more comprehensive software such as Grammarly (Grammarly Inc.) to their computers. MacArthur (in his 2009 review) mentions that some spellcheckers include features to help bring homophones and similar words to the writer's attention. VeritySpell (Oribi Software) for example, alerts writers to 'confusables'. Microsoft Word can also 'speak' text selected as standard feature in Word 2016 which is useful for proofreading as misspellings that result in other words (and are not homophones) can become more obvious when heard than when read.

Suggesting candidates

In MacArthur et al.'s (1996) spellchecker study, spelling checkers offered the correct target word as replacement within the top 10 items on the list for 50-65% of the 555 errors spellcheck identified. Despite employing the algorithms described previously, if a misspelling is too different from the target word, the target word will not appear at the top of the suggestion list and may not appear at all. For example, the target word is less likely to be included in the candidate list if the misspelling has a large Levenshtien distance from the target word. An example of a spelling error with a large Levenshtien distance has been provided by MacArthur (2009): *Frenichur* for *furniture*, as written by 10-year-old child with spelling difficulties is five letters from the target. This example is decades old but typing it now into Microsoft Word (version 2016), the suggestions that appear are *Frenchie*, *Frenches*, and *French*. Due to difficulties with spelling, writers with dyslexia make spelling errors that are significantly less plausible than their peers do (Coleman et al., 2009) it is possible that their spellings are more likely to be further from the target word than their peers and that, even with spellcheck active, poor spellers may still need to make multiple attempts to spell the target word in order to trigger the target word to appear on the list of candidate words. Interestingly, when read aloud, *Frenichur* and *furniture* are phonetically

similar, suggesting that making more use of phonetic information might help software to propose the target word within the candidate list.

Selecting the target word

Based on performance reviews of the spellcheckers, if writers were to select the first word in list, they would only be accurate 2-20% of the time (MacArthur et al., 1996). Writers successfully corrected 37% of their errors, considering that another 37% were not even flagged, writers corrected 59% or so of flagged errors. Thus writers were not selecting only the first candidate offered. Selecting the target word from the list produced by spellcheck may be straight forward for most writers, but due to difficulties with reading, individuals with dyslexia might not be as successful at selecting the target word from the list as peers (MacArthur et al., 1996). Poor spellers were unable to identify the correct target word from the list presented to them by spellcheck in 18% of cases, thus almost 1 in 5 cases and they replaced the error with the wrong word (MacArthur et al., 1996). Thus, writers may add real-word errors into their final texts and spellcheck (without grammar check) is unlikely to identify them.

Currently, in Word 2016 many (but not all) words that appear on the candidate list are accompanied by synonyms (see Figure 3.2). The accompanying synonyms allow the writer to check the meaning of the word before selecting it, possibly reducing accidental selection of other similar looking words. However, it is likely that writers with dyslexia will need more time to read the list of candidates and their synonyms and then select the target word than their peers. In later reviews MacArthur (MacArthur, 2006; MacArthur, 2009) suggests that using word processors (and spellcheck) is an added burden to the writing process thus the writer must learn to use it effectively to reduce the burden it adds to writing.

Figure 3.2 Replacement list in Microsoft Word 2016 spellcheck.

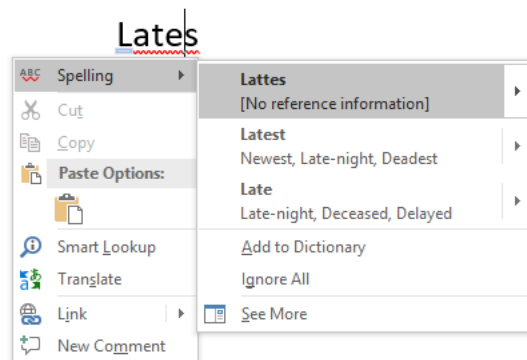


Figure 3.2 A screenshot of an example of a replacement list offered by spellcheck in Microsoft Word 2016.

Further comments

At the time of MacArthur et al.'s (1996) study, most integrated spellcheckers operated only when the user activated them. Furthermore, spellcheck presented errors and candidate words to replace errors in a window that was separate from the text itself. However, one spellcheck program (Write this Way, a spellcheck designed for writers with learning difficulties) automatically underlined misspelled words. Interestingly, MacArthur et al. (1996) suggested that this feature may present problems for the writer as it is contrary to recommendations to ignore spelling during drafting. Writers using Write this Way also needed to position the in-text cursor (the flashing line which indicates the position within the text, also referred to as the caret) within each underlined word in order to activate the list of candidate words. MacArthur et al. (1996) identified this as an unusual feature. Both automatic underlining and positioning the caret to activate the list of candidate replacement words have become common features in word processing programs today.

It appears that today writers are still advised to ignore spelling during text production. Adults (in HE) are not given advice specific to writing, however, younger students are. In the current UK national curriculum for year two to year six, the advice for writing composition is to draft and write, evaluate and edit (for effectiveness, grammar, and vocabulary), then proofread for spelling and punctuation (Department for Education, 2013). Thus checking for spelling errors is a separate writing activity to initial production. Even at the final year of secondary school (key stage four) spelling comes under advice for revising editing and proofreading which is separate from advice provided for text production. If automatic underlining encourages spelling revision during text production, it encourages writing behaviour against advice of the national curriculum.

The evidence base used to make decisions for the national curriculum advice is not made public. There is however some evidence that revisions made after production are less cognitively costly than revisions made during production (Chanquoy, 1997, in Alamargot & Chanquoy, 2001). Managing cognitive costs during text production influences text quality (Beauvais et al., 2011). Thus it seems sensible to avoid adding spelling error revisions to the cognitive load during text production.

Summary

Importantly, texts that were revised with spellcheck contained fewer errors than those revised without spellcheck (MacArthur et al. 1996). If writers can produce words close enough to the target word to cause the target word to appear in the candidate list, and are able to select the target word from that list, then spellcheck should reduce the number of spelling errors in the final text (MacArthur et al., 1996; Pedler, 2001). Unfortunately, identification of target words is likely to be difficult for writers with dyslexia. Furthermore, the use of word processing programs, and spellcheck in particular, may be a burden to the writing process and automatic underlining could make it difficult to ignore spelling errors during text production.

This sentiment is reflected in Ronneburg et al.'s (2018) recent work, which is also based on literature included in this chapter, particularly MacArthur et al.'s (1996) study. Ronneburg et al. (2018) evaluated word processing programs, and spellcheck in particular, as a support for the writing process. Authors indicated that these writing tools encourage writers to focus on making the final output correct and aesthetically well-presented. This focus is considered to be for the benefit of the reader more than the benefit of the writer. Thus these tools do not support the process of writing as well as they could. In particular, the automatic feedback of spellcheck is thought to be unhelpful and distracting, at the cost of 'meaning making' (p128) (by which authors appear to mean conceptualisation and translation processes steered by an overview of the text and writing goals). In fact, generally the idea that word processing programs increase surface revision (revision of words) at the cost of deeper, meaning related, revisions has been a concern to a number of researchers for long time (Figueredo & Varnhagen, 2006; Fitzgerald, 1987; Piolat, 1991; Piolat, Roussey, & Thunin, 1997; Ronneburg et al., 2018).

3.4.2 Spellcheck in proofreading

Like MacArthur (2006), Figueredo and Varnhagen (2006) suggested that the automatic underlining of spellcheck could be problematic. They suggested that 'flagged errors could draw attention towards surface features and away from processing content' (p.722). They go on to explain that, if during revision, spellcheck draws attention to surface errors then content errors would be affected. The authors do not specify how, only that content errors would be affected, presumably they would be accidentally overlooked or perhaps purposefully ignored.

Figueredo and Varnhagen (2006) planted spelling errors, punctuation errors, and errors with sentence order and sentence level logic (inappropriate wording to violate sequential logic) in two essays. University students ($N=65$) were presented with both essays in a word processing program, one at a time. Students edited one essay using a word processing program with spellcheck and grammar check activated. For the other essay, students did not have access to spellcheck or grammar check but did have access to a dictionary. Students described edits aloud as they made them, their descriptions were recorded, and edits were categorised into types (content, spelling, or punctuation).

Significantly more spelling errors were corrected when using spellcheck and grammar check (88.2%) than with a dictionary (59.5%). The percentage of spelling errors corrected with spellcheck is much higher for this study than in MacArthur et al.'s (1996) study, which was 37%. This higher percentage of error correction could be due to multiple factors. Firstly, although the planted spelling errors in Figueredo and Varnhagen (2006) are not described in detail, it is unlikely that they resulted in other real words, which was a key problem for poor spellers using spellcheck in MacArthur et al.'s study. Secondly, as this study was carried out later than MacArthur et al. (1996) a newer version of spellcheck may have been used which may be better at suggesting candidates for replacement, however, the word processing program used is not

specified. Thirdly, participants in Figueredo and Varnhagen's (2006) study were university students without any diagnosed spelling difficulties and likely to be more adept at using spellcheck to identify and correct spelling errors than the younger, poor spellers in MacArthur et al.'s (1996) study. Even if the university students selected the wrong candidate from the list, grammar check was switched on and may have identified the incorrectly used word and assisted in correction of this.

A key finding in this study is that in the dictionary condition, spelling ability (measured with single word dictated spelling test from the Diagnostic Spelling Potential Test) correlated with the number of surface errors corrected suggesting that better spellers are better at noticing and correcting spelling errors. This correlation was not found when writers used spellcheck and grammar check. Importantly, spellcheck reduced the effects of spelling ability on spelling error detection and correction. This suggests that spellcheck is particularly beneficial to poor spellers, which is surprising given MacArthur et al.(1996) found poor spellers did not use spellcheck to its full potential.

Similar numbers of sentence error types (sentence order and within sentence logic) were corrected across conditions (71-75% for sentence order, 42-43% for logical wording of a sentence). Because spellcheck did not cause fewer corrections at the sentence level, authors suggest that using spellcheck does not require enough working memory resources to restrict resources elsewhere. However, in the experimental design, the flagged spelling errors do not need to be processed at the same time as sentence errors. Thus, there is no direct competition for working memory resources. What the results do show is that when used during revision of a completed text, spellcheck does not cause sentence-level errors to go unnoticed. There does not appear to be a detrimental effect of spellcheck on revisions of completed text.

Whether spellcheck draws attention to spelling errors enough to impact text production processes is not known. The impact of the automatic red underline of spellcheck on the writers' error detection and correction behaviour during text production has yet to be assessed.

3.4.3 Spellcheck and transcription, writers with dyslexia

Interestingly, even though spellcheck generally reduces the number of spelling errors in final texts (MacArthur et al., 1996; Pedler, 2001), and by doing so reduces the effects of poor spelling ability on detection and correction of spelling errors (Figueredo & Varnhagen, 2006), Hiscox et al.(2014) found that using spellcheck to correct spelling errors appeared to be a larger burden to the writing process for writers with dyslexia (who are poor spellers) than writers without dyslexia.

Students with ($n=22$) and without ($n=27$) dyslexia, from a UK university transcribed three texts (excerpts from novels) from dictation. Two excerpts needed to be transcribed accurately, one transcribed with access to Global AutoCorrect (GAC) (LexAble Ltd) and one without. When transcribing the third excerpt, writers were asked not to correct their typing, this was transcribed

without GAC (Hiscox et al., 2014). GAC is a program that automatically corrects some spelling errors as soon as they are typed, and by doing so reduces the number of spelling errors in the text. Thus, writers made fewer spelling revisions in the autocorrect condition. Transcription tasks were set one week apart. Before starting each task, writers were made aware that they would need to recall the content of the text. Hiscox et al.(2014) assumed that better recall reflected more available working memory. In all conditions, writers used Microsoft Word (version not specified) with the inbuilt spellchecker activated (there is no mention of grammar check in the paper). Between 6 and 24 hours later, writers responded to a questionnaire to prompt them to recall the material that they had transcribed.

Although overall recall performance was not significantly different between groups, Hiscox et al.'s (2014) results show that with GAC writers with and without dyslexia showed similar recall performance but without GAC writers with dyslexia performed more poorly than writers without dyslexia. The authors suggested that because GAC automatically corrected spelling errors, and therefore decreased the number of spelling revisions made, it reduced the demand on working memory resources for spelling error correction, reducing competition between spelling error correction and information processing. This may be a general reduction in competition for working memory resources, as suggested by Hiscox et al. (2014), or it might be that, with GAC active, there were fewer occasions where spelling error correction competed with information processing.

When writers with dyslexia transcribed accurately with GAC, recall performance was significantly better than when they transcribed accurately without GAC, and equal to when they transcribed without GAC and did not need to make corrections. GAC did not impact recall performance of writers without dyslexia. The authors suggest that spelling error correction with spellcheck did not demand enough working memory resources to interfere with information processing for writers without dyslexia, but did for writers with dyslexia because they had poorer working memory, measured as digit span recall (Hiscox et al., 2014). As described previously, these writers may appear to have poorer working memory during this spelling related task and the digit span (in which information is phonologically encoded) due to a phonological deficit, but this is not evidence for generally poorer working memory.

Importantly, although writers with dyslexia made more errors than writers without dyslexia, they also left more errors in text than writers without dyslexia because both groups made equal numbers of corrections using spellcheck across conditions. Thus the greater impact on recall performance for writers with dyslexia was not due to the quantity of corrections made with spellcheck. Unfortunately, the number of spelling errors or corrections made were not displayed as percentages, thus cannot be compared to results of MacArthur et al. (1996).

It is interesting that GAC corrected enough spelling errors to have an impact on writers with dyslexia. For GAC to work, spelling error words must be very similar to the target word, very different from all other words, and not be real-word errors. This description does not reflect

the spelling errors discussed by MacArthur (1996) who suggested that, for writers with dyslexia, misspellings too different from the target word for spellcheck to generate the target word on the candidate list (e.g. *Frenichur* for *furniture*), and real-word errors, were particularly problematic.

It may be the case that the sample of adult writers, who elected to attend university, in Hiscox et al.'s (2014) study made spelling errors that triggered GAC because they were better spellers than the younger (11-14 years) writers in MacArthur et al. (1996). Alternatively, typing errors could be more likely to result in words that trigger GAC compared to the kinds of spelling errors described by MacArthur (1996). It is possible that because writers in Hiscox et al. (2014) were typing to dictation, they had a tendency to make typing errors while trying to keep pace, whereas writers in MacArthur et al. (1996) who produced their own texts made spelling errors that did not resemble typing errors. However, unless writers with dyslexia are poorer at typing than writers without dyslexia, typing errors would not explain why, in Hiscox et al.'s study (2014) writers with dyslexia made more errors and had more errors autocorrected than writers without dyslexia. Typing speed was not significantly different per group, but typing accuracy was not measured.

To sum, revising spelling errors, even with spellcheck, is more cognitively cumbersome for writers with dyslexia than for writers without dyslexia. However, how spellcheck impacts spelling revision during text production, as opposed to revision of static text or during transcription to dictation, is still unknown.

3.5 Conclusions From the Introductory Chapters

Combined, the research described in these three introductory chapters indicate how spellcheck might have positive and negative influences on writing. Furthermore, because spellcheck supports spelling revision, and because writing is more heavily influenced by spelling for writers with dyslexia than without, spellcheck is likely to have a larger impact on writing for writers with dyslexia (whether positive or negative).

Spellcheck is expected to help writers identify and successfully revise spelling errors. In static text, spellcheck is very effective in supporting revision without negative consequences (Figueredo & Varnhagen, 2006). However, during writing, in the default settings, spellcheck draws attention to spelling errors as they are made, and may be adding the burden of spelling error revision to the writing process at inopportune moments. For a long time, there have been concerns over how word processing programs alert writers to problems in text. For example Fitzgerald (1987) suggests that the effectiveness of a word processing program lies in facilitation of cognitive factors and she expresses concern that '...prompting, [...] could even be a hindrance to an already smooth-running revision routine' (p.495). Revision routines are not necessarily that smooth-running, we know that revision interrupts text production, even without spellcheck present (Chenoweth & Hayes 2003, 2007; Hayes 2012). However spellcheck may increase the

frequency of this interruption, by drawing focus to spelling errors on the page perhaps causing writer to attend to spelling errors sooner (MacArthur et al., 1996; Ronneberg et al., 2018; van Waes et al., 2010), or to attend to more spelling errors (Hiscox et al., 2014), than they would without it active.

Revision appears to interfere with the storage and flow of information being processed (van Waes et al., 2010). Disruptions to transcription could indicate when writers experience disruption to cognitive processes involved in storage and processing of the lexical representation. Managing revision and text production is likely to be especially tricky for writers with dyslexia. Due to a phonological deficit, writers with dyslexia struggle with spelling (Afonso et al., 2015; Elliot & Grigorenko, 2014; Ellis, 2016; Snowling, 2012) and have less working memory resources available for other writing processes (McCutchen, 1996). Thus for these writers, text production is more cognitively costly. Furthermore, even with spellcheck active, spelling revision requires more working memory for writers with dyslexia than peers (Hiscox et al., 2014).

Advice for writers who need to edit spelling errors seems to be to wait until after production and revise the spelling errors as a proofreading exercise (Department for Education, 2013; MacArthur et al., 1996; Torrance et al., 2016), or to wait for a natural pause in production (Ronneberg et al., 2018) or to at least wait until the lexical representation has been safely stored on the page (van Waes et al., 2010). However, for writers with dyslexia, ignoring underlined errors in order to continue devoting working memory to processing and storage of the lexical representation may be particularly demanding due to difficulties managing the multiple writing processes with limited working memory capacity due to poor executive functioning in terms of inhibition (Brosnan et al., 2002) and attention switching (Hari & Renvall, 2001; Valdois et al., 2004).

The automatic underlining could lead to a particularly high frequency of spelling error revision for writers with dyslexia, who make a higher quantity of spelling errors in writing (Sumner et al., in press; Torrance et al., 2016; Wengelin, 2007) and, without spellcheck, would not usually notice large proportions of these errors (Morken & Helland, 2013; Torrance, et al., 2016). Thus, being alerted to the errors during text production would mean that writers with dyslexia have to manage spelling error correction alongside writing production more frequently than they would without spellcheck, and more frequently than writers without dyslexia.

There are many unanswered questions concerning whether spellcheck disrupts writing, and what this means in terms of how writers manage cognitive processes, especially for writers with dyslexia. For example, would spellcheck disrupt writing and cause writers with dyslexia to experience loss of the lexical representation from working memory more than writers without dyslexia? Such research questions are investigated in Chapter 5.

Poor, and cognitively costly, spelling appears to restrict lexical diversity (Sumner et al., in press, 2016; Torrance et al., 2016; Wengelin, 2007). Writers appear to avoid using difficult-to-spell words, evaluating and revising word choice to select words which they can spell before

transcribing the text onto the page. Writers with dyslexia also demonstrate avoidance of spelling errors in text by replacing or deleting words or phrases instead of correcting the spelling (Wengelin, 2007). Using spellcheck should reduce the number of spelling errors in their texts (Figueredo & Varnhagen, 2006; MacArthur et al., 1996). Spellcheck could even help writers to correct their spelling errors without the need to substitute other words. Knowing that spellcheck supports spelling error revision may even encourage writers to evaluate word choice on the appropriateness of meaning rather than spelling accuracy. Thus spellcheck may reduce avoidance of difficult-to-spell words by writers with dyslexia. The relationship between spelling and lexical diversity for writers with dyslexia needs investigating, especially in the context of writing with spellcheck active. This thesis poses the research questions concerning whether spellcheck helps writers with dyslexia to achieve spelling accuracy equal to writers in a control group and whether spellcheck increases lexical diversity, especially for writers with dyslexia, and does this appear to be related to avoidance of difficult-to-spell words. These research questions are investigated in Chapter 6.

Before investigating how spellcheck impacts writing behaviour, cognitive processing, or the relationship between spelling and lexical diversity, it is important to investigate how spellcheck is used in day-to-day writing, by writers with and without dyslexia, and to establish the context and wider environment that spellcheck is a part of. For example, conclusions drawn throughout the previous three chapters have relied on the assumption that spellcheck is used in its default settings, but without any recent empirical studies regarding use of spellcheck, whether this tends to be the case is not known. Identifying the typical writing environment is important for creating studies with ecological validity and for generalising findings to typical writing situations.

There has been much speculation as to the effects that spellcheck may have on writing and on text produced (positive or negative), yet there has been no investigation into whether writers are aware of such effects, such as whether writers feel that spellcheck is disruptive, or whether they find spellcheck particularly helpful. Positive effects of spellcheck could even be reasons that writers choose to use word processing programs. On the other hand, if aware of negative effects of spellcheck, writers may actually tend to write with spellcheck off, they may only use word processing programs because the writing task demands it as opposed to because they prefer it to handwriting. Information about why writers include spellcheck and word processing programs in their writing environment could help to build an understanding of relationships between the writing environment and other components of writing.

The next section of this thesis is made up of three empirical studies. The first study, in Chapter 4, addresses research questions regarding choices writers make concerning the use of word processing programs, what common features in the virtual writing environment are, and whether writers perceive that spellcheck impacts their writing.

Section Two: Empirical Studies

Chapter 4: Survey Exploring the Use and Perceptions of Spellcheck

Chapter 5: The Impact of Spellcheck During Writing

Chapter 6: The Impact of Spellcheck on Spelling and Lexical Diversity in Essay Texts

[blank page]

A Survey Study Exploring the Use and Perceptions of Spellcheck

4.1 Introduction

The introductory chapters highlighted ways that spellcheck could impact writing, particularly for writers with dyslexia. Spellcheck can be found in various digital writing platforms (such as email programs, messaging apps, and search engines), and is a common and well-recognised part of word processing programs. Word processing programs are popular digital writing platforms for producing texts and could form a large part of the everyday writing environment for some populations, undergraduate students in particular (who produce a lot of written coursework) and for people in various jobs that include written communication.

The writer's environment influences their writing (Hayes & Berninger, 2014). Hayes and Berninger's (2014) writing model includes physical and social factors of the writing environment but does not currently account for the part of the writing environment that does not physically exist because it is created by software when writing with word processing programs. However, writers must interact with this part of their environment, navigating menus and using tools (such as spellcheck) that are part of word processing programs in order to produce and manipulate text on the page. So that this part of the writing environment can be easily referred to, in this thesis it is named the virtual writing environment. Furthermore, the Hayes and Berninger (2014) writing model does not account for the writer's motivation for selecting their environment. To date, there has been very little investigation into writing with word processing programs, and little attention towards the virtual writing environment.

In this chapter, a survey study has been carried out to explore the use of word processing programs by adults with and without dyslexia, in particular their perceptions about using spellcheck. The survey gathers information about the common features in the virtual writing environment among writers with and without dyslexia; the motivations behind the choices made regarding word processing programs; and how writers perceive that spellcheck impacts their writing.

4.1.1 Common features in the virtual writing environment

Part of writing with a word processing program is navigating and making choices about the virtual writing environment. For example, the tools in word processing programs (such as spellcheck) can be activated, deactivated or modified. For Microsoft Word and other word

processing programs, spellcheck is activated by default and monitors spellings of words as they are produced, automatically underlining spelling errors. In their support webpages regarding altering the spellcheck settings, Microsoft comment:

You're typing along, you make a mistake, and you see the wavy red underline. You fix the mistake, but you've lost your flow, your idea. To avoid that distraction, you can turn spell check off, then check spelling manually when you're done writing. Here's how...

(<https://support.office.com>, Microsoft). This description indicates an awareness from Microsoft that the default settings of spellcheck are potentially distracting and that this could cause writers to decide to change the settings.

Writers can also alter their virtual writing environment by installing additional software that can be used in word processing programs, such as Mendeley (a referencing program), or by using additional software that is active on the PC at all times such as Global AutoCorrect, or writers might transfer all or parts of their text into other writing platforms, such as the online version of Grammarly, for specific feedback. Several pieces of software have been designed to support writing for writers with dyslexia, such as Dragon, Oribi Verity Spell and Grammarly. Software designed to support difficulties or to promote accessibility is often called 'assistive technology'. It is possible that writers with dyslexia may benefit from assistive technology more than writers without dyslexia, thus they might be more likely to include them in their virtual writing environment. It is also likely that writers with dyslexia, as the target consumers, are more aware of programs available and are encouraged to use them more than writers without dyslexia are. For example, anyone searching online for assistive technology to support writers with dyslexia will come across many recommendations.

The BDA webpages include a shop page for partnered organisations (e.g. Nessy, Spellzone, Word Shark). The BDA New Technologies Committee (BDA.NTC), who evaluate how useful various technologies are in helping people with dyslexia to work more independently, recommend the use of assistive technologies for students with dyslexia (The BDA NTC, 2018; Crivelli, 2013). Their web page links to many types of technology and under the link for spellcheck, is a list of software with descriptions including Microsoft Word, ClaroRead, Read & Write and 11 others.

Dyslex.io is another trusted webpage that provides information about dyslexia, it is funded by the Department for Education and led by the BDA. On their webpage, they list many types and brands of software, some of which are specific to writing. They also provide advice on how to locate and adjust features built in to operating systems on computers (e.g. Apple or Windows), and they link to Goodwill Community Foundation computer basics accessibility pages, which describe how to activate helpful tools available on all computers (such as text-to-speech, zoom, sticky keys) plus links to accessibility pages of various software companies (Microsoft, Apple, Google and Firefox). The Dyslexia Association webpages also advise adults to make use of technology and lists several general types of software (spellcheck, scanning software, text-to-

speech) as well as providing links to the webpages of the brands Dragon, textHELP and Livescribe (the Dyslexia Association).

In addition, use of some software is encouraged though academic institutions, thus students may be more likely to use software that is made available to them. For example, Oxford Brookes University put writing software on pooled room PCs, including Inspirations, Mind Genius and Read and Write which include speech feedback, phonetic spellchecking, homophone checking, word prediction. Thus, in theory, writers with dyslexia are more likely to use additional writing software than writers without dyslexia, and to make use of certain settings on their word processing programs, however currently there are very few, if any, comparison studies investigating this.

If more is known about the typical virtual writing environment, for writers with and without dyslexia, then researchers can begin to consider how findings from writing research apply to day-to-day writing for these groups. For example often, when research into writing processes involves typing, study designs do not include spellcheck (e.g. Torrance, Thomas, & Robinson, 2016; van Waes et al., 2010; Wengelin, 2002). Preventing access to spellcheck is often necessary in order to make the experiments more controlled and to focus on specific components of writing. However, if writers typically write with spellcheck automatically monitoring their spelling then not allowing writers to use it is distancing the writing task from the usual writing experience, reducing ecological validity and may make findings less generalisable. Furthermore establishing the typical writing environment can highlight similarities and differences between typical writing conditions and restricted writing conditions such as experimental conditions or examination conditions. The current study will examine the choices writers with and without dyslexia make when creating their virtual writing environment, focussing on the use of spellcheck.

4.1.2 Why use a word processing program?

Word processing programs make adding, deleting or moving text quick and easy, and unlike handwriting, revisions made are not shown in the text. Furthermore, revision of many word-level errors is supported by tools such as spellcheck and grammar check. Whilst these functions have potential to improve text, word processing programs have been criticised for focusing on word-level editing and perfecting the appearance of the final text when writing software should focus on supporting the process of writing (for a recent review see Ronneberg, et al., 2018). It has been suggested that creating texts that look ready to print, even if the text is only a first draft, causes writers to juggle presentation with content-related goals (Figueredo & Varnhagen, 2006; Fitzgerald, 1987). Thus word processing programs could increase the cognitive load of the writing process. Particularly when spellcheck automatically underlines spelling errors. As outlined in the previous chapter, spellcheck has not been found to restrict content related revision during proofreading of a static text (Figueredo & Varnhagen, 2006), but may increase

competition for working memory resources during text production. It is possible that using a word processing program for initial text production is more cognitively costly than handwriting, which raises the question of why writers choose to use word processing programs.

The decision to use word processing programs could be influenced by the need for word-level editing to perfect the appearance of text and please the reader, who, for students, is also the marker. UK HE students are often expected to produce digital copies of coursework for marking online (which is increasingly popular in UK HE) and for using plagiarism checking software, which requires digital versions of text. Therefore, writers may choose to use word processing programs because they are expected to produce their texts in a digital format.

Interestingly, word-processed texts are marked more harshly if they contain spelling errors than handwritten texts that contain spelling errors (Graham et al., 2011). It is assumed that word-processed texts have been written with spellcheck active and the presence of spelling errors leads readers to question the writer's ability (Figueredo & Varnhagen, 2005) therefore when producing text with word processing programs, spelling is particularly influential to readers judgements of quality. In some cases, marking criteria explicitly states that spelling, grammar and punctuation are included in determining the overall mark. For example, the participant sample in this study are from Oxford Brookes University, and the marking criteria for psychology student coursework guides markers to consider spelling, grammar and punctuation when grading reports (see Appendix A). Thus spelling (and grammar) errors create a barrier to attaining the highest grades.

Even when spelling is not an explicit marking criterion, it can influence readers judgements. Texts which are easier to read (neater with fewer spelling errors) are rated as better (Figueredo & Varnhagen, 2005; Huck & Bounds, 1972; Johnson, Wilson, & Roscoe, 2017; Marshall & Powers, 1969) even when compared with the same word for word text with no spelling errors (Marshall & Powers, 1969; Rezaei & Lovorn, 2010). Essays that included spelling errors were rated as having poorer quality of ideas than the same essays presented without spelling errors (Graham, Harris, Hebert, 2011). Often documents written by students with dyslexia are flagged to markers, so that they grade documents without penalising overall presentation and writing style. However, how well markers can ignore spelling errors and determine precisely what causes them to judge a text as lower quality is questionable.

Authors likely benefit from accurate spelling because the marker's judgement of quality depend on it. Thus spelling accuracy is important and likely to be included in writing goals assigned by the task initiator. Spellcheck helps writers improve the spelling accuracy of their texts, which creates a better reading experience and could be particularly beneficial for texts that will be graded. Therefore, writers may choose to use word processing programs because of tools available to support their writing, such as spellcheck.

Choosing to use word processing programs may be related to the nature of the writing task for example, using word processing programs is an increasingly popular transcription method for taking notes to dictation in seminars or lectures (Cassany, 2012; Weaver & Nilson, 2005; in

Aragón-mendizábal, Delgado-Casas, & Menacho-jiménez, 2016). For transcription-based tasks, such as note taking, (as opposed to composing texts), writers might benefit from greater speed and comfort when typing compared to handwriting. Bui, Myerson, and Hale (2013) suggest that the writer cannot physically handwrite as fast, or for as long, as they can type. This statement follows studies in which US undergraduates produced more text when typing than when handwriting for short essay tasks in timed conditions (10 or 15 minutes) (Lovett, Lewandowski, & Gathje, 2010). This was also the case for dictation tasks (11 minutes) (Bui, Myerson, & Hale, 2013).

Whether this is also true for UK HE students is not clear. UK HE students ($N=140$) completed a survey after being offered the choice to type or handwrite during their examinations. Only 36% reported that they type faster than they handwrite, 29% that they handwrite faster than they type and the remainder report that they write at similar speeds in both modes or do not know which is faster (Mogey, Cowan, Paterson, & Purcell, 2012). Thus results indicate that these UK students generally do not believe that their typing is faster than their handwriting, which does not findings from groups of US students (Bui et al., 2013; Lovett et al., 2013). Interestingly, undergraduates who handwrote their exams reported more physical discomfort towards the end of exams (Lovett et al., 2010; Mogey et al., 2012). Writers may choose typing over handwriting when writing for extended periods of time for greater comfort, but not necessarily for greater speed.

While coursework (and other texts) might need to be submitted in a word-processed format, preparation for such texts can still be carried out with handwriting. In a UK HE university, 40 undergraduates were asked about how they prepare non-examination essays. Interestingly, 80% report that they make lots of notes using a pen and paper and 42.5 % create a detailed plan on paper while only 20% create a detailed plan on a computer (15% report not planning their essays)³ (Mogey & Fluck, 2015). Concerning revisions to the essays 91% report that they are more likely to make revisions to their texts with a computer and 90% that they avoid making revisions when using pen and paper. This raises the question of whether writers use word processing programs for some writing activities but not others, thus create different writing environments for different writing activities (such as planning compared to proofreading and revision).

For proofreading and revision, features of word processing programs such as spellcheck, autocorrect and grammar check are useful for identifying and correcting word-level errors. Access to tools such as spellcheck may contribute to the writer's choice to use a word processing program. Spelling is a particular issue for writers with dyslexia, even into adulthood (Hatcher et

³ Participants in Mogey and Fluck's (2015) study could select multiple options, which is why reported percentages do not add up to 100%.

al., 2002). Spellcheck assists with identifying and revising spelling errors and using it reduces the number of spelling errors left in texts (Figueredo & Varnhagen, 2006; MacArthur et al., 1996; Pedler, 2001). Writers with dyslexia are encouraged by educational institutions to use word processing programs for revision support. For example, the participant sample in this study is from Oxford Brookes University. In the university guide to teaching, on the page regarding dyslexia, Oxford Brookes University writes that they ‘encourage students to do all writing on a computer rather than by hand, since it is so much easier to check spellings and edit.’ (<https://www.brookes.ac.uk>, Oxford Brookes University). In addition, trusted sources for information about dyslexia, the British Dyslexia Association (BDA), Dyslex.io, and the Dyslexia Association all promote using spellcheck (see next section for more details of software promoted by them).

Including spellcheck in the writing environment is beneficial for producing spelling-error-free texts, which is a particular difficulty for writers with dyslexia, however, as discussed in the previous chapter, the presence of spellcheck has also been found to cause a particular cognitive burden for writers with dyslexia (Hiscox et al., 2014). It has not previously been established whether writers with dyslexia choose to incorporate spellcheck into their usual writing environment. Similarly, it is not known whether writers without dyslexia tend to incorporate it into their writing environment.

It is not known whether writers with and without dyslexia value the same features of word processing programs. Why and how writers with and without dyslexia use word processing programs has not previously been explored. What motivates writers to use word processing programs and the features of these programs, such as spellcheck, will be a focus of this study.

4.1.3 Do writers feel that spellcheck impacts writing?

It is important to investigate writers perceptions of using spellcheck. One might assume that writers create their virtual writing environment with features that they use, but it is not necessarily the case. For example, if writers leave programs in default settings then spellcheck will automatically underline the words as they type, but writers may not make use of this. Writers might notice their spelling errors before leaving the word (before pressing spacebar which activates spellcheck) and might not rely on the automatic underlining. Furthermore, writers may retype words that are misspelled instead of using spellcheck to replace the error with a word from the candidate list. Thus it is also important to ask writers whether they carry out such behaviours in order to ascertain how they are using spellcheck.

As highlighted in Chapter 3, writing researchers have suggested that the automatic underlining of spellcheck is distracting during writing, but have not investigated this (Figueredo & Varnhagen, 2006; MacArthur et al., 1996; Ronneberg et al., 2018). As described in Chapter 1, writing is a very demanding task, placing large cognitive demand on limited resources as writers manage multiple information packages, processing them in parallel (Olive 2014, see Figure 1.3

page 43). Revising interrupts writing (Chenoweth & Hayes, 2003). When the writer is disrupted by the need to revise, and resources being used in text production need to be used for revision, the information being processed is at risk of being lost or damaged (van Waes et al., 2010). This is likely experienced as disruption to thought. To reduce the loss of information (disruption to thought) writers can postpone revision in favour of transcribing the information to the page where it is stored safely (van Waes et al., 2010). Spellcheck could increase the disruption to writing and the disruption to thought, by increasing how often writers notice misspelled words, and could make them more difficult to ignore by underlining them.

As described in Chapters 2 and 3, writing and coordinating writing processes is even more difficult for a writer with dyslexia. On top of that, writers with dyslexia may find automatic underlining of spellcheck more distracting than their peers do. Difficulties with inhibition and attentional mechanisms (Hari & Renvall, 2001; Valdois et al., 2004) make ignoring distractions difficult for adults writers with dyslexia (Smith-Spark et al., 2016). Thus, writers with dyslexia may be less able to ignore the appearance of an underline, thus more likely to be disrupted by spellcheck.

While studies have shown that spellcheck assists with the detection and correction of misspelled words for writers with and without dyslexia (Figueredo & Varnhagen, 2006; MacArthur et al., 1996; Pedler, 2001), it may also distract writers, especially those with dyslexia, during text production. To date, there has been no investigation of the impact of the automatic underlining feature of spellcheck during text production for writers with and without dyslexia. The current study explores whether writers with dyslexia perceive that they are interrupted by spellcheck during text production, whether they think it causes them to stop writing, and whether they experience disruption to their thoughts.

4.1.4 The current study

There are gaps in our knowledge of writing with word processing programs, the virtual writing environment, and the writing behaviours related to using spellcheck. These gaps form the research questions for the present study:

1. What are the common features in the virtual writing environment that writers create for themselves?
2. Why do writers choose to write with a word processing program, particularly, why instead of handwriting?
3. Do writers perceive that spellcheck impacts their writing behaviour? If so how?

A survey is the most efficient way to find out about the choices writers make in regard to their writing. The writing studies discussed in the introduction are mostly experimental, however, to answer these research questions it is necessary to know what writers think, and a survey is a valid way of doing this. Participants beliefs and intentions are often good ways of predicting their behaviour (Armitage & Conner, 2001). Researchers who have investigated writers' choices and

beliefs about writing behaviours tend to use surveys (Mogey et al., 2012; Mogey, Paterson, Burk, & Purcell, 2010; Mogey et al., 2008; Mogey & Fluck, 2015). An online survey was developed to investigate the questions outlined above, to gain insight into the opinions of adult writers with and without dyslexia.

4.2 Method

4.2.1 Survey design and development

The questions and response options were developed through pilot work. Three examples of the changes made are described below:

1. Some response options were created from answers given by participants in piloting. For example, when writers were asked to select the writing tool they find most useful, initially participants could only select one, but participants suggested that selecting all the tools that they find useful would provide a better picture of how word processing programs are useful. Thus the response options were changed so that participants were able to select all the tools they find useful. Furthermore, participants reported that they needed a wider list of tools to choose from, and so an *'other'* response option was added.

The final question became: *'Word processors have a number of writing tools to aid writing. Please indicate which tools you find useful.'* The response options were: *'Spellcheck', 'Grammar check', 'Synonyms/thesaurus', 'Dictionary', 'Tools which effect aesthetics (font, style, layout)', 'Ability to insert items (images, graphs, tables)'* and *'Other'*. Participants were able to select as many options as they wanted. Participants who selected *'other'* were asked to specify what they meant by this.

2. Initially for the question: *'Does the notification of a spelling error ever cause you to stop writing?'* the response options were *'yes'* or *'no'*. Participants explained that their writing habits differ on certain occasions and felt that to select *'yes'* or *'no'* was not giving an honest picture of their writing habits thus, the response option *'it depends'* was added.
3. Participants reported that although they were able to select options which closely described their writing behaviours, it was frustrating to think that they might be misunderstood and so they wished to justify or further explain their responses. Thus a text box was added for participants to add information about their writing behaviours. The question: *'If you would like to add any comments about your writing practices, please write in the box below.'* was added to the survey.

The final survey consisted of 19 compulsory questions, with three follow-up questions that only appeared after selecting certain responses to compulsory questions. Questions are listed in Table 4.1 and shown in Appendix B. In the table, the questions have been grouped into three sections to correspond with the research questions. The survey was displayed over 13 pages, followed by a page to collect demographic information such as age, gender, whether the participant considered themselves to have any reading or writing difficulties, and whether they were a student. These questions are not listed in Table 4.1, but results from these questions are described in the participant section. The final version was created using the survey design software *Qualtrics* and presented online. The survey took around ten minutes for participants to complete.

Table 4.1 List of questions from the survey

The following items are related to the research question: What are the common features in the virtual writing environment that writers create for themselves?	
Question	Response options
‘Writing with a computer typically involves using a word processor (such as Microsoft Word or Apple Pages).	Participants were able to rate each option from never (1) to always (5)
When using a word processor to produce formal pieces of text (over a paragraph in length), how often do you use each of the following programs?’	• Microsoft Word • Apple Pages • Google Documents • Lotus Word Pro • Adobe InCopy • Other (please specify)
‘How often do you use spellcheck in its default settings?’	Participants could select one option
‘How often do you use spellcheck without it being active as you write?’	1. Never 2. Occasionally 3. Often 4. Most of the time 5. Always
‘The spellcheck settings can be altered. Have you ever altered the spellcheck settings?’	Participants could select one option
	‘yes’
	‘no’

Participants who responded yes to the previous question were presented with the following two questions:

(f) 'Please describe the alterations that you have made to spellcheck'

Text box

(f) 'When writing with a word processor, how often do you use these altered spellcheck settings?'

Participants could select one option

1. Never
2. Occasionally
3. Often
4. Most of the time
5. Always

'Sometimes words may be spelled correctly but become underlined as if they are wrong (this often happens for proper nouns, names, or specialist vocabulary). Do you ever add words into the spelling dictionary so that they are recognised in the future?'

Participants could select one option

'Yes'

'No'

'Do you ever switch autocorrect off?'

Participants could select one option

'Yes'

'Have you ever added any words into the autocorrect list of words?'

'No'

'Do you use any specialised writing software (such as text to speech software)?'

Participants could select one option

'Yes'

'No'

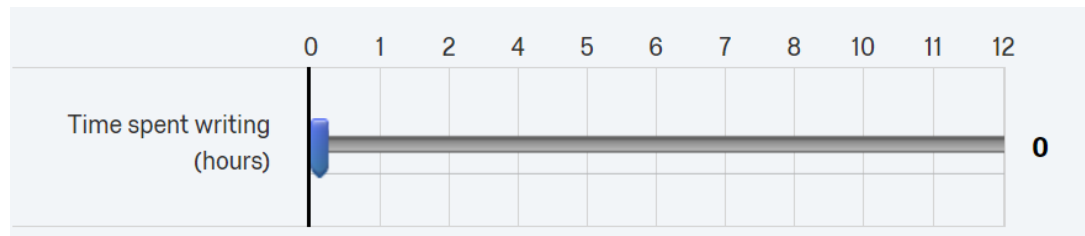
Participants who responded yes to the previous question were presented with:

Text box

(f) What software do you use?

‘On average, how many hours a day do you spend on tasks that include writing? (please click and drag the bar to indicate your answer)’

Participants used a sliding scale to respond and were able to submit any number of hours between 0 and 12, in increments of 0.5. The number chosen was displayed to the right-hand side of the graphic (graphic shown overleaf).



The following items are related to the research question: Why do writers choose to write with a word processing program, particularly, why instead of handwriting?

Question	Response options
'When you write using a word processor, why do you choose to do so rather than write using a pen and paper. Please select all reasons which apply to you.'	Participants were able to select multiple options from this list: • The writing is expected to be produced with a word processor • Typing is quicker than handwriting • Typing is easier than handwriting • Text appears neater than handwriting • The tools in word processors are helpful (e.g. thesaurus or spellcheck) • Text is easier to edit (e.g. it is easy to delete, move and copy text) • The document can be accessed from different devices and locations • The document can be shared virtually • Other (please specify)

The options that the participant selected in the previous question were presented on screen.

‘Please click and drag each of the reasons that you use a word processor and arrange them from most important at the top to least important at the bottom (1 = most important).’

‘Word processors have a number of tools to aid writing. Please indicate which tools you find useful.’

‘Please think about when you construct important pieces of writing (e.g. essays, reports, proposals, formal letters, long emails) for the following questions:’

‘When writing, how often do you write a plan (short notes or bullet points) of what you will include in the text?’

‘If you write plans, how often do you write a plan using a pen and paper?’

The reasons (previously selected by the participant) could be moved up and down and were automatically numbered to reflect the order of most (1) to least importance.

Participants were able to select multiple options from this list:

- Spellcheck
- Grammar check
- Synonyms/thesaurus
- Dictionary
- Tools which effect aesthetics (font, style, layout)
- Ability to insert items (images, graphs, tables)
- Other (please specify)

For each of the questions listed, participants could select one option.

1. Never
2. Occasionally
3. Often
4. Most of the time
5. Always

‘If you write plans, how often do you write a plan using a word processing program?’

‘How often do you write a draft (a rough version of the whole text) before writing the final text?’

‘If you write a draft, how often do you write a draft with a pen and paper?’

‘If you write a draft, how often do you write a draft with a word processor?’

‘If you would like to add any comments about your writing practices, please write in the box below.’

Text box.

The following items are related to the research question: Do writers perceive that spellcheck impacts their writing behaviour? If so how?

Question	Response options
‘Does the notification of a spelling error (e.g. the appearance of a red line) ever cause you to stop typing?’*	Participants could select one option 'Yes' 'No' 'It depends (please specify)'
‘Does the notification of a spelling error (e.g. the appearance of a red line) ever disrupt your train of thought when writing?’*	Participants could select one option 'Yes' 'No' 'it depends (please specify)'
‘When spellcheck is used in its default setting (so that spelling errors are underlined as you type), how often do	For each of the questions listed, participants could select one option.

you spot a spelling mistake before it becomes underlined or highlighted?'

'When a spelling mistake occurs, how often do you correct it by selecting a word from the list of suggestions supplied by spellcheck?'

1. Never
2. Occasionally
3. Often
4. Most of the time
5. Always

'When a spelling mistake occurs, how often do you correct spelling errors without using the list of words provided by spellcheck (i.e. retype or alter the existing text)?'

'When a spelling error occurs in your writing, how often do you correct the error as soon as you notice it?' *

'After noticing a spelling error, some people continue to write before choosing to correct the error.

When you notice a spelling error, how far do you usually continue to write before stopping to correct the error?'

Participants could select one option

- To the end of the word
- To the end of sentence
- To the end of the paragraph
- To the end of the whole text
- I continue to write until the thought held in my head is down in writing
- Other (please specify)

Note: where response options indicate 'please specify' writers were able to write in a text box to explain their response.

* = questions with this symbol were presented on the same page and the following text was displayed at the top of that page 'For the following questions please think about when you construct important pieces of writing (e.g. essays, reports, proposals, formal letters) using spellcheck in its default settings (so that spelling errors are underlined or highlighted as you type).

(f) = follow up questions.

4.2.2 Recruitment

This study was advertised through the Oxford Brookes University participant panel and posters placed around the university. The participant panel is a research community mail group. Students and staff with an Oxford Brookes University email address can sign up to receive emails about research being undertaken by research staff and PhD students at Oxford Brookes University and in the wider academic community. The mail group is overseen by the University Research Ethics Committee. In order to capture a broad sample of adult writers, both students and non-students were invited to complete the survey. Inclusion criteria dictated that participants must be over 18 and speak English as a first language. The survey could be accessed by anyone via a link, on any device with internet access. All studies in this thesis received ethical approval from the Oxford Brookes University Research Ethics Committee (see Appendix C for approval letter).

The first page of the questionnaire was a digital participant information sheet, as shown in Appendix B. A participant information sheet was also included in the email sent by the gatekeeper of the participant panel mailing list. This participant information sheet is included in Appendix D. Underneath the participant information sheet participants were presented with this statement ‘Thank you for taking time to read this information. If you would like to take part in this questionnaire, please tick the box to indicate that you have read and understood this information, then click on the green rectangle at the bottom right hand side of the screen.’. Giving consent in this way was required before participants could move onto the next page. After clicking the green rectangle the next page included this statement ‘By submitting this questionnaire you are providing consent for your responses to be collected. If at any point you no longer wish to take part you may leave the questionnaire and no information will be recorded unless you submit your responses. In order to record your responses you must press submit at the end of the questionnaire. Once your responses have been submitted it will not be possible to change them.’.

In addition, the final page of the questionnaire reminded participants that they could choose not to submit their responses. It was explained that if they did want to submit their responses they needed to click on a green rectangle at the bottom right hand side of the screen (the same green rectangle used to move from the consent form screen to the main questionnaire, with the word ‘submit’ on it) and that when responses had been recorded a thank you message would appear. It was also explained that if they did not want to submit their data they should not click the green rectangle and they could leave the questionnaire without submitting their data by closing the browser.

4.2.3 Participants

Of the 279 people who accessed the survey, 207 completed it. Only completed surveys were included in data analysis. This sample of 207 participants consisted of 110 students (53.14%) and 97 non-students (46.86%), 41 men (19.81%), 165 women (79.71%) and one

participant who did not specify their gender. Participants were aged 18-51 years (mean 37.78). Thirty participants (14.49%) reported that they have dyslexia, although no other information was available to confirm this diagnosis. Dyslexia is reported to affect 5-15% of the population (Elliot & Grigorenko, 2014) and so this proportion of participants in the sample is towards the higher end of what would be expected. The other 177 (85.51%) participants reported having no reading or writing difficulties. See Table 4.2 for details of age, gender and student: non-student ratios.

Table 4.2 Description of participant groups with and without dyslexia

	Gender ratios			Student (S), non-student (N-S) ratios	
	Mean age	<i>n</i>	%	<i>n</i>	%
	(years)	M:F	M:F	S:N-S	S: N-S
Dyslexia group	33.20	6:24	20%:80%	21:9	70.00%:30.00%
Control group	38.66	35:141	19.89%:78.34%*	89:88	50.28%:49.72%

*does not sum as 100% due to one participant who did not specify their gender.

There were no significant differences between the dyslexia group and control group for age $U(N=207)=1999, p=.560$, or gender $\chi^2(N=207)=.171, p=.918$. Although there is a gender imbalance, with more women than men, the gender ratio is matched in both groups thus is unlikely to cause any differences between groups. There was an association between student status and dyslexia status, individuals with dyslexia were more likely to be students than non-students, $\chi^2(N=207)=.139, p=.045$. Therefore, where survey results indicated significant differences between groups with and without dyslexia, data was then compared between students and non-students. There was a significant difference between students and non-students only on one occasion. This is presented at the end of the results section. Thus, there was no reason to separate data into student and non-student responses throughout the results section apart from that one occasion. Considering that participants were recruited through the university, it is likely that non-students were members of staff or recently graduated students (recently graduated because student email accounts close 300 days after course completion, thus they would not receive the email from the participant panel if they had graduated more than 300 days earlier).

To provide an idea of this sample's writing practices, they were asked how much of a typical day is devoted to writing. Previously it has been found that undergraduates spend 9-15 hours writing an essay (Torrance, Thomas, & Robinson, 2000), however, it was not clear over what period of time this is or how much per time per day is devoted to writing. It has been found that students use computers for 4.1-4.3 hours per day (Jacobs et al., 2011) however it is not known how much of this time is writing-related and does not include time spent writing without

using a computer. In this study participants report spending, on average, 5 hours a day on writing-related activities. There was no significant difference between students and non-students or between writers with and without dyslexia $U(206)=2301.50, p=.257$. This is a novel finding in writing research.

4.2.4 Data analysis

Due to uneven group sizes, non-parametric tests, such as Man-Whitney U tests, chi-square tests of independence, were used in all analyses comparing data between groups (dyslexia and control groups). Effect sizes are reported and interpreted using Cohen's criteria as small (.10) medium (.30) or large (.50) (Cohen 1988, in Pallant, 2013). For questions where the response options consisted of a 5-point Likert scale, the median rating has been used.

4.3 Results

The results section is presented in three parts to correspond with the three research questions (and three sections in the introduction):

1. What are the common features in the virtual writing environment that writers create for themselves?
2. Why do writers choose to write with a word processing program, particularly, why instead of handwriting?
3. Do writers perceive that spellcheck impacts their writing behaviour? If so how?

4.3.1 Common features in the virtual writing environment

Questions in this section were designed to examine the choices writers make in creating their virtual writing environment. Participants were asked 'When using a word processing program to write substantial pieces of text, how often do you use each of the following programs?' Responses are displayed per group in Table 4.3. Microsoft Word was reported as the most popular word processing program. As shown by the median rating, groups did not differ on how often they use each word processing program. The participants who selected *other* specified which programs they use. The most popular program reported in *other* was 'Open Office' (used by 5 of the 22 participants who selected *other*). This is open-source software from Apache, this is not a word processing program in itself, but an office software suite which includes a word processor called 'Writer'. 'Writer' includes a spellcheck function as well as autocorrect and autocomple. None of the programs specified in *other* are programs designed specifically for writers with dyslexia or other difficulties with reading or writing.

Table 4.3 Ratings of how often writers use each word processing program.

Word processing program	Frequencies					Median rating	
	1	2	3	4	5	Dyslexia	Control
	(Never)	(Occasionally)	(Often)	(Most of the time)	(Always)	group (<i>n</i> =30)	group (<i>n</i> =177)
Microsoft Word	1	6	13	59	143	5	5
Google Documents	80	83	33	20	4	1	1
Apple Pages	194	17	5	1	3	2	2
Adobe in Copy	207	11	1	0	0	1	1
Lotus Word Pro	219	0	0	1	0	1	1
Other (please specify)	178	8	6	6	3	1	1

Participants were asked about the spellcheck settings they usually use. Participants tend to use spellcheck in its default settings, to automatically underline spelling errors, most of the time (17.3%) or every time (66.3%) that they write. Writers report that they only occasionally (5.3%) or never (5.8%) use it outside of these settings, where the writer would need to open spellcheck in a side tab, or new window, for it to produce a list spelling errors it has identified. As shown in Table 4.4 median ratings were matched across groups.

Table 4.4 Median ratings, per group, regarding the use of spellcheck settings.

Question	Median rating	
	Dyslexia group (<i>n</i> =30)	Control group (<i>n</i> =177)
How often do you use spellcheck in its default settings?	5 (Always)	5 (Always)
How often do you use spellcheck without it being active as you write?	1 (Never)	1 (Never)

Participants were asked if they had ever altered the spellcheck settings. Responses are shown per group in Table 4.5. A chi-square test for independence was carried out on these data and indicated that there was no association between group and spellcheck settings $\chi^2 (1, N=207)$

=0.68, $p=.408$ $\phi=.06$. Participants who responded that they had altered the spellcheck settings were asked to specify the alterations that they had made. The most common alteration made is to change the language setting to British English.

Participants were asked how often they use these settings. The control group had a median rating of 4 (most of the time), the dyslexic group had a lower median rating of 3 (often), however, this was not a significant difference, $U(207)=2215.50$, $p=.084$, $r=.06$.

Table 4.5 The amount of writers, per group, who have altered the spellcheck settings.

Response:	Dyslexia group ($n=30$), N (%)	Control group ($n=177$), N (%)
Yes	16 (53.33)	83 (46.89)
No	13 (43.33)	94 (53.11)
Missing	1 (3.33)	0 (0.00)

Participants were asked whether they switch autocorrect off, results are shown in Table 4.6. The majority of participants do not switch autocorrect off (without dyslexia, 78.53%; with dyslexia, 90.00%). A chi-square test for independence was carried out on these data and indicated that there was no association between group and response, $X^2(1, N=207)=1.86$, $p=.173$, $\phi=.10$.

Table 4.6 The amount of writers, per group, who switch autocorrect off.

Response	Dyslexia group ($n=30$), N (%)	Control group ($n=177$), N (%)
Yes	3 (10.00)	36 (20.34)
No	27 (90.00)	139 (78.53)
Missing	0 (0.00)	2 (1.13)

Participants were asked whether they add words to the spellcheck or autocorrect dictionaries. Results are shown in Table 4.7 and Table 4.8. The majority of writers have not added any words to the spellcheck dictionary, or to the autocorrect dictionary. Results of chi-square tests for independence indicated that there is no association between group and dictionary response, $X^2(1, N=207)=1.33$, $p=.248$, $\phi=.08$, or group and autocorrect response, $X^2(1, N=207)=.144$, $p=.704$, $\phi<.01$.

Table 4.7 The amount of writers, per group, who add words into the spelling dictionary.

Response	Dyslexia group ($n=30$), N (%)	Control group ($n=177$), N (%)
Yes	5 (16.67)	47 (26.55)
No	25 (83.33)	130 (73.44)

Table 4.8 The amount of writers, per group, who add words to autocorrect.

Response	Dyslexia group ($n=30$), N (%)	Control group ($n=177$), N (%)
Yes	9 (30.00)	59 (33.33)
No	21 (70.00)	117 (66.10)
Missing	0 (0.00)	1 (0.56)

Writers were asked if they use additional specialist software. Results are shown in Table 4.9. A significantly higher percentage of writers with dyslexia use specialised writing software compared to writers without dyslexia, the effect size was medium $X^2(1, N=207) = 34.48, p < .001, \phi = .38$. Participants who declared that they use specialised writing software were asked to specify which software they use. The most popular software reported by participants was Dragon (Nuance), speech recognition software which allows writers to dictate their text used by 10 of the 24 participants who used specialised writing software.

Table 4.9 The amount of writers, per group, who use specialised writing software.

Response	Dyslexia group ($n=30$), N (%)	Control group ($n=177$), N (%)
Yes	13 (43.33)	11 (6.21)
No	17 (56.67)	166 (93.79)

4.3.2 Why use a word processing program?

Nine questions were asked in order to investigate why writers choose to write with a word processing program, particularly, why instead of handwriting, and whether the spellcheck feature of such programs is a factor in this decision.

Results for the question *'When you write using a word processor, why do you choose to do so rather than write using a pen and paper. Please select all reasons which apply to you.'* are displayed in Table 4.10. The popularity of each item is presented as the percentage of participants in each group that selected that item.

Table 4.10 Reasons that participants use a word processor (median ranks, 1= most important) compared between groups.

Responses	Dyslexia group (<i>n</i> =30)			Control group (<i>n</i> =177)			<i>X</i> ² values and effect size (<i>phi</i>)	U score and effect size (<i>r</i>)
	<i>N</i>	(%)	Median rank	<i>N</i>	(%)	Median rank	comparing response % and group	comparing rank between groups
The text is easier to edit	28	(93.33)	2	163	(92.09)	2	<i>X</i> ² (1, <i>n</i> =207)=1.00, <i>phi</i> =.02	U (207) =1886.00, <i>r</i> =.03
The writing is expected to be produced with a word processor	24	(80.00)	4	131	(74.01)	2	<i>X</i> ² (1, <i>n</i> =207)=.649, <i>phi</i> =.04	U (207) =1013.50, <i>r</i> =.14*
The text appears neater than handwriting	21	(70.00)	3.5	121	(68.36)	4	<i>X</i> ² (1, <i>n</i> =207)=1.00, <i>phi</i> =.01	U (207) =912.50, <i>r</i> =.15
The tools in word processors are helpful	21	(70.00)	2	104	(58.76)	4	<i>X</i> ² (1, <i>n</i> =207)=.314, <i>phi</i> =.08	U (207) =570.00, <i>r</i> =.26**
The document can be accessed from different devices and locations	18	(60.00)	4	124	(70.06)	4	<i>X</i> ² (1, <i>n</i> =207)=.398, <i>phi</i> =.07	U (207) =1048.50, <i>r</i> =.04
The document can be shared virtually	15	(50.00)	4	102	(57.63)	5	<i>X</i> ² (1, <i>n</i> =207)=.552, <i>phi</i> =.05	U (207) =609.50, <i>r</i> =.04
Typing is quicker than handwriting	13	(43.33)	3	108	(61.02)	3	<i>X</i> ² (1, <i>n</i> =207)=.109, <i>phi</i> =.12	U (207) =587.00, <i>r</i> =.05

Typing is easier than handwriting	13	(43.33)	3	81	(45.76)	4	$X^2(1, n=207)=.692, \phi=.04$	U (207) =467.00, $r=.08$
Other ⁴ (please specify)	2	(6.67)	5	18	(10.17)	6	$X^2(1, n=207)=.744, \phi=.05$	U (207) =10.00, $r=.20$

*= $p \leq .05$, **= $p \leq .001$.

⁴ Several responses given under the *other* category were typing related (two comments suggesting that typing is more comfortable than handwriting and five comments that their handwriting is messy or illegible). Five comments were related to tools in word processing programs: '*spelling*', '*referencing*', '*highlighting*', '*translation*' including the comment '*easy to expand essay later*' which may refer to easier editing or that text can be stored digitally to be revisited another time. Some comments were related to general functionality of digital text: '*environmentally friendly*', plus two comments about digital storage. One comment was '*expected by others*', this participant also selected *the writing is expected to be produce by a word processor* as a reason, but perhaps wanted to highlight this or intended the comment to mean something different to the option available. There were also three more comments: '*email is a real thing*', '*do not use computer*', and '*just prefer it*'.

The most popular response for both groups was that *the text is easier to edit*. This was also ranked as most important for both groups. Chi-squared tests of independence revealed no significant associations between group and whether the response was selected or not for any of the responses included. Importance ranking was compared between groups and two significant differences were found: the dyslexia group rank *the writing is expected to be produced with a word processor* as a significantly less important factor than the control group, this has a small effect size. Writers with dyslexia rank *the tools in word processors are helpful* as a significantly more important factor than the control group, with a small to medium effect size.

Results for the question ‘*Word processors have a number of tools to aid writing. Please indicate which tools you find useful.*’ are shown in Table 4.11.

Table 4.11 The amount of writers that find each tool useful and chi-square tests for independence between groups.

Responses	Dyslexia group (<i>n</i> =30) <i>N</i> (%)	Control group (<i>n</i> =177) <i>N</i> (%)	χ^2 values and effect size based on percentage (<i>phi</i>)
Spellcheck	30 (100.00)	159 (89.83)	χ^2 (1, <i>n</i> =207)=3.34, <i>phi</i> =.08
Ability to insert items (images, graphs, tables)	23 (76.67)	146 (82.49)	χ^2 (1, <i>n</i> =207)=.580, <i>phi</i> =.05
Tools which effect aesthetics (font, style, layout)	22 (73.33)	145 (81.92)	χ^2 (1, <i>n</i> =207)=1.21, <i>phi</i> =.07
Synonyms/thesaurus	22 (73.33)	114 (64.41)	χ^2 (1, <i>n</i> =207)=.907, <i>phi</i> =.06
Grammar check	23 (76.67)	90 (50.85)	χ^2 (1, <i>n</i> =207)=6.89, <i>phi</i> =.18*
Dictionary	16 (53.33)	43 (24.29)	χ^2 (1, <i>n</i> =207)=10.61, <i>phi</i> =.23*
Other ⁵	2 (6.67)	7 (3.95)	χ^2 (1, <i>n</i> =207)=.454, <i>phi</i> =.04

*= $p \leq .01$.

Spellcheck was rated as useful by the most participants in both groups. There was no significant association between group and whether spellcheck was selected as a useful tool. The only significant associations between group and whether a tool was rated as useful or not, was for

⁵ In ‘other’ one participant with dyslexia reported ‘dragon software’ and one reported ‘word count’. The seven participants from the control group reported the following: ‘wordcount’, ‘spellcheck checking for typos rather than spelling’, ‘word referencing tool’, ‘referencing plugins’, ‘I use thesauri and dictionaries but not the ones in word processors’, ‘drag and drop for reordering text’, ‘layout review’.

grammar check and for dictionary whereby the participants with dyslexia were more likely to rate these tools as useful, effect sizes were small to medium.

A Spearman's correlation was used to explore relationships between planning and drafting activities and the use of word processing programs or handwriting. Results for both groups combined are displayed in Table 4.12 and Table 4.13. Frequent planners use using pen and paper more than word processing programs, but frequent drafters use word processing programs more.

Table 4.12 Spearman Correlations between responses to questions about drafting, $N=207$.

Question	1	2
1. How often do you write a plan	-	-
2. How often do you write a plan using a pen and paper?	.277**	-
3. How often do you write a plan using a word processing program?	.135	-.375**

Note: Plans were defined as short notes or bullet points, $*=p \leq .05$, $**=p \leq .001$.

Table 4.13 Spearman Correlations between responses to questions about planning, $N=207$.

Question	1	2
1. How often do you write a draft	-	-
2. How often do you write a draft with a pen and paper	-.008	-
3. How often do you write a draft with a word processing program	.308**	-.448**

Note: Drafts were defined as a rough version of the whole text, $*=p \leq .05$, $**=p \leq .001$.

When asked if they would like to add any comments about their writing practices, participants frequently described writing practices as editing a single document. Some examples of these comments, from each group, are provided below (exactly as written, including letter case and spelling).

- Dyslexia group:
 - I do a draft then edit until i'm happy - i never write separate draft as it is too time consuming
 - my drafts are continual working documents, i do not save different versions of drafts.
 - I draft and edit until happy
- Control group:
 - I draft my work, then continually edit the same document until I am happy with it.

- I draft my work then edit it until I am satisfied with it overall
- I draft an essay and then review it multiple times making updates, in effect redrafting

4.3.3 Do writers feel that spellcheck impacts writing?

Questions in this section were designed to find out how writers feel spellcheck impacts their behaviour.

Participants were asked: '*Does the notification of a spelling error ever cause you to stop writing?*' 116 participants responded 'yes', 52 responded 'no' and 39 responded that '*it depends*'. Those who responded *it depends* were invited to explain their answer. Here are four examples of typical explanations:

- Dyslexia group:
 - If i know what i'm writing i will want to get it down on paper before i forget what i wanted to say. in this case i will wait until i've finished and then go back to correct spellings etc.
 - if i have a sentence in my head then i will finish it, otherwise i will go back to the word
- Control group.
 - Normally i know that i can leave it to the end, so it doesn't stop me; unless i can see the mistake immediately and haven't gone too far to go back and change it.
 - On time - if I'm in a rush to get something on paper I don't care too much about the spelling at the time.

The responses have been split by group and are shown in Table 4.14. The majority of both groups reported that notification of a spelling error causes them to stop writing. Results of a chi-square test for independence indicated that there was no significant association between group and reported spellcheck interruption, $\chi^2 (2, N=207) = 0.09, p = .957, \phi = .04$.

Table 4.14 The amount of writers, per group, that report spellcheck causes them to stop writing.

Response	Dyslexia group (n=30), N (%)	Control group (n=177), N (%)
Yes	16 (53.33)	99 (55.93)
No	8 (26.67)	45 (25.42)
Depends	6 (20.00)	33 (18.64)

Participants were asked: '*Does the notification of a spelling error ever disrupt your thoughts?*' 90 participants responded 'yes', 103 responded 'no' and 14 responded that '*it depends*'.

Those who responded *it depends* were invited to explain their answer. Below are examples of typical explanations from each group.

- Dyslexia group:
 - On how focused i am on getting words on to the paper
 - How quick I am typing and how often I look at the screen
- Control group:
 - When I'm typing quickly I make many errors and tend to ignore it however when I'm typing at a slower pace because the work is more difficult, i tend to lose my train of thought and focus as I tend to be paying more attention to the actual screen.
 - It can do - depends on what I'm writing and how fluently that writing is flowing

The responses have been split by group (see Table 4.15). Whilst 40% of individuals in the control group reported that the notification of a spelling error disrupts their thoughts, a significantly higher percentage of individuals with dyslexia reported this (60%). Results from a chi-square test for independence indicates a significant association between dyslexia status and disruption to thought, the effect size was small to medium, $\chi^2 (2, N=207) = 8.05, p = .018, \phi = .21$.

Table 4.15 The amount of writers per group that report the notification of a spelling error disrupts their thoughts.

Response	Dyslexia group ($n=30$), N (%)	Control group ($n=177$), N (%)
Yes	18 (60.00)	72 (40.68)
No	8 (26.67)	95 (53.67)
Depends	4 (13.33)	10 (5.65)

Participants were asked how often they notice and correct their spelling errors without the need for spellcheck, and how often they use the spellcheck function to correct spelling errors. All responses were recorded on a rating scale of 1 (*never*) to 5 (*always*). Questions and the responses per group are shown in Table 4.16. Writers with dyslexia report: noticing errors before they become underlined less frequently; correcting spelling errors without the use of spellcheck less frequently; and correcting spelling errors with spellcheck more frequently, than the control group, effect sizes were small to medium.

Table 4.16 Median ratings, (1=*never*, 5=*always*), for frequency of error detection and correction behaviours, per group.

Question presented	Median rating		U score	Effect size (<i>r</i>)
	Dyslexia	Control		
	group (<i>n</i> =30)	group (<i>n</i> =177)		
'When spellcheck is used in its default setting (so that spelling errors are underlined as you type), how often do you spot a spelling mistake before it becomes underlined or highlighted?'	2	3	U(207)=1886*	.26
'When a spelling mistake occurs, how often do you correct it by selecting a word from the list of suggestions supplied by spellcheck?'	4	3	U(207)=1770*	.18
'When a spelling mistake occurs, how often do you correct spelling errors without using the list of words provided by spellcheck (i.e. retype or alter the existing text)?'	2	3	U(207)=1595**	.16
'When a spelling error occurs in your writing, how often do you correct the error as soon as you notice it?'	3	3	U(207)= 2157	.14

* = $p \leq .01$, ** = $p \leq .001$

Participants were asked '*After noticing a spelling error, some people continue to write before choosing to correct the error. When you notice a spelling error, how far do you usually continue to write before stopping to correct the error?*'. Responses can be seen in Table 4.17. The most popular response from writers without dyslexia was to write to the end of the sentence before correcting the error. However, the most popular response from writers with dyslexia was to write until the thought held in their mind is committed to the page. *Other* was the least popular response from both groups, participants who selected *other* were asked to specify what they meant by this. Examples of *other* responses are shown below:

- Dyslexia, only one writer:
 - All if the above
- Control group:

- It varies. If I know the spelling I can it then and there, if I don't then I wait until the end of the sentence to click on the word to see how it is spelt.
- to the end of the "chunk" of writing, be it sentence or paragraph
- until im rereading the piece i have written

Table 4.17 The amount of writers, per group, that selected each revision behaviour response option.

Response	Dyslexia group ($n=30$), N (%)	Control group ($n=177$), N (%)
I continue to write until the thought held in my head is in writing	15 (50.00)	52 (29.38)
To the end of the word	3 (10.00)	22 (12.43)
To the end of the sentence	7 (23.33)	75 (42.37)
To the end of the paragraph	4 (13.33)	16 (9.04)
To the end of the entire text	0 (0.00)	6 (3.39)
Other	1 (3.33)	6 (3.39)

In order to check for associations between group and response, a chi-square test for independence was applied. Due to low numbers in some categories four response options have been consolidated into one category named '*text boundary*', this is shown in Table 4.18. There are also too few data points to keep *other* as a separate category. Participants who selected *other* were asked to expand on this response in a text box, none of these comments suited either *text boundary* or *I continue to write until the thought held in my head is in writing*, therefore these were removed from the data. A chi-square test of independence suggested that there was a significant association between group and where participants stop writing, with a small effect size, $X^2(1, n=200) = 5.28, p = .032, \phi = .17$. This is the only finding where different proportions of students and non-students may have influenced the results between groups, student and non-student data are displayed in Table 4.19. There is a significant association between student/non-student groups and response, though with a very small effect size $X^2(1, n=200) = 7.52, p = .006, \phi = .07$.

The other empirical studies in this thesis focus on students, therefore student data is of more interest and so non-student data were excluded, shown in Table 4.20. Data from students with and without dyslexia resulted in a significant association between group and response, with a small to medium effect size $X^2(1, N=104) = 4.66, p = .031, \phi = .20$.

Table 4.18 Amount of writers who selected each response regarding revision behaviour, consolidated categories.

Response	Dyslexia group, <i>N</i> (%)	Control group, <i>N</i> (%)
I continue to write until the thought held in my head is in writing	15 (53.33)	51 (32.39)
Text boundary	14 (46.67)	119 (67.61)

Table 4.19 Amount of student and non-students who selected each response regarding revision behaviour, consolidated responses.

Response	Student group, <i>N</i> (%)	Non student group, <i>N</i> (%)
I continue to write until the thought held in my head is in writing	39 (35.5)	29 (29.6)
Text boundary	67 (60.9)	66 (67.3)

Table 4.20 Amount of students who selected each response regarding revision behaviour, consolidated responses.

Response	Students with dyslexia, <i>N</i> (%)	Students without dyslexia, <i>N</i> (%)
I continue to write until the thought held in my head is in writing	12 (57.14)	27 (30.34)
Text boundary	9 (42.86)	58 (65.17)

4.4 Discussion

4.4.1 Common features in the virtual writing environment

The writers' virtual writing environment is a new area of investigation for writing research. It was found that both groups of writers tend to use Microsoft Word. Although the automatic underlining could be disruptive, writers report always using spellcheck in its default settings and never turning off the automatic underlining in favour of only activating spellcheck at times where they want to check their spellings. The most common adjustment made to spellcheck is to change the dictionary to British English in about 50% of cases.

As expected, proportionately more writers with dyslexia use specialised writing software than writers without dyslexia. This could be because writers with dyslexia find this software more useful or are simply more aware of the software available than writers without dyslexia. The most popular assistive software used is Dragon speech recognition software. Dragon supports transcription by providing the option of speech to text, allowing writers to dictate their texts. Speech to text is also available as part of Windows (v.7 released in 2009 and later versions) and MacOS (OS X 10.5 released in 2007), however Dragon may be superior to these free versions.

Dragon also features on the webpages by dyslexia association, Dyslex.io and the BDA. Although a larger percentage of writers with dyslexia use specialised software than writers without dyslexia, interestingly, this is still less than half of the sample with dyslexia. It has been suggested that lack of awareness of entitlement, low availability or limited access to the technology prevents people who would benefit from assistive technology from using it (Draffan, James, Cudd, & Bentley, 2015). It is possible that if more writers were aware of the software available to them they would be more likely to use it.

These findings have identified common features of the virtual writing environment that writers with and without dyslexia create for themselves and provided an insight into the typical virtual writing environment, which is a novel finding in writing research literature. Knowing about the typical virtual writing environment is useful for future writing research. This knowledge will help researchers to gauge the extent to which controlled writing conditions reflect the typical writing environment. For example, because writers usually use spellcheck in its default settings, to monitor their texts as they type, writing without it active in this way is an unusual experience. Thus in order to create experimental conditions which mimic natural writing, spellcheck should be active to automatically underline spelling errors as they occur. If it is not appropriate for the experimental conditions to include spellcheck in the writing environment, then outcomes (writing behaviour and the text produced) should be viewed as part of an unusual writing experience.

Findings are also useful when considering appropriate conditions for university exams. Some students are offered the opportunity to use word processing programs instead of handwriting, sometimes these students are permitted to use spellcheck and other times not. It is known that writing is more effortful and texts are poorer quality when writers use less familiar methods of transcription (Connelly et al., 2007); it is possible that lack of familiarity with a writing environment, such as writing without spellcheck, could also hinder the writing process and quality. This information should be taken into account when considering examination conditions.

4.4.2 Why use a word processing program?

The most popular, and most important, reason to use a word processing program instead of handwriting, for both groups, was that text is easier to edit (e.g. it is easy to delete, move and copy text). Results build on previous research where writers were more reluctant to edit handwritten texts than texts on word processing programs (Mogey et al., 2012; Mogey & Fluck, 2015). The importance of easy editing could be explained by writers' approach to text production. Where writers were invited to comment on their writing practices, many of them described repeatedly revising a single document into the final text. Thus, because revision is such a large part of writing, it is reasonable for writers to choose to write with a word processing program where the text is easy to edit.

Other motivations for writing with a word processing program differed per group. For writers with dyslexia, the helpfulness of writing tools such as spellcheck was particularly important, more so than for writers without dyslexia. Writers without dyslexia reported that the most important reason for using a word processing program (equal to easy editing) was because they are expected to use one. This was a popular reason for both groups, but more important to writers without dyslexia.

Tools such as spellcheck could be more important to writers with dyslexia because they benefit from them the most. For example, writers with dyslexia struggle with spelling and spelling revision (Elliot & Grigorenko, 2014; Nergård-nilssen & Hulme, 2014; Torrance et al., 2016), thus one would expect that spellcheck would make a larger difference to the spelling accuracy of texts by writers with dyslexia than to texts by writers without dyslexia. In addition, spelling errors negatively influence readers judgements of quality (Figueredo & Varnhagen, 2005; Johnson et al., 2017; Marshall & Powers, 1969), therefore, using spellcheck to reduce the amount of spelling errors in text should improve readers judgement of quality. For students this could help them to achieve a better grade, especially for students with dyslexia, hence why tools that support writing are particularly important to this group.

Out of the writing tools available in word processing programs, spellcheck was reported as useful to the largest number of people. While the introduction to this chapter suggested that writers with dyslexia are especially encouraged to make use of spellcheck, both groups reported it is useful. All writers with dyslexia find spellcheck useful and, although fewer writers without dyslexia do this was not a significant difference.

Grammar check and dictionary were considered useful by a significantly larger percentage of writers with dyslexia than writers without dyslexia. Interestingly, spellcheck, grammar check and the dictionary tool all relate to revision, especially spelling revision. Spellcheck aids detection by underlining potential spelling errors and assists with correction by offering a list of potential target words that can be used to replace the error. Similarly, grammar check underlines errors and supports revision, including errors real-word errors, which commonly occur in texts by writers with dyslexia (MacArthur et al., 1996; Pedler, 2001). The dictionary tool allows writers to check the definition of words used which may be particularly useful to writers with dyslexia who may have some difficulties distinguishing similarly spelled words from each other, for example when presented in a list by spellcheck (MacArthur et al., 1996). Revising text with these tools helps rule out word level errors whereas the other tools listed in the survey do not (thesaurus; or inserting items such as images, graphs, tables). Like spellcheck, these tools may help create a text that readers judge favourably. Authors can benefit from this, for example in receiving a better grade, however tools that focus on word-level revision, and in fact word processing programs in general, have been criticised for focussing on making the text better for the reader when the priority should be to support the writing process (Ronneberg et al., 2018).

Although 80% of writers with dyslexia reported that being expected to use a word processing program was one of the reasons that they write with one, this was ranked as their second-to-least important reason. Thus, while the popularity of this response indicates that this is a contributing factor, writers with dyslexia use word processing programs predominantly for other reasons, particularly for easier revision and access to tools such as spellcheck. Interestingly, writers without dyslexia ranked being expected to produce text with a word processing program as one of their most important reasons. This raises the question of whether writers without dyslexia would handwrite more if they were not expected to word process their texts. Writers might be expected to use word processing programs because they need to produce texts in a digital format, for example coursework is often marked online and checked by plagiarism software. The implications of these findings are that writers could be making choices about their virtual writing environment to meet the perceived needs of the reader/marker, possibly at cost to the writing process.

One writing activity where handwriting could be more beneficial, or at least preferred to writing with word processing programs, is planning a text (writing short notes or bullet points in preparation of writing a text). Findings indicate that writers who tend to write plans, tend to use pen and paper to do so. This reflects findings from Mogey and Fluck (2015), described in the introduction, where large numbers of the UK HE writers in their sample preferred to handwrite rather than use word processing programs to plan their texts. In addition, Mogey and Fluck's (2015) sample reported that they felt limited to thinking about only the sentence that they were writing when using word processing programs but felt able to think more widely when using pen and paper (Mogey & Fluck, 2015). Thus, it appears that writers tend to find handwriting preferable for planning texts, this may be related to finding it easier to think about the overall text when using pen and paper compared to when using a word processing program.

Results indicate that writers who draft more (write a rough version of the whole text), tend to draft using word processing programs. Choosing to draft texts with a word processing program might appear to contradict the choice to plan with pen and paper, however, planning and drafting could be quite different activities. While planning a text is separate from writing a text, for many writers, drafting appears to be synonymous with writing a text. This method of editing and revising a single text reported by many writers in this sample suits word processing programs more than handwriting particularly because revision is easier and tools that support revision are available.

Writers might select their environment to meet their writing needs and goals and to suit their method of writing. In terms of the Hayes and Berninger (2014) writing model, the choices writers make about their virtual writing environment seem to be shaped by components in the control level, the writer's goals from the planner and the perceived reader/markers judgements of quality from the task initiator. It is also possible that the affordances of word processing programs (the ease of editing and tools that support revision) are what encourage writers to continually

revise a single document into their final text. Thus components at the control level influence the writers choices about the virtual writing environment, and the features of the virtual writing environment and the writing processes interact.

4.4.3 Do writers feel that spellcheck impacts writing?

Researchers have predicted that the automatic underlining of spellcheck is disruptive (Berget & Sandnes, 2015; MacArthur et al., 1996; Ronneberg et al., 2018). Over half of the participants report that the notification of a spelling error causes them to stop transcription; there was no significant difference between groups. A large percentage of writers in both groups reported that they experience disruption to their train of thought due to the notification of a spelling error, particularly writers with dyslexia. Writers with dyslexia may be disrupted more so than writers without dyslexia because they tend to make spelling errors more frequently in writing (Berninger, Nielsen, et al., 2008; Snowling, 2012; Tops et al., 2012). Additionally, writers with dyslexia may be less able to inhibit processing of an error due to poorer executive functioning than writers without dyslexia (Brosnan et al., 2002) and may find underlined errors particularly distracting.

Disruption to thought is likely to reflect disruption to the flow and storage of information in working memory. Hayes (2012) revisited work that he and Chenoweth (Chenoweth & Hayes, 2001, 2003; Hayes & Chenoweth, 2007) conducted into language bursts (P and R bursts described Chapter 1) and identified two memory sensitive bottlenecks: one where thoughts cannot be translated into words; and a second one where the lexical representation cannot be transcribed to the page (Hayes, 2012). These bottlenecks reflect findings from van Waes et al. (2010) where, if the writer is attempting to mentally arrange words into a phrase (translation) but then detects an error, the lexical representation begins to fade in working memory, thus preventing transcription. Writers in van Waes et al.'s (2010) study tended to reduce risk to the lexical representation by first attending to transcription of the lexical representation then attending to the error (in 90% of cases). Thus it can be presumed that generally writers tend to defer error revision, but how long they defer revision has not been previously investigated. How long writers defer likely relates to how well writers can ignore the spelling error and focus on text production. It is likely that writers with dyslexia would find this more difficult due to difficulties with executive functioning, or difficulties with parallel processing or bottlenecks at translating or transcribing, and therefore would not defer correction for as long as writers without dyslexia.

Writers were asked, after noticing a spelling error, how far would they continue writing before correcting that error. Writers with and without dyslexia report that they often correct spelling errors as soon as they notice them. When they do not correct spelling errors straight away, the groups differed on the how far they continue writing before correcting the error. A larger percentage of writers with dyslexia reported that they tend to continue writing until the thought held in their mind is committed to text. Writers without dyslexia were more likely to

report that they continue to write until they reach a text boundary such as at the end of a sentence. Writers without dyslexia might stop at text boundaries because their lexical representations are in chunks defined by these boundaries and they are transcribing the whole lexical representation. Alternatively, these writers may be able to write more than a single lexical representation but choose to stop writing at lexical boundaries. This second option requires good executive functioning control. Fewer writers with dyslexia report that they stop at lexical boundaries. This might be because their lexical representations are not defined by the same boundaries, or because they have more difficulty controlling how far they continue writing and how long they can defer revision.

Reports from writers with dyslexia indicate that they are less likely to notice or correct spelling errors without the help of spellcheck than writers without dyslexia, thus are less likely to notice errors as they make them (before pressing spacebar) and are less likely to attempt to correct errors by retyping. Writers with dyslexia might rely on spellcheck for the detection and correction of spelling errors more than writers without dyslexia because of difficulties with spelling and recognising spelling errors.

While the automatic underline aids detection of spelling errors (MacArthur et al., 1996; Pedler, 2001), reports in the current study indicate that, for a lot of writers, it also interrupts writing and it disrupts thoughts, particularly for writers with dyslexia. Spellcheck could impact the cognitive processes involved in writing. Disruption to thoughts quite likely reflects disruption to the flow of information and difficulties with the maintenance of the lexical representation. Disrupting thoughts could negatively impact the text that is produced.

4.4.4 Limitations

Generalisability

The sample population is split fairly evenly between students and non-students. However, as the research was advertised through the Oxford Brookes University, it should be noted that a large proportion of non-students are likely to be connected to Oxford Brookes University in some way, most likely as recent alumni or academic staff. Therefore the 'non-students' may have more experience with writing formal texts than average non-students in the general population. This may explain why none of their responses differed from students' responses. Findings from this study are generalizable to university students, and adults connected to universities. It is expected that the results are representative of the student population used in the following studies of this thesis; but should be interpreted with care if generalised to a wider population. Results may not generalise well to populations in other workplaces. For example, results indicate that this sample writes for an average of 5 hours per day, however this is unlikely to be the case for individuals with jobs for which writing is not a key part.

Due to the nature of the online survey, the group of writers with dyslexia were the participants who reported that they have dyslexia. Participants do not necessarily have a formal diagnosis. Thus generalisation of group differences reported in this study should be treated with caution. As discussed in chapter two, it is estimated that 5-15% of the general population in the UK has dyslexia (BDA, 2018; Elliot & Grigorenko, 2014; Hulme & Snowling, 2009; Snowling, 2012) and so the sample, of which 14.49% have dyslexia, is at the high end of this. Of the non-students in this sample, 9.28% of have dyslexia, which is within the expected range. However, 19.09% of students in this sample have dyslexia and therefore are overrepresented, particularly as it is estimated that fewer than 5.22% of students in UK HE has dyslexia (Higher Education Statistics Agency 2018, also see section 2.2.4 Prevalence of dyslexia in the UK). There may have been more students with dyslexia than non-students with dyslexia who saw the advert or who elected to complete the survey. In addition, the sample of individuals with dyslexia, being from a student population, may be unusually high performing and not representative of the general population of adults with dyslexia.

It is commonly reported that dyslexia is more prevalent in boys than girls (Elliot & Grigorenko, 2014), thus it may be expected that there would be a higher proportion of men than women in the group of writers with dyslexia. This is not the case in this study. More women than men completed the survey. However, this was the case for both groups, not only for the writers with dyslexia. The gatekeeper of the research mailing group, where the survey was advertised, reported that the group consisted (at the time) of approximately 1200+ members, around 70% of which identify as women. Higher proportions of women in this list most likely caused the high proportions of women in this study. High numbers of women in research samples are not uncommon. Other studies have also found higher response rates in women than men in online surveys (Markanday, Brennan, Gould, & Pasco, 2013; Smith, 2008).

Groups have similar numbers of men and women and so it is unlikely that the high proportion of women in this sample has impacted the differences found between groups. Some writing research, often with school-age children, has found gender differences in writing skills, with boys performing more poorly than girls (Moss & Washbrook, 2016), however, this is not commonly reported in adults. In fact, the sample of writers with dyslexia, as university students, regardless of gender, are likely to reflect adults who have developed good mechanisms for overcoming difficulties in writing. Even those who are not students are likely to be alumni or working at Oxford Brookes University and spend large proportions of their day writing (5 hours on average) thus are expected to be well practised at writing.

This survey study focussed on the use of spellcheck in word processing programs, but there are other platforms for digital text production, many of which include spellcheck. Furthermore, the current survey focussed on the production of important pieces of writing (e.g. essays, reports, formal letters, long emails) however other writing activities may involve shorter writing tasks (such as messaging, social media posting, informal emails or notes). Therefore findings apply to a

specific type of writing in a specific writing environment and do not necessarily generalise well to other environments or writing activities that have not been a focus of this survey study. On the other hand, the initial question, asking writers how long they spend on writing-related activities is very broad and so informal writing tasks (e.g. messaging, taking notes) could make up a large proportion of the average 5 hours of writing activities reported by the sample in this study. Therefore, how far results can be generalised to all writing tasks is questionable.

Due to the nature of the survey, results are based on participants' opinions. Therefore when considering the self-reported behaviours it is important to bear in mind that these opinions may not reflect the participants' actual behaviours during writing. In order to find out how writers behave during text production, empirical evidence of writing behaviours is necessary.

Survey limitations

There are a few limitations of the survey. With an aim to find out how spellcheck is used, participants were asked about how often they write with spellcheck in its default setting (switched on and automatically underlining spelling errors) and how often they use it not in default settings. However, it would also be useful to also clarify how often participants write without using spellcheck at all, in order to put this information into a wider context.

There was a ceiling effect when almost every participant reported that they consider spellcheck to be useful. It is possible that differences between groups were masked by the ceiling effect. It may have been beneficial to include a measure of importance for writing tools, similar to the measure of the importance ratings of reasons to use a word processing program, in order to further investigate how important spellcheck is to each group in comparison to other writing tools and to compare between groups.

There are several research questions that could have been answered by collecting more demographic information from participants. For example, finding out more about the respondents' daily writing demands and which courses they study or jobs they hold could indicate whether adults with dyslexia are likely to avoid courses or jobs that require a lot of writing. Generally, little demographic information was collected, information on ethnic background, whether participants were in receipt of Disabled Student Allowance (DSA), or experienced any difficulties that were not reported as impacting their reading or writing performance.

While the survey included questions to find out what the typical virtual writing environment is like, further questions could have been used to find out why writers make certain choices. For example, it is not known whether writers tend to use Microsoft word because it is the most easily available word processing program (e.g. through their university or place of work) or because they prefer it to others, or because they are more familiar with it than with others.

Finally, while findings indicate that large proportions of writers perceive spellcheck as disruptive, behavioural evidence is needed to confirm whether this is the case.

4.4.5 Conclusion

Results indicate that when writers use a word processing program, their most popular choice is Microsoft Word, that they tend to use spellcheck in its default settings, and that a little under half of the writers with dyslexia also use additional writing software. Easier editing is a particularly important and popular reason to use word processing programs, furthermore, the tools within word processing programs that support revision are also important, particularly to writers with dyslexia. Out of the tools that word processing programs offer, spellcheck is reported to be useful by the largest number of writers (almost all of them). However, many writers also report that spellcheck causes them to stop writing and disrupts their thoughts.

As discussed in Chapter 3, there are several researchers who have suggested that spellcheck could be disruptive during writing, and findings in the current study support this, however writing behaviour must be observed in order to find out how using spellcheck, or not using it, influences writing. In particular to find out if, and in what ways, spellcheck increases disruptions to writing and to thought and whether writers with dyslexia are impacted by spellcheck more than writers without dyslexia. Furthermore, naturalistic writing studies are required to investigate how writing with or without spellcheck influences the text by writers with and without dyslexia.

[blank page]

The Impact of Spellcheck During Writing

5.1 Introduction

Text production is a very cognitively demanding task. In the midst of text production, a writer is likely to be storing and transcribing a lexical representation while also processing and storing more information to be written after that (Olive, 2014). When a writer notices a spelling error, revision processes place even more demand on working memory resources. If the combined cognitive demands of writing processes exceed working memory capacity, then writers are forced to reduce parallel processing (Hayes & Berninger, 2014; Olive, 2014; Olive & Kellogg, 2002, and as described in Chapter 1). Online management of writing processes is a fundamental component of writing skill (Levy & Ransdell, 1995; McCutchen, 1986).

Devoting cognitive resources to spelling error revision restricts resources available to process and store the lexical representation to be written. Without sufficient working memory resources to process and store the lexical representation, it risks becoming damaged or lost (van Waes, 2010). Bourdin and Fayol (2002) wrote that, in order to manage multiple demands in writing, “educated adults can behave in a strategic way, in particular by deferring certain operations, or by organizing their production in stages which are processed sequentially” (p.6). Thus, in order to manage spelling error revision and text production, writers can defer revision for a short amount of time (Galbraith & Torrance, 2004). When writers do not defer revision, but instead halt text production in favour of revising text on the page, this indicates disrupted writing (as described by Chenoweth and Hayes, 2003, 2007, and detailed in Chapters 1 and 2).

Even if writers have the cognitive capacity to process the revision of the spelling error and to continue transcribing the lexical representation in parallel, word processing programs do not allow the writer to simultaneously revise the text on the page and produce text. Thus writers must choose which to do first, text production or spelling error revision. This choice provides observable writing behaviour. As described previously at the end of Chapter 1, van Waes et al. (2010) used a writing task in a word processing program that emulated situations where a writer notices an error during text production. Undergraduate writers ($N=32$) were aurally presented with one or three words, then visually presented with a partial sentence that contained a spelling error. Writers needed to complete the sentence, incorporating the content word(s) and to revise the spelling error. Writers rarely revised the error before completing the sentence (only 10% of the time) but when they did it was more likely to be in conditions with a lower cognitive load (one word). In addition, when writers did this, the longer they took to revise the error, the less likely writers were to incorporate the content words in the sentence end, indicating damage to the

lexical representation. The authors suggested that deferring revision in favour of transcription is a strategy to preserve the lexical representation (as text transcribed onto the page). Authors also suggested that writers responded with revision in low load trials more than high load trials because, in low load trials writers have more available cognitive resources which allowed for flexibility in task management.

This writing situation has not been investigated for writers with dyslexia. Findings from such an investigation could have theoretical implications related to theories of dyslexia. As identified in Chapter 2, for writers with dyslexia, a phonological deficit means that managing cognitive processes for multiple tasks that require phonological processing (such as storing and processing a lexical representation as well as spelling error revision) in parallel is more demanding than it is for writers without dyslexia. In addition, writers with dyslexia demonstrate poorer selective attentional skills than their peers when tasks involve processing phonological information (Elliot & Grigorenko, 2014; Hari & Renvall, 2001). These writers also experience difficulties with attention switching (Valdois et al., 2004). Therefore, once the spelling error has been noticed, writers with dyslexia are likely to struggle to inhibit and defer error processing. Because of these difficulties, writers with dyslexia are more likely to experience disruption to writing and revise spelling errors earlier than writers without dyslexia.

Conclusions at the end of Chapter 3 indicated how spellcheck might be disruptive to the writing process. The automatic underlining of spellcheck directs attention to potential spelling errors that might otherwise have been missed, and is thought to increase the disruption of error correction in writing because it causes writers to focus on spelling errors more than other aspects of the text (Figueredo & Varnhagen, 2006), or attend to spelling errors sooner (MacArthur et al., 1996; Ronneberg et al., 2018; van Waes et al., 2010), or to attend to more spelling errors (Hiscox et al., 2014), than they would without spellcheck active.

In Chapter 4, results from the survey revealed that large proportions of writers (53% with dyslexia, 56% without dyslexia) feel that the appearance of a red underline from spellcheck causes them to stop writing. This fits with the idea that spellcheck increases the disruption of spelling error revision. Many writers (60% with dyslexia, 41% without dyslexia) also reported that it disrupted their thoughts. The disruption to thought may reflect damage to, or loss of, the lexical representation. Considering that writers with dyslexia were more likely to report disruption to thought, they are particularly likely to experience damage to, or loss of, the lexical representation when disrupted by spellcheck.

How spellcheck impacts online revision behaviours has yet to be investigated. Figueredo and Varnhagen (2006) compared the number of errors corrected during a proofreading task when using spellcheck to when using a hard copy of a dictionary. They found spellcheck did not have a negative impact on the amount of revisions made to the unfamiliar, static text that was provided to participants. However, findings of the survey in Chapter 4 showed that writers tend to use spellcheck in its default settings, thus it is active during text production. To investigate the impact

of spellcheck on the writing process, it is important that participants are producing text during the experiment rather than revising a static text. This introduces competition between text production and spelling error revision and is a more ecologically valid design. As described in the introductory chapters, spellcheck is not currently included in writing models or revision models. If spellcheck is shown to impact writing behaviour, it needs to be accounted for and writing models will need to adapt in order to do this.

5.1.1 Sentence completion tasks

Objectives

The objective is to develop and carry out a keystroke logging study to provide empirical evidence of how writers with and without dyslexia respond when presented with spelling errors that are underlined by spellcheck and spelling errors that are not underlined by spellcheck. Two experiments are presented in this chapter. Both experiments use a similar design to van Waes et al.'s (2010) sentence completion task. Experiment two extends experiment one. The experiments have been designed to answer the following research questions:

1. Does spellcheck increase disruption to writing?
2. Does such disruption cause the lexical representation to fade from working memory?
3. Are writers with dyslexia impacted by this more than writers without dyslexia?

Monitoring online revision

Initial studies into online revision relied on visible trails of crossings out and added words, to reveal the changes made to handwritten texts (Sommers, 1980). However, when using word processing programs, revision does not leave a trace and so the final document does not expose revisions made. Fortunately, the development of keystroke logging programs enables observation of the writing process. By attaching a timestamp to each key pressed it is possible to know the actions taken to revise text. Keystroke logging has been used to successfully record typing behaviour of online revision in writing research (for example: Leijten, De Maeyer, & Van Waes, 2011; Quinlan, Loncke, Leijten, & Van Waes, 2012; van Waes, Leijten, & Quinlan, 2010).

Possible responses to the sentence completion task

Writers' can respond to the task either by revising the text, or by deferring revision. To defer revision, inhibition processes are required. Inhibition requires good selective attentional skills and uses working memory resources. Thus, the ability to inhibit error revision and continue to effectively orchestrate writing components will influence a writer's response to the sentence completion task. The extent to which writers can parallel process information will also impact their behaviour. Writers need to either divide cognitive resources between maintaining the lexical representation and revising the error, or between inhibiting revision and transcribing the lexical representation to the page. The combination of initial response (revise or defer revision) and

processing (parallel or sequential) creates four possible strategies for completing the partial sentence task. These are outlined below.

Defer, parallel processing

This response may occur when writers can parallel process and can inhibit. The most efficient response to the sentence completion task would be to transcribe the lexical representation of the sentence ending whilst simultaneously processing the spelling error. Revisions can then be executed immediately after the sentence is completed. This would result in a smooth continuous flow transcription without loss of information from working memory.

Revise, parallel processing

This response may also occur when writers can parallel process and can inhibit. If the writer is able to manage the lexical representation and revision in parallel, the more efficient method is to defer revision, however, the writer might choose to store the lexical representation while revising the error. In this case the writer would need to process the error when they notice it, which could lead to a longer latency. During revision, maintenance of the lexical representation competes with revision processes for phonological working memory resources, thus there is some risk of fading or loss of the lexical representation.

Defer, sequential processing

This response may occur when writers cannot parallel process but can inhibit. If writers must reduce parallel processing, it would be most efficient to defer revision, inhibiting error processing, until the writer finishes transcribing the lexical representation. This is likely to result in pausing between completing transcription and starting revision because the writer will need time to process the revisions needed. If the writer can process the revisions quickly then the pause will be small.

Revise, sequential processing

If the writer does not, or cannot, parallel process and does not, or cannot, inhibit processing the error then they will process and revise the error first. If the writer is storing a lexical representation, there is a high risk that it will become lost or faded. Thus it is likely that the writer will need to repair or (re)create a lexical representation before continuing with text production. If the writer can do this whilst revising, then there will be little pausing between revising the error and continuing with text production.

The response options *revise, parallel processing* and *defer, sequential processing* reflect van Waes and colleagues (2010) explanation of their results, that writers respond with revision when the cognitive load is low and when they can manage parallel processing without difficulty. The response options *defer, parallel processing* and *revise, sequential processing* are alternative responses that writers might take.

In the current study, writers were presented with three content words, as per the high cognitive load condition from van Waes et al., (2010). Therefore, the cognitive load should have

been too high for writers to parallel process, thus ruling out responses which rely on parallel processing. Encouraging writers to process sequentially should enable investigation into inhibition of error correction because writers' behaviour should depend on their ability to inhibit error processing. Therefore, if a writer can defer revision this indicates that they can inhibit processing.

5.2 Experiment One

This experiment investigated the effect of the red underline of spellcheck on writing for writers with dyslexia and a control group. In natural writing situations, writers with dyslexia produce more spelling errors than writers without dyslexia, and so would come across spelling errors in their texts more frequently, making it difficult to compare between groups. Providing each group the same frequency of spelling errors enables comparison between groups. Writers with dyslexia and a control group were presented with a series of partial sentences and were required to correct an embedded spelling error where present. They also needed to complete each sentence, incorporating three content words provided. Trials were presented and data were collected using a program built especially for this study, Writespell. Writespell was created to meet the needs of the experiment design, as specified by the researcher. As well as presenting audio and visual stimuli, Writespell recorded the keystrokes made in each trial with a timestamp, providing data for the measures of initial response, response latencies and writing times. Writespell also activated the red underline function of spellcheck, that alerts writers to potential spelling errors but, due to program limitations did not include the right-click function that would generate a list of candidate words to replace the error, thus writers needed to manually revise spelling errors. Writespell randomised the trial order and counterbalanced error presence and whether the red underline was activated or not.

5.3 Predictions

Initial response

A writer can start the task with revision or by deferring revision. It was predicted that, overall, writers would usually defer revision. The presence of an underline was expected to increase how often writers respond to the task with revision. This effect was expected to be larger for writers with dyslexia than writers in the control group.

Lexical representation

It was expected that, when the writers start the task with revision, the lexical representation would be more likely to become lost. As a consequence, fewer content words would be included in the end of the sentence, especially for writers with dyslexia.

Latency and writing time

It was predicted that, when writers start the task with revision, then latency and writing time would be longer, especially for writers with dyslexia who are expected to have longer latencies and writing time than the control group.

5.4 Experiment One Method

5.4.1 Participants

Criteria.

Inclusion criteria: To take part in this study writers needed to be enrolled on an undergraduate course, be aged 18-22-years old and speak English as their first language. In addition, all writers in the dyslexia group needed to have previously been diagnosed with dyslexia.

Exclusion criteria: Writers with any difficulties, other than dyslexia, which impact their reading or writing skills, and writers who do not speak English as their first language, were excluded from taking part.

Number: An overall sample of 36 provides a suitable size for performing 2x2 mixed between-within analysis of variance tests (ANOVA's) (Pallant, 2013) allowing investigation into the impact of spellcheck condition, the impact of group and interactions of group, and spellcheck condition. Furthermore, this number reflects group sizes used in similar studies (for example, in Warmington et al.'s, 2012, paper, they used two groups of twenty used for MANOVAS).

Recruitment

Participants volunteered to take part in this study following advertisements placed around Oxford Brookes University. First-year psychology students were also alerted to this study via the psychology participant panel, an online program used to advertise studies within the psychology department to first-year undergraduate psychology students who are encouraged to gain experience of research studies by taking part in them. First-year psychology students were offered course credits for taking part. Course credits have no value to students outside of first-year psychology, so they were only awarded to first-year psychology students, and other students were not disadvantaged by not receiving them.

All participants were provided with participant information sheets (Appendix E) via email from the researcher when organising a suitable time to take part in the study. They were also provided with a hard copy upon meeting the researcher and given time to read this and ask questions about the procedure. When satisfied with the information provided, participants were given a hard copy of the consent form (Appendix F) to sign. Upon signing participants were reminded that they could still choose to stop participating and withdraw any unprocessed data at any time.

Measures

Although all participants in the dyslexia group reported having a previous diagnosis of dyslexia, in order to confirm that these students experience difficulties associated with dyslexia, particular skills were assessed. Measures used are described below. Where available, manual instructions were closely followed for procedure and scoring.

Nonverbal reasoning

The Block Design Matrix Reasoning task from the Wechsler Adult Intelligence Scale 4th edition (WAIS-IV, Wechsler, 2008) was used to assess nonverbal reasoning skills to check writers with dyslexia were not exhibiting signs of more general learning difficulties. Participants were shown a pattern and were required to complete the pattern by selecting the most appropriate image from five options given. This task is designed to assess ability in the form of nonverbal reasoning skills, thus phonological difficulties do not create a disadvantage. Raw scores were converted into scaled scores to account for age differences. The test-retest reliabilities over a two-to-twelve-week time period, for the matrix reasoning subscale are high at 0.91 (Massa & Rivera, 2009).

Reading

Reading accuracy, speed and rate were measured using the York Adult Assessment – Revised (YAA-R, Warmington, Stothard, & Snowling, 2012). Audio recordings were taken as participants read a passage of text aloud ('The History of Chocolate' Appendix G). As a measure of reading accuracy, the number of inaccuracies (mispronunciations, substitutions, omissions and additions) was counted from audio recordings, summed and then subtracted from the total number of words in the text, the passage is 492 words. Reading speed refers to the total time taken to read the text. Reading rate is measured in words per minute as 492 (total number of words in the text) divided by total reading time in minutes. The YAA-R provides norms and confidence intervals boundaries from a sample of 106 university students with no reading or writing difficulties and is considered suitable for adult students. Reliability estimates for the YAA-R were generally good (ranging from 0.71 to 0.95, 0.81 for reading accuracy, 0.76 for phonemic awareness accuracy).

Phonemic awareness

To assess how well participants with dyslexia were able to identify and manipulate sounds in language, the spoonerism task from the YAA-R (Warmington et al, 2012) was used. Participants completed two practice trials and twelve recorded trials. Each trial consisted of a famous name (first name and surname) which the participant needed to swap the initial sounds of (e.g., John Lennon becomes Lohn Jennon). This was scored as one point per name (one for first name, one for surname), a maximum of 24 points was available. Time taken to complete trials was measured from audio recordings as the time between the start of the item announced by the researcher to the end of the participant's response. Rate was measured as the average time spent on correct responses.

Typing

Typing ability was not intended to be used as an indication of dyslexia. Typing ability was measured in case it better explained any differences found between the groups than having dyslexia does. To monitor typing speed and accuracy, participants were asked to copy a sentence as many times as they could in 2 minutes. This task has been taken from the YAA-R. It is not stated in the YAA-R why this particular sentence was used. The sentence to be copied was:

‘Transportation is the movement of people and goods from one location to another.’

The sentence was displayed at the top of the screen using Microsoft Word 2010 and was read aloud to participants. A timer was started just after the writers pressed their first key, then after two minutes the timer went off and writers were asked to stop typing. Inputlog, a keystroke logging program, was used to record the timing of each keystroke and mouse movement as writers typed and then to trim the recording to exactly 2 minutes (to nearest ms), recordings were then used to measure typing speed and accuracy. These measures are described in the following subsections and results are shown in Table 5.1.

Typing speed

The YAA-R suggests counting the number of words in the text produced then dividing this by two (the number of minutes spent typing) to provide a measure of typing speed as words typed per minute (WPM). However, writers may delete words thus the number of words in the product may not reflect the number of words that have been typed. Measures from typing behaviour were also taken to provide an additional, a more accurate, measure of typing speed. The number of words in texts have been used to provide a separate measure of product length.

Characters per minute: This is the mean number of character keys, including spaces, that were typed per minute.

Words per minute, process: This is the mean number of words which were typed per minute.

Product length

Number of characters: This is the number of characters, including spaces that were in the text produced within 2 minutes of writing.

Words per minute, product: This is the number of words in the final product, minus the initial writing prompt, divided by two (the number of minutes spent typing).

Accuracy

A writer may produce a final text with no inaccuracies however their writing process could involve revision of several inaccuracies. Thus, both the accuracy of typing behaviour and accuracy of the typed product have been measured to indicate how much text the writer revised and how many errors remained in the text. Measures are shown as percentages to make texts of different lengths comparable.

Percentage of characters typed that were kept in the product: The number of characters in product, divided by number of characters typed, multiplied by 100.

Percentage of errors in the product: This is the number of errors (incorrect characters) divided by the number of characters in the text, multiplied by 100.

Percentage of errors in the product, adjusted: The aim of measuring typing accuracy is to measure how accurately the writer types what they intend to type. Five writers (three with dyslexia, two from the control group) repeatedly omitted the same words from the sentence line after line, omitting 46-88 characters each. Other than these repeatedly missed words, writers rarely omitted characters (7 writers missed 1-3 characters, 19 did not omit any).

These writers with missing words may have misread the initial sentence or forgotten the exact wording, but after making the error once, they appear to copy their own incorrectly written sentence again and again. Arguably, these writers had no intention of producing the omitted word and repeatedly missing the same words reflects (poor) copying ability, but not typing ability. To account for this copying error, omitted words have been excluded in this measure of typing accuracy, in doing so, the number of errors reduced from $M=13.44$ ($SD=27.65$) to $M=2.17$ ($SD=2.18$) for writers with dyslexia and from $M=8.67$ ($SD=22.81$) to $M=.89$ ($SD=7.02$) for writers without dyslexia, and reflects typing ability more accurately. To measure this as a percentage of text, the remaining number of errors were divided by the number of characters in the text, multiplied by 100.

Spelling

All participants completed the dictated single-word spelling task from the Wide Range Achievement Test (WRAT 4, Roberts and Wilkinson, 2006). Each target word was accompanied by a sentence containing that word in order to provide context. The list of words and accompanying sentences were read aloud, as specified in the administration directions provided in the WRAT 4. Participants typed their responses in Microsoft Word 2010 (without spellcheck activated). The WRAT 4 was chosen because it is designed to assess adults up to 94 years old and so was deemed more suitable than available British standardised tests (such as the British Ability Scales, Elliott, Smith, & McCulloch, 1996) which are not suitable for adults. However, the norms available are from a US population, and so to check that the groups with dyslexia performed more poorly than the control group, both groups took part in this measure and mean scores were compared. The green form was used, alternate form immediate retest reliability coefficients are good and ranged from .78 to .89 (Robertson & Wilkinson, 2006).

Final groups

Four writers with previous diagnoses of dyslexia, who volunteered to take part in this study, did not meet the criteria previously described. Two participants performed poorly on the non-verbal reasoning task and were not included in the final group as these writers may have had other difficulties. Two writers performed highly on the reading, phonemic awareness and spelling

tasks and were not included in the final group as they did not appear to have difficulties usually associated with dyslexia. Eighteen writers (five males, thirteen females) met the criteria for the dyslexia group, with a mean age of 20.33 years (range 18-to-22). All writers in this group were full-time undergraduates, seven students were in their first year, five students were in their second year, six students were in their third year and one in their fourth year. The writers in this group studied a range of subjects (seven psychology students, three students were studying psychology combined with another subject, 11 students studied other subjects). Eighteen writers (five males, thirteen females) without dyslexia were selected for the control group, with a mean age of 19.33 years (range 18-to-22). All writers in the control group were full-time first-year psychology students (or psychology combined with other subjects). Scores for participant measures (spelling, reading, phonemic awareness and non-verbal reasoning) are shown in Table 5.1.

Table 5.1 Performance on participant measures across groups, experiment one.

Measure	Measure details	Dyslexia group (<i>n</i> =18)	Control group (<i>n</i> =18)
		Mean (SD)	Mean (SD)
Spelling score	Out of 42	26.83(3.99)	32.72 (2.11)***
Typing Speed	Characters typed per min	224.88 (68.95)	335.83 (124.00)**
	WPM process	31.76 (6.31)	44.00 (11.34)***
Typing Product length	No. of characters	521.33 (125.98)	642.13 (146.20)*
	WPM product	32.91 (6.34)	49.04 (13.95)***
Typing Accuracy	% characters kept in product	94.86 (4.71)	85.30 (7.11)***
	% errors in the product	2.49 (5.13)	1.65 (3.76)
	% errors in the product, adjusted	0.37 (0.72)	0.17 (0.16)
Reading	Total time (s)	225.50 (38.06)	-
	Rate (wpm)	134.49 (22.61)	-
	Accuracy	480.44 (4.44)	-
Phonemic awareness	Rate (s per correct trial)	6.62 (3.52)	-
	Accuracy (out of 24)	19.39 (3.20)	-
Non-verbal reasoning	Raw	18.11 (1.94)	-
	Scaled	9.50 (1.26)	-

*= $p < .05$, **= $p < .01$, ***= $p < .001$

Writers with dyslexia scored significantly lower on the dictated spelling task than writers in the control group, $t(35)=5.54$, $p < .001$. All participants with dyslexia performed within 1 SD of

the mean for non-verbal reasoning. These two results suggest that writers with dyslexia are poorer at spelling than the control group but perform as expected in a task which does not rely on phonemic awareness. This fits a profile of dyslexia.

In the two-minute typing task writers with dyslexia produced shorter texts than the control group $t(35)=2.55, p=.016$. This is likely due to slower typing (WPM $t(35)=-.149, p=.013$), there is a strong correlation between WPM product and WPM process for writers with dyslexia $r=.918, p<.001$) and for writers without dyslexia $r=.960, p<.001$. In fact, despite the earlier stated reservations over measuring speed as WPM from the product instead of from the process, the two measures are very highly correlated. The accuracy of the text (percentage of errors, adjusted) was not related to spelling ability $r=-.26, p=.134$, typing speed $r=.03, p=.864$, or amount of revision $r=.20, p=.235$.

Typing behaviour of writers with dyslexia (slower speed, and fewer deletions, $t(35)=4.62, p<.001$) could indicate slow and careful copying which resulted in texts that were equally accurate as texts by the control group. Overall, faster typing correlates with more revision, the faster someone types the more text they delete, $r=.44, p=.008$. It is possible that faster typing caused typos that required revision.

It was assumed that writers without dyslexia would perform within expected norms and so measures used to indicate dyslexia were not taken for this group (measures of reading ability, phonemic awareness, and non-verbal reasoning). The YAA-R provides confidence interval boundaries (95%) based on the performance of 106 university students. Thus, using the confidence interval boundaries from the YAA-R, the performance of writers with dyslexia can be compared to what is expected of university students without dyslexia. The mean scores for WPM product, all reading measures, and all phonemic awareness measures fall outside these boundaries, suggesting that the writers with dyslexia have poorer mean performances than is expected of 95% of a population without a history of reading or writing difficulties. Furthermore, the means and standard deviations are similar to those found by Warmington et al.(2012) in a similarly sized group of UK undergraduates with dyslexia. Selected measures are compared in Table 5.2.

Table 5.2 A comparison of participant measures from the YAA-R.

Ability	Measure details	Current Study	Warmington et al., (2012), subsamples from YAA-R		YAA-R (2012) norms (N=106)		
		Dyslexia group (n=18)	Dyslexia group (n=20)	Control group (n=20)	M (SD)	Range (min-max)	Confidence interval boundaries (95%)
		M (SD)	M (SD)	M (SD)			
Typing speed	WPM in product	32.91 (6.34)	33.45 (11.05)	43.52 (15.15)	45.06 (14.79)	21.50–89	42.21-47.91
Reading	Total time (s)	225.50 (38.06)	235.94 (42.94)	182.28 (22.41)	182.77 (24.20)	143–263	178.11-187.43
	Rate (wpm)	134.49 (22.61)	128.98 (22.85)	162.27 (19.99)	164.15 (20.39)	112–206	160.2-168.07
	Accuracy (No.correct)	480.44 (4.44)	476.15 (10.91)	486.30 (5.08)	486.33 (4.69)	463–492	485.43-487.23
Phonemic awareness	Rate (s per correct trial)	6.62 (3.52)	5.29 (9.59)	4.37 (13.45)	1.76 (1.36)	0.58–13	1.50-2.02
	Accuracy (No.correct)	19.39 (3.20)	18.30 (5.77)	21.95 (3.10)	21.89 (2.97)	9–24	21.32-22.47
Spelling score	Out of 42	26.83(3.99)	-	-	-	-	-
	Raw	18.11 (1.94)	-	-	-	-	-
Non-verbal reasoning	Scaled	9.50 (1.26)	-	-	-	-	-

5.4.2 Design

There were two independent variables, group (dyslexia or control) and condition (with or without spellcheck) in a two by two design. The combination of the presence/absence of a spelling error and presence/absence of spellcheck created four types of trials (error present & spellcheck, error present & no spellcheck, no error & spellcheck, no error & no spellcheck). Trials without spelling errors were included in the design as filler trials. In the condition ‘no error and spellcheck’ no underline is present because there is no spelling error to trigger spellcheck. This type of trial does not reflect the paradigm being investigated; it was included in the design due to the way the trials were counterbalanced by Writespell, but data from these trials is excluded from analyses.

Participants in van Waes et al.’s (2010) study completed five or six trials of each type and four practice trials. Similarly, in the current study, each participant completed five trials of each type (20 in total) plus four practice trials. The presence of spellcheck was counterbalanced, trials were presented in a randomised order, and the same condition was never presented more than three times in a row.

5.4.3 Procedure

This sentence completion task was designed to investigate the coordination of spelling error revision and sentence composing during writing. Writers were presented with a series of trials using a design based on van Waes et al.’s (2010) study. Stimuli were presented via a computer using Writespell. A single trial was presented as shown overleaf.

Figure 5.1 Details of procedure in experiment one.

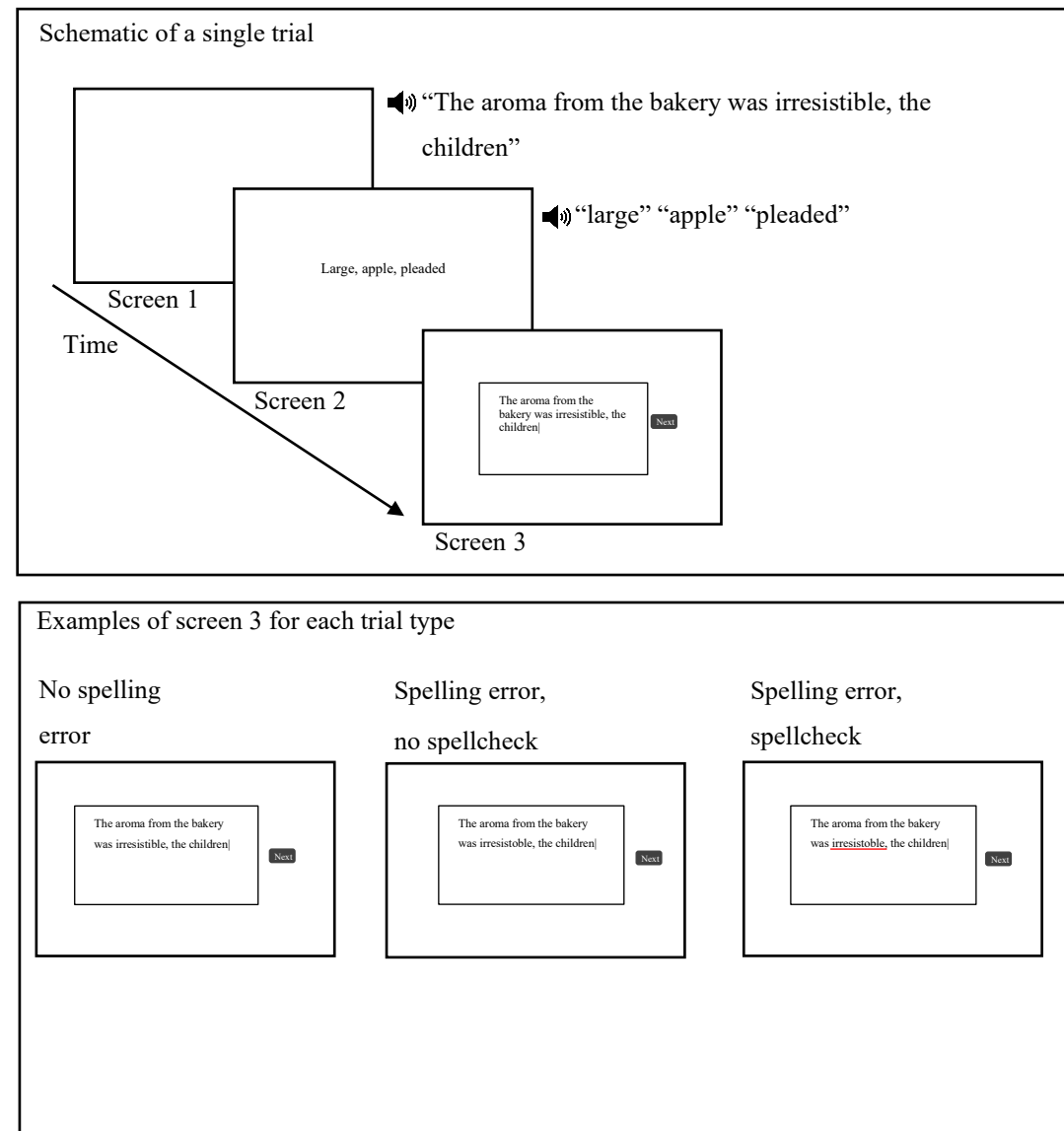


Figure 5.1 This figure depicts the procedure of a single trial, described below, and provides examples of the presentation for each trial type.

Screen 1. Remains blank while audio clip of the partial sentence plays.

Screen 2. Audio clip of content words is played and words are displayed on for 3 seconds.

Screen 3. A text box containing the partial sentence is displayed. To write the rest of the sentence writers could begin typing. To revise the spelling error, the writer needed to use the mouse or the arrow keys to move the caret to the spelling error. Screen 3 differed for each trial type, as shown.

Participants were given instructions which reflect those described by van Waes et al. (2010):

‘Please complete the sentence, incorporating all three words shown. If necessary, correct spelling errors in the text provided. You may correct errors and complete the sentence in any order. Try to complete this task as quickly and accurately as you can.’

Similarly to van Waes et al. (2010), the three content words were topically related to the partial sentence to minimise the need for generating, each partial sentence was 9-12 words long and contained a spelling error 50% of the time. Spelling errors were never positioned as the first or last word of the partial sentence. The next trial began when writers clicked a button labelled ‘next’. The experiment was thus self-paced. This activity took approximately 20 minutes. In trials with spellcheck active, spelling errors were underlined in red. If participants corrected the spelling error, the red line disappeared.

5.4.4 Materials

Creating spelling errors

Van Waes et al. (2010) created errors by replacing target words with other words that were one phoneme and one to two graphemes away from the target word (e.g. ‘knuffle’ *cuddly toy* was replaced with ‘knupple’ *truncheon*). The errors are semantic errors. A semantic error is not suitable for the current investigation because real words will not activate spellcheck. This study requires spelling errors that are not recognised by spellcheck in order to become underlined in red. Spelling errors can be created using van Waes et al.’s (2010) description of orthographically near errors (one phoneme, and one to two graphemes from the target word). Making only small changes to the look and sound of the word should mean that the target word is recognisable from the spelling error. Lists of commonly misspelled words were used to find common spelling mistakes made in English. The lists came from websites such as the Times Educational Supplement, Oxford Dictionaries, and Grammar Dictionary (list of websites available in Appendix H). Words which appeared on multiple lists were selected to be spelling errors in the partial sentence, replicating spelling errors that writers make in real-world writing situations. The list by Oxford Dictionaries also included common misspellings alongside the target word (e.g. accommodation/accomodation), however, most misspellings were phonologically plausible thus did not match van Waes et al.’s (2010) description of errors. Even when there was a phonological difference between the misspelled word and the target word it was often not noticeable when said aloud (e.g. appearance/appeareance).

Once selected, commonly misspelled words were typed into an error generator (<http://tools.seoachat.com/tools/online-keyword-typo-generator/>). This generator uses a bank of common English misspellings and typos to create a list of likely errors for words entered. Error words which match van Waes et al.’s (2010) description (one phoneme and one or two graphemes

from the target word) were selected. Each error was checked to ensure spellcheck would underline it, demonstrating it was a spelling unrecognised by spellcheck.

While it might be assumed that writers with dyslexia make errors from which the target word is not recognised by spellcheck (MacArthur et al., 1996), Hiscox et al. (2014) found that many errors made by UK HE writers with and without dyslexia were corrected by autocorrect which indicates that the errors were very similar to the target word. Thus, it was also checked that error words caused the spellcheck in Microsoft word (2010) to generate the target word as the first word on its list for replacement, demonstrating that the spelling error was close to the target word, mimicking typical misspellings of UK HE writers with and without dyslexia. The final list of 20 misspellings included in trials are listed in Appendix I.

Piloting

The spelling errors were piloted in partial sentences with three content words: one noun, one verb and one describing word (either an adjective or an adverb) and did not appear on any list of common misspellings. The stimuli of the partial sentence task were piloted using Microsoft PowerPoint to present stimuli in text boxes. A total of 51 trials were piloted. Participants ($N=25$) were asked to feedback about any trials that were particularly difficult or easy. Feedback indicated variation in which trials were easy or difficult, any trials which participants agreed were more easy or more difficult than others were changed based on their feedback. For example the partial sentence *He considered himself to have a very high pain threshold, and yet* with the content words: [*tiny, papercut, weep*] was considered easier than other trials, but with the content words changed to [*stubbed, cried, toe*] the sentence was no easier or more difficult than other trials. Trials that continued to be easier or more difficult were deleted until the 51 trials were narrowed down to 24, which were considered neither more or less difficult than each other to ensure similar levels of difficulty in all 24 remaining trials. Two of the trials were removed because Writespell initially used an American English dictionary which meant some words were not suitable because they became underlined when spelled correctly, these involved the words *manoeuvre* and *realised*, and were removed.

Word frequency effects

It is assumed that for the spelling errors to appear on lists of commonly misspelled words, they could be frequently encountered in everyday language. On the other hand, PDP and connectionist models of spelling indicate that high-frequency words are easier to spell (Coleman et al., 2009; Coltheart et al., 2001; Seidenberg, 2005; Treiman & Kessler, 2006) which means spelling errors are more likely to be low-frequency words. The frequency of error words was checked using SUBTLEX-UK (van Heuven, Mandera, Keuleers, & Brysbaert, 2013).

SUBTLEX-UK is a word frequency norm list based on the subtitles from UK television channels (BBC1-4, BBC News, BBC Parliament, BBC HD) from January 2010-December 2012. SUBTLEX-UK has been used by several recent pieces of research (Breadmore & Deacon, 2019; Brysbaert & Ellis, 2016; Mirault, Snell, & Grainger, 2019; Parker, Slattery, & Kirkby, 2019;

Payne & Tainturier, 2018; Snell & Grainger, 2017). The frequency of words is calculated using the Zipf Scale. The Zipf scale is a standardised frequency measure created by Van Heuven et al.(2013). The calculation of Zipf values is $\log_{10}(\text{frequency per billion words})$ or $\log_{10}(\text{frequency per million words}) + 3$. This measure is not affected by the size of the corpus.

Frequency is described using a logarithmic scale of 1-7. A Zipf value of 1 corresponds to words with frequencies of 1 per 100 million words (or lower), a Zipf value of 2 corresponds to words with frequencies of 1 per 10 million words, a Zipf value of 3 corresponds to words with frequencies of 1 per million words, and so on. Thus, 1 represents very low-frequency words; 6, very high-frequency content words; 7, a few function words, pronouns, and verb forms like “have”. Most spelling-error-words selected for the experiment had a frequency between 3 and 5, averaging 4.04. To counterbalance any effect of the word frequency, the frequency of the words was considered when grouping the trials for counterbalancing. Words that were above 5 or below 3 were used in practise trials so that they would not impact results. For example, *government* was approaching score of 6 (5.76) which indicates very high frequency, thus was used in a practise trial.

5.4.5 Measures

Revision

If the text submitted at the end of a trial contained the partial sentence exactly as it was presented to the writer then it showed no signs of revision. Revision is key to the current investigation, only sentences which showed signs of revisions have been included in later analysis.

Initial response

Writers’ initial response was either to revise the error or to defer revision in favour of completing the sentence and was indicated by the position of the first letter typed within the text, which was recorded using Writespell.

Lexical representation

The extent of loss and damage of the lexical representation was assessed by how many content words were present in the text submitted at the end of each trial, this was scored from 0 to 3. Van Waes et al. (2010) used a binary measure for lexical representation which was either scored as 3 or less than 3. To make data comparable, the scores in the current study have also been converted into binary scores.

Latency

The time between when the text appears on screen, which is the first moment the writer was able to type, and when the writer made their first mouse click or keypress was recorded by Writespell in milliseconds, however in the results section latencies are reported in seconds to 2

decimal places for easier comparison. All time based measures that are recorded in milliseconds are reported in seconds.

Typing time

Typing time was defined as the time between the first and last action (keypress or mouse click) in milliseconds. This was recorded by Writespell in milliseconds.

5.5 Experiment One Results

5.5.1 Analysis

Trials with no error present and spellcheck activated were removed from analysis. Some issues with the counterbalancing feature of Writespell were revealed after data collection. This meant that around 90 trials were presented per condition but not precisely 90, as shown in Table 5.3. Writers revised text in fewer than half of the trials with spelling errors, even when spelling errors were underlined. They also frequently revised correctly spelled words.

Table 5.3 The amount of trials showing signs of revision per group, experiment one.

Error	Dyslexia group (n=18)		Control group (n=18)	
presence	No underline	Underline	No underline	Underline
	<i>n</i> /Total, %	<i>n</i> /Total, %	<i>n</i> /Total, %	<i>n</i> /Total, %
No error	42/92, 45.65%	NA	37/94, 39.36%	NA
Error	41/89, 46.07%	*36/90, 40.00%	33/88, 37.50%	*30/91, 32.97%

n = of trials showing signs of revision , *trials with an underlined spelling error

Only trials where the writer completed the sentence and revised the text provided to them are included in analysis. Trials included in analysis are shown in Table 5.4. The number of trials in which the text has been revised is split by whether an underline is present or not. For the trials which included revisions, there is no significant association between group and whether the error was underlined $\chi^2(1, n=544) = 2.99, p = .083$.

Table 5.4 The amount of trials included in analyses, per group and condition.

Spellcheck condition	Dyslexia group	Control group
	<i>n</i> (%)	<i>n</i> (%)
No underline	83/181 (45.86%)	70/182 (38.46%)
Underline	36/90 (40.00%)	30/91 (32.97%)

n = the number of trials included in the analyses.

To answer the research question ‘does spellcheck increase disruption to writing?’, chi-square tests for independence were run to check for an association between spellcheck condition or group and writers' first action (revision or defer revision); Following this, logistic regressions were performed to ascertain the effects of group and spellcheck on the likelihood that writers' initial response was to revise. The sample size was adequate for a logistical regression and there were no outliers (due to using binary categorical data). Events in logistic regressions are considered ‘rare’ if less than 5%, this was not the case for any of the logistic regressions thus this is suitable method for this data (King & Zeng, 2001).

To find out whether a disruption to writing (shown as immediate revision of text) causes loss of the lexical representation, and whether writers with dyslexia are impacted by this more than the control group, it would be best to test for an interaction using a mixed, within-between ANOVA, however, there were 12/36 participants without data points for revision as first action. Thus an ANOVA is not suitable. Therefore whether a disruption to writing causes the loss of a lexical representation and whether writers with dyslexia are more likely to experience loss of the lexical representation has been investigated separately using independent samples t-tests.

The scores for lexical representation have been measured out of 3, with 0 meaning writers did not include any given words in their texts and 3 meaning they included all given words in their texts. To answer the research question ‘Does such disruption cause the lexical representation to fade from working memory?’, individual trials have been compared using independent t-tests. The large data set of individual trials makes up for the limited range in the data (scored 0-3).

The lexical representation scores have been averaged across trials per condition (spellcheck, no spellcheck) for each participant, creating two pieces of data per participant. This allowed the average score for lexical representation to be compared between groups, which can answer the research question: are writers with dyslexia more likely to experience loss of the lexical representation than the control group?. It also allowed the score for the lexical representation to be compared between condition, to find out whether the presence of spellcheck increased the likelihood of damage to the lexical representation. Independent t-tests are the most appropriate test to compare mean accuracy scores between groups. Tests of normality revealed a negative skew for the averaged scores (standard error = 0.39, skew = -1.44) due to all 3 words being included in many trials. However parametric tests are tolerant of skew in sample sizes over 30 (Pallant, 2013), and the sample, in this case, is 36 (two data points per participant). A Levene's test for homogeneity of variance indicated equal variance.

As indicated in the materials section, to make data comparable to previous research, the lexical representation scores have also been converted into binary data as all words present, or some absent. Chi squared tests of independence were used to check for an association between group and all present or all absent, condition and all present or all absent, and first action and all present or all absent.

Longer latencies and writing times indicate difficulties managing cog load. As described above, due 12 participants who did not defer revision, data were unsuitable for an ANOVA with initial response and spellcheck condition. To investigate whether revising immediately causes longer latencies and writing times than deferring revision, independent samples t-tests were used to compare the latencies and writing times between trials where the writers deferred revision or did not defer revision. There were several participants who always deferred revision, thus there was more data for immediate revision than deferred revision, but because each participant has contributed more than one data point, non-parametric tests are less appropriate than parametric tests (Pallant, 2013). To investigate the impact of spellcheck and group, on latency and writing time 2-way mixed ANOVA's were used.

Significance levels for all tests were set at $p < .05$. For Chi squared effect sizes have been calculated as phi coefficient, which is suitable for 2x2 tables (Pallant, 2013). For ANOVA's effect sizes were calculated through partial eta-squared (η^2). Because ANOVAs were carried out with two levels (two groups), post hoc tests were not necessary (Pallant, 2013).

5.5.2 Initial response

As shown in Table 5.5, generally, writers were likely to respond to the task by deferring revision. A chi-square test of independence showed no association between group and initial response $\chi^2(1, N=219) = .594, p = .385, \phi = -.04$. Although writers did not begin trials with revision very often, when they did, it was more likely to be when the error was underlined than when it was not. This effect was significant for each group, with a medium to large effect size for writers with dyslexia and a medium effect size for writers without dyslexia (writers with dyslexia, $\chi^2(1, n=119) = 17.82, p < .001, \phi = .39$; control group $\chi^2(1, N=100) = 8.39, p = .009, \phi = .29$).

Table 5.5 The amount of trials per initial response, group, and condition.

	Dyslexia		Control group	
	No underline ($n=83$) n (%)	Underline ($n=36$) n (%)	No underline ($n=70$) n (%)	Underline ($n=30$) n (%)
Initial response				
Revision	2 (2.41%)	10 (27.78%)	2 (2.86%)	6 (20.00%)
Defer revision	81 (97.59%)	26 (72.22%)	68 (97.14%)	24 (80.00%)

A binary logistic regression was used to further investigate the effects of group and presence of an underline on participants' initial response and to compare the effect sizes between groups. The full logistic regression model was statistically significant $\chi^2(3, n=219) = 24.27, p < .001$ and correctly identified 90.9% of cases where writers continued with sentence completion rather than edit the existing text. The model explains 22.9% (Nagelkerke R^2) of the variance in

first action. Results suggest that the presence of an underline is a predictor of revision, with an odds ratio of 8.5, (Wald $\chi^2 = 6.33$, $p=.012$ B=2.14, SE=0.85, 95% CI lower=3.82, upper=37.49). This indicates that writers are eight and a half times more likely to start trials by revising text when a red underline is present compared to when it is not present. Group does not predict first action (Wald $\chi^2 = 0.03$, $p=.863$, B=-.175, SE=1.01; 95% CI lower=-.49, upper=3.59). There was no significant interaction between group and condition ($p=.605$).

5.5.3 Lexical representation

Independent t-tests compared the number of content words included in the sentence (maximum = 3) when writers deferred revision (M=2.81, SD=.46) and when they began trials with revision (M=2.85, SD=.37). There was no significant relationship between the number of content words in the text submitted and the writers first action $t(217)=.38$, $p=.703$. The mean number of content words included in the sentence was slightly less for writers with dyslexia (M=2.75, SD=.51) than the control group (M=2.89, SD=.37) and does show a significant relationship $t(217)=2.38$, $p=.018$.

When data is divided into binary scores (some content words absent or all content words present) there is no association between score and whether revision was deferred or not $\chi^2(1, N=219)=.016$, $p=.900$.

Table 5.6 The amount of trials per presence of content words and per initial response.

Presence of content words	Revision ($n=20$)	Defer revision ($n=199$)
	N (%)	N (%)
Some absent	3 (15.00)	32 (16.08)
All present	17 (85.00)	167 (83.92)

5.5.4 Latency

Table 5.7 shows the means and standard deviations of latency. An independent t-test comparing mean latency, revealed significantly longer latencies when writers responded with revision compared to deferring revision $t(217)=2.35$, $p=.020$. ANOVA results show that neither underline $F(1,32)=.05$, $p=.824$, $\eta_p^2<.01$, nor group $F(1,32)=1.86$, $p=.182$ $\eta_p^2=.06$ showed a significant main effect on latencies, there was also no significant interaction $F(1,32)=1.20$, $p=.281$, $\eta_p^2=.04$.

Table 5.7 Latency, per group and initial response, in seconds.

Measure	All trials		Dyslexia		Control group	
	Revision	Defer	Revision	Defer	Revision	Defer
	(<i>n</i> =20)	revision	(<i>n</i> =12)	revision	(<i>n</i> =8)	revision
	M(SD)	(<i>n</i> =199)	M(SD)	(<i>n</i> =107)	M(SD)	(<i>n</i> =92)
		M(SD)		M(SD)		M(SD)
Latency (s)	6.51 (8.16)	3.81 (4.45)	4.28 (1.66)	3.18 (3.43)	9.86 (12.46)	4.55 (5.33)

5.5.5 Writing time

Mean writing times are displayed in Table 5.8. Independent t-tests indicate no significant relationship between writing time and writers' initial response $t(216)=1.80, p=.074$. When groups were analysed separately, for writers with dyslexia, mean writing times were significantly higher when they responded by revising text compared to deferring revision $t(117)=2.67, p=.009$. There was no significant effect for writers without dyslexia $t(97)=0.79, p=.431$.

Table 5.8 Writing time, per group and initial response, in seconds.

Measure	All trials		Dyslexia		Control group	
	Revision	Defer	Revision	Defer	Revision	Defer
	(<i>n</i> =20)	revision	(<i>n</i> =12)	revision	(<i>n</i> =8)	revision
	M(SD)	(<i>n</i> =199)	M(SD)	(<i>n</i> =107)	M(SD)	(<i>n</i> =92)
		M(SD)		M(SD)		M(SD)
Writing time (s)	30.14 (19.29)	23.06 (16.53)	39.87 (17.36)	25.79 (17.33)	15.53 (11.40)	19.84 (15.00)

ANOVA revealed a significant interaction for mean writing times $F(1,31)=1.53, p=.026, \eta_p^2=.05$ with a larger increase of writing times for the dyslexia group than for the control group. Furthermore, main effects showed that the presence of a red underline significantly increased writing time $F(1,31)=4.54, p=.041, \eta_p^2=.13$ and writers with dyslexia write for significantly longer $F(1,31)=6.41, p=.017, \eta_p^2=.17$.

Writing time does not correlate with typing speed $r = -.312$, $p = .068$, or accuracy, $r = -.044$, $p = .803$, as measured in the two-minute typing task described in the participant measures, which indicates that how long writers spent on task is not related to typing ability.

5.6 Experiment One Discussion

Results show that, when writers have to choose between revising a spelling error or deferring revision. To transcribe the lexical representation onto the page, they tend to defer revision. This reflects the results of previous research using a similar design. Without spellcheck, writers in both groups of the current study deferred revision in 97% of trials, writers in Leijten et al.'s (2007) study deferred revision in 94% of trials, and writers in van Waes et al.'s (2010) study deferred in 90% of trials. Interestingly, writers in the current study deferred revision less often when errors were underlined by spellcheck, however, even then, writers still deferred revision the majority of the time (72% of trials for writers with dyslexia and 80% for the control group).

When errors were underlined by spellcheck, writers with dyslexia started 28% of trials with revision and the control group started 20% of trials with revision, much more often than when there was no form of spellcheck. Without spellcheck, writers from both groups started trials with revision in only 2-to-3% of cases, which is even fewer than the writers in van Waes et al.'s study (2010) who started 10% of trials with revision, and lower than the writers in Leijten et al.'s study (2010) who started 6% of trials with revision (also without any form of spellcheck available).

Van Waes et al. (2010) suggested that writers are more likely to begin trials with revision when the cognitive load is low and writers are able to process the error and the lexical representation simultaneously which allows flexibility to revise the error with little risk to the lexical representation. Thus, it may be the case that writers were better able to parallel process in trials with underlined errors. On the other hand, the experiment design was based on van Waes et al.'s (2010) high load condition thus parallel processing should have been difficult. If writers reduced parallel processing then deferring revision should indicate ability to inhibit error processing, and starting with revision should indicate that the writer had not inhibited revision. Thus results could indicate that inhibiting spelling error revision is more difficult when the spelling error is underlined compared to when it is not.

If writers were not using parallel processing, then starting trials with revision is likely to disrupt maintenance of the lexical representation. This alternative explanation reflects results in the previous chapter, where writers report that spellcheck disrupts their train of thought and interrupts writing. However, in the current study, measuring the content words revealed that revising the error first did not cause damage to, or loss of, the lexical representation. Writers incorporated all three content words almost every time. Thus it appears that writers were able to attend to the error while maintaining the lexical representation in working memory. Thus the task

was not challenging enough to prevent writers from parallel processing and deferring revision did not necessarily indicate inhibition.

Latencies were much longer when writers defer revision (2.7 seconds difference between means). Longer latencies may be caused by difficulties deciding how best to orchestrate writing processes (Beauvais et al., 2011). Because writers hear the stimuli before they can begin writing, they can create a lexical representation ready for transcription before the textbox is available to write in. Thus writers can be ready to begin transcription as soon as the textbox appears. However, writers cannot process the error until it has appeared on screen. Therefore, longer latencies when starting trials with revision most likely reflect time needed to process the error and to adjust management of cognitive resources to deal with this. Van Waes et al.(2010) found a smaller difference of 0.6-seconds in the same direction. Neither underline nor group caused a significant main effect to latencies.

Writers with dyslexia spent longer on trials when their initial response was revision than when they deferred revision. This indicates that, for these writers, something about completing the task was more difficult when revising first. The longer time does not appear to be needed for creating a whole new lexical representation because writers were just as successful at incorporating all content words into their texts. However, the longer time might reflect time needed to repair a faded representation. The initial response had no impact on writing time for the control group. The fact that the first response only caused a significant effect for writers with dyslexia may be related to limitations of working memory (especially phonological loop capacity) because the tasks require phonological resources and writers with dyslexia are likely to struggle with this.

The presence of an underline increased the amount of time writers spent on each trial. However, this result could be a function of the study design. In the current experiment, when spellcheck was on, spelling errors trigger a red underline but the 'select and replace' function was not available to support correction. Thus writers needed to revise spelling errors manually, and the red line would not disappear until the word was correctly spelled. Writers may have spent longer revising spelling errors when feedback indicated whether the revision was successful or not compared to in trials without feedback. Interestingly, writers with dyslexia were impacted more than the control group, which could reflect spelling difficulties during revision.

5.6.1 Conclusions

Both groups of writers tend to complete the sentence before correcting the error. This reflects previous research on writers without dyslexia in a similar task (Leijten et al., 2007; van Waes et al., 2010). Interestingly, the presence of a red underline encourages writers to revise the error before completing the sentence. These results suggest that writers are more likely to experience disruption (in the form of an R-burst, Chenoweth and Hayes 2003, 2007) when errors are underlined compared to when they are not underlined. This supports participant reports in

Chapter 4, that the appearance of a red underline causes them to stop writing. Starting trials with revision did not appear to impact the integrity of writers' lexical representations in experiment one, which indicates that writers were capable of processing the spelling error and maintaining the lexical representation at the same time. Several limitations of experiment one have been identified, these are outlined below and addressed in experiment two.

5.7 Improvements to the Experimental Design

As already indicated, writers did not have access to the select and replace function of spellcheck. In a natural writing situation, the select and replace function would be available. With full spellcheck available, any differences between conditions would more accurately reflect the impact that spellcheck has on writing in day-to-day writing situations. Thus, Writespell was updated for experiment two to include the select and replace function of spellcheck, mimicking spellcheck in Microsoft Word 2010. Survey results indicated that Microsoft Word was the most popular writing program. In addition, Microsoft Word 2010 was on shared computers in classrooms throughout Oxford Brookes University at the time of data collection. Thus it is the most appropriate word processing program to mimic for the participants of this study.

The number of trials where writers revised the text was surprisingly low. Even with an underlined spelling error present, writers revised just over a third of trials. This is far fewer than undergraduate writers in Figueredo and Varnhagen's (2006) study, where writers corrected 88.2% of underlined errors. Results are closer to MacArthur et al.'s (1996) findings where school-age writers with dyslexia corrected 37% of total errors with spellcheck. Writers frequently revised correctly spelled words. This is not unusual, for example, Figueredo and Varnhagen (2004) found that 22 out of 53 undergraduates without dyslexia identified false positives when reading for spelling errors. Because fewer trials than expected were edited than expected, there were fewer data available for analysis than planned. In experiment two spelling errors were presented in 20 out of 30 trials as opposed to 50% of trials. This was to encourage editing so that more trials could be included in the analysis and hopefully create evenly sized groups when unedited trials are removed and remaining trials are divided by presence of spellcheck. Spellcheck was active in half of the trials containing spelling errors.

Unfortunately, latency results in experiment one are likely to have been impacted by the starting position of the caret. The caret was positioned at the end of the partial sentence to mimic the position that the caret would take if the writer was truly producing their own text. Thus when writers choose to continue writing the sentence they could begin typing straight away, however, if they chose to correct the error first then they needed to move the caret to the error. If writers used the mouse to reposition the caret to the spelling error (as opposed to using arrow keys) it would most likely have increased the latency. This may explain why the difference between means (2.7 seconds) is larger than found in van Waes et al.'s (2010) study (0.6 seconds). To address this issue

in study two, the writer always needed to use the mouse to insert the caret into the text at the point they wished to begin typing. Thus in experiment two, initial latencies always ended with a mouse click, regardless of whether writers' initial response is to revise or if they defer revision. Although this is less like a natural writing situation it enables better comparison across conditions. In addition, the moment that writers first began typing or used a right-click to activate spellcheck was captured to provide further information of when writers responded to the task.

The design of experiment one was based on the high load task in van Waes et al.'s (2010) study with the expectation that keeping three content words in working memory would prevent writers from parallel processing so that deferring revision would indicate ability to inhibit revision processes. However all writers managed to incorporate all three content words almost every time, this was not a sufficient cognitive load. Thus, in experiment two, five content words are used, including a difficult to spell content word. Increasing the working memory load should mean that writers will be unable to process both the error and the lexical representation at the same time (ruling out parallel processing), thus behaviour will reflect ability to inhibit revision processes. For more information regarding difficulties completing the task, typing speed has also been measured (this was not measured in experiment one). It was expected that slower typing would indicate difficulties with the task.

One of the findings from the survey in Chapter 4 was that writers with dyslexia were less likely than controls to report that, after noticing a spelling error, they continue writing to a text boundary before revising the spelling error. Experiment one did not investigate how far writers continue writing before revising a spelling error and did not give writers the opportunity to write more than half a sentence. Encouraging writers to produce more text should provide more information about writing practices and the management of cognitive resources. Thus, in experiment two, writers were asked to complete a second sentence in each trial and how far they wrote before revising was measured.

It is thought that writers tend to defer revision because they want to transcribe the lexical representation safely onto the page so that they do not need to continue maintaining it in working memory (Leijten et al., 2007; van Waes et al., 2010). However, from experiment one, it is not possible to know the extent to which the writer has a lexical representation ready for transcription at the moment that they notice the error. Therefore, it is not known how much of a lexical representation is at risk. In experiment two writers were asked whether they decide what to write before seeing the text. If writers decide what to write before seeing the text, then failing to incorporate the content words would indicate that the lexical representation has faded or changed.

5.8 Experiment Two

The research questions for experiment two are the same as experiment one, however, because of changes made to experiment two, results are expected to better address them.

5.8.1 Predictions

Results regarding initial response were expected to replicate experiment one. Due to the changes made to the experiment design results regarding the lexical representation were not expected to replicate experiment one, instead, it was expected that writers would be less likely to incorporate all content words if they started trials with revision, and writers with dyslexia were expected to be less successful at incorporating content words than writers in the control group.

The presence of spellcheck, writers' initial response, and group, were all expected to cause main effects for measures of latency, revisions, writing time and writing speed. It was expected that the presence of spellcheck, revising as initial response, and having dyslexia would all cause longer latencies, earlier revisions, longer writing times, and slower typing.

Some interactions were expected. It was expected that without spellcheck, writers with dyslexia would take longer to start typing or revising than writers in the control group. However with spellcheck on, no difference was expected between groups and writers were expected to take less time to begin revision than to begin writing new text. It was expected that writers would produce less text before revising if spellcheck was on compared to off. It was expected that without spellcheck, writers with dyslexia would submit texts with more spelling errors than writers without dyslexia, but with spellcheck, it was expected that neither group would leave spelling errors in texts.

5.9 Experiment Two Method

5.9.1 Participants

A new set of participants were recruited for experiment two. Inclusion and exclusion criteria were the same as experiment one.

Number: Statistical power is sufficient when data points reach 100 per condition (Pallant, 2013). Ten writers per group completing 10 trials per condition provide 100 trials per combination of group and condition (dyslexia and control, spellcheck on and off). With 100 data points and medium effect size the power is estimated as 0.85 for chi-square tests of independence and as 0.94 for t-tests (calculated using the power analysis calculator by Faul, Erdfelder, Lang, & Buchner, 2007). Thus groups consisted of 10 writers each. A mixed-design ANOVA can be carried out with this sample group.

Recruitment: Participants volunteered to take part in this study after seeing advertisements around Oxford Brookes University and in response to emails sent via university research mailing lists. Each participant received £20 as compensation for their time. All participants were provided with participant information sheets (Appendix J) via email from the researcher when organising a suitable time to take part in the study. They were also provided with a hard copy upon meeting the researcher and given time to read this and ask questions about the procedure. When satisfied

with the information provided, participants were given a hard copy of the consent form (Appendix F) to sign. Upon signing this, participants were reminded that they could still choose to stop participating and withdraw any unprocessed data at any time.

Final groups

All participants were full-time undergraduate students at Oxford Brookes University. The group of writers with dyslexia consisted of five men and five women, with a mean age of 20.20 years (range of 19 to 22). One participant was in their first year, seven were in their second year, and two in their third year of undergraduate study of a range of subjects (business management, city and regional planning, film studies, Japanese, mechanical engineering, psychology). The control group consisted of five men and five women, with a mean age of 19.7 (range of 18 to 21). Four participants were in their first year of study, three in their second year, and three in their third year of study. There was not a significant difference in ages between groups $t(18)=-.97$, $p=.343$. All participants in the control group were undertaking a psychology undergraduate course. All participants completed the same battery of tests described in experiment one, however this time both groups completed all tests. Means and standard deviations for all participant measures are shown in Table 5.9.

The spelling scores of writers with dyslexia were significantly lower than the control group $t(18)=4.18$, $p=.001$. In the phonemic awareness measure, writers with dyslexia took significantly longer per correct trial than writers without dyslexia $t(14.87)=-.97$, $p=.347$. This reflects poorer phonemic awareness of the dyslexia group than the control group. Phonemic awareness accuracy was not a distinguishing feature between groups, however the means (writers with dyslexia 18.60, control group 21.30) are very close to that seen in the paper by Warmington et al. (2012) (writers with dyslexia $M=18.30$, $SD=5.77$; control group $M=21.95$, $SD=3.10$) and writers without dyslexia performed similarly to the norms of the YAA-R ($M=21.89$, $SD=2.97$).

The group of writers with dyslexia showed poorer performance than the control group on other measures of abilities that are associated with dyslexia, but performed equally well in non-verbal reasoning, indicating equal levels of intelligence, shown by raw scores $t(18)=-.240$, $p=.813$, and scaled scores $t(14.971)=-.171$, $p=.867$. Thus groups fit expected profiles and were suitable for comparison.

Phonemic awareness in the control group

Writers in the control group took on average 2.73 seconds ($SD=0.62$) per correct trial. In their description of the YAA-R, Warmington et al. (2012) measured the performance of 106 undergraduates without dyslexia to find norms ($M=1.76$, $SD=1.36$) and confidence interval boundaries (1.50-2.02). According to norm performances, writers without dyslexia in the current study were slower than expected of an undergraduate. However, when, Warmington et al. (2012) compared average trial length of undergraduates with ($n=23$) and without ($n=20$) dyslexia, the writers without dyslexia took a mean time of 4.37 ($SD=13.45$) seconds, thus the writers in the current sample were faster Warmington et al.'s (2012) control group.

Confusingly, the performance by the control group sits between results of control groups captured by authors of the YAA-R. It was deemed that this group performed as expected for a group of undergraduates. It is possible that there are inconsistencies in how rate was measured across the studies. The variation between studies reflects poorly on the measure. Poorer phonemic awareness is a distinguishing feature of dyslexia but it is possible that something about the task itself is not capturing this ability accurately. However, encouragingly, in the current study, better performance in the phonemic awareness task is related to better spelling performance. Better spellers took less time $r = -.515, p = .020$ and were more accurate $r = .596, p = .006$ when responding to the phonemic awareness task.

Typing measures

Typing measures revealed that: writers with dyslexia typed fewer words $t(18) = 3.50, p = .003$, and fewer characters $t(18) = 3.51, p = .003$, per minute than writers without dyslexia (includes deleted characters and words). Texts by writers with dyslexia were shorter than texts by the control group $t(18) = 3.61, p = .002$. The WPM product was significantly lower for writers with dyslexia than for the control group $t(18) = 3.66, p = .002$. There was no significant difference between groups $t(18) = .82, p = .425$ for typing accuracy. Unlike experiment one, writers with dyslexia revised more than writers in the control group, $t(18) = 2.50, p = .022$. There was no difference between groups for the number of typing errors, $t(18) = 1.08, p = .294$.

Relationships between measures

Spelling was not correlated with typing accuracy (percentage of errors, adjusted) $r = .264, p = .260$, it is unlikely that spelling mistakes in the spelling task were due to poor typing.

Typing speed was not correlated with typing accuracy measured from the final product (percentage of errors, adjusted) $r = -.015, p = .950$, but was correlated with the percentage of characters kept in product $r = .627, p = .003$ indicating that the more editing that occurred, the slower the typing speed. Typing speed also correlated with spelling scores, poorer spellers were slower typists $r = .490, p = .028$.

Table 5.9 Performance on participant measures across groups, experiment two.

		Dyslexia group (<i>n</i> =10)	Control group (<i>n</i> =10)
Measure		M (SD)	M (SD)
Spelling score	Out of 42	27.7 (3.20)	32.8 (1.78)***
Typing speed	Characters typed per min	191.57 (51.12)	274.62 (49.30)**
	WPM process	29.83 (8.72)	43.02 (8.15)**
Typing Product length	No. characters in product	358.40 (86.02)	511.60 (93.97)**
	WPM product	28.80 (8.27)	41.15 (7.73)**
Typing Accuracy	% characters kept in product	75.30 (5.84)	81.32 (4.24)*
	% errors in the product	0.33 (0.37)	1.79 (3.99) ⁶
	% errors in the product, adjusted	0.14 (0.18)	0.27 (0.45)
Reading	Total time (s)	211.89 (29.45)	188.52 (19.07)
	Rate (wpm)	142.02 (19.84)	158.18 (15.77)
	Accuracy (out of 492)	480.30 (2.98)	485.90 (4.18)**
Phonemic Awareness	Rate (s per correct trial)	4.32 (2.02)	2.73 (0.62)*
	Accuracy (out of 24)	18.60 (3.80)	21.30 (1.79)
Non-verbal reasoning	Raw	18.50 (2.11)	18.30 (1.35)
	Scaled	9.60 (1.50)	9.50 (0.92)

*= $p<.05$, **= $p<.01$, ***= $p<.001$

⁶ Similarly to experiment one, the most common reason for inaccurate typing was omission and a writer in this group omitted the same two words (9 characters) per line, resulting in 63 errors in omitted characters. This is a good example of poor copying that does not necessarily indicate poor typing. This is why it is important to use typing accuracy scores without omitted words.

5.9.2 Design

Every writer completed 30 trials (10 with no errors, 10 with a spelling error and spellcheck active, 10 with a spelling error and no spellcheck) plus three practice items. Twenty out of thirty trials contained spelling errors.

5.9.3 Materials

The same misspellings from experiment one were used in experiment two (see Appendix I). The difficult-to-spell words were selected from the same lists of common misspellings that were used in experiment one. Like experiment one, content words included at least one noun, one verb and an adjective or adverb in each trial and did not appear on any list of common misspellings. The difficult to spell word was not limited to a particular word type. Content words and the difficult to spell word were selected to fit the theme of the partial sentence so that the trial could be completed without breaking the theme of the text provided. Examples of stimuli are shown below in Table 5.10.

Table 5.10 Examples of stimuli texts.

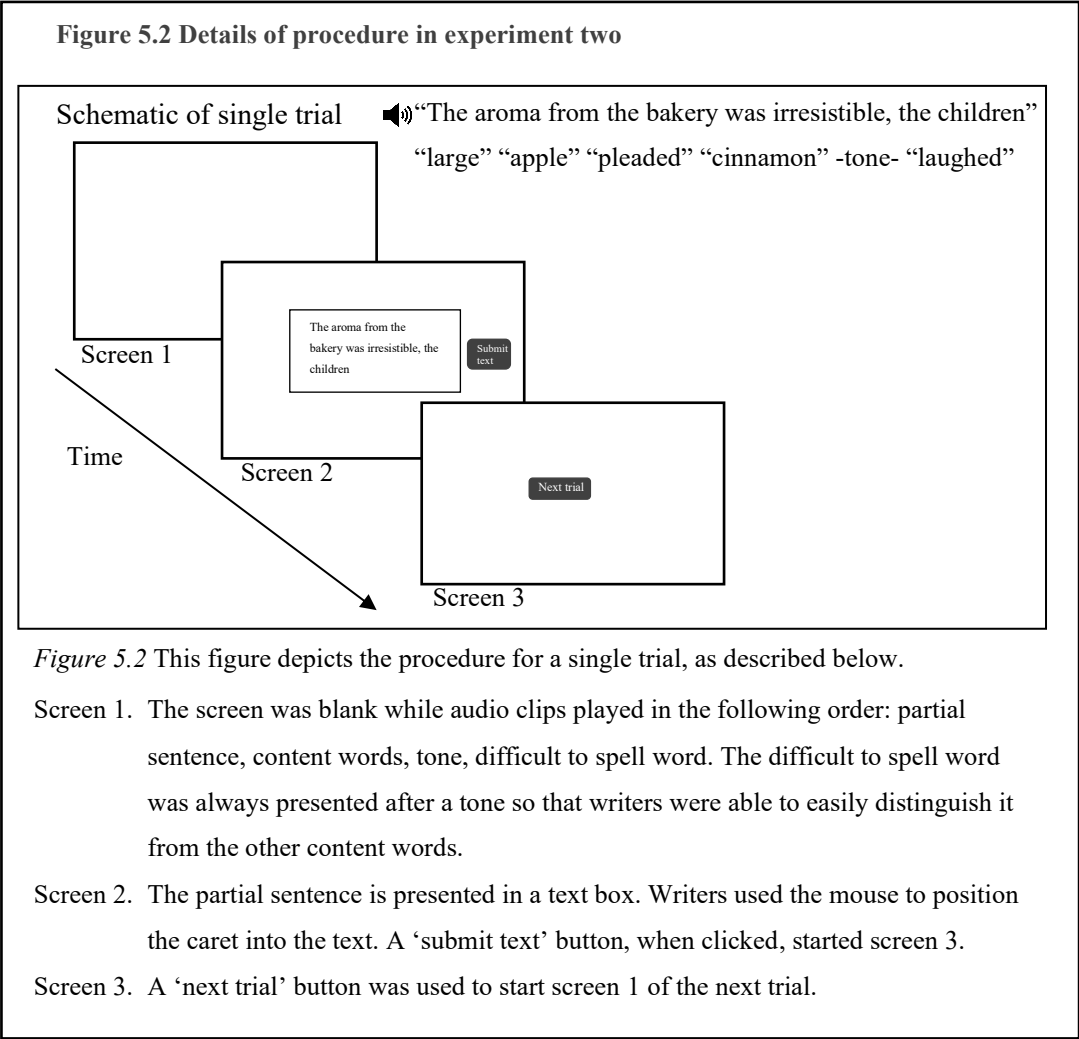
Condition	Partial sentence	Content words	Difficult to spell content word
With error	After practciing for his driving test, the instructor suggested	wait, booking, before, test,	manoeuvres
With error	As the waitress accidntally slipped on someone's discarded napkin she	heavy, dropped, salad, tray	vinaigrette
No error	Despite the unbearable heat and the billowing black smoke,	firefighter, ran, burning, rescue	fluorescent

Piloting

All 33 trials (including the 3 practice items) were piloted to ensure similar levels of difficulty. Participants ($N=20$) provided feedback about how easy or difficult the trials were. The trials were variations on stimuli that had already been piloted for experiment one. Feedback indicated that very few changes needed to be made this time. The content words for some trials were altered, for example, the content words for the second example in Table 5.10, were originally “*salad, spilled, floor, fresh*” and were changed to “*heavy, dropped, salad, tray*”. Participant reports indicated that all difficult-to-spell words were similarly difficult.

5.9.4 Procedure

Writers were given the following instructions: ‘You will hear a partial sentence, then four words, a tone, then one more word. The partial sentence you heard will then appear on the screen. Please complete the sentence, incorporating all four words played before the tone; write a whole sentence that incorporates the word played after the tone, this sentence should be related to the first sentence; and if necessary, correct spelling errors in the text provided. You may correct errors and complete the text in any order. Try to complete this task as quickly and accurately as you can.’ A blank screen with a start button was presented, when the start button was clicked on, the first practise trial began. Each trial appeared as described below



Writers were given three practice trials, one without an error, one with an error and spellcheck active, and one with an error and no spellcheck. Writers received reminders of instructions when necessary and were encouraged to use Screen 3 to pause if they wish to take a break during the experiment. Writers proceeded to the task only after completing the final practice trial correctly unaided. All participants successfully completed the third practice trial

unaided, no participants were excluded. To make the task more demanding than experiment one, the screen remained blank while audio clips played, this was to prevent writers from using the words on the screen to assist with spelling particularly for the difficult-to-spell word.

5.9.5 Measures

Similarly to experiment one, revisions to initial text and initial response were recorded by Writespell.

Latencies

Click latency: The time between the appearance of Screen 2 and the first mouse click in text was measured to indicate the time taken to decide which action to carry out first.

Action latency: The time between the first mouse click and the first keypress or right-click of the mouse was measured to indicate the time taken to start typing or begin error revision. Writespell records time in milliseconds however in the results section latencies are reported in seconds to 2 decimal places for easier comparison. All measures that are recorded in milliseconds are reported in seconds.

When revisions are made.

How far writers typed before revising their text has been measured. Just before the cursor is moved to the text to be revised, the number of characters between the cursor and the text provided was counted as a proxy for how far writers had typed before revising the error.

Typing speed

Typing speed has been measured as the average number of keystrokes per minute between first click into the text box and the last click to submit text at the end of the trial. Slower typing suggests increased effort and reduced parallel processing.

Writing time

Time spent writing has been measured as the time between the first and last click. Writespell records time in milliseconds.

Lexical representation

The number of content words included in the first sentence is scored out of four (one per word included). Whether or not the difficult to spell word is included in the second sentence was also recorded. The lexical representation is also split into trials that indicate a whole lexical representation (all five given words) or a damaged lexical representation (less than five words).

Misspellings

All incorrectly spelled words were counted. This includes the misspelling presented in text, misspelled content words, misspelled difficult-to-spell words, and any other incorrectly spelled words.

After task questions

After the sentence task is complete writers were given a piece of paper with two questions:

- A. 'Did you decide what you wanted to write while listening to the audio?' With the response options of 'yes' or 'no'.
- B. 'In some of the trials you might have corrected the spelling error before completing the sentence. If you did correct the error before writing your text, which of the following statements best describes what you did.' writers were provided the following response options:
 - 1. I held the text that I had decided to write in my mind whilst correcting the error.
 - 2. I remembered parts of the text that I had decided to write and recreated it best I could.
 - 3. I forgot the text that I had decided to write and needed to create new text.
 - 4. I did not decide what to write until just before I wrote it.
 - 5. I never corrected the error before writing the text.

5.10 Experiment Two Results

5.10.1 Analysis

The same statistical analyses described in experiment one were applied in experiment two. The partial sentences presented should have totalled as 200 trials with spellcheck off (100 of which contained an error) and 100 trials with spellcheck on (all of which contained a spelling error). However, due to problems with the program used during data collection, for a few participants, the spellcheck on/off randomising was restarted and so the number of trials in each condition was not exactly even. This only occurred for some of the writers without dyslexia, the majority of whom were recruited at the beginning of the data collection period. This is why, in Table 5.11, the total number of trials presented without spellcheck is 190 instead of 200 and with spellcheck is 110 instead of 100. This small change in trial numbers does not appear to have impacted that proportions of partial sentences that have been edited. The number and percentages of trials edited per group and condition are shown in Table 5.11.

Table 5.11 The amount of trials showing signs of revision per group and condition, experiment two.

Spellcheck condition	Dyslexia group <i>n</i> revised/total (%)	Control group <i>n</i> revised/total (%)
Spellcheck off	44/200 (22.00)	69/190 (36.32)
Spellcheck on	87/100 (87.00)	93/110 (84.55)

When spellcheck was off, fewer sentences than expected were edited. As a result, the number of trials with spellcheck off is lower than with spellcheck on; particularly for writers with dyslexia. Only trials where the writer edited the initial text are included in the analyses that follow. Mean performances from trials with spellcheck on have been compared to mean performance from trials with spellcheck off.

In this sample, three writers with dyslexia and five from the control group never started trials with revision. Thus to compare data by initial response, the number of participants would have to be reduced to seven writers with dyslexia and five writers from the control group. These small and uneven group sizes are not suitable for ANOVA. Instead of comparing mean values of each participant, every trial contributes to the data, providing a larger sample size (46 trials that began with revision, 262 trials where revision was deferred). Thus the data is suited to t-tests, however, the group numbers are uneven which can affect the homogeneity of variance. Levene's test for equality of variances revealed whether or not this was an issue for independent t-tests on a case by case basis and results from this were used as a guide to ensure appropriate tests are used for analysis. If Levene's test showed that the variances for each group were not equal, then a Welch-Satterthwaite t-test has been reported instead of a Student's t-test.

5.10.2 Initial response

To answer the research question 'does spellcheck increase disruption to writing?' how often writers respond to the task with immediate revision and deferred revision was compared between spellcheck conditions, per group. Immediate revision indicates disruption to writing. As shown in Table 5.12, writers started a higher percentage of trials by deferring revision than with immediate revision. Writers with dyslexia are more likely to begin trials with immediate revision if spellcheck is on than if it is off $\chi^2(2, n=131)=.045, p=.023, \phi=.19$. Writers in the control group are less likely to begin trials with revision if spellcheck is on than off $\chi^2(2, n=162)=.022, p=.033, \phi=.18$. The size of effect is small to medium in both cases.

Table 5.12 The amount of trials included in analyses per first action, group and condition.

Initial response	Dyslexia group		Control group	
	No spellcheck (<i>n</i> =44) N (%)	Spellcheck (<i>n</i> =87) N (%)	No spellcheck (<i>n</i> =69) N (%)	Spellcheck (<i>n</i> =93) N (%)
Revision	5 (11.36)	24 (27.62)	10 (14.49)	4 (4.30)
Defer revision	39 (88.64)	63 (72.38)	59 (85.51)	89 (95.70)

A binary logistic regression was used to investigate the effects of group and spellcheck on participants' initial response and to compare the effects between groups. The full logistic regression model was statistically significant $X^2(3, n=293) = 20.64, p < .001$ and correctly identifies 85.3% of cases. The model explains 12.0% (Nagelkerke R^2) of the variance in first action. Results indicate that writers are less likely to begin trials with revision if spellcheck is on (Wald $X^2=4.66, p=.031, \exp(B)= 0.27, B=-1.33, SE= 0.62; CI\ 95\% \text{ lower}= 0.46, \text{ upper}=1.83$). Group did not have a significant effect (Wald $X^2=0.23, p=.633$). A significant interaction revealed that groups are impacted differently (Wald $X^2=8.83, p=.003, \exp(B)=11.21, B=2.42, SE=0.81; CI\ 95\%, \text{ lower}= 0.17, \text{ upper}= 1.83$). Writers with dyslexia were almost three times more likely to begin trials with revision when spellcheck was on compared to when spellcheck was off, however, writers in the control group were less likely to begin trials with revision when spellcheck is on.

5.10.3 Lexical representation

To answer the research question 'does disruption cause the lexical representation to fade from working memory?', the number of content words (out of five) incorporated into the texts submitted has been compared between trials where writers started with revision and where they deferred revision. Writers incorporated fewer content words into their texts when they started trials with revision, ($M=3.47, SD= 1.47$) compared to when they deferred revision ($M= 4.15 SD= 1.01$), $t(48.98)=2.93, p=.005$. The data were not suitable for an ANOVA, which would indicate if writers with dyslexia are impacted more than the control group. Therefore to find out if groups were impacted differently, the number of content words in texts submitted were compared between groups using a t-test. There is an overall effect of group, writers with dyslexia include significantly fewer content words in their texts ($M=3.86, SD=1.20$) than writers without dyslexia ($M=4.20, SD=1.01$), $t(291)=2.58, p=.010$. This difference was only significant with spellcheck on (writers without dyslexia $M=4.27, SD=.99$; writers with dyslexia $M=3.86, SD=1.16$) $t(178)=2.53, p=.012$, and not with spellcheck off (writers without dyslexia $M=4.10, SD=1.05$, writers with dyslexia $M=3.86, SD=1.27$), $t(111)=1.08, p=.281$.

The amount of content words in the text was also scored as all five words present (four content words, one difficult to spell word) or only some of them present in text. No texts submitted contained zero words. As shown in Table 5.13 and Table 5.14, texts were less likely to include all five words when writers begin trials with revision. Writers with dyslexia were less likely to include all content words than the control group. The difficult-to-spell word was not causing writers with dyslexia to incorporate fewer words than the writers without dyslexia, as each group was just as likely to incorporate the difficult-to-spell word into their text, as shown in Table 5.15. Results in Table 5.16 indicates that spellcheck is not associated with whether or not all five words are incorporated into texts.

Table 5.13 The amount of trials per presence of content words and first action.

Presence of content words	Defer revision (<i>n</i> =250) <i>n</i> (%)	Revision (<i>n</i> =43) <i>n</i> (%)
Some present	130 (53.20)	29 (74.42)
All present	120 (46.80)	14 (25.58)

$\chi^2(1, N=293)=6.72, p=.010, \phi=.15$

Table 5.14 The amount of trials per presence of content words and group.

Presence of content words	Dyslexia group (<i>n</i> =131) <i>n</i> (%)	Control group (<i>n</i> =162) <i>n</i> (%)
Some present	87 (66.41)	78 (48.14)
All present	44 (33.59)	84 (51.86)

$\chi^2(1, N=293)=9.82, p=.002, \phi=.18$

Table 5.15 The amount of trials with and without the difficult-to-spell word, per group.

Presence of difficult to spell word	Dyslexia group (<i>n</i> =131) <i>n</i> (%)	Control group (<i>n</i> =162) <i>n</i> (%)
Word absent	17 (12.98)	16 (9.87)
Word present	114 (87.02)	146 (90.13)

$\chi^2(1, N=293)=.697, p=.404, \phi=.05$

Table 5.16 The amount of trials per presence of content words and condition.

Presence of content words	No spellcheck (<i>n</i> =113) <i>n</i> (%)	Spellcheck (<i>n</i> =180) <i>n</i> (%)
Some present	63 (55.75)	96 (53.33)
All present	50 (44.25)	84 (46.67)

$\chi^2(1, N=293)=.16, p=.686, \phi=.02$

5.10.4 Latencies

Longer latencies can indicate heavy cognitive load and difficulties managing the cognitive load. Latencies of trials where writers started with revision were compared to trials where writers deferred revision, to further investigate disruption to the writing process that immediate revision might cause. In addition, mean latencies per group were compared to investigate whether writers with dyslexia struggle more than the control group. To investigate the impact of spellcheck on latencies, the latencies in trials with and without spellcheck present were compared.

Click latency

Click latencies are reported in seconds. Writers take significantly longer to click in the text when they begin trials with revision ($M=3.66$, $SD=2.00$) than when they defer revision ($M=2.15$, $SD=1.55$), $t(291)=4.69$, $p<.001$. This is true with spellcheck off (revision $M=3.82$, $SD=2.26$; deferred revision $M=2.01$, $SD=1.47$) $t(15.86)=3.02$, $p=.008$) or on (revision $M=3.57$, $SD=1.89$; deferred revision $M=2.25$, $SD=1.61$) $t(178)=3.89$, $p<.001$. Writers with dyslexia took significantly longer to click in the text box ($M=2.82$, $SD=1.96$), than writers in the control group ($M=2.01$, $SD=1.37$) $t(291)=4.01$, $p<.001$. There is no significant effect of spellcheck (spellcheck off $M=2.25$, $SD=1.70$; spellcheck on $M=2.45$, $SD=1.72$), $t(291)=.99$, $p=.323$.

Action latency

Action latencies are reported in seconds. There is a main effect of group, writers with dyslexia take longer latencies ($M=1.99$ $SD=2.34$) than writers in the control group ($M=1.23$ $SD=1.67$), $t(227.64)=3.15$, $p=.002$. There is no main effect of spellcheck, writers take similar latencies whether spellcheck is off ($M=1.54$ $SD=1.94$), or on ($M=1.58$ $SD=2.09$), $t(291)=.162$, $p=.872$.

Effects of initial response differ with spellcheck condition. With spellcheck, writers take longer to begin revising ($M=3.26$, $SD=2.99$) than to begin writing new text ($M=1.28$ $SD=1.72$) $t(30.34)=3.40$, $p=.002$. Without spellcheck, there is no significant difference between time taken to start revising $M=3.04$ $SD=3.66$ or to write new text $M=1.32$, $SD=1.43$, $t(14.66)=3.33$, $p=.092$. Effects of initial response also differ per group. Writers with dyslexia took significantly longer latencies before starting revision ($M=3.99$, $SD=3.55$) than before starting to write new text ($M=1.42$, $SD=1.45$) $t(30.69)=3.81$, $p=.001$, while writers in the control group were not affected $t(160)=.63$, $p=.528$ (start revision $M=1.50$, $SD=1.19$; write text $M=1.20$, $SD=1.71$).

Effects of group differ with spellcheck condition. With spellcheck on there was no significant difference between groups (with dyslexia $M=1.89$, $SD=2.15$; no dyslexia $M=1.30$, $SD=2.00$) $t(178)=1.90$, $p=.059$). Without spellcheck, writers with dyslexia take significantly longer latencies ($M=2.20$, $SD=2.69$) than writers in the control group ($M=1.13$, $SD=1.09$) $t(52.07)=2.50$, $p=.015$.

5.10.5 Writing time

More time spent writing the one and a half sentences needed to complete a trial could indicate more difficulties managing the cognitive load. The average time spent writing, per condition for each participant, has been compared per group using an ANOVA to indicate whether writers with dyslexia are impacted more than the control group. Whether initial response impacted the writing time has been compared using a t-test because, as described in the analysis section, the data was not suitable for an ANOVA.

Table 5.17 Time spent typing, per group and condition, in seconds.

Spellcheck condition	Dyslexia group ($n=10$)	Control group ($n=10$)
	M (SD)	M (SD)
Spellcheck off	65.55 (15.88)	59.82 (27.45)
Spellcheck on	58.83 (16.32)	52.12 (21.13)

Mean typing times per condition and per group, are shown in Table 5.17. ANOVA revealed that writers typed for longer without spellcheck than with spellcheck $F(1,18)=7.05$, $p=.016$ ($\eta^2=.281$). There was no main effect for group $F(1,18)=.49$, $p=.492$ ($\eta^2=.027$) and no interaction $F(1,18)=.03$, $p=.859$ ($\eta^2=.002$).

When spellcheck was off writers with dyslexia wrote for significantly longer than the control group, $t(116)=2.60$, $p=.011$, however with spellcheck on, there was no significant difference $t(178.80)=1.55$, $p=.123$.

When spellcheck was off, initial response has no significant impact on writing time (revision $M=66.59$, $SD=34.94$; defer revision $M=50.74$, $SD=30.78$) $t(111)=1.83$, $p=.071$. However with spellcheck on, writing time was significantly longer when writers respond with revision ($M=68.89$, $SD=24.86$) compared to deferring revision ($M=46.71$, $SD=23.95$), $t(178)=4.48$, $p<.001$, with a difference of approximately 22 seconds.

Both groups wrote for longer when starting with revision (dyslexia $M=71.85$, $SD=26.62$; control $M=70.05$, $SD=34.66$) than when deferring revision (dyslexia $M=53.63$, $SD=24.07$; control group $M=46.79$, $SD=28.77$). This was significant for the dyslexia group $t(129)=3.51$ and the control group $p=.001$; $t(160)=2.84$, $p=.005$.

5.10.6 Typing speed

Slower typing could indicate heavy cognitive load and difficulties managing the cognitive load. The average typing speeds were compared to further investigate disruption to the writing process that immediate revision might cause, ANOVA has been carried out to compare between group and between spellcheck condition and to indicate whether writers with dyslexia are impacted by spellcheck more than the control group. To find out whether responding to the task with immediate revision causes slower typing, independent samples t-tests have been used to compare typing speed between trials where writers start with revision and trials where writers defer revision.

Table 5.18 Typing speed per group and condition, in keys per minute.

Spellcheck condition	Dyslexia group ($n=10$)	Control group ($n=10$)
	M (SD)	M (SD)
Spellcheck off	160.69 (41.96)	194.47 (59.24)
Spellcheck on	169.69 (31.15)	200.27 (67.05)

ANOVA for typing speed revealed no significant main effects of group $F(1,18)=1.87$, $p=.189$ ($\eta^2=.099$), or spellcheck $F(1,18)=.68$, $p=.421$ ($\eta^2=.038$), and no interaction $F(1,18)=.01$, $p=.927$ ($\eta^2=.001$).

Writers typed significantly faster when they deferred revision ($M=191.02$, $SD=77.65$) compared to when their first action was revision ($M=154.02$, $SD=43.64$) $t(95.42)=4.47$, $p<.001$. This result appears to be driven by trials with spellcheck on (defer revision $M = 174.05$, $SD=62.51$; start with revision $M=148.83$, $SD= 37.34$), $t(188)=2.137$, $p=.034$. When spellcheck was off there was no significant difference whether writers deferred revision ($M=166.19$, $SD =60.01$) or started with revision ($M =159.42$, $SD =52.06$) $t(116)=.426$, $p=.671$.

5.10.7 When revisions are made

For more detailed information about how long writers defer revision for, how much text has been produced at the moment participants revised has been checked for associations between group and spellcheck condition. This is to indicate whether writers are more likely to revise sooner when spellcheck is on, and whether groups behave differently. How much text was produced was measured as the number of characters. Only trials in which revision was deferred were included in the following analyses (see Table 5.19). There was no main effect of spellcheck $F(1,16)=2.80$, $p=.113$ ($\eta^2=.149$) or group $F(1,16)=.238$, $p=.632$ ($\eta^2=.0945$) and no interaction $F(1,16)=1.55$, $p=.231$ ($\eta^2=.088$) for the number of characters typed at the moment revision takes place.

Table 5.19 The number of characters typed before revision, per group and condition.

Spellcheck condition	Dyslexia group ($n = 10$)	Control group ($n = 10$)
	M (SD)	M (SD)
Spellcheck off	86.40 (22.35)	85.45 (21.92)
Spellcheck on	72.85 (27.71)	83.46 (20.10)

Where in the text writers stop writing in order to revise has been split into four categories: within the first sentence, at the end of the first sentence, within the second sentence or at the end of the text (which is the end of the second sentence). The number of trials where writers stopped per category listed is shown in Table 5.20.

Table 5.20 The amount of trials per category indicating when writers revised text.

Categories, when writers revise	Dyslexia group ($n=131$)	Control group ($n=162$)	No spellcheck ($n=113$)	Spellcheck ($n=180$)
	n (%)	n (%)	n (%)	n (%)
Sentence 1	11 (8.40)	23 (14.20)	15 (13.27)	19 (10.56)
Sentence 1 end	25 (19.08)	16 (9.88)	18 (15.93)	23 (12.78)
Sentence 2	44 (33.59)	29 (17.90)	28 (24.78)	45 (25.00)
Whole text end	51 (38.93)	94 (58.02)	52 (46.02)	93 (51.67)

Chi-square tests for independence indicated no significant association for group and whether or not writers revised text within the first sentence $\chi^2(1, n=293)=2.38$ $p=.123$, $\phi=.09$. Writers with dyslexia were more likely to stop at the end of the first sentence $\chi^2(1, N=293)=5.10$ $p=.024$, $\phi=.13$, and within the second sentence $\chi^2(1, N=293)=9.53$ $p=.002$, $\phi=.18$, than writers without dyslexia were. Writers without dyslexia were more likely to revise text after reaching the end of the text than writers with dyslexia were $\chi^2(1, N=293)=10.56$ $p=.001$ $\phi=.19$.

Spellcheck was not associated with revising at any point of the task: during the first sentence $\chi^2(1, N=293)=.50$ $p=.479$, $\phi=.04$; at the end of the first sentence $\chi^2(1, N=293)=.57$ $p=.449$, $\phi=.04$; within the second sentence $\chi^2(1, N=293)=.002$, $p=.996$, $\phi<.01$; or at the end of text $\chi^2(1, N=293)=.89$, $p=.347$, $\phi=.06$.

5.10.8 Spelling errors

To indicate how successful writers were at producing text free from spelling errors, the average number of misspelled words in submitted texts were compared between groups and between conditions, shown in Table 5.21.

Table 5.21 The mean number of spelling errors per trial, per group and condition.

Spellcheck condition	Dyslexia group ($n=10$) M (SD)	Control group ($n=10$) M (SD)
No spellcheck	1.75 (.87)	.85 (.48)
Spellcheck	.35 (.59)	.36 (.52)

An ANOVA revealed a significant interaction $F(1,18)=5.277$, $p=.034$ ($\eta^2=.227$), using spellcheck decreased the number of errors in text and had a larger effect for writers with dyslexia than the control group. There was also a main effect of spellcheck condition, writers left fewer errors in texts when spellcheck was on compared to when it was off $F(1,18)=22.689$, $p<.001$ ($\eta^2=.558$). There was also a main effect of group, writers with dyslexia left more spelling errors in texts than writers in the control group $F(1,18)=4.877$ $p=.040$ ($\eta^2=.213$).

5.10.9 Questions post task

To indicate how writers managed the lexical representation in working memory during the writing task, writers were asked to identify which statement, listed in Table 5.22, most closely matched their strategy. The majority of writers (17) reported that they did decide what to write while listening to the audio, three writers (1=dyslexia, 2=control group) reported that they did not. Twelve writers, (six from each group) believed that they never corrected the error as their first action, indicated in Table 5.22. However, the typing data shows that only five writers without dyslexia and three with dyslexia actually never corrected the error before writing the text. Thus

one writer without dyslexia and three writers with dyslexia falsely believed that they never did this. Of the eight writers who report what they did when correcting the error first, none of them responded that they held the text in their mind while revising the text, all of them report either forgetting or not thinking about the text while revising.

Table 5.22 The number of participants who selected each statement.

Statement	Dyslexia group	Control group
I held the text in my mind while correcting the error	0	0
I remembered parts of the text and recreated it best I could	2	1
I forgot the text and needed to create new text	3	2
I did not think about the text until just before I wrote it down	0	1
I never corrected the error before writing the text	6	6

5.11 Overall Discussion

Having to either revise a spelling error or continue with sentence production is a dilemma commonly encountered in writing. The purpose of this study was to investigate how spellcheck influences writers' behaviour when they are presented with a spelling error during text production, and more specifically, to answer the following research questions:

- Does spellcheck increase disruption to writing?
- Does such disruption cause the lexical representation to fade from working memory?
- Are writers with dyslexia are impacted by this more than writers without dyslexia?

This study has shown that when presented with a spelling error during text production, writers tend to defer revision of that error in favour of text production. Starting trials with revision indicates disruption in the same way that an R-burst indicates disruption (Chenoweth & Hayes, 2003; Hayes, 2012; Hayes & Chenoweth, 2007). In both experiments, spellcheck increased how often writers began the task with revision from 2% (experiment one) and 11% of trials (experiment two) without any spellcheck to 28% of trials (both experiments) with spellcheck. To answer the first research question, spellcheck does increase disruption to writing. The misspellings provided in text were the same in both experiments, thus had no influence on any differences found between experiments one and two. Disruption may be a response to task complexity, as discussed in the next few paragraphs.

Experiment two was a more complex version of experiment one. By comparing results of the two experiments, it can be deduced that, without spellcheck, increasing task complexity increased how often writers started trials with revision (from 2-3% in experiment one to 11-14% in experiment two). Thus writers were more likely to be disrupted by revision when the task was

more difficult and required more cognitive resources. This is the opposite to van Waes et al.'s (2010) findings. Writers in van Waes et al.'s (2010) experiment started more trials with revision in the easier task (low cognitive load condition) and authors interpreted this as demonstration of flexibility in task management rather than a disruption to writing.

It is plausible that writers show this flexibility when the task is easy (e.g. van Waes et al.'s low cognitive load task) and in a more demanding, but still manageable task, show less flexibility and behave in a more strategic way (e.g. van Waes et al.'s high cognitive load task and experiment one of this chapter), but in a very cognitively demanding task (experiment two of this chapter) revision becomes a sign of disruption and inability to defer. This interpretation is supported by measures of lexical representation (the presence and absence of content words) in experiments one and two.

In experiment one, writers were almost always successful at incorporating all content words into their text whether they deferred revision or not, thus they can manage parallel processing of revision and text production without difficulty. Completing the writing tasks in experiment two required more cognitive resources and should have prevented parallel processing. In this very demanding task, writers were less successful at incorporating all content words when they did not defer revision, indicating difficulty with parallel processing and with inhibiting revision processes.

When the underline of spellcheck draws attention to the spelling error, it could increase demand of the task or it could make it difficult to ignore the error and inhibit revision. Comparing findings across the two experiments shows that writers with dyslexia were equally likely to begin trials with revision when the error was underlined as they were when spellcheck included the select and replace function (28% of trials in both cases). Writers in the control group were disrupted less often, at 4% of the time with full spellcheck, than with the underline only (20% of the time). In fact, writers were interrupted less by spelling errors in trials with full features of spellcheck than in trials with no spellcheck at all (14%). The select and replace function reduced the cognitive demand of the task for writers in the control group, but it did not affect writers with dyslexia.

Based on the premise that beginning trials with revision indicates disruption and difficulties meeting cognitive demand then, for the control group, the underline increased demand but full spellcheck decreased demand. For writers with dyslexia the impact of spellcheck on disruption does not appear related to cognitive demand as much as it is related to their ability to inhibit revision. Writers with dyslexia were less able to inhibit revision than the control group. This can be explained by previous research that indicates writers with dyslexia are more likely to struggle with inhibition due to poorer selective attentional skills than peers (Hari & Renvall, 2001; Valdois et al., 2004). Thus inhibiting revision of an underline error is difficult and spelling support (select and replace function) does not help these writers to overcome this difficulty.

As well as deferring or revising, writers can also respond to the task by doing nothing, by ignoring the error completely. In the findings discussed so far, trials where writers did not revise the text, have been excluded. Interestingly, the number of trials that were not revised at all was reduced by the select and replace function of spellcheck. In experiment one, where writers did not have access to the select and replace function, a surprisingly large number of trials with underlined spelling errors showed no signs of revision (about 64% of trials). In experiment two only 14% of underlined errors showed no sign of revision. This means that writers revised about 86% of errors when they had access to the select and replace function compared to 22-36% without it.

Writers surely noticed the underlined errors in experiment one as much as they did in experiment two. Therefore whether writers carried out any revision or not seems to be related to being able to easily correct the error. The key difference that increased the amount of revision is the select and replace function of spellcheck assisting with revision. Hacker et al. (1994) write that sometimes writers in their studies did not try to revise errors if they were uncertain of how to correct them. This supports conclusions from Hiscox et al. (2014) that spellcheck causes writers to revise more spelling errors than they would without spellcheck and explains why the select and replace function, and not the underline, causes writers to revise more frequently. The underline causes writers to revise earlier in production. The fact that the separate elements of spellcheck impacts writing behaviour differently indicates that both functions, the underline and the select and replace function, need to be accounted for in writing models.

Most writers (17 out of 20) reported that they had already decided what to write before seeing the text. This indicates that generally, writers did have a lexical representation in working memory at the moment they are presented with the text. Damage to, or loss of lexical representation, was demonstrated when writers did not incorporate all content words into their texts. It is assumed that inability to keep information in the working memory is experienced as disruption to thought. In experiment one writers almost always incorporated all content words into the sentences, thus the cognitive load was not sufficient to cause disruption to thought. However, in experiment two, the task was more complex and writers often (54.27% of all trials) failed to incorporate all content words into their texts, particularly when they started tasks with revision (74.42% of trials started with revision). This agrees with findings from van Waes et al. (2010), that deferring revision in favour of transcribing information held in working memory (the lexical representation) onto the page, is the most efficient response for avoiding damage to the lexical representation. Results support the assertion that the lexical representation is at risk of loss or damage while being stored in the working memory (as suggested and van Waes et al., 2010), particularly when carrying out a task such as revision that causes direct competition for the same cognitive components (the phonological loop, or inner voice) (Chenoweth & Hayes, 2003).

Interestingly, of the eight writers who report revising the error first, none of them responded that they held the text that they planned to write in their mind while revising, all of

them report either forgetting it or not thinking about it while revising. This indicates that while revising, writers were not (knowingly) rehearsing the lexical representation and explains why writers were less likely to include all content words in their texts.

To answer the second research question ‘Does such disruption cause the lexical representation to fade from working memory?’, when writers are disrupted, they are more likely to forget parts of the lexical representation. However, while spellcheck increases disruption, it is not directly associated with how well the lexical representation is maintained during the task. Thus, by increasing disruption to writing, spellcheck indirectly leads to increased disruption to thought. Writers with dyslexia, are disrupted more than the control group, forgetting more content words more often. However only when spellcheck is on. This reflects reports from the survey (previous chapter) that spellcheck disrupts thought, especially for writers with dyslexia. The implication of increased disruption is that writers with dyslexia are less able to meet the cognitive demands of revision and text production than the control group. Findings are in line with the phonological deficit theory of dyslexia in that, the phonological processes involved in text production and revision are more difficult and thus demand larger amounts of cognitive resources for writers with dyslexia than the control group. Furthermore, disruptions indicate difficulties inhibiting revision and so findings also support theories that writers with dyslexia experience poorer executive functioning (Hari & Renvall, 2001; Krause, 2015; Valdois, Bosse, & Tainturier, 2004).

How long writers can defer revision could indicate how well writers are able to parallel process information. Spellcheck had no overall effect on how long writers deferred revision, differences were related to group only. Interestingly, where groups stopped text production in order to revise was not different in terms of the number of characters produced but in terms of the structure of the text. This may indicate that the boundaries of lexical representations are related to the structure of the text. Writers with dyslexia were more likely to stop at the end of the first sentence or within the second sentence than writers in the control group. Writers in the control group were more likely to defer revision until completing the text. This indicates that writers with dyslexia were less able to transcribe and translate the lexical representation while also inhibiting revision than the control group.

In experiments one and two, whether spellcheck was on or off, writers were faster to begin trials when deferring revision. It was thought that results of experiment one could be a product of the naturalistic position of the caret, however in experiment two, the caret was not present until writers clicked into the textbox and yet the result is replicated. It is likely that writers began trials faster when deferring revision because they had a lexical representation ready to transcribe, but they cannot prepare for revision until seeing the text, at which point they need time to adjust to this and to prepare to revise the spelling error.

Van Waes et al. (2010) also found longer latencies when writers began trials with revision, which they believed to be due to time spent searching for the spelling error. They found no

difference in the overall length of trials, suggesting that latencies indicated a redistribution of time but no overall difference. In the current study, trials that began with revision had longer latencies but also had longer typing times, thus there was not a redistribution of time, writers took longer to complete the trials when starting with revision.

When spellcheck was on and writers began trials with revision, they showed longer latencies, slower typing and longer typing times than when they deferred revision. All of which are likely to indicate some cognitive management difficulties, such as struggling to maintain the lexical representation and difficulties orchestrating writing components. When spellcheck was off, deferring revision or not, had no impact on click latency, typing speed or time spent typing. Thus writers experienced more difficulties starting trials with revision when spellcheck was on than when it was off.

In experiment one, writers with dyslexia spent longer writing after starting trials with revision than when they deferred revision, while the control group were not impacted. Needing additional time indicates that writers with dyslexia experienced more difficulty when starting trials with revision than when deferring. In experiment two, when the task was more demanding, both groups of writers spent longer on trials when their initial response was revision.

Importantly, the results of experiment two demonstrate that spellcheck supports spelling revision. Fewer spelling errors were present when spellcheck was on. Without spellcheck, writers with dyslexia left, on average, 1.75 spelling errors in text per trial when a maximum of one spelling error was presented, indicating that they probably missed spelling errors and certainly made spelling errors. With spellcheck on writers with dyslexia left approximately one spelling error in text per every three trials. For writers in the control group, spellcheck reduced the number of errors in text from 0.85 to 0.36 per trial. Without spellcheck, writers with dyslexia made more errors than writers in the control group, supporting previous research that shows high achieving adults (i.e. university students) with dyslexia still struggle with spelling (Elliot & Grigorenko, 2014; Snowling, 2012). However, spellcheck reduced the number of errors for both groups to roughly one error per every three trials. Because, when writing without spellcheck, writers with dyslexia produced more spelling errors than writers in the control group, spellcheck had a greater effect for these writers.

Automatic underlining in experiment one increased writing time, most likely due to more time devoted to manually editing the underlined errors. This may be because writers were alerted to errors that they did not know how to fix, thus took longer to think about, or made more attempts at revising the error using the red underline for feedback using trial-and-error. Full spellcheck, on the other hand, decreased overall writing time and increased typing speed. Faster typing and shorter writing times suggest that using the select and replace function was faster than manually revising errors. In natural writing situations spellcheck includes this function, thus allows faster correction of spelling errors. Support with spelling error correction is particularly good for reducing writing time for writers with dyslexia. Without spellcheck writers with dyslexia

spent longer writing than peers did, but when spellcheck was active the difference between groups disappeared.

Finally, to answer the third research question, ‘Are writers with dyslexia are impacted by this more than writers without dyslexia?’, as indicated throughout the discussion, writers with dyslexia were impacted more than the control group. They experienced disruption more often and when they did they were more likely to forget parts of the lexical representation than writers in the control group. On a more positive note, spellcheck had a greater impact on writers with dyslexia by improving their spelling accuracy and shortening their writing times more than for writers in the control group.

5.12 Limitations.

Participant measures

It has been assumed that writers with dyslexia were not only impacted by spellcheck more than writers without dyslexia because of spelling difficulties but also because of difficulties with cognitive load and inhibition. This interpretation would have stronger support if further information about working memory and executive functioning, particularly attention switching and inhibition, were available to demonstrate that the groups with dyslexia did indeed have more difficulties than the control groups in those areas.

In experiment one, the participants measures for the control group were particularly limited, it was simply assumed that they would have performed within expected norms. This limitation was addressed in experiment two with measures for both groups using a new set of participants.

The measure of phonemic awareness from the YAA-R (Warmington et al., 2012) was important for measuring ability to manipulate sounds. While the YAA-R has suitable norms for the population being tested, the test itself appears dated due to the use of famous names. Informal feedback from participants suggested that they varied a lot in how familiar they were with the famous names, familiarity would give some participants an advantage. An alternative test may provide a more accurate measure of phonemic awareness.

Other limitations

It was assumed that writers noticed the spelling error when the partial sentence appeared on screen, thus to defer revision would require inhibition. However, writers may not notice the spelling error until after they started writing text. In fact, audio presentation in a sentence completion task encourages writers to complete the sentence before revising any errors (Leijten et al., 2007). Therefore, it is possible that the design of the task encouraged writers not to read the text when it was presented, but trust that it was the same as the audio and to click at the end of the text where they could begin typing, then check for errors afterwards. To find out whether

deferring revision really does indicate inhibition, as opposed to indicating unnoticed spelling errors, reading behaviours should be monitored.

In addition, as with any experimental design, writers may not have performed as they would in a natural writing situation. For example, while audio presentation of the stimuli was used to simulate the familiarity writers would feel if they had written the text themselves (replicating presentation of stimuli by van Waes et al., 2010), it might in fact be moving the writing situation further from natural writing, where writers do not generally receive audio of their work before typing it. This is indicated by the reports of 17 out of 20 writers who indicated that they decided what to write before being presented with the text, which was the aim of audio presentation of the stimuli. However, Chenoweth and Hayes (2003) found that when writing without audio prompts only 4 out of 18 participants reported having a complete sentence in mind before writing. Thus the design of this sentence completion task, while effective at investigating how writers manage lexical representations and revision, may not replicate natural writing closely enough to generalise results to typical writing habits.

The stimuli provided may be too dissimilar to participants' own typical writing for them to adopt it as their own, for example, it is possible that writers were presented with words that were not necessarily stored in their lexicon. In addition, the controlled design provided the same quantity of spelling errors to both groups of writers, but, ordinarily, writers with dyslexia make more spelling errors in their writing than writers without dyslexia, which should be taken into consideration if generalising findings to writers with and without dyslexia in less controlled writing situations. Furthermore, in terms of revision, it has been found that writers with dyslexia avoid difficult-to-spell words (Sumner et al., 2016; Wengelin, 2007) which was not an option open to them in the sentence completion task. Thus findings from the sentence writing task are limited in their generalisability.

A naturalistic writing experiment would provide better generalisability. For undergraduates an essay writing task would resemble a familiar writing task, it would allow writers to make their own spelling errors and revise them as they normally would, including avoiding words if they wish. Writing should be observed with writers having access to spellcheck in its default settings with the select and replace function working to replicate their typical writing environment, as indicated by survey results (Chapter 4). Furthermore, an essay writing task would provide enough text to explore the under-investigated relationship between spelling and lexical diversity that occurs for writers with dyslexia, (Connelly et al., 2006; Sumner et al., in press, 2016; Wengelin, 2007) as indicated in the introductory chapters. This relationship between spelling and lexical diversity, and the impact that spellcheck has on this is investigated in the next chapter using an essay writing task.

5.13 Conclusions.

Generally, writers tend to defer revision in favour of text production, however, spellcheck increased how often writers halt text production in order to revise, especially for writers with dyslexia. Thus spellcheck impacts writing behaviour, interacting with abilities to meet cognitive demands and to inhibit revision, particularly for writers with dyslexia. This is a new finding, unaccounted for by current models of writing or models of revision. Revising spelling errors before text production appears to be associated with high cognitive demand of the writing task, and difficulties inhibiting revision. Findings add to body of knowledge concerning dyslexia and writing, supporting theories concerning difficulties meeting cognitive demand of tasks which involve phonological processing and difficulties with inhibition (phonological deficit and SAS theories). Findings also introduce a practical implication for writers with dyslexia in that, when writing with spellcheck active, they experience disruption more frequently and it is more likely to cause them to forget information from working memory than peers, reflecting reports in the survey (Chapter 4).

Importantly results have also demonstrated positive practical implications of using spellcheck. As expected, significantly fewer spelling errors are present in texts written with spellcheck than in texts written without spellcheck.

[blank page]

The Impact of Spellcheck on Spelling Accuracy and Lexical Diversity in Essay Texts

6.1 Introduction

In the previous chapter, without spellcheck, writers with dyslexia left more misspelled words in their texts than the control group did, indicating poorer spelling and poorer spelling error revision. However, with spellcheck active, both groups of writers reduced the number of misspellings left in their texts to approximately one misspelled word every 6 sentences. Thus, despite concerns that writers with dyslexia experience difficulties using spellcheck to successfully revise misspellings (MacArthur et al., 1996), results of the previous study indicate that writers with dyslexia revised more misspellings than the control group and appear to be proficient at using spellcheck.

For writers with dyslexia, spelling difficulties appear to restrict word choice and lead to poorer lexical diversity (Sumner et al., 2016; Wengelin, 2007). When spellcheck is active and assisting with spelling, it may reduce the restrictions on word choice that poor spelling imposes. Therefore, using spellcheck could impact the writing process and text produced by writers with dyslexia in ways that it does not impact writers without dyslexia, who do not struggle with spelling. The effects of spellcheck on the relationship between spelling and lexical diversity in texts by writers with dyslexia had not been investigated until the current study.

6.1.1 Spelling

It is well documented that adults with dyslexia have particular difficulties with spelling (Ellis, 2016; Sumner et al., in press; Tops et al., 2013, 2012; Warmington et al., 2012). The proportions of misspellings that these writers make in their texts vary from study to study. For example, a sample of UK HE students wrote for 10 minutes to produce a summary of a text that they had read (as part of the YAA-R, Warmington et al., 2012). Texts by writers without dyslexia ($n=20$) contained 1.51% misspelled words, while texts by writers with dyslexia ($n=20$) contained 6.49% misspelled words (Warmington et al., 2012). However, another sample of UK HE students ($n=21$ with dyslexia, $n=20$ age-matched control group) wrote essays for 30 minutes and essays by writers with dyslexia contained 3.07% misspelled words, which is less than writers in

Warmington et al, (2012) but significantly more than the age-matched control group (1.21% misspellings) (Connelly et al., 2006). Furthermore, using a similar essay writing task as Connelly et al. (2006) but a different prompt, set for 20 minutes, Sumner and Connelly (2020) also tested UK HE students and found that essays by writers with dyslexia contained 4% misspelled words and texts by aged matched controls contained 0.5% misspelled words. Combined, these results confirm that adult writers with dyslexia tend to produce more misspellings than writers without dyslexia and provide an indication of the variation in spelling ability found in UK HE writers, even when using the same task.

When writing without time limits, so that writers can revise spelling errors as much as they like (without spellcheck), writers with dyslexia still produce texts which contain more misspelled words (Morken & Helland, 2013; Torrance et al., 2016; Wengelin, 2007). For example, Wengelin (2007) observed Swedish speaking adults with and without dyslexia make thousands of edits during production of five texts each, all without spellcheck. She found that writers with dyslexia made a similar number of edits (1,255 edits, group $n=11$) as the control group (1,201 edits, $n=10$), but more of the edits made by writers with dyslexia were related to spelling (28%) than by the control group (less than 2%). Yet, even with more spelling related editing, writers with dyslexia left more spelling misspellings in texts, averaging 7.7% misspellings across texts per person, compared to an average of almost zero misspellings per person in the control group (31 misspellings out of the total 9319 words written by the control group). Swedish has a different orthography to English and so it is possible that writers approach spelling and spelling revision differently. However, Sumner and Connelly's (2020) results indicated that UK undergraduates with ($n=32$) and without dyslexia ($n=32$) also made similar numbers of revisions, during and after transcription (also without spellcheck) and for writers with dyslexia, a higher proportion of these revisions were related to spelling in comparison to their peers. Yet writers with dyslexia only corrected 20% of their misspellings, thus a larger number of misspellings remained in text ($M=9.56$) than in texts by writers without dyslexia ($M=1.25$). Thus, even with more spelling related revision, writers with dyslexia produce texts that contain more misspellings. Writers with dyslexia produce texts with more misspellings in comparison to peers' due to a combination of initially producing more spelling errors and poorer revision of spelling errors.

It is generally expected that 'typical' texts by writers with dyslexia demonstrate poor spelling accuracy, however this expectation has been built from writing research where writers do not have access to spellcheck. There has been no recent investigation into the impact of spellcheck on spelling accuracy of texts by UK HE writers with dyslexia, even though they commonly write with spellcheck active by default settings (Chapter 4). Considering that, in Chapter 5, when writing with spellcheck, writers with dyslexia produced texts with equally few misspellings as the control group, it is possible that, actually, texts produced by writers with dyslexia may not typically contain large numbers of misspellings because they typically write with spellcheck active. There is a question of whether discussions of 'typical' texts should refer to

what is typical for the writer (with spellcheck) or what is typical in writing research (without spellcheck). The current study compares spelling accuracy of texts produced with and without spellcheck by UK HE writers with and without dyslexia. The findings of this investigation have implications for how we view 'typical' texts by writers with dyslexia.

Spelling revision and spellcheck

Spellcheck will flag misspellings and will not flag correctly spelled words. Thus writers are likely to notice more, if not all, of their misspellings and will recognise that words without a red underline are likely to be spelled correctly. The writer can replace the underlined misspelling without needing to produce the correct spelling themselves. Thus using spellcheck leads to fewer misspelled words in final texts (Figueredo & Varnhagen, 2006; MacArthur et al., 1996; Pedler, 2001).

Even writers without dyslexia are likely to benefit from using spellcheck. When UK HE students without dyslexia were presented with a text that contained planted misspelled words for them to detect (Figueredo & Varnhagen, 2004), 22 out of 53 participants detected one or more false positives. When these writers without dyslexia were divided into average and above average spellers, it was found that the average spellers were more likely to mistake correctly spelled words as misspellings and were poorer at revising the spelling errors however, even the above average spellers did not correct all spelling errors successfully. Thus, all writers are likely to benefit from support in detection and correction of spelling errors.

As described in Chapter 2, Wengelin (2007) proposed that writers with dyslexia, who are particularly concerned over spelling, may become preoccupied with evaluation and revision of spellings of words, thereby increasing the word-level focus. However, when using spellcheck, writers do not need to monitor their spellings as carefully, which may allow writers to focus on other areas of writing, reducing the word-level focus. All writers are likely to improve their spelling accuracy when writing with spellcheck, but writers with dyslexia are likely to improve the most, and, if they are free to devote cognitive resources elsewhere, may even experience benefits beyond spelling accuracy.

One of the few studies on the effectiveness of spellcheck (MacArthur et al., 1996) reported that writers aged 11-14 years, with moderate to severe spelling problems produced texts with 13.4% misspellings. Writers then successfully corrected only 37% of misspelled words when using spellcheck. This was more than when correcting their texts without spellcheck (9% of misspelled words) but was nowhere near perfect. Writers with spelling difficulties sometimes select an incorrect word from the candidate list (in 16.5% of cases if the intended spelling was the first candidate and 29.4% if the target word was not first). However, this previous work was published in the mid-1990's and over 25 years on, user's may now be much more familiar with spellcheck as an everyday tool, particularly undergraduate writers who, as demonstrated in Chapter 4, use spellcheck regularly. Furthermore, due to program updates over the years, spellcheck is likely to be better at suggesting the intended word as the first candidate. As

indicated in Chapter 3, many algorithms have been developed to identify the target word and these will have become more advanced over time. The current study compares the spelling accuracy of texts produced with and without spellcheck, between writers with and without dyslexia. If writers with dyslexia use spellcheck to make as much improvement in their spelling accuracy as the control group, it will indicate that they are equally proficient at using spellcheck.

One problem that spellcheck cannot help with is real-word errors. As discussed in Chapter 3, real-word errors (errors that result in correctly spelled words) are not flagged by spellcheck. Writers with dyslexia have been shown to make real-word errors, in fact in MacArthur et al.'s (1996) 37% of misspellings were real-word errors. In addition, writers with dyslexia have been found to select incorrect words from spellcheck list in 18% of cases (MacArthur et al., 1996), thus spellcheck not only fails to identify real-word errors, which are problematic for writers with dyslexia, but may even increase the number of real-word errors in final texts for these writers. There has been limited research into real-word errors and spellcheck. It is not known how often real-word errors occur in texts by university students, whether spellcheck has any effect on them, or whether this differs for writers with and without dyslexia. The current study investigates how many real-word errors occur in texts by university students with and without dyslexia and whether or not spellcheck has any impact on this.

6.1.2 Lexical diversity

Lexical diversity is a measure of the variety of the words within a text, is often used as a measure of vocabulary in writing and is linked strongly to quality of text greater lexical diversity is found in better quality texts (Connelly et al., 2006; Olinghouse & Wilson, 2013; Sumner et al., 2016; Wengelin, 2007). Crossley and McNamara (2011) measured argumentative essays by undergraduates ($N=120$, 60 by native English speakers and 60 by non-native speakers) and found that lexical diversity was predictive of ratings of essay quality. The choice of technically appropriate vocabulary in undergraduate texts, such as essays, is a key component of the quality of the text produced. Text quality is particularly important to undergraduates, whose grades are impacted by written coursework.

It is thought that spelling ability restricts lexical choice in writing (Berninger, Nielsen, et al., 2008; MacArthur et al., 1996; Morphy & Graham, 2012). For example, Berninger, Nielsen, Abbott, Wijsman, and Raskind (2008) observed that many participants with dyslexia reported that they choose to use words that they can spell, even though it limits the ideas they express in writing. Tops et al. (2013) found that the amount of misspellings by HE students with and without dyslexia were much lower in composed essays than when writing to dictation, indicating that both groups of students tended to avoid words with tricky spellings in spontaneous writing.

When poor spelling ability restricts lexical choice, it can cause poor written lexical diversity (Sumner et al., 2016; Wengelin, 2007). This is not caused by generally poorer vocabulary; as demonstrated when writers with dyslexia produce spoken narratives with lexical

diversity equal to their peers but produce written texts that have poorer lexical diversity than peers (Sumner et al., 2016; Wengelin, 2007). Two of the possible explanations for why poor spelling impacts lexical diversity, suggested by Wengelin (2007), are that: evaluation of word choice includes whether or not the word can be spelled correctly, thus difficult-to-spell words are avoided; or effortful spelling restricts working memory capacity available for word choice. Therefore, writers could be more likely to choose a word which they have a strong representation for and are likely to spell correctly. Writers might repeat this word because they know how to spell it or because it is easier to reactivate the representation of a recently used word than a word that has not been used recently (Strömqvist et al., 2002). Either way, word repetition limits the lexical diversity of text.

The idea that spelling affects vocabulary may seem opposed to the idea that spelling occurs after vocabulary choice (based on writing models described in Chapter 1) however, evaluation and revision of word choice occur throughout the entire writing process, before, during and after transcription (Fitzgerald, 1987; Hacker et al., 1994; Hayes, 2004; Wengelin, 2007). Through evaluation and revision, writers can avoid attempting to spell difficult words in favour of easier words, or, after attempting to spell and transcribe difficult words, writers might avoid correcting them by replacing them with easier to spell words. Evidence for avoidance is described below.

In a study on children's handwriting (Sumner et al., 2016, as described in Chapter 2), children with dyslexia (aged 9 years-old, $n=31$ with dyslexia, plus two control groups) made many between-word pauses which were related to spelling and lexical diversity, but not to oral vocabulary. This provided strong evidence that selection of the next word is highly linked to spelling ability, and not to oral vocabulary. Thus the writer carefully selects words which they can spell, sometimes at the cost of lexical diversity. However, the authors did not indicate whether the words following the pauses were repeated in the text, thus it is not possible to be certain that these words were reducing lexical diversity.

Wengelin (2007) also found evidence for lots of word level pausing, particularly intra-word level, indicating that writers were spending time thinking about the word they were writing and focusing on the spelling. In addition, Wengelin (2007) observed that while all writers with dyslexia tried to correct at least one misspelling by directly editing it, six out of eleven writers also edited their text in order to remove spelling errors by changing the word to a synonym, rephrasing part of the sentence or even replacing or deleting the entire sentence. Editing frequency predicted 55% of variation in lexical diversity for writers with dyslexia, whose edits were largely spelling related. No effect was found for the control group, who made few spelling related edits. Thus replacing and avoiding difficult-to-spell words is linked with poorer written lexical diversity for writers with dyslexia. However, like Sumner et al. (2016), it was not reported whether the words which were edited were repeated in text, thus it is not known whether the words that were edited were also responsible for low lexical diversity.

To decrease lexical diversity, writers must repeat the same words, thereby impacting the ratio of the number of unique words (types) to the number of total words (tokens). Therefore for avoidance to reduce lexical diversity, writers must repeat the same easy to spell words in place of a variety of synonyms. On the flip side, this means that if difficult-to-spell words were to be included in the text, they would increase lexical diversity. Indeed, this appears to be the case for two groups of UK HE writers with dyslexia who produced essays that contained more misspelled words than expected, but were equally as lexically diverse as essays by age matched control groups (Connelly et al., 2006; Sumner & Connelly, 2020). This relationship between spelling and lexical diversity has, to date, only been shown in writers with dyslexia. Neither the misspelled words, or words which writers struggle over, have been directly linked to lexical diversity. The current study investigated whether misspellings directly contribute to lexical diversity. Furthermore, this study also investigated the possibility that spelling and lexical diversity are related through word frequency. Why word frequency might be a key part of this relationship is explained in the following paragraph.

In terms of spelling theory (PDP and connectionist models), writers are more likely to develop strong representations of spellings for high-frequency words and therefore more likely to be correctly spelled whereas low-frequency words are less likely to be correctly spelled (Coltheart et al., 2001; Seidenberg, 2005; Treiman & Kessler, 2006). In addition, high-frequency words are more likely to be repeated in a text while low-frequency words are less likely to be repeated in text. Therefore, word frequency may be involved in the connection between spelling and lexical diversity because when low-frequency words are included in text (as opposed to avoided or substituted for high-frequency, easier to spell synonyms), these words are more likely to be spelled wrong and these low-frequency words are also less likely to be repeated. Thus, misspelled words and unique words come from the same pool of low frequency words. This would explain why higher proportions of misspelled words have been linked to increased lexical diversity (Connelly et al., 2006; Sumner & Connelly, 2020).

Both spelling and lexical diversity have been found to be related to text quality (Connelly et al., 2006; Olinghouse & Wilson, 2013; Sumner et al., 2016; Wengelin, 2007). Therefore, these are areas of writing that could benefit from targeted intervention. However, the nature of the relationship between spelling and lexical diversity means that improving one factor could have negative consequences for the other. For example, spelling accuracy could be improved by using only words which the writer knows how to spell, consequently reducing lexical diversity, or reducing the repetition of words in the text could cause writers to resort to words which are not easy to spell, thus decreasing spelling accuracy. Insights into this relationship would be useful for developing support for individuals who struggle with these areas of writing. In particular, there could be some involvement of word frequency. The involvement of word frequency in this relationship has yet to be investigated and could be key to understanding how the two factors are related, or why they appear to be related.

6.1.3 Spellcheck

Writers with dyslexia produce more misspellings than their peers and struggle with revision (Ellis, 2016; Sumner et al., 2018.; Tops et al., 2013; Tops, Callens, Lammertyn, van Hees, & Brysbaert, 2012; Warmington et al., 2012, and the previous chapter in this thesis), and so they should benefit from spellcheck the most. With spellcheck identifying and assisting with correction of spelling errors, writers with dyslexia could increase the spelling accuracy of their texts to match texts by writers without dyslexia.

By investigating the impact of spellcheck on lexical diversity the current study investigated whether lexical diversity is restricted by a propensity to retrieve previously used words or whether spelling acts as a filter (via evaluation and revision). With spellcheck supporting spelling revision, writers could be less likely to replace or delete misspelled words because they can easily correct the spelling error by replacing the misspelling to the intended word, thus, for writers with dyslexia, lexical diversity should be higher in texts written with spellcheck if spelling acts as a filter. However, with or without spellcheck, recently encoded words would still be more readily available than other words. Therefore, if writers repeat recently used words in order to reduce cognitive costs then spellcheck would have no impact on lexical diversity.

Berninger et al., (2008) noted that because spellcheck is activated by spelling errors after the whole misspelled word is written, it does not help with the initial production of words. Thus if writers avoid trying to write difficult-to-spell words, then spellcheck may not effect lexical diversity. However, just knowing that spelling errors can be easily revised could still have an impact on this. Ronneberg et al. (2018) contrast writers with dyslexia with confident writers, suggesting that while writers with dyslexia struggle over spellings, ‘confident writers know that they can handle the situations that are likely to emerge, and they spend their effort on planning ahead rather than worrying about what can go wrong’ (p.121). Spellcheck could provide writers with confidence in their ability to revise spelling errors, thus reducing worries about spelling accuracy, reducing avoidance of words, and increasing lexical diversity.

The conclusions drawn so far are seemingly obvious: (1) writers with dyslexia struggle with spelling and spelling revision, (2) writing with spellcheck reduces the amount of misspelled words in texts, (3) writers prefer to write words which are easier to spell and so are likely to avoid words that are difficult to spell, which reduces lexical diversity. Combined, these observations suggest that, by supporting spelling, spellcheck may also increase lexical diversity. Indeed Morphy and Graham (2012) expected that spellcheck, as part of a word processing program, would allow writers to select words they deemed most appropriate to convey their message, even when uncertain of spellings, thus lexical diversity would not suffer as a result of poor spelling ability. Authors conducted a meta-analysis of 27 peer reviewed journals and dissertations from 1983 to 2005 but did not find enough evidence to either support or disprove their hypothesis. Only six pieces of research contained information about vocabulary and only two of these also used spellcheck, which reflects the general lack of research into spellcheck, spelling difficulties

and lexical diversity. The relationship between spelling ability, spellcheck, and lexical diversity, as well as frequency and text quality, had not been investigated experimentally until now.

6.1.4 The current study: spellcheck and text product.

Due to limited research into how spellcheck impacts texts, there are several gaps in the literature, leading to several research questions:

- Does spellcheck increase spelling accuracy more for writers with dyslexia than the control group? Does it help writers with dyslexia achieve spelling accuracy equal to writers in the control group?
- Does spellcheck increase lexical diversity?
 - Does this appear to be related to avoidance of difficult-to-spell words?
- Does lexical diversity relate to the quality of text? If spellcheck increases lexical diversity, does it also improve the quality of the text?
- Are spelling accuracy and lexical diversity related to word frequency?
- Do any of these effects differ for writers with and without dyslexia?

To answer these research questions, spelling accuracy, lexical diversity, word frequency and text quality of essays produced with and without spellcheck by undergraduates with dyslexia have been examined and compared to essays by a control group of undergraduates without dyslexia of the same age. Predictions are outlined below.

6.1.5 Predictions

Spelling accuracy: Texts produced with spellcheck were expected to contain fewer misspellings than texts written without spellcheck. Without spellcheck, it was expected that writers with dyslexia would leave more misspellings in texts than writers without dyslexia, but with spellcheck active, there would be similarly low numbers of misspellings in texts produced by writers with and without dyslexia. Thus the difference between the number of misspelled words in text produced with and without spellcheck would be larger for writers with dyslexia than writers in the control group. It was also expected that poor typing (from participant measures, Chapter 5) would relate to more misspellings.

Real-word errors: It was expected that texts by writers with dyslexia would contain more real-word errors than texts by writers without dyslexia. Spellcheck was expected to increase the number of real-word errors made by writers with dyslexia, who might accidentally select the wrong candidate word during revision with spellcheck. Spellcheck was not expected to make any difference to the number of real-word errors made by writers in the control group.

Lexical diversity: It was expected that, with spellcheck active, participants with dyslexia would be less likely to avoid difficult-to-spell words, therefore their texts would have higher lexical diversity than texts produced without spellcheck. For writers without dyslexia, spellcheck was not expected to impact lexical diversity. Thus, spellcheck was expected to cause a larger

increase in lexical diversity in texts by writers with dyslexia than in texts produced by the control group.

Lexical diversity was expected to either positively correlate with spelling ability, supporting findings by Wengelin (2007) and Sumner et al. (2016), or with the number of misspelled words in text, supporting findings by Connelly et al. (2006) and Sumner and Connelly (2020).

Word frequency: Misspellings are expected to be lower frequency words than the rest of the text. It was expected that words which are not repeated in text would be lower frequency than words which are repeated.

Quality: It was predicted that texts by writers with dyslexia would be poorer than texts by writers in the control group. Spellcheck was not expected to directly impact quality, but that by increasing lexical diversity, quality would be improved.

Text length: Text length has been measured because it is known to impact quality (Alves, de Sousa, & Strömquist, 2007; Connelly et al., 2006; Crossley, Cai, & McNamara, 2012; Guo, Crossley, & McNamara, 2013) and so may account for quality differences in this experiment. Longer texts were expected to be rated as higher quality. In the two-minute typing task (see participant measures in Chapter 5) the writers with dyslexia produced less text than the control group, and so it was expected that, in another timed writing task, they would produce less text than the control group, and this was expected to be related to poorer spelling ability. Typing abilities, from participant measures, were expected to relate to text length, in that better typing abilities would correlate with longer texts.

6.2 Participants

The same 36 undergraduates from Chapter 5, experiment one, took part in this study, for details see the participant section of Chapter 5 (page 132).

6.3 Procedure: Written Composition Task

Participants responded to two writing prompts, one at a time (see page 190). They wrote for 15 minutes per prompt, the timer was left where participants could see it and they were encouraged to use the full time. The writing prompts have been taken from the Graduate Record Examinations (GRE) of the revised general test, analytical writing measure. The GRE features questions designed to reflect the kind of thinking required in graduate school and is a test taken by prospective graduate school applicants interested in pursuing a master's, or doctoral degree (Educational Testing Service, 2010) for undergraduate students. This is therefore an age and ability appropriate choice of writing activity. The prompts were designed to measure the ability to articulate and support complex ideas clearly and effectively. The writing prompts are designed to provoke thought and analytical writing without requiring domain specific knowledge. Each prompt has been piloted with *GRE* test-takers to ensure that: regardless of their field of study or

special interests, they each understood the task and could easily respond to it; the task elicited complex thinking and persuasive writing; the responses were varied in content and in the way the writers developed their ideas (Educational Testing Service, 2010).

The GRE can be administered either in paper or electronic form (using Educational Testing Service's own software). Spellcheck and grammar check are not available in the Educational Testing Service software. This is largely to maintain fairness with those examinees who must handwrite their essays (Educational Testing Service, 2010). However, because the focus of this research is the impact of spellcheck on specific aspects of the text, this task needs to be administered through software which includes a spellcheck program. This task was administered through Microsoft Word (version 2010), which the survey study (Chapter 4) revealed as the most popular writing processing program. One text was produced without spellcheck active and one with spellcheck active. The writing prompts were read aloud so as not to disadvantage writers with dyslexia. Prompt type, order and spellcheck conditions were all counterbalanced.

6.3.1 Task instructions.

No specific verbal instructions accompany the GRE analytical writing subtest. Usually questions are read and answered under exam conditions and test-takers are likely to have practiced similar tests. As this is not the case for the participants of this study, some verbal instructions were provided, and participants had the opportunity to ask questions about the procedure. The general advice to test takers on the GRE website is to provide the best possible example of writing (Educational Testing Service, 2010). Thus, participants were urged to provide a good example of their writing.

The following task instructions were given verbally before the writing prompt was displayed:

The purpose of this task is to measure writing skills. An essay question will appear at the top of the screen, I will read this aloud and then you will have the opportunity to ask questions before you begin writing. You will then have 15 minutes to write your response to the essay question. Your response will be scored on the content, your ideas and how well you support these ideas; as well as spelling and vocabulary.

Do you have any questions?

The prompt, presented in a Microsoft Word 2010 document, was read aloud and remained at the top of this document as participants typed.

Writing prompts:

1. Educational institutions should dissuade students from pursuing fields of study in which they are unlikely to succeed.

Write a response in which you discuss your views on the policy and explain your reasoning for the position you take. In developing and supporting your position, you should consider the

possible consequences of implementing the policy and explain how these consequences shape your position.

2. As people rely more and more on technology to solve problems, the ability of humans to think for themselves will surely deteriorate.

Discuss the extent to which you agree or disagree with the statement and explain your reasoning for the position you take. In developing and supporting your position, you should consider ways in which the statement might or might not hold true and explain how these considerations shape your position.

6.4 Measures

6.4.1 Spelling accuracy

The number of misspelled words in each of the final texts produced after 15 minutes was counted and measured as a percentage of the total number of words in the text to reduce effects of text length. Only incorrectly spelled words were included in this count, real-word errors were not counted as misspelled words, they have been investigated separately.

6.4.2 Real-word errors

The number of words used incorrectly within the context of the surrounding text was counted and converted to a percentage of the total number of words in the text. For examples of real-word errors, see Table 6.1.

Table 6.1 Examples of real-word errors.

Group, condition	Original text	Should be
Dyslexia, no spellcheck	... we are more able to fully understand the problem rather <u>then</u> the idea that...	... we are more able to fully understand the problem rather <u>than</u> the idea that...
Dyslexia, spellcheck	...the majority of the time it corrects automatically but also <u>are</u> time is no longer consumed by...	...the majority of the time it corrects automatically but also <u>our</u> time is no longer consumed by...
Control, no spellcheck	...shows that humans' ability to think for themselves <u>with</u> deteriorate,...	...shows that humans' ability to think for themselves <u>will</u> deteriorate,...
Control, Spellcheck	...there is a huge shortage of women which has <u>lead</u> to a shortage of engineers...	...there is a huge shortage of women which has <u>led</u> to a shortage of engineers...

6.4.3 Lexical diversity

Lexical diversity is often measured as the number of *types* that occur in a text in relation to the number of tokens. The more that words are repeated, the lower the diversity is. There are several measures of lexical diversity, type token ratio (TTR) is the simplest. TTR refers to the

number of word types in the text divided by the total number of tokens in the text. However, this measure and other similar versions, are sensitive to text length because the shorter the text is, the less likely words are going to be repeated and so short texts tend to end up with very high lexical diversity scores (Torruella & Capsada, 2013). The Measure of Textual Lexical Diversity (MTLD) however, is not affected by the text length and is more suitable for comparing texts that vary in length (McCarthy & Jarvis, 2010; Torruella & Capsada, 2013).

MTLD uses the assumption that once a text reaches a TTR of .720 the lexical diversity becomes stable. This value comes from a series of tests, using texts from multiple sources (McCarthy & Jarvis, 2010). A TTR score is calculated for each word in the text as a part of the text prior to that word. The score begins at 1 (1 type/1 token =1) then as words are repeated the score decreases. Once the score reaches .720 (or below) a new sample begins, and the first word of this sample is scored at 1. This is repeated over the whole text. The number of times a text reaches a TTR of .720 creates a factor count. For example, if the TTR value of .720 (or below) was reached four times within the text then the factor count is four. The final sample is unlikely to finish precisely at .720 but MTLD does not discard any remaining data. The final TTR value is converted into a percentage of the range between 1 and .720 (for example, the range between .720 and 1 is .280, if the final word has a TTR of .887 this is .113 away from 1, .113 as a percentage of .280 is 40.4%, the final sample has a factor count of 0.404). The total number of words in the text is divided by that factor count. The higher the MTLD value, the more lexically diverse the text is.

6.4.4 Word frequency

Each word written in each essay was checked for word frequency against words in the SUBTLEX-UK (van Heuven et al., 2013) database, as described in the previous chapter.

6.4.5 Quality

The essays were evaluated using the GRE scoring for overall quality (scoring rubric in Appendix F). Essays were scored on ‘the ability to reason, assemble evidence to develop a position and communicate complex ideas and the grammar and the mechanics of writing.’ (Educational Testing Service, 2019). Each essay is scored on a scale of 1-6. The analytical writing measure has reliability estimate of 0.85 (Educational Testing Service, 2018). Spelling would usually contribute to the scoring as part of mechanics, however because spelling is measured separately, essays were scored after spelling errors were corrected. A second rater also scored a sample of 20 essays using the GRE rubric. There was 91% agreement with an intraclass correlation of .910, with a 95% confidence interval from .773 to .964, $F(19,19)=1.11$, $p<.001$.

6.4.6 Essay length

Essay length was measured as the number of words in the text produced after 15 minutes of writing. This is the number of words on the page (not including the writing prompt which was provided) and does not include any words which were typed then deleted.

6.5 Analysis

To check whether one prompt was ‘easier’ to respond to than the other, lexical diversity, quality and text length data were checked for effects of prompt. In addition to ensure the order in which essays were written was not impacting the outcomes, lexical diversity, quality and text length data were checked for order effects. Lexical diversity, quality and text length data were all normally distributed, thus suitable for independent sample t tests between prompts and between the order in which the essays were written (first or second). No effects of prompt were found for lexical diversity $t(70)=1.37, p=.175$; quality $t(70)=0.79, p=.432$; or text length $t(70)=0.70, p=.489$. No order effects were found for lexical diversity $t(70)=1.73, p=.088$; quality $t(70)=1.06, p=.294$ or text length $t(70)=0.37, p=.716$.

Two by two mixed between-within ANOVAs were used to compare means between groups to investigate the effects of dyslexia, compare means within groups to investigate the impact of spellcheck, and to compare the effect sizes between groups to check for interactions. These were carried out for measures of spelling accuracy, real-word errors, lexical diversity, overall quality, and essay length. No post hoc tests were performed for the ANOVAs because they are not necessary on tests when IV’s have only two levels (Pallant, 2013). Paired samples t-tests were used to further investigate some effects of condition that was indicated by the ANOVAs, and independent t-tests were used to further investigate effects of group.

Independent t-tests were used to find out if spelling or repetition were related to word frequency within the UK English language as well as for group. Each word written was coded for whether it was spelled correctly or not and whether it was unique or repeated within each essay. Pearsons correlations were used to explore associations between word frequency, spelling ability (from the WRAT and the number of misspelled words in essays), lexical diversity, word count, quality and typing skills (from participant measures). Spearmans correlations were used to investigate relationships between spelling accuracy, spelling ability and typing ability. Analyses involving misspelled words were only carried out for essays written without spellcheck active because, with spellcheck, the amount of misspellings was often zero and thus spelling accuracy data were not suitable.

6.6 Results

6.6.1 Spelling accuracy

To address the first research question, ‘Does spellcheck increase spelling accuracy more for writers with dyslexia than the control group?’ the percentage of misspelled words have been compared using an ANOVA. Similarly, the percentage of real-word errors have also been compared using an ANOVA. Results are shown in Table 6.2. The F values in the table are organised to show first, the main effect of condition, second, the main effect of group and third, the interaction for each of the measures.

Table 6.2 ANOVA results for spelling accuracy and real-word errors.

Measure	Dyslexia group (<i>n</i> =18)		Control group (<i>n</i> =18)		ANOVA results	η^2
	No	Spellcheck	No	Spellcheck		
	spellcheck	M(SD)	spellcheck	M(SD)		
	M(SD)		M(SD)			
Spelling	4.35	0.03	0.82	0.17	F(1,34)=75.24**	.689
accuracy,	(2.29)	(0.12)	(0.79)	(0.23)	F(1,34)=34.44**	.503
percentage of					F(1,34)=41.23**	.584
misspellings						
Percentage of	0.39%	0.98%	0.35%	0.32%	F(1,33)=4.57*	.122
real-word error	(.48)	(.88)	(.34) ¹	(.38)	F(1,33)=2.14*	.167
					F(1,33)=18.05*	.629

* $p < .05$, ** $p < .001$, ¹One text by a writer with dyslexia in the no spellcheck condition contained 4.05% real word errors, which was an outlier and not included in the sample.

In the analysis conducted on the percentage of misspellings in text, the main effects and the interaction between spellcheck and group were significant and all showed very large effect sizes. As expected, without spellcheck, students with dyslexia, who are poorer spellers, produced texts containing a significantly higher percentage of incorrectly spelled words (4.35%) than the texts produced by writers in the control group (0.82%), $t(34)6.18$, $p < .001$. Also as expected, texts written with spellcheck contained almost no misspellings as spellcheck supported spelling revision for both groups (with dyslexia $t(17)=7.95$, $p < .001$; control $t(17)=3.56$, $p = .002$). There was a significant interaction between group and condition indicating that spellcheck had a larger impact on spelling accuracy for writers with dyslexia than the control group.

To indicate whether misspelled words are more likely due to spelling ability or to typing ability, correlations were performed between spelling ability scores and the number of misspelling in text, with and without spellcheck active. There was a significant correlation between spelling ability on the WRAT-4 task and the percentage of misspelled words in texts produced without spellcheck across all participants demonstrating that the poorer the spelling score, the more misspelled words there were in text, $r = -.649$, $p < .001$. The amount of misspelled words in essays written without spellcheck does not correlate with typing skills, as measured in the two minute typing task (see participant measures): percentage of typing errors per character (writers with dyslexia $r = .24$, $p = .326$; control group $r = .08$, $p = .766$), keys per minute, (writers with dyslexia, $r = -.22$, $p = .378$, control group $r = -.09$, $p = .711$) revision (writers with dyslexia $r = -.18$, $p = .480$; control group $r = .151$, $p = .550$). This indicates that misspelled words in essays are likely to be caused by spelling errors and not by typing errors.

To check whether the amount of misspelled words in text related to the text quality, the percentage of misspelled words in texts written without spellcheck were checked for correlation. There was no correlation between the number of misspellings and the quality of the text ($r=-.043$, $p=.804$).

Real-word errors

As indicated in Table 6.2, there is a significant main effect of spellcheck, and group and an interaction because of the higher amount of real-word errors that occur in texts written with spellcheck active by writers with dyslexia.

6.6.2 Lexical diversity

To answer the research question: ‘Does spellcheck increase lexical diversity?’ and to find out whether it has a different effect for writers with dyslexia than the control group, the lexical diversity of texts produced with and without spellcheck was compared for each group.

Table 6.3 shows, there were no significant main effects of condition or group on lexical diversity but considering the opposite directions of the spellcheck effect per group, general effects are not expected. There was a significant interaction with a large effect size, and an independent t-test indicated that the effect of spellcheck was significantly different per group, $t(34)=2.04$, $p=.049$. For writers with dyslexia, the mean effect of spellcheck on MTLT is to increase it by 6.89 (SD=19.69) while for writers in the control group MTLT is decreased by 5.64, (SD=17.00). Overall, there was no significant difference in lexical diversity between groups either without spellcheck active $t(34)=1.18$, $p=.244$, or with spellcheck active, $t(34)=0.99$, $p=.329$.

To answer the research question ‘Does lexical diversity relate to the quality of text?’, correlations were performed between lexical diversity and text quality. Lexical diversity did not correlate with overall quality for writers with dyslexia (without spellcheck $r=.14$, $p=.592$; with spellcheck $r=.20$, $p=.434$) or for writers in the control group (without spellcheck $r=.08$, $p=.741$; with spellcheck $r=.02$, $p=.932$). Lexical diversity did not correlate with spelling ability, $r=.038$, $p=.748$, but did positively correlate with the amount of misspelled words in text, $r=.54$, $p=.020$.

Table 6.3 ANOVA results for lexical diversity (MTLD) of essays.

Measure					ANOVA	ηp^2
	Dyslexia group (<i>n</i> =18)		Control group (<i>n</i> =18)		Condition	
	No	Spellcheck	No	Spellcheck	Group	
	spellcheck	M(SD)	spellcheck	M(SD)	Interaction	
		M(SD)		M(SD)		
Lexical	79.06	85.94	85.75	79.73	F(1,34)=0.02	.048
diversity	(18.99)	(17.44)	(17.79)	(15.03)	F(1,34)<0.01	.009
(MTLD)					F(1,34)=4.42*	.143

* $p=.05$

The positive correlation between the percentage of misspelled words and lexical diversity suggests that misspellings, as a collection of words, are more lexically diverse than the rest of the text. MTLD was calculated using essays exactly as they were written. As described earlier, TTR is used in calculations of MTLD. It is possible that the spelling errors caused multiple spellings of the same word and contributed to the count of type when they should not have, thus giving false readings of TTR for calculations of MTLD. If so, then correcting spelling errors should decrease lexical diversity compared to the lexical diversity of original texts. Spelling errors were corrected and MTLD measures were taken again, see Table 6.4. However, correcting the spelling errors made little difference to MTLD compared to the original essays, decreasing MTLD by a small amount. Furthermore, the number of corrections made does not correspond to the reduction in lexical diversity. For example, texts by writers in the control group contained 0.82% misspelled words and correcting these reduced MTLD by 1.75, whereas texts by writers with dyslexia without spellcheck contained 4.35 % of misspelled words yet correcting these only reduced lexical diversity by 1.29. Thus multiple misspellings were not solely responsible for the relationship between misspelled words and MTLD.

Table 6.4 Mean lexical diversity MTLD of essays with corrected spellings.

Measure	Dyslexia group (<i>n</i> =18)		Control group (<i>n</i> =18)	
	No spellcheck	Spellcheck M(SD)	No spellcheck	Spellcheck M(SD)
	M(SD)		M(SD)	
Lexical	77.77 (18.61)	85.20 (17.79)	84.00 (16.63)	80.71 (14.63)
diversity				
(MTLD)				

MTLD is not impacted by length of text (McCarthy & Jarvis, 2010; Torruella & Capsada, 2013), thus, if removing misspellings decreases MTLD it would indicate that the misspellings are a more lexically diverse collection of words than the rest of the text. A comparison of MTLD results, shown in Table 6.5, and results of original MTLD results, in Table 6.3, indicate that removing misspelled words decreases lexical diversity for texts written without spellcheck by writers with dyslexia $t(17)=4.43, p<.001$, and in the control group $t(17)=3.89, p=.001$. Texts written without spellcheck contained almost no misspelled words, thus removing them made little difference.

Table 6.5 Means lexical diversity (MTLD) of essays with misspelled words removed.

Measure	Dyslexia group		Control group	
	No spellcheck	Spellcheck	No spellcheck	Spellcheck
	M(SD)	M(SD)	M(SD)	M(SD)
Lexical diversity (MTLD)	70.66 (15.32)	85.15 (17.75)	83.70 (17.33)	80.60 (14.50)

6.6.3 Word frequency

To answer the research question ‘Are spelling accuracy and lexical diversity related to word frequency?’, the word frequency of misspelled words and correctly spelled words have been compared, and the frequency of unique and repeated words has also been compared. The tipping point between high- and low-frequency words is between three and four (van Heuven et al., 2013). Misspelled words averaged a medium frequency ($M= 4.32$ $SD=.99$). This was a significantly lower frequency than correctly spelled words, which are considered very high-frequency words ($M = 5.99, SD= 1.24$), $t(258.6)=26.39, p<.001$.

Words which were repeated in texts were higher frequency words ($M =6.43, SD=1.07$) than words which were unique in text ($M= 5.04$ $SD=1.08$) $t(18820)=83.70, p<.001$. Thus words which are used with higher frequency in the English language were more likely to be repeated in texts. There was no difference in average word frequency of text between groups (control group $M= 5.97$ $SD= 1.26$; dyslexia $M = 5.97, SD= 1.26$), $t(18820)=.45, p=.924$.

6.6.4 Quality

To find out if the quality of text is impacted by spellcheck differently per group, the quality rating has been compared using an ANOVA shown in Table 6.6. Text length is often an indicator of text quality, an ANOVA has been used to find out if text length is impacted by spellcheck differently per group. Means, standard deviations of text quality and text length are shown in Table 6.6 with the ANOVA results.

Table 6.6 ANOVA results for essay quality scores and text length.

Measure					ANOVA	ηp^2
	Dyslexia group (<i>n</i> =18)		Control group (<i>n</i> =18)		Condition	
					Group	
					Interaction	
	No spellcheck M(SD)	Spellcheck M(SD)	No spellcheck M(SD)	Spellcheck M(SD)		
Quality,	3.06	3.33	3.11	3.39	F(1,34)= 2.68	.073
GRE score	(0.64)	(0.77)	(1.02)	(1.09)	F(1,34)=0.05	.001
					F(1,34)=0.00	<.001
Essay	289.14	271.72	289.72	303.08	F(1,34)=0.01	.015
length,	(94.62)	(84.06)	(81.81)	(94.13)	F(1,34)=0.65	.007
word count					F(1,34)=2.75	.103

No main effects of group or spellcheck condition were found, and there was not a significant interaction. Spelling ability, as measured by the WRAT-4, did not correlate with the writing quality scores for either group in either spellcheck condition (dyslexia group without spellcheck $r=.21$, $p=.400$, with spellcheck $r=.21$, $p=.400$; control group without spellcheck $r=-.12$, $p=.632$, with spellcheck $r=-.36$, $p=.144$). Quality positively correlated with text length, in essays written without spellcheck $r=.355$, $p=.033$, and when written with spellcheck $r=.444$, $p=.007$, the longer the text, the better the quality. A significant positive correlation between quality of essays with and without spellcheck ($r=.36$, $p=.030$), suggests that if a writer did well in one essay, they were likely to do well in their other essay.

Essay length

The essays written averaged a little under 300 words long and the word count was not impacted by condition or group. The length of the essays did not correlate with spelling ability, as measured by WRAT, (with spellcheck $r=.05$, $p=.782$, or without spellcheck $r=-.12$, $p=.487$). The word count of the essays written without spellcheck did not correlate with the percentage of misspelled words $r=-.29$, $p=.085$.

For writers with dyslexia, typing speed (see participant measures) correlates with essay length. This is true for the number of words produced per minute, both with spellcheck $r=.61$, $p=.010$ and without spellcheck $r=.70$, $p=.002$ and for key presses per minute, both with spellcheck $r=.51$, $p=.029$, without spellcheck $r=.61$, $p=.007$. Essay length did not correlate with typing accuracy (without spellcheck, $r=.08$, $p=.752$, or with spellcheck $r=.21$, $p=.422$) or with the amount of revisions (without spellcheck $r=.03$, $p=.897$, or with spellcheck $r=.08$, $p=.756$), from the two-minute typing task (see participant measures).

For the control group, no typing measures correlated with essay length. This includes number of words produced per minute (without spellcheck $r=-.23$, $p=.364$ or with spellcheck $r=-.10$, $p=.682$), key presses per minute (without spellcheck $r=-.19$, $p=.452$, or with spellcheck $r=.03$, $p=.921$), typing accuracy (without spellcheck $r=.26$, $p=.291$, or with spellcheck $r=.21$, $p=.403$) and amount of revision (without spellcheck $r=-.35$, $p=.151$, or with spellcheck $r=-.23$, $p=.362$).

While typing speed relates to essay length for writers with dyslexia it does not for writers in the control group.

6.7 Discussion

Four main points have emerged from the results: spellcheck reduces the number of misspelled words in final texts for all writers to almost zero; neither spelling accuracy nor lexical diversity related to the quality of text; there is a relationship between misspelled words and lexical diversity, this appears to involve word frequency; writers with and without dyslexia are impacted by spellcheck differently. The impact of spellcheck on spelling accuracy, and on text quality, is addressed first, followed by how spellcheck and misspellings relate to lexical diversity and word frequency. Group differences are discussed in relation to previous research and theories throughout.

Without spellcheck, students with dyslexia, who are poorer spellers, produced texts that contained a significantly higher percentage of misspelled words (4.35%) than the texts produced by writers in the control group (0.82%). Results closely match findings from Sumner and Connelly (2020), who also tested UK HE writers, and found that essays by writers with dyslexia contained 4% misspelled words and texts by aged matched controls contained 0.5% misspelled words.

In texts produced without spellcheck, the proportion of misspelled words did not correlate with typing skills, which suggests that typing errors did not contribute to the number of misspelled words. Therefore, it is likely that few typing errors occurred or, if they did occur, that they were corrected. The proportion of misspelled words made correlated with spelling ability; poor spellers produced texts containing more spelling errors. Thus, spelling ability was reflected in the amount of misspelled words in texts written without spellcheck while typing ability was not.

Reassuringly, texts written with spellcheck contained almost no misspellings. Writing research is generally not carried out with spellcheck active thus, based on writing research, the typical profile of a text by someone with dyslexia is assumed to include poor spelling accuracy (for example, studies by Coleman et al., 2009; Tops et al., 2013; Torrance, Rønneberg, et al., 2016). However, writers (with and without dyslexia) reported that they typically write with spellcheck in default settings, that is to say with spellcheck active as they write (Chapter 4). Thus although writers with dyslexia experience difficulties with spelling, they could actually, typically,

produce texts that, once revised with spellcheck, do not contain spelling errors, or at least contain no more spelling errors than texts by their peers. Therefore, we may need to adjust our assumptions of what is typical. However, it is important to bear in mind that in order to achieve this, writers with dyslexia likely have to put more time and effort into revising a greater number of spelling errors than their peers do, and so achieving similar texts takes more time and effort.

If we assume that writers initially made similar amounts of misspellings when writing with or without spellcheck, but thanks to spellcheck successfully revised almost all of their spelling errors, then results suggest that writers with dyslexia corrected over 6.5 times more misspelled words than writers in the control group. Thus, despite concerns raised by MacArthur et al. (1996), that writers with dyslexia struggle to correct misspelled words using spellcheck, writers in the current study used spellcheck very effectively. This supports findings by Figueredo and Varnhagen (2006) that indicated spellcheck reduces effects of poor spelling on detection and correction of spelling errors. However, results do not support previous findings by Hiscox et al. (2014) who found that while UK HE writers with dyslexia made more misspellings than a control group, they made a similar number of corrections, thus in their investigation, more misspelled words remained in texts by writers with dyslexia. Findings may differ between the current study and that by Hiscox et al. (2014) due to the writing activity. Writers in Hiscox et al. (2014) typed to dictation, where writers needed to keep pace with audio and write words provided to them, whereas in the current investigation, the task was essay writing, which had a time limit, but writers were able to write at their own pace and to choose their own words.

As indicated in Chapter 3, real-word errors are not identified by spellcheck. In the current study, the rate at which real-word errors occurred was very low. In MacArthur et al.'s (1996) study 37% of errors by writers with dyslexia were real-word errors, which is approximately 5% of the text. In comparison, in the current study, 8% of errors were real-word errors, which is 0.39% of the overall text by writers with dyslexia, writing without spellcheck. Thus they were less problematic for UK HE writers in this study than for younger writers in MacArthur et al. (1996). In fact, the occurrence of real-word errors was so low that the data were not suitable for correlations with typing or spelling abilities to investigate possible causes.

Without spellcheck, both groups of writers produced roughly one real-word error per essay (essays averaged 300 words). The number of real-word errors by writers in the control group was not affected by spellcheck. However, there were significantly more real-word errors in texts by writers with dyslexia when using spellcheck, averaging almost three per essay. This caused significant main effects of group, spellcheck condition, and an interaction. Real-word errors may occur from misspelling or mistyping or from incorrect word choice. For example, one writer used the word *moral* when the appropriate word choice was *morale*, which could occur due to any one of three reasons. However, in a couple of cases, real-word errors were unlikely to have been a misspelling, typo or confused word. It appears that writers occasionally selected an incorrect word from the candidate list when correcting misspellings with spellcheck. The clearest example

of this is from a text produced by a writer with dyslexia: ‘In my experience it is rare to see anyone writing down equations or attempting mental arrhythmia.’. In this case, it is likely that the target word is *arithmetic* but has been accidentally replaced with *arrhythmia* via spellcheck. The implication of this finding is that, for writers with dyslexia, using spellcheck could increase the number of real-word errors in their texts, luckily findings indicate that even with this increase, less than 1% of words in a text are likely to be real-word errors.

Previous research has indicated that writers with dyslexia produce texts that are poor in areas other than spelling (Tops et al., 2013). There was no significant difference in quality between groups. In the current study, the group of writers with dyslexia (12 of whom were second year or above) were more experienced at writing at university level than the control group (who tended to be a first year students) and it is possible that this contributed to the lack of difference between groups. This possibility is discussed further in limitations. Neither spelling ability, or quantity of misspelled words in the essays, correlated with quality for either group. Thus poor spelling did not appear to have an effect on quality beyond the quantity of misspellings.

Furthermore, previous research has found that increased lexical diversity relates to better quality texts (Connelly et al., 2006; Olinghouse & Wilson, 2013, Sumner et al., 2016) however, in the current study, quality was not related to lexical diversity for either group, for texts written with or without spellcheck. This may be due to the GRE scoring criteria, which includes ‘precise’ vocabulary and ‘vocabulary to convey meaning clearly’ but does not include any mention of repetitiveness or variety of words. The scoring criteria of the holistic quality measure, Wechsler’s Objective Language Dimensions (WOLD, Wechsler 1996) on the other hand, as used by Connelly et al., (2006) and Sumner et al., (2016), indicates that if vocabulary ‘lacks variety’ then the text quality should be scored as lower. Thus the relationship between lexical diversity and quality likely depends on quality measures. Olinghouse and Wilson (2013) also used rubrics to measure quality but the exact scoring criteria that relates quality to vocabulary was not described beyond ‘Sentences/Word Choice/Voice’ (p.52).

Quality was related to text length, the longer the text the higher the quality. Previous research has also indicated that, for undergraduate writers, longer essays are rated as higher quality, and this is the case for a variety of rating scales. For example, UK undergraduates with dyslexia ($n=21$) produced essays in response to GRE prompts, holistic quality was scored using the WOLD, and this positively correlated with word count (Connelly et al., 2006). Essay length and text quality have also been found in studies with large samples. Guo, Crossley and McNamara, (2013) rated 240 argumentative essays by undergraduate L2 writers, scoring them for holistic quality using a scale of 1-5. Longer essays were scored higher, and text length accounted for 26.4% of the variance. Similarly to the current study, Crossley, Cai, and McNamara, (2012) used a SAT rubric with a scale of 1-6 to rate holistic quality of 313 undergraduate’s essays, that had been written in 25 minutes in response to SAT prompts. Quality ratings were highly correlated with text length. The relationship between text length and quality may be related to the

criteria used, particularly if some criteria could not be met in the shorter texts, for example there tends to be more information in longer texts than shorter texts (Alves et al., 2007). To achieve the upper scores on the GRE Analytical Writing measure, used to score texts in the current study, texts must be an 'in-depth analysis of complex ideas' and 'develop and support main points' which is less likely to be accomplished in very short texts (see Appendix K for full details of scoring). There was no significant difference in text length between groups. This is not that unusual in typing tasks, for example, Wengelin (2007) also found no difference in text lengths of essays written by adults with and without dyslexia.

Unlike previous studies (Sumner et al., 2016; Tops et al., 2013; Wengelin, 2007), group did not have an overall effect on lexical diversity. Without spellcheck, writers with dyslexia produced text with lower lexical diversity than writers in the control group, but this difference was not significant. UK HE groups in Sumner and Connelly (2020) and Connelly et al. (2006) also did not show significant difference in written lexical diversity.

The lower MTL values (writers with dyslexia without spellcheck $M=79.06$, $SD=18.99$; writers in the control group with spellcheck $M=79.73$, $SD=15.03$) are similar to average MTL values of essays rated as high proficiency by Crossley and McNamara (2011), $M=78.71$ ($SD=13.19$) ($N=120$, 60 by native English speakers and 60 by non-native speakers). Essays regarded as low proficiency by Crossley and McNamara (2011), average a significantly lower MTL of 72.64, $SD=10.89$. Another similar performance by undergraduates has been reported recently by Medimorec and Risko (2017) ($N=101$, described as fluent English speakers) and, like the current study, undergraduates wrote essays in Microsoft Word (version 2010 or 2013). Without spellcheck, texts averaged an MTL of 78.35 in narrative essays and 81.37 with argumentative essays (Medimorec & Risko, 2017). Thus the essays with lower MTL from the current study are within the expected range of proficient native English speakers, however, upper scores in the current study are higher than found in previous studies that use MTL to measure the lexical diversity of essays by undergraduates. While lexical diversity did not actually relate to essay quality in this instance, in comparison to the other samples described, the writers in the current study are capable of producing texts with lexical diversity equivalent to very high proficiency essay writing, when writing in particular conditions. For writers with dyslexia, essays produced with spellcheck averaged an MTL of 85.94 ($SD=17.44$) while for writers in the control group essays produced without spellcheck, averaged 85.75 ($SD=17.79$). The implication of each group responding differently to each condition implies that different writers respond better to different writing environments, or at least that writers with dyslexia respond differently to writers without dyslexia to the presence or absence of spellcheck.

In the current study, the standard deviations for lexical diversity measures appear quite large. Interestingly, most studies using MTL to investigate essays, use essays by writers using their second language (L2), and show that, while L2 writers produce samples of text with lower means than writers in the current study do, the standard deviations are similarly sized. For

example, when describing differences between texts written in different modes of writing, Barkaouri and Knouzi (2018) reported MTLT means that ranged from 64.57 to 77.02, and standard deviations that ranged from 14.16 to 18.23 for 184 essays by university students in L1 and L2. Younger writers ($N=107$, age 10-11 years) also show large standard deviations, while means ranged from 52.76 to 61.67, standard deviations ranged from 17.49 to 21.98 when writing a variety of genres (Olinghouse & Wilson, 2013). Thus it appears to be quite normal for MTLT to elicit large variance between texts, this may be because MTLT is a particularly accurate, thus also very sensitive, measure of lexical diversity (Torruella & Capsada, 2013).

It was questioned whether misspelled words cause higher lexical diversity. The misspellings from the texts produced in the current study, even when corrected, were more lexically diverse than the correctly spelled words from the same texts. This suggests that misspelled words are words that are less likely to be repeated in a text than words which are spelled correctly. Thus, misspelled words contributed to lexical diversity more than correctly spelled words. To clarify, spelling errors do not inherently increase lexical diversity because they are incorrect, the words which increase lexical diversity are words that are not repeated in the text and misspelled words also tend to be words which are not repeated in the text.

To investigate this further, word frequency of (corrected) misspelled words was also measured. Misspellings averaged significantly lower frequency than correctly spelled words. As outlined in Chapter 3, if we consider that spellings are learned via connectionist or PDP models, low-frequency words are more difficult to spell (Seidenberg, 2005). Words which tend to be spelled wrong are low-frequency words. Words which are not repeated, thus increase lexical diversity, are also likely to be low-frequency words. Thus words that tend to be spelled incorrectly and words that increase lexical diversity are from the same pool of low frequency words. If writers include more low-frequency words in their texts, there would probably be more unique words and more misspelled words. This may explain why writers with dyslexia in Connelly et al., (2006) and Sumner and Connelly (2020), who made more misspellings than expected, produced texts with lexical diversity equal to their peers. Writers in those studies appeared to prioritise using a variety of words and whether or not they could spell the words was less of a priority, and as a result they used words which contributed to the lexical diversity of their texts even though it meant they made more misspellings.

Interestingly, in the current study, with spellcheck on, the lexical diversity in texts by writers with dyslexia increased. It seems likely that without spellcheck, some words which are difficult to spell are avoided and instead easier to spell alternatives are used, and used repeatedly thus decreasing lexical diversity. This is in agreement with findings from Sumner et al. (2016) and Wengelin (2007) where writers avoided writing words that are difficult to spell resulting in lower lexical diversity. When spellcheck was available to support spelling revision, avoidance of words was reduced thus lexical diversity increased. It is worth noting that when writing without

spellcheck writers with dyslexia did not avoid all difficult-to-spell words, if they did there would be no misspelled words in their texts.

Unexpectedly, spellcheck decreased lexical diversity for writers in the control group. More words were repeated when spellcheck was on than when spellcheck was off. Why this occurred is not clear. Sommers (1980) indicated that the predominant concern of student writers during revision is vocabulary, in what she called a ‘thesaurus philosophy of writing’ (p.381) where writers focus on eliminating repetition at the word level (but not the meaning level). Similarly, in interviews, student writers (aged 14-16-years-old) reported that the aim of their revisions were to reduce repetition and write with sufficient variety in their vocabulary choice (Myhill & Jones, 2007). Thus one possible explanation for this finding is that, without spellcheck, writers in the control group focussed their revision on reducing word-level repetition, and by doing so, increased the lexical diversity. However, with spellcheck active, writers in the control group no longer focussed on reducing word-level repetition and instead focussed on addressing misspellings, thus lexical diversity remained the same.

6.7.1 Limitations

The results and interpretation of findings regarding lexical diversity support previous research, however, measures of spoken lexical diversity could have helped match the two groups of participants. Measures of spoken lexical diversity could have been used to indicate how much spellcheck compensates for poor spelling on written lexical diversity. For example, most writers without dyslexia experience an advantage of writing and produce better written lexical diversity than spoken, however, writers with dyslexia tend not to experience this advantage but comparing spoken lexical diversity measures to written lexical diversity measures, with and without spellcheck active, would show whether spellcheck provide writers with dyslexia with an advantage when writing. In addition, measures could indicate whether writers in the control group lose this advantage when spellcheck was activated.

Based on previous research, it was predicted that written lexical diversity, text quality and text length would all be higher for writers in the control group. This was not the case. This could be due to participant selection. It was thought that a small age range (18-22 is relatively small age range for adults) would be sufficient to prevent one group from having a meaningful advantage in writing skill/experience over the other. However, the dyslexia group included many students who had been attending their undergraduate course for one to two (and for one student, three) years more than the control group, who were all in their first year. This increased experience of writing at university level may have increased the general quality of their writing. Writers with dyslexia produced text of equal quality to a group of less experienced writers. Closer matching for writing experience in the control group would have avoided this issue.

The impact of spelling ability on text may have been better investigated by comparing writing to spelling ability matched groups. However, spelling matched writers would likely be

younger, with little or no experience writing at undergraduate level. When Sumner and Connelly (2020) matched their dyslexia group aged 20 years old, with writers of equal spelling ability, their spelling ability matched group were 13 years old, midway through secondary school. Thus a spelling matched group would be quite disadvantaged in terms of writing experience.

The quality of essays was measured with an overall score suitable for the age of participants and designed for specific GRE writing tasks, and no differences were found (which may also have been due to different amounts of writing experience in participant groups). It might have been more informative to measure essay quality using a more fine-grained set of scales like the WOLD (Wechsler, 1996), as reported by Sumner and Connelly (2020) and Connelly et al. (2006). The WOLD measures various dimensions of text as well as providing an overall quality rating. Monitoring specific dimensions of text could have provided insight into text quality and processing that one overall quality score does not show.

It is possible that writers did not perform as they would if writing their own coursework. The essay writing task was fairly naturalistic, writers were asked to respond to an age appropriate writing prompt. However, there were still elements of the design which were unlike natural writing situations. For example, writers were restricted to 15 minutes of writing time, the prompt was not specific to what they have been learning on their courses, and the essay had no bearing on grades.

When investigating the relationship between spelling and lexical diversity, spelling errors were corrected for analysis. Correcting errors relies on the readers judgement as to what the target word is, thus correcting the spelling errors introduced some subjectivity because some words may have been corrected to words that were not the intended by the writer. This should be taken into account when interpreting results. Corrections would be more reliable if writers clarified the intended words so that errors can be corrected accurately.

Findings indicate that word frequency plays a role in the correct spelling of words, and whether or not they tend to be repeated in text. According to models of learning spelling (Coltheart et al., 2001; Seidenberg, 2005), regularity of words interacts with frequency and impacts how well spellings of words are learned. The regularity of words was not measured. Future follow up studies could measure the regularity of words and investigate how this interacts with frequency, misspelled words and lexical diversity.

There were no behavioural measures in this study. Monitoring R- and P-burst lengths would have provided data for direct comparison to results of Chenoweth and Hayes (2003) and supported interpretations of findings from Chapter 5, that revising spelling errors is disruptive to text production, especially for writers with dyslexia when spellcheck is on. Monitoring revision could also help indicate whether real-word errors were caused by revising with spellcheck. In addition, monitoring revision behaviours would allow investigation into how often writers replace words in different conditions, in particular how often writers with dyslexia replace misspelled

words with other words and how often writers in the control group replace repeated words with different ones.

6.7.2 Conclusions

In answer to the research questions, spellcheck does reduce the amount of misspelled words produced in texts by writers with dyslexia to almost zero, matching the spelling accuracy in texts by writers in the control group. Spellcheck impacts lexical diversity differently for each group. For writers with dyslexia, it appears that avoidance strategies negatively impact lexical diversity, but spellcheck reduces the need to avoid difficult-to-spell words. For writers without dyslexia, spellcheck appears to increase lexical diversity, possibly by reducing revision of word-level repetition. Misspelled words are related to the lexical diversity of texts, seemingly because misspelled words and words that contribute to lexical diversity tend to be the same pool of low-frequency words. Neither spelling accuracy nor lexical diversity had additional effects on text quality. Practical implications and recommendations are described in the discussion chapter.

Section three: Discussion

[blank page]

General Discussion

7.1 Introduction

Despite the common use of word processing programs and spellcheck, there has been little previous investigation into writing with them. The overall aim of this thesis was to start addressing this gap in the literature by investigating three research questions: (1) how and why do writers use word processing programs and spellcheck in particular? (2) does spellcheck disrupt writing, particularly for writers with dyslexia, and what does this mean in terms of cognitive processing? (3) Does spellcheck improve spelling accuracy and lexical diversity, and does this only impact writers with dyslexia?

Three separate studies were carried out. A survey was used to collect opinions about using spellcheck and the broader context of word processing programs. A sentence completion task was used to produce behavioural data for an investigation into disruptions of spellcheck. Effects of spellcheck on essay texts were measured, particularly the effects on spelling accuracy and lexical diversity. Together the three studies create a rounded investigation covering multiple aspects of writing. In this final chapter, the overall findings are summarised then theoretical implications are discussed, focussing on research and theories that have been introduced throughout this thesis. This is followed by practical implications of the findings and recommendations for effective writing. The chapter ends with limitations and suggestions for future research.

7.2 Overall Findings

7.2.1 Findings from the survey

The use of word processing programs, and of spellcheck in particular, was explored through an online survey. Adults with English as their first language ($N=297$), with and without dyslexia responded to the survey. The most notable findings were that approximately half of the writers with and without dyslexia reported that noticing underlined errors disrupts transcription and large proportions of both groups reported that noticing underlined errors disrupts their thoughts. These reports of disruption were investigated further with essay writing and sentence completion experiments.

Despite these reports of disruption, writers generally reported that they always use spellcheck in its default settings, to automatically underline spelling errors as they occur. This does not appear to be due to a general reluctance to alter settings, about half of the participants in

each group reported that they had altered the spellcheck settings at some point. Thus it seems that writers choose to leave spellcheck active. Findings from the survey also help to describe the context in which spellcheck is used (the virtual writing environment). For example, writers tend to use Microsoft Word.

Writers, many of whom were university students, reported writing for an average of 5 hours each day, thus writing is a large part of their daily life. Their descriptions of their writing practices suggested a tendency to revise a single piece of text until they are happy with it. Understandably, it was found that, for both groups, being able to easily make changes to their texts was the most important reason to use word processing programs.

Both groups also reported other important reasons for using word processing programs. Writers with dyslexia reported that they use word processing programs because the tools such as spellcheck are helpful. This most likely reflects an appreciation for the support that these tools provide with revision of word-level errors, and spelling errors in particular. Writers in the control group reported using a word processing program because it is expected of them.

7.2.2 Findings from sentence completion and essay writing experiments

After writers in the survey study reported that underlined spelling errors disrupt their writing and train of thought, two sentence task experiments, with a design similar to Leijten et al. (2007) and van Waes et al. (2010), were used to investigate this disruption. Disruptions to writing were measured through typing behaviour. When writers halt text production to revise spelling errors, it indicates a disruption to writing, as previously demonstrated by Chenoweth and Hayes (2003). This is the same paradigm used in other sentence completion experiments (Leijten et al., 2007; van Waes et al., 2010) and was also used in Chapter 5.

Generally, writers tended to inhibit revision, however, sometimes the need to revise spelling errors did disrupt writing, supporting previous research (Chenoweth & Hayes, 2003; Ronneberg et al., 2018; Torrance, Rønneberg, et al., 2016; van Waes et al., 2010). When spelling errors were underlined, writers were more likely to be disrupted by the need to revise them. Thus generally writers in the current thesis were capable of inhibiting revision in order to manage multiple writing goals, however, the automatic underline function of spellcheck sometimes made this difficult and caused disruption to text production, especially for writers with dyslexia.

These findings extend previous research by demonstrating that error correction sometimes interrupts writing, both with and without spellcheck active, and the automatic underlining of spellcheck increases the disruption for both groups of undergraduate writers. When the select and replace function of spellcheck was available, writers in the control group were no longer disrupted by spellcheck, but writers with dyslexia continued to be disrupted by the underline.

Disruption to thought was investigated by measuring how well writers managed to preserve information in working memory. When writers forgot words provided to them, it indicated damage to the lexical representation and was considered to demonstrate disruption to thought. A

significant association between disruption to writing and disruption to thought suggests that when writers (in both groups) stopped text production in order to revise a spelling error, they were less likely to successfully maintain the lexical representation.

The focus of the essay writing study (Chapter 6) was to investigate the impact of spellcheck on spelling accuracy and lexical diversity. Writers produced two essays in response to writing prompts, one with spellcheck in default settings (underlining errors as they were made, with the select and replace function available) and one without spellcheck. As expected, without spellcheck, writers with dyslexia left more spelling errors in texts than the control group. Overall, writers left fewer spelling errors in essays when writing with spellcheck compared to when writing without it, in fact, writers (with and without dyslexia) left near to zero spelling errors in texts written with spellcheck. Thus spellcheck helped writers to correct almost all of their spelling errors, and results indicate that writers with dyslexia made more revisions than their peers. Thus spellcheck had a greater effect on essays by writers with dyslexia. Spellcheck did not improve essay quality for either group of writers.

When spelling errors were present in essays they tended to be words that are used less in language (low-frequency words) and that contributed to the measure of textual lexical diversity (MTLD) of the essays. Groups were impacted differently. Writers with dyslexia produced text with lower MTLD when writing without spellcheck compared to with spellcheck, it may be the case that some difficult-to-spell words were avoided when writing without spellcheck, which limited MTLD. This finding reflects results from Wengelin (2007) and Sumner et al. (2016). For writers with dyslexia, spellcheck reduced avoidance and thereby increased MTLD. Spelling ability imposed less restriction on word choice when spellcheck was active. However, texts by writers without dyslexia showed lower lexical diversity when written with spellcheck active.

Spellcheck has positive and negative effects on writing. Spelling accuracy of the text is improved when writing with spellcheck. However, using spellcheck to automatically check text during production increases disruption to writing, which is associated with disruption to thought. Such disruption is likely to occur particularly frequently for writers with dyslexia who make more spelling errors, triggering automatic underlining more frequently than peers.

The results in this thesis indicate that spellcheck disrupts the writing process, but also aids spelling revision. In the next section, theoretical implications, findings from all three studies are discussed in relation to literature and these findings are used to answer the research questions. The section is organised using the research questions and is presented to reflect the order of the empirical chapters.

7.3 Theoretical Implications

7.3.1 How and why do writers use word processing programs and spellcheck in particular?

When writing with a computer, writers interact with an environment that exists inside word processing programs, the virtual writing environment. Writers need to navigate menus and tools (such as spellcheck) in order to produce and manipulate text on the page. Writers make choices about the virtual environment by selecting which program to use and making decisions about the various settings within that program. In terms of how writers use spellcheck, they tend to use it in its default settings, to automatically underline errors as they are typed. Thus spellcheck, in default settings, is part of the virtual writing environment. As shown in Chapters 5 and 6, spellcheck impacts the writing process and the text outcome, therefore spellcheck should be accounted for within writing models. This has theoretical implications for the writing model by Hayes and Berninger (2014).

The writing environment in Hayes and Berninger's (2014) writing model includes text-written-so-far, task materials, transcribing technology and collaborators and critics. None of which currently account for spellcheck. Collaborators and critics refer to social factors in the immediate physical environment that influence the writing process, more specifically, it means people in the presence of the writer. Spellcheck is not a person, not is it physically present. However, it identifies spelling errors, acting as a critic, and the select and replace function assists with revision, acting as a collaborator. Spellcheck could potentially be accounted for by Hayes and Berninger's writing model as part of collaborators and critics, if the current writing environment is expanded to include the virtual writing environment.

It is worth noting that spellcheck does not fit into transcribing technology. Transcribing technology only refers to the physical implements used for transcription, pens and pencils for handwriting or keyboards for typing (Hayes & Berninger, 2014). Spellcheck does not change the method of transcription. Although spellcheck impacts transcription speed and latencies (shown in chapter 5), this occurs through the impact spellcheck has on spelling processes and on executive functioning. The fact that spellcheck impacts writing indicates that other elements of the virtual writing environment could also impact writing, in which case they should also be accounted for in writing models.

In terms of why writers use word processing programs, survey results indicate a number of reasons. The most popular and important reason for using word processing programs (according to writers with and without dyslexia) was that revision is easier with word processing programs. Revision appears to be important to writers, which may be surprising considering some researchers have indicated that many writers do not revise their texts, or revise poorly (Adams, Simmons, Willis, & Pawling, 2010; Hayes, 2012; Madraso, 1993).

Sommers (1980), indicated that for students, revision is governed by compliance to rules set by teachers, the marking criteria. Aligning writing goals with marking criteria is beneficial. Flower et al. (1986) indicate that writers viewed as ‘poor revisers’ have writing goals that differ from the ‘instructor’ goals (instructor assumed to be teacher or marker and the marking criteria). In more recent work, Hayes and Berninger (2014) outline that writing goals can be influenced by the task initiator, who is often a teacher or marker. In addition, Ronneberg et al. (2018) describe some writing goals as being influenced by the needs of the reader who, for HE students, is often a teacher or marker. The implications are that writers choose their environment to support revision, the aim of revision is to meet writing goals set by teachers/markers, thus the goals set by teachers/markers could influence choices writers make about their environment. For example, placing emphasis on spelling accuracy could encourage writers to use spellcheck.

This implication explains why writers with dyslexia reported that access to tools such as spellcheck is an important reason for them to use word processing programs. Spelling accuracy influences judgements of quality (Figueredo & Varnhagen, 2005; Johnson, Wilson, & Roscoe, 2017; Marshall & Powers, 1969; Sommers, 1980) and can be part of marking criteria (see appendix A for example). Writers are more likely to meet spelling-based writing goals when using spellcheck, and because individuals with dyslexia struggle with spelling, spellcheck has a large, positive, impact on the spelling accuracy of their texts (as demonstrated in Chapters 5 and 6). Therefore, for writers who want to minimise the number of spelling errors in their text, opting to use spellcheck is sensible.

Both groups of writers reported using word processing programs because they are expected to, this was rated as a particularly important reason by the control group. Being expected to use a word processing program could refer to social factors, or to the final product (e.g. being expected to produce a digital text, rather than a text on paper, which is common in UK HE), or because writers are expected to meet certain goals which are achieved best with word processing programs.

There appears to be a relationship between writing goals (which are impacted by the task initiator, often a teacher, marker or marking criteria) and choosing the writing environment. To answer the research question, writers use word processing programs in order to meet their writing goals. This includes using spellcheck in its default settings to act as a collaborator and critic and support writers in meeting their spelling-related writing goals.

7.3.2 Does spellcheck disrupt writing, and what does this mean in terms of cognitive processing, particularly for writers with dyslexia?

Theoretical implications related to this research question are discussed in two parts, first, whether spellcheck disrupts writing for writers with and without dyslexia, and, second, the cognitive processing involved, and how this differs for writers with and without dyslexia. While spellcheck helps writers to meet spelling accuracy goals, using spellcheck to automatically

underline spelling errors as they are made increases disruption. The automatic underlining function of spellcheck caused writers to revise errors sooner. This has been suggested, but not investigated by other researchers (MacArthur et al., 1996; Ronneberg et al., 2018). Thus this finding is a new and unique contribution to the field.

Interestingly, revision models generally suggest that errors are noticed during reading (Bereiter & Scardamalia, 1987; Chenoweth & Hayes, 2001; Flower et al., 1986; Hayes et al., 1987). However, with spellcheck automatically underlining spelling errors this may not be the case. The appearance of a red underline is a visual cue designed to draw attention to that word. By noticing the red underline, it is possible for writers to notice the presence of a spelling error in text without reading it. This situation, where the writer's attention is drawn to spelling errors while they are not searching for errors, and may not even be reading the text, has not previously been considered in revision models (or general writing models). However, considering that writers tend to write with spellcheck in its default settings, it is likely a common situation for writers. In addition, while revision models (Bereiter & Scardamalia, 1987; Chenoweth & Hayes, 2001; Flower et al., 1986; Hayes et al., 1987) describe that writers can revise or defer revision, they do not explain what difference this makes in terms of managing revision and text production (Alamargot and Chanquoy, 2001). The next few paragraphs offer an explanation.

Once the writer's attention is drawn to a spelling error, a new goal (to correct that error) is added to the writer's goals. At this point, executive functioning must devote some cognitive resources to revising the error or to inhibiting revision of the error. Automatic underlining is likely to cause writers to notice errors whilst in the midst of text production, when they will be storing and processing more information (such as what to write next). Thus there are multiple information packages to manage at once.

To manage revision and text production writers can either halt text production and revise the error, or defer revision and continue with text production. For a long time, it has been thought that word processing programs, and spellcheck in particular, might encourage writers to focus on meeting goals for final presentation (including spelling) at the detriment of initial text production (Fitzgerald, 1987; Ronneburg et al., 2018). The automatic underline of spellcheck did increase the likelihood that writers (with and without dyslexia) would halt text production in order to revise spelling errors, and this had negative consequences for storing the lexical representation in working memory. In Chapter 5, writers generally (17/20) reported that they had decided what to write before seeing the text in the sentence completion task. Thus writers were storing a lexical representation when they noticed a spelling error, as they would be if in the midst of text production. Thus findings support these concerns.

During text production, the lexical representation flows from the formulation level to execution level where it can be transcribed (Olive's, 2014, writing model, page 43). However, halting text production also halts flow of information, causing the lexical representation to be maintained in working memory for longer. Findings from the sentence completion task (Chapter

5) indicated that, after listening to audio stimuli, writers were prepared for text production at the moment they were presented with a text box. Thus when writers halted production in order to revise spelling errors, the flow of information was stopped and writers needed to take a moment before starting to revise the text, so that executive functioning could reorganise attention and resources for revision. While resources are devoted to revision, the lexical representation needs to be maintained in working memory and it risks becoming lost due to insufficient resources for maintenance. This explains why, when writers halted text production to revise spelling errors, they were more likely to experience some loss of the lexical representation compared to when they deferred revision. Results indicate that deferring revision is the most efficient response for successfully transferring the lexical representation to the page.

Difficulties maintaining the lexical representation explain the interruption to train of thought experienced by many writers, particularly by writers with dyslexia, as reported in the survey study (Chapter 4). Although disruption caused fewer content words to be included in the text, none of the writers failed to include all of the content words. Thus writers were less able to maintain the lexical representation, but not unable to. The lexical representation tended not to become lost, but damaged or faded in some way. This supports Olive's (2014) assertion that writers can reduce parallel processing without necessarily needing to run processes sequentially (if maintenance of lexical representation stopped completely all content words would be lost). The damage to the lexical representation when revising spelling errors indicates competition between text production and word-level revision, which reflects McCutchen's (1996) capacity writing theory where storage and processing compete for limited working memory resources.

Revision models have also been critiqued for not explaining what primes the revision process (Alamargot & Chanquoy; 2001). For example, existing models (Bereiter & Scardamalia, 1987; Chenoweth & Hayes, 2001; Flower et al., 1986; Hayes et al., 1987) do not attempt to explain why writers revise or defer revision. Factors involved in what causes writers to revise or defer revision are described below.

In order to defer revision, writers need sufficient available working memory and good executive functioning to inhibit revision whilst transcribing the lexical representation to the page. Writers were more likely to immediately revise spelling errors in the more complex task than the less complex task, thus immediate revision appears to be a response to task complexity. However, in van Waes et al.'s (2010) study, writers were less likely to immediately revise when facing a more complex task. This led van Waes et al., (2010) to suggest that while some researchers indicate revision can act as a disruption (such as Chenoweth & Hayes, 2003, 2007), perhaps a better term is 'opportunistic' in that, according to their results, writers were more likely immediately revise in the less complex task and therefore show flexibility in task management when cognitive load was low.

Combining findings from van Waes et al. (2010) and from the current thesis, it appears that when the task is easy-to-manageable, such as in van Waes et al.'s (2010) experiment, immediate

revision could be considered opportunistic and a sign of cognitive flexibility. However, when revision is added to an already demanding task, such as experiment two in Chapter 5, then immediate revision becomes a sign of disruption. Thus the term ‘disruptive’ appears to be a more suitable description for revision in this case. The theoretical implication is that how well executive functioning and the amount of available cognitive resources can meet demands of task complexity contribute to a writer’s response, which has not previously been specified in revision models.

By alerting writers to spelling errors during text production, a demanding task, as opposed to them noticing errors during reading, a less demanding task, automatic underlining causes a complex and demanding writing situation where writers are more likely to be disrupted by revision.

Writers with dyslexia were more likely to immediately revise spelling errors than writers in the control group and spellcheck increased this. Theoretical implications concern theories specific to dyslexia, in particular, the presence of a phonological deficit and inhibition difficulties (SAS theory). Due to a phonological deficit, tasks which use phonological processing require more working memory for writers with dyslexia (described in Chapter 2), in addition, writers with dyslexia appear to struggle with executive functioning, particularly inhibition (Hari & Renvall, 2001; Valdois et al., 2004).

In the more complex task, writers with dyslexia took longer to begin the task than the control group, which may reflect difficulties involving executive functions required to coordinate writing processes in response to noticing a spelling error. Writers with dyslexia included significantly fewer content words in their texts than writers in the control group. This finding is in line with the idea that, due to a phonological deficit, writers with dyslexia require more cognitive resources for activities involving phonological processing (Elliot & Grigorenko, 2014). Writers with dyslexia were more likely to struggle to maintain the lexical representation because, they needed to devote more resources to revising the error, therefore due to limited cognitive resources, had to reduce parallel processing. Insufficient cognitive resources devoted to maintaining the lexical representation, via the inner voice/phonological loop, caused it to become damaged (but was not completely forgotten).

For writers with dyslexia, with or without the select and replace function, spellcheck caused them to immediately revise more often than without spellcheck. For the control group, introducing the select and replace function counteracted the effect of task complexity thus they were more likely to defer error correction when the select and replace function was available. This indicates that writers in the control group were capable of inhibiting revision and their response was related to the nature of the task, or availability of spelling knowledge. However, for writers with dyslexia, inhibition was most likely the main difficulty when using spellcheck.

For writers with dyslexia, even if the cognitive demand of revision is decreased by spellcheck providing spelling knowledge, it is still difficult to shift attention away from the

spelling error and back to production of text. This finding supports SAS theory (Hari & Renvall, 2001; Valdois et al., 2004). Thus inhibition contributes to why writers defer revision sometimes and other times not, especially for writers with dyslexia (Hari & Renvall, 2001; Valdois et al., 2004). Because working memory resources and inhibition are important in managing revision, writers with dyslexia are at a disadvantage when revising during text production.

7.3.3 Does spellcheck improve spelling accuracy and lexical diversity, and does this only impact writers with dyslexia?

Spelling accuracy results show that, without spellcheck, writers with dyslexia make a higher quantity of spelling errors than peers (Chapters 5 & 6). These findings are in line with previous research (Sumner et al., in press; Torrance et al., 2016; Wengelin, 2007) and match the general profile of dyslexia (Lyon, Shaywitz & Shaywitz, 2013).

As predicted, texts contain fewer spelling errors when written with spellcheck active, supporting previous research that suggests spellcheck assists with the identification and correction of spelling errors when producing or editing texts (Figueredo & Varnhagen, 2006; MacArthur et al., 1996; McNaughton, Hughes, & Clark, 1997; Pedler, 2001). In the sentence completion task, with full spellcheck activated (including the select and replace function), both groups of writers left spelling errors in only one-third of trials, which is about one error per every six sentences. In the essay task both groups of writers left almost zero spelling errors in their texts. Writers may have performed better in the essays because, unlike the sentence completion tasks, writers can choose to use only words which they are familiar with. However, it is worth noting that in the sentence completion task, the planted errors were designed so that the first word offered by spellcheck was the correct word, and so revision, using the select and replace function, should have been straightforward. It is possible that writers were simply better at using spellcheck in the essay writing task because it closely resembled a familiar writing situation.

Interestingly, previous investigations into the use of spellcheck indicated that writers with dyslexia made many real-word errors and so spellcheck was often not useful to them (MacArthur et al., 1996; McNaughton et al., 1997; Pedler, 2001). However in the essay task, real-word errors did not cause a problem for either group of writers. Furthermore, considering that writers with dyslexia made more spelling errors than peers, and both groups produced texts with almost zero spelling errors, this means that writers with dyslexia used spellcheck to correct a larger number of spelling errors and were therefore proficient at using spellcheck. Spellcheck was especially useful for writers with dyslexia. This supports findings by Figueredo and Varnhagen (2006) that spellcheck reduces effects of poor spelling ability on the detection and correction of spelling errors.

Findings from sentence completion tasks suggest that full spellcheck (including the select and replace function) encouraged revision more than the underline alone. This supports the assertion that knowledge of the word is necessary for revision (Hacker et al., 1994; Hayes, 2004)

because when the writer is provided with the information necessary for revision, they are more likely to revise the error. The theoretical implication of this finding is that writers can use spellcheck to supply spelling knowledge, as opposed to the writer recalling it from their lexicon. While researchers have questioned the need for spelling knowledge in the detection and correction of spelling errors (Figueredo & Varnhagen, 2004; Hacker et al., 1994; Hayes, 2004), receiving this knowledge from spellcheck is not a situation that has previously been explored either empirically or in theory until now. Providing writers with the opportunity to select a correctly spelled word and replace the spelling error allows them to use word recognition knowledge without needing to spell the word. This proved particularly helpful for writers with dyslexia, allowing accurate spelling correction, and for writers without dyslexia as it allowed them to defer revision. When knowledge for revision is available, writers are very likely to revise (chapter 5) and do so successfully (chapter 6). Furthermore, these findings highlight the importance writers place on easy revision, as indicated by results of the survey.

For writers with dyslexia spellcheck improved spelling accuracy and lexical diversity in the essay writing tasks (Chapter 6). One possible explanation for this relationship between spelling and lexical diversity, put forward in the introductory chapters and in Chapter 6, is that lexical diversity is reduced when writers reuse words which are easier to recall. However, if this was the case then spellcheck would not have impacted the lexical diversity because words that are easier to recall would continue to be repeated with or without spellcheck present. An alternative explanation is that word choice is constrained by spelling ability. Wengelin (2007) indicated that, generally, accurate spelling is important to writers with dyslexia, and that because they struggle with spelling, selecting words which they can spell limits the lexical diversity of their texts (when writing without spellcheck). Writers with dyslexia are less likely to use words which are difficult to spell than words which are easier to spell.

In terms of writing theory, the combination of spelling accuracy goals and poor spelling leads to a cycle of evaluation and revision as writers with dyslexia carefully select words which express their meaning and that they can spell. This cycle may be responsible for translation acting as a bottleneck in writing, as reported by Hayes (2012). In a review of his work, (Chenoweth & Hayes, 2003; Hayes & Chenoweth, 2007; Hayes, 2009), Hayes (2012) found that when cognitive resources are used by translation this slows transcription and increases pauses. Hayes' (2012) findings are consistent with Olive's (2014) depiction of the flow of information. Information cannot flow beyond translation (formulation in Olive's, 2014, model) until suitable words have been selected, resulting in paused transcription until the lexical representation flows to execution level. Furthermore, this cycle of evaluating and revising word choice describes a word-level focus (explained in Chapter 2) where writers with dyslexia focus on word production, devoting effort to spelling words and making decisions about word choice, leaving less cognitive resources available to other processes in writing (Torrance et al., 2016; Wengelin, 2007).

A revision cycle at translation explains findings of Chapter 6: with spellcheck available, the lexical diversity of texts by writers with dyslexia improved because, with spelling support, writers were free to use more difficult-to-spell words allowing more variety of word choice. The theoretical implication is that, without spellcheck, for writers with dyslexia, spelling restricts word choice (via evaluation and revision) supporting Wengelin's (2007) findings. Support with spelling revision allows writers to relax spelling goals, dwell less on whether or not they can spell words and instead evaluate word choice based on appropriateness of the word, reducing the bottleneck at translation caused by spelling evaluation, reducing the word-level focus at initial production and increasing the amount of available words. Thus spellcheck could even reduce avoidance that occurs at translation, and not only after transcription.

Writers do not avoid all spelling errors, some are present in their texts. Interestingly, spelling errors in the essays produced in Chapter 6 (even when corrected) tend to be words that increase lexical diversity. Word frequency appears to be involved in the connection between spelling and lexical diversity. Misspelled words are significantly lower frequency than correctly spelled words. This makes sense if accepting that spellings are learned via PDP and connectionist models (Houghton & Zorzi, 2003; Seidenberg, 2007) where low-frequency words are more difficult to learn to spell (outlined in Chapter 3). In addition, as indicated by those spelling models, representations of these words will be weaker than representations of high-frequency words. Spelling errors tend to be words that are used less in language (hence low frequency) and are used less in the essays (hence lower MTLTD). This would explain why higher proportions of spelling errors have previously been linked to increased lexical diversity (Connelly et al., 2006; Sumner & Connelly, 2020).

For writers without spelling difficulties, an important goal of revision is to reduce repetition of words (Myhill & Jones, 2007a; Sommers, 1980). However, in Chapter 6, when spellcheck was active, writers from the control group decreased the lexical diversity in their text. This finding has been interpreted to mean that the control group did not address repetition of words when spellcheck is active. The reason for this could be that spellcheck causes writers to focus on spelling revision at the detriment to other areas of text. This has been suggested previously (Figueredo & Varnhagen, 2006; Fitzgerald, 1987; Piolat, 1991; Piolat et al., 1997; Ronneberg et al., 2018). Importantly, spellcheck impacts writers with and without dyslexia differently.

In summary, this thesis indicates that including spellcheck in the writing environment has theoretical implications for all levels of the Hayes and Berninger's (2014) writing model by supporting goals of spelling accuracy at the control level, and interacting with executive functioning and working memory at the resource level, and by supporting evaluation and other writing processes used in revision at the process level. Importantly, spellcheck impacts writers with dyslexia differently than writers without dyslexia.

7.4 Practical Implications

Findings indicate that writers choose their environment to support their writing as they attempt to meet their goals. Factors that influence writing goals (such as teachers and marking criteria) therefore impact choices writers make about their environment. It seems that writers use spellcheck, in its default settings, because spelling accuracy is important to them. When spellcheck was active in essay writing, the resulting amount of spelling errors was close to zero. Spellcheck helps all writers (with and without dyslexia) to revise their spelling errors. This is a very positive finding and the practical implication is that spellcheck does assist undergraduate students with spelling revision, particularly those with dyslexia.

Text quality was measured separately from spelling accuracy. Text quality was not impacted by the availability of spellcheck. The implication of this is that spellcheck supports spelling accuracy without affecting other areas of writing that impact text quality. Unfortunately, spelling errors can influence readers' judgements of quality (Figueredo & Varnhagen, 2005; Johnson, Wilson, & Roscoe, 2017; Marshall & Powers, 1969) and spelling accuracy can be part of marking criteria in UK HE (See appendix A for example). Thus when coursework and exam scripts are graded, while spellcheck does not actually make a difference to the quality of written content, because spelling accuracy can influence judgements of quality, if a writer does not use spellcheck to revise their spellings then they would be at a disadvantage compared to if they did use it.

In Chapter 6, without spellcheck available, writers with dyslexia produced essays in which 4.35% of the words were spelled incorrectly, which is roughly one spelling error per every 23 words. Writers without dyslexia produced essays with roughly one spelling error in every 122 words. Thus, when writing without spellcheck, spelling accuracy will have a larger negative impact on readers judgements of quality of texts by writers with dyslexia than of texts by writers without dyslexia. When writing without spellcheck, writers without dyslexia are at somewhat of a disadvantage compared to their peers.

For coursework, all writers can choose to use spellcheck or not, however, in exams writers do not always have the option to use spellcheck. Often, in the UK, students with dyslexia are allowed to write with word processing programs in exams, this sometimes includes using spellcheck (but not always). The intention of this is to provide support for these writers and reduce the disadvantage writers with dyslexia experience. Writing with word processing programs, and therefore spellcheck, is not typically available to all students, even though it helps all writers to improve their spelling accuracy. Similarly to coursework grades, exam grades can be influenced by spelling accuracy, which means that any writer without access to spellcheck is at a disadvantage compared to having access to spellcheck. One way to avoid this disadvantage would be for all writers to use spellcheck to support their spelling accuracy.

As described previously, spellcheck appears to increase lexical diversity for writers with dyslexia and decreases it for writers without dyslexia. Essays in Chapter 6 were scored using the GRE rubric, which gives better grades to texts with vocabulary that clearly conveys meaning, but word variety or repetition (lexical diversity) had no impact on the quality score. Thus lexical diversity was not related to text quality. These findings indicate that using spellcheck for coursework or for exams would not provide an advantage unless variety of vocabulary was included in the marking criteria, in which case writers with dyslexia would be likely to benefit from the use of spellcheck however writers without dyslexia might actually experience a disadvantage.

As well as affecting the outcome of graded texts, spellcheck affects the writing process. If using spellcheck in its default settings, writers with dyslexia face a disadvantage compared to peers because underlines will appear more frequently during their writing, causing more disruption. In Chapter 5 writers with dyslexia were disrupted by the automatic underlining in 28% of cases (compared to 11.4% without spellcheck). In practical terms what this means for writing is that if one in every 23 words is a spelling error (reflecting essay writing tasks in Chapter 6), then writers with dyslexia would stop text production in order to revise underlined errors roughly once every 82 words. In the context of essay writing, this is roughly one to two disruptions per paragraph. This may seem fairly infrequent, however it is more frequent than when writing without spellcheck, which is approximately one disruption per every 209 words. In comparison, the average writer without dyslexia is interrupted by spellcheck approximately once every 2,837 words. Writers with dyslexia are interrupted by spellcheck substantially more often than their peers, thus using spellcheck in its default settings could be a particular disadvantage to the writing process for this group.

Furthermore, following such disruption, writers are likely to lose lexical representation in 74% of cases. Without spellcheck writers with dyslexia lose the lexical representation once every 282 words, with spellcheck that is increased to every 111 words. Writers from the control group, however, lose the lexical representation every 1,137 words without spellcheck and, because for them spellcheck seems to reduce the cognitive load of the task, with spellcheck they lose lexical representation less often at once every 3,834 words. This explains why a larger percentage of writers with dyslexia (60%) than writers without dyslexia (41%) report loss of train of thought (Chapter 4). In terms of exam conditions, it might be best for writers to have spellcheck available, but not in its default settings. Spelling errors might be best corrected after the writer has the content of their text on the page. This should prevent spellcheck from disrupting initial text production while still preventing spelling accuracy from impacting readers judgements of quality.

Even outside of exams, findings from Chapter 4 indicate that the average university student writes for 5 hours a day. Thus disruptions of spellcheck likely have a noticeable impact on writing and so writers would benefit from strategic use of spellcheck in day-to-day writing.

7.5 Practical Recommendations

In terms of general writing practice, it is recommended that university students are alerted to findings in this thesis and advised to use the following recommendations for best writing practise using spellcheck. Writers should ignore spelling errors and continue with text production until they reach a natural pause in writing and are ready to proofread their text. To help writers ignore spelling errors they should turn spellcheck off during periods of text production and only turn it on for proofreading. This would allow the writer to preserve working memory capacity for maintaining the lexical representation and text production reducing any negative effects it may have to the flow of text production. With this strategy writers would benefit from spellcheck, producing texts that are near free of spelling errors.

As indicated in the practical implications writers, particularly writers with dyslexia, are likely to be distracted by spelling errors, even without spellcheck active. Therefore they may benefit from training to ignore spelling accuracy until they have transferred their thoughts onto the page to help reduce disruptions.

While spellcheck increases lexical diversity of texts by writers with dyslexia, ignoring spelling accuracy could also help improve lexical diversity if it encourages writers to use words even when they are unsure of the spelling because it could prevent excessive or prolonged revision cycles (as described in theoretical implications). Writers without dyslexia would benefit from a slightly different strategy. For these writers, lexical diversity was poorer when writing with spellcheck. Proofreading, without spellcheck, should help limit word repetition. however, if proofreading proves difficult or ineffective, it may be useful to use text to speech software to listen for repetition of vocabulary. Microsoft Word, the most popular word processing program among participants of this thesis, has speech to text software as standard although alternatives are available. After proofreading for repetition, spellcheck can be used to revise spelling errors without limiting lexical diversity.

As indicated earlier, spellcheck fails to identify real-word errors. While very few real-word errors occurred in essays, standard grammar check or specialist writing software such as Oribi Verity Spell or Grammarly can identify, and support revision of, real-word errors. Speech-to-text software can also help to identify real-word errors. This may be one of the reasons that speech-to-text software was the most popular add-on software reported by writers with dyslexia in Chapter 4.

When it comes to coursework and exams, the impact of spelling accuracy needs to be carefully considered. For example, if spelling accuracy is not an intended measure, then markers need to review scripts that are free from spelling errors to prevent spelling accuracy from impacting their judgements of content quality. One way to do this would be to encourage all students to use spellcheck with strategies recommended in earlier paragraphs. However, it should be noted that writers perform best in familiar writing conditions (Connelly et al., 2007) and for

spellcheck this means in default settings. Thus, university students must first practice using spellcheck in recommended settings to familiarise themselves with this, and should not reserve this strategy only for exams.

Findings can also be used to make recommendations for software. Spelling support could be developed to provide feedback at appropriate times that are non-invasive to the writing process, that do not disrupt writing but that support the flow of writing. This is in agreement with Ronneberg et al.'s (2018) suggestion for a 'what you get is what you need form' of spelling support. It would help writers to follow the above recommendations if spellcheck is inactive by default and remains inactive until the writer is ready to revise their spelling errors. In addition, activating spellcheck should be made easier, for example with a keyboard shortcut or ribbon icon, rather than being hidden in the menus. In Microsoft 2010 (used for essay writing task in Chapter 6) writers need to navigate three menus and two new windows before spellcheck options are available. In Microsoft 2016 it is easy to launch spellcheck in split-screen view, by clicking a ribbon icon (where it displays a list of spelling errors separately from the text). However to turn off spellcheck or switch between it being off and on without using the split-screen view, for example if writers prefer to see their spelling error in the context of the rest of the page of writing, writers still need to navigate several menus to do so.

It is also possible to reduce the need for spellcheck by using additional spelling support software. For example, autocorrect reduces the number of errors that need to be revised by the writer (Hiscox et al., 2014). Autocorrect is included in some word processing programs, certainly in Microsoft word. However additional autocorrect programs such as Global AutoCorrect can work with word processing programs. Alternatively, writers who find that the production of written words remains laborious with revision support may need to use other transcription methods such as a speech to text. How well these additional software packages reduce the need for spelling revision is beyond the scope of this thesis however findings do suggest that reducing spelling revision would be beneficial to smooth text production.

While the recommendations to writers suggest that writers should not use spellcheck in its default settings, findings from this thesis indicate that currently, most writers do use default settings. Therefore, in experiments involving word processing programs, using spellcheck in its default settings (where possible) will increase ecological validity. In addition, because results indicate that the presence or absence of spellcheck impacts aspects of writing such as word choice, proofreading, and revision behaviour, researchers investigating these aspects of writing should consider the impact that (the absence or presence of) spellcheck may have on findings.

7.6 General Limitations

Limitations of individual empirical studies have been described within each chapter with specific suggestions for improvements in selecting participants and ideas for addressing issues

with measures in ways that could strengthen the evidence base for interpretations and explanations of findings.

Generally, it should also be noted that all the studies in this thesis were conducted in English, an opaque orthography. It is not known how well findings can be generalised to more transparent orthographies. In addition, findings are restricted to writing with word processing programs with the inbuilt spellcheck and may not reflect other forms of digital text production with spelling support, for example producing digital texts with autocorrect or predictive text, which are both common forms of spelling support on smartphones. Other forms of spelling support are likely to improve spelling accuracy of texts, but how they impact the writing process is unknown.

Furthermore, adults with dyslexia in HE can be considered a subgroup of adults with dyslexia (Coleman et al., 2009; Mapou, 2008). They are academically inclined and capable of keeping up with the writing demands placed on undergraduates. Therefore findings concerning differences between groups are best generalised to university students with and without dyslexia.

In fact, like other studies using university students, all findings are best generalised to university students rather than the broader population. University students are somewhat of a subgroup of the general population and may not be suitable for generalisation to younger students in compulsory education or to adults who have not attended university. The participants of the writing experiments were all undergraduates and even most survey respondents that were not university students were affiliated with Oxford Brookes University in some way. Undergraduates are regularly expected to complete long, well-formed texts using word processing programs for their coursework. This means that these individuals are likely to outperform other writers on tasks such as essay writing (as used in Chapter 6). Furthermore, frequent essay writing is why research into spellcheck is particularly pertinent for this group and much less pertinent to other writers. Furthermore, because undergraduates' academic achievements are heavily influenced by written work, investigation into how the writing environment could enhance or restrict their writing is important.

7.7 Suggestions for Future Research

Future research could be targeted to further explore how spellcheck triggers revision. Generally, models of revision, and literature concerning revision of text, assume that revision is triggered after reading (Bereiter & Scardamalia, 1987; Chenoweth & Hayes, 2001; Flower et al., 1986; Hayes et al., 1987; Ronneberg et al., 2018; Torrance et al., 2016). However, as suggested in this thesis, with spellcheck automatically underlining spelling errors, it is possible that the writer may notice the underline and become aware of the presence of an error before reading the word.

In previous studies, authors have investigated the role of reading in revision by comparing writing behaviour when writers were able to read the text that they produced and when they were prevented from reading the text (Chenoweth & Hayes, 2001; Torrance et al., 2016). When writers

could not read the text, they made fewer revisions. It was assumed that this demonstrated that reading is involved in revision (Chenoweth & Hayes, 2001; Torrance et al., 2016). However, with spellcheck, writers may only need to see the text, not necessarily read it. Eye-tracking would allow researchers to monitor how long the eye fixates on a word which would indicate whether a word (underlined or not) has been read or only seen (Ellis, 2016; Rayner, 2009).

In addition, timelines can be created from combining typing and eye-tracking data. A timeline of when writers make a spelling error, see it, read it, and revise it would provide more detailed information about the cognitive processing involved in revision. For example, if spellcheck causes changes in the time between noticing the error and correcting the error then this would indicate differences in processing. Findings would provide further information about how spellcheck interacts with writing, contributing to knowledge of how spellcheck fits into writing models such as Hayes and Berninger's writing model (2014).

The combination of typing and eye-tracking data may even allow researchers to tease apart typing errors and spelling errors. Noticing typing errors has been described as a proprioceptive sense (van Waes et al., 2010), they are corrected instantaneously (Wengelin, 2002) and writers can make some revisions to typing errors without looking at the text (Torrance et al., 2016). Little is known about revising typing errors. Writing behaviour and cognitive processing may differ from revising spelling errors.

This thesis has indicated that working memory and executive functioning influence how writers respond to spelling errors, with and without access to spellcheck. Thus working memory and executive functioning should be a key area of investigation in future studies examining online spelling revision, spellcheck, and the differences between writers with and without dyslexia. As outlined in the introductory chapters, working memory is frequently reported to be poorer in individuals with dyslexia (Connelly et al., 2006; Smith-Spark et al., 2016; Snowling, 2012), but only when tasks involve language processing (for a review see Elliot & Grigorenko, 2014 or Swanson, 2006). In particular, the working memory components causing difficulties for adults with dyslexia tend to be the phonological loop and executive functioning (Berninger, Nielsen, et al., 2008), which tend to be independent difficulties (Pickering, 2006; Swanson, 2006). Therefore, future studies should include measures of executive functioning that are and are not influenced by phonemic awareness.

For working memory capacity, Swanson (2006) suggests that the Tower of Hanoi which measures executive problem solving without interference from phonemic awareness, whereas listening span tasks and tasks involving semantic associations are likely to involve phonological coding (thus are influenced by phonemic awareness). Inhibition can be measured using the traditional colour Stroop test (Stroop, 1935), which involves reading and therefore is influenced by phonemic awareness, and a numerical Stroop effect test (Besner & Coltheart, 1979; Henik & Tzelgov, 1982) using keypress responses, which does not rely on phonemic awareness. Taking into account these aspects of cognitive functioning should inform explanations of behaviour, and

particularly of group differences. This would lend strength to interpretations of results and explanations presented in this thesis.

7.7.1 Research on other writing tools

Predictive text has been available for many years (e.g. Predictype by Scetlander ltd, from the 1980s), and is increasingly popular as it is often used on phones, yet research into predictive text is limited. The small amount of research available on predictive text research, is often devoted to evaluating the how likely the program is to predict words intended by the user (Badr, Ghorra, & Chaccour, 2016; Newell, Booth, & Beattie, 1991; Waller Fiona Dennis Janet Brodie Al, Dennis, Brodie, & Cairns, 1998) which is useful, but not the only important aspect of predictive text that needs investigation. Little research into predictive text has focussed on writing behaviour or text quality for writers with or without dyslexia.

The use of autocomplete, in the form of Google's search bar, has been investigated by Berget and Sandnes (2015). Google predicts whole search phrases. Students in higher education with dyslexia used autocomplete options with similar frequency to the control group. Authors suggest that writers with dyslexia could make more use of autocomplete than they did and would benefit from it more than the control group because it reduces the writing and information searches were not hindered by spelling errors.

Predictive text and autocomplete may speed up writing and reduce spelling errors by reducing the number of keypresses necessary to produce whole words or phrases. On the other hand, these programs could disrupt writing because they are activated before the writer completes a word, and sometimes require writers to read multiple options before the target word appears. Selecting suggested words also has potential to cause common phrases to be repeated which could limit lexical diversity when it comes to writing longer pieces of text.

Autocorrect, is not activated until the writer has completed a word and does not require action from the writer, thus should not disrupt writing. Currently, not all spelling errors can be reliably autocorrected, however, autocorrect has been shown to reduce the number of errors, thus if used in combination with spellcheck, also reduces how often writers need to use spellcheck (Hiscox et al., 2014). Autocorrect is widely used, it is available in a number of platforms, including messaging, search bars, email and word processing programs, thus findings from research into writing with autocorrect could be generalised to a number of writing activities.

Undergraduates (and other adults) perform many writing activities such as, messaging, emails, and information searching, all of which are carried out in different software with different spelling support. Emerging writing support software must be investigated for all populations and should be evaluated in terms of how well it supports good writing practices (writing behaviour and text quality). Writing support should benefit users and may particularly benefit certain populations. Writing support can have unintended consequences and might impact certain

populations differently, as demonstrated in this thesis. Research into writing support software will identify potential issues and highlight where and how such software can be improved for writers.

7.8 Concluding Remarks

This thesis has investigated spellcheck in writing for undergraduates with and without dyslexia using multiple methodologies to collect a variety of measures regarding the use of spellcheck: self-reports from survey questions, writing behaviours measured in controlled experimental conditions, and measures of texts produced in naturalistic writing tasks. Findings have been interpreted using a cognitive perspective referring to existing writing models and theories as well as previous empirical research. Results from empirical studies in this thesis have also been extrapolated to outline the practical effects of spellcheck on writing.

Opinions and self-report data indicate that writers usually use spellcheck in its default settings, even though large proportions feel that it disrupts their writing and train of thought, particularly writers with dyslexia. The behavioural data presented demonstrated that the automatic underlining of spellcheck is indeed disruptive and that when writing is disrupted, writers can lose information that was being held in their working memory. Results indicate that this is more problematic for writers with dyslexia than for writers in the control group.

When spellcheck is active, writers with and without dyslexia produce texts with almost no spelling errors in essay texts. Overall, despite disruptions to writing and to thought, spellcheck has a positive influence on the text for writers with dyslexia.

The fact that spellcheck significantly impacts the writing process and the text produced, and does so differently for writers with dyslexia compared to writers without dyslexia, has implications for writing theory. Findings indicate that cognitive costs of text production and revision are particularly demanding for writers with dyslexia and suggest that they struggle with inhibition and cognitive management, which supports phonological deficit and SAS theories of dyslexia. Furthermore, findings indicate a relationship between spelling errors, lexical diversity and word frequency, this relationship appears to be related to PDP and connectionist models for developing spelling knowledge.

The main theoretical implication is that spellcheck needs to be incorporated into writing models so that it can be accounted for in future writing research. In terms of practical implications, findings should be used to provide advice for best writing practice and to inform software companies on how to improve default settings for spellcheck.

[blank page]

8 References

- Abbott, R., Berninger, V. W., & Fayol, M. (2010). Longitudinal relationships of levels of language in writing and between writing and reading in grades 1 to 7. *Journal of Educational Psychology, 102*(2), 281–298. <https://doi.org/10.1037/a0019318>
- Adams, A. M., Simmons, F., Willis, C., & Pawling, R. (2010). Undergraduate students' ability to revise text effectively: Relationships with topic knowledge and working memory. *Journal of Research in Reading, 33*(1), 54–76. <https://doi.org/10.1111/j.1467-9817.2009.01432.x>
- Adi-Japha, E., Landau, Y. E., Frenkel, L., Teicher, M., Gross-Tsur, V., & Shalev, R. S. (2007). ADHD and dysgraphia: Underlying mechanisms. *Cortex, 43*(6), 700–709. [https://doi.org/10.1016/S0010-9452\(08\)70499-4](https://doi.org/10.1016/S0010-9452(08)70499-4)
- Afonso, O., & Alvarez, C. (2011). Phonological effects in handwriting production : evidence from the implicit priming paradigm, *Journal of Experimental Psychology 37*(6), 1474–1483. <https://doi.org/10.1037/a0024515>
- Afonso, O., Suárez-Coalla, P., & Cuetos, F. (2015). Spelling impairments in Spanish dyslexic adults. *Frontiers in Psychology, 6*(466), 1–10. <https://doi.org/10.3389/fpsyg.2015.00466>
- Alamargot, D., & Chanquoy, L. (2001). *Through the Models of Writing*. Kluwer Academic Publishers. <https://doi.org/10.1007/978-94-010-0804-4>
- Alves, R.A., Castro, S.L., & de Sousa, L. (2007). Influence of typing skill on pause–execution cycles in written composition. In G.Rijlaarsdam, (Series Ed.); M. Torrance, L. van Waes, & D. Galbraith (Volume Eds.), *Writing and Cognition: Research and Applications* (Studies in Writing, Vol. 20, pp. 55–65). Amsterdam: Elsevier.
- Aragón-mendizábal, E., Delgado-casas, C., & Menacho-jiménez, I. (2016). A Comparative Study of Handwriting and Computer Typing in Note-taking by University Students. *Media Education Research Journal, 24*(48) 99–107.
- Armitage, C. J., & Conner, M. (2001). Efficacy of the Theory of Planned Behaviour: A meta-analytic review. *British Journal of Social Psychology, 40*(4), 471–499. <https://doi.org/10.1348/014466601164939>
- Baddeley, A. D. (2000). The episodic buffer : a new component of working memory? *Trends in Cognitive Sciences 4*(11) 417-423.
- Baddeley, A.D. and Hitch, G.J. (1974) Working memory. In G.A. Bower. (Ed) *The psychology of learning and motivation* (pp. 47-89), Academic Press
- Badr G., Ghorra A., Chaccour K. (2016) MobiCentraList: Software Keyboard with Predictive List for Mobile Device. In: Kurosu M. (Ed.) *Human-Computer Interaction. Interaction Platforms and Techniques. HCI 2016. Lecture Notes in Computer Science* (pp 268-277). Springer.
- Barkaoui, K. (2007). Revision in Second Language Writing: What Teachers Need to Know. *TESL Canada Journal, 25*(1), 81. <https://doi.org/10.18806/tesl.v25i1.109>

- Beach, R. (1984). The effect of reading ability on seventh graders narrative writing. *American Journal of Evaluation* (9) 502–507
- Beach, R. (1979). The Effects of Between-Draft Teacher Evaluation versus Student Self-Evaluation on High School Student's Revising of Rough Drafts. *Research in the Teaching of English*, 13(2), 111–119. Retrieved March, 2019, from www.jstor.org/stable/40170747
- Beach, R., & Eaton, S. (1984). Factors influencing self-assessing and revising by college freshmen. *New directions in composition research*, 149–170.
- Beauvais, C., Olive, T., & Passerault, J.-M. (2011). Why are some texts good and others not? Relationship between text quality and management of the writing processes. *Journal of Educational Psychology*, 103(2), 415–428. <https://doi.org/10.1037/a0022545>
- Bereiter, C., & Scardamalia, M. (1987). *The Psychology of Written Composition*. Hillsdale: Lawrence Erlbaum Associates.
- Berget, G., & Sandnes, F. E. (2015). Do Autocomplete Functions Reduce the Impact of Dyslexia on Information-Searching Behavior? The Case of Google. *Journal of the association for information science and technology*. <https://doi.org/DOI: 10.1002/asi.23572>
- Berninger, V. W., Nielsen, K. H., Abbott, R., Wijsman, E., & Raskind, W. (2008). Writing problems in developmental dyslexia: Under-recognized and under-treated. *Journal of School Psychology*, 46(1), 1–21. <https://doi.org/10.1016/j.jsp.2006.11.008>
- Berninger, V. W., Raskind, W., Richards, T., Abbott, R., & Stock, P. (2008). A multidisciplinary approach to understanding developmental dyslexia within working-memory architecture: Genotypes, phenotypes, brain, and instruction. *Developmental Neuropsychology*, 33(6), 707–744. <https://doi.org/10.1080/87565640802418662>
- Berninger, V. W., Rijlaarsdam, G., & Fayol, M. (2012). Mapping research questions about translation to methods, measures and models. In M. Fayol, D. Alamargot., & V. Berninger, (Eds.) *Translation of thought to written text while composing: Advancing theory, knowledge, research methods, tools, and applications*. New York: Psychology Press. (pp. 27–70).
- Berninger, V. W., & Swanson, L. (1994). Modifying Hayes and Flower's model of skilled writing to explain beginning and developing writing. In E.C. Butterfield, (Ed.), *Children's writing: toward a process theory of the development of skilled writing* (pp. 57–81). London: JAI press.
- Berninger, V. W., Vaughan, K., Abbott, R., Begay, K., Coleman, K. B., Curtin, G., ... Graham, S. (2002). Teaching spelling and composition alone and together: Implications for the simple view of writing. *Journal of Educational Psychology*, 94(2), 291–304. <https://doi.org/10.1037//0022-0663.94.2.291>
- Besner, D., & Coltheart, M. (1979). Ideographic and alphabetic processing in skilled reading of English. *Neuropsychologia*, 17(5), 467–472.

- Bishop, D. V. M., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different? *Psychological Bulletin*, 130(6), 858–886.
<https://doi.org/10.1037/0033-2909.130.6.858>
- Blachman, B. A. (2000) Phonological awareness. In M.L. Kamil, P. Mosenthal, D. Pearson, & R. Barr. (Eds.) *Handbook of Reading Research*, (pp.403-417) Routledge Handbooks Online.
<https://doi.org/10.4324/9781410605023.ch27>
- Bosse, M., Chaves, N., Largy, P., & Valdois, S. (2015). Orthographic learning during reading: The role of whole-word visual processing. *Journal of Research in Reading*, 38(2), 141–158.
<https://doi.org/10.1111/j.1467-9817.2012.01551.x>
- Bourdin, B., & Fayol, M. (2002). Even in adults, written production is still more costly than oral production. *Journal of International Psychology*, 37(4), 1–18.
- Breadmore, H. L., & Deacon, S. H. (2019). Morphological processing before and during children’s spelling. *Scientific Studies of Reading*, 23(2), 178–191.
<https://doi.org/10.1080/10888438.2018.1499745>
- Brosnan, M., Demetre, J., Hamill, S., Robson, K., Shepherd, H., & Cody, G. (2002). Executive functioning in adults and children with developmental dyslexia, *Neuropsychologia* 40, 2144–2155.
- Brysbaert, M., & Ellis, A. W. (2016). Aphasia and age of acquisition: are early-learned words more resilient? *Aphasiology*, 30(11), 1240–1263.
<https://doi.org/10.1080/02687038.2015.1106439>
- Bui, D. C., Myerson, J., & Hale, S. (2013). Note-taking with computers: Exploring alternative strategies for improved recall. *Journal of Educational Psychology*, (2), 299–309.
<https://doi.org/10.1037/a0030367>
- Bullinaria, J. (1994). Connectionist modelling of spelling. *Proceedings of the Sixteenth Annual Conference of the Cognitive Science Society*, 78–83.
- British Dyslexia Association. (n.d.). About us. Retrieved July 2019, from
<http://www.bdadyslexia.org.uk/about>
- Caramazza, A., Miceli, G., Villa, G., & Romani, C. (1987). The role of the graphemic buffer in spelling: evidence from a case of acquired dysgraphia. *Cognition*, 26(1), 59–85.
[https://doi.org/10.1016/0010-0277\(87\)90014-X](https://doi.org/10.1016/0010-0277(87)90014-X)
- Catts, H. W., Adlof, S. M., Hogan, T. P., & Weismer, S. E. (2005). Are specific language impairment and dyslexia distinct disorders? *Journal of Speech Language and Hearing Research*, 48(6), 1378-1396. [https://doi.org/10.1044/1092-4388\(2005/096\)](https://doi.org/10.1044/1092-4388(2005/096))
- Chenoweth, N. A., & Hayes, J. R. (2001). Fluency in writing - generating text in L1 and L2. *Written Communication*, 18(1), 80–98.
- Chenoweth, N. A., & Hayes, J. R. (2003). The inner voice in writing. *Written Communication*, 20(1), 99–118. <https://doi.org/10.1177/0741088303253572>

- Coleman, C., Gregg, N., McLain, L., & Bellair, L. W. (2009). A comparison of spelling performance across young adults with and without dyslexia. *Assessment for Effective Intervention*, 34(2), 94–105. <https://doi.org/10.1177/1534508408318808>
- Coltheart, M., Rastle, K., Perry, C., Langdon, R., Ziegler, J., Andrews, S., ... Ki, S. (2001). DRC : A dual route cascaded model of visual word recognition and reading aloud, *Psychological Review*, 108 (I), 204–256.
- Connelly, V., Campbell, S., MacLean, M., & Barnes, J. (2006). Contribution of lower order skills to the written composition of college students with and without dyslexia. *Developmental Neuropsychology*, 29(1), 175–196. https://doi.org/10.1207/s15326942dn2901_9
- Connelly, V., & Dockrell, J. E. (2017). Writing development and instruction for students with learning disabilities. Using diagnostic categories to study writing difficulties. In C. A. MacArthur, S. Graham, & J. Fitzgerald (Eds.), *Handbook of writing research* (2nd ed., pp. 349–368). London: The Guilford Press.
- Connelly, V., Dockrell, J. E., Walter, K., & Critten, S. (2012). Predicting the quality of composition and written language bursts from oral language, spelling, and handwriting skills in children with and without specific language impairment. *Written Communication*, 29(3), 278–302. <https://doi.org/10.1177/0741088312451109>
- Connelly, V., Gee, D., & Walsh, E. (2007). A comparison of keyboarded and handwritten compositions and the relationship with transcription speed. *The British Journal of Educational Psychology*, 77, 479–492. <https://doi.org/10.1348/000709906X116768>
- Crivelli, V. (2013). Using Technology to support Dyslexic pupils, *The British Dyslexia Association New Technologies Committee*, 1–8.
- Crossley, S. A., Cai, Z., & McNamara, D. (2012). Syntagmatic, Paradigmatic, and Automatic N-gram Approaches to Assessing Essay Quality. *Proceedings of the Twenty-Fifth International Florida Artificial Intelligence Research Society Conference*, 214–219.
- Crossley, S. A., & McNamara, D. S. (2011). Understanding expert ratings of essay quality: Coh-Metrix analyses of first and second language writing. *International Journal of Continuing Engineering Education and Life-Long Learning*, 21(2/3), 170. <https://doi.org/10.1504/IJCEELL.2011.040197>
- Dennis, F., Brodie, J., & Cairns, A. Y. (1998). Evaluating the use of TalksBac, a predictive communication device for nonfluent adults with aphasia. *International Journal of Language & Communication Disorders*, 33(1), 45–70. <https://doi.org/10.1080/136828298247929>
- Department for Education. (2013). The national curriculum in England: Framework for keystages 1 to 4. Retrieved August 2019, from <https://www.gov.uk/government/collections/national-curriculum>
- Dickman, E. (2017). Do We Need a New Definition of Dyslexia? Retrieved February 2019, from <https://dyslexiaida.org/do-we-need-a-new-definition-of-dyslexia/>

- Dockrell, J. E., Lindsay, G., Connelly, V., & Mackie, C. (2007). Constraints in the Production of Written Text in Children With Specific Language Impairments. *Council for Exceptional Children.*, 73(2), 147–164.
- Draffan, E. A., James, A., Cudd, P., & Bentley, C. (2015). Barriers and Facilitators to Uptake of Assistive Technologies: Summary of a Literature Exploration. *Studies in Health Technology and Informatics*, 217, 350–356. <https://doi.org/10.3233/978-1-61499-566-1-350>
- Dragon Speech Recognition Software. (n.d.). Nuance Communications, Inc. Retrieved April 2019, from <https://www.nuance.com/en-gb/dragon.html>
- Dyslex.io (2017): Assistive Technology. Retrieved April 2019, from <http://dyslex.io/over-16-assistive-technology>
- Educational Testing Service. (2010). Graduate Record Examinations, Overview of the Analytical Writing Section. Retrieved March 2019, from https://www.ets.org/gre/revised_general/prepare/analytical_writing/
- Educational Testing Service. (2018). *GRE Reliability and Standard Error of Measurement*. Retrieved March 2019, from https://www.ets.org/s/gre/pdf/gre_guide_reliability_sem.pdf
- Educational Testing Service. (2019). Scoring Guide for the Issue Task. Retrieved March, 2019, from https://www.ets.org/gre/revised_general/prepare/analytical_writing/issue/scoring_guide
- Elliot, J. G., & Grigorenko, E. L. (2014). *The Dyslexia Debate*. New York: Cambridge University Press.
- Elliott, C. D., Smith, P., & McCulloch, K. (1996). *British Ability Scales*. London: Nelson.
- Ellis, A. W. (2016). *Reading, writing and dyslexia: A cognitive analysis*. Routledge
- Faccioli. (2008). Poor readers but compelled to read : Stroop effects in developmental dyslexia, 14:3, 277-283, DOI: 10.1080/09297040701290040
- Facoetti, A., Paganoni, P., Turatto, M., Marzola, V., & Mascetti, G. G. (2000). Visual-spatial attention in developmental dyslexia. *Cortex*, 36, 109–123. [https://doi.org/10.1016/S0010-9452\(08\)70840-2](https://doi.org/10.1016/S0010-9452(08)70840-2)
- Faigley, L., & Witte, S. (1981). Analyzing revision. *College composition and communication*, 32(4), 400-414. <https://doi.org/10.2307/356602>
- Faul, F., Erdfelder, E., Lang, A., & Buchner, A., (2007) G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods* 39: 175. <https://doi.org/10.3758/BF03193146>
- Fayol, M. L., Alamargot, D., & Berninger, V. W. (2012). Introduction to the book: From cave writers to elite scribes to professional writers to universal writers, translation is fundamental to writing. In M Fayol, D. Alamargot, & V. . Berninger (Eds.), *Translation of thought to written text while composing: Advancing theory, knowledge, research methods, tools, and applications (pp. 3-14)*. New York: Psychology Press.
- Ferretti, R. P., & Fan, Y. (2017). Argumentative writing. In *Handbook of writing research*

(second edi, pp. 301–315). New York: The Guilford Press.

- Fidalgo, R., Torrance, M., Rijlaarsdam, G., van den Bergh, H., & Lourdes Álvarez, M. (2015). Strategy-focused writing instruction: Just observing and reflecting on a model benefits 6th grade students. *Contemporary Educational Psychology*, 41, 37–50.
<https://doi.org/10.1016/j.cedpsych.2014.11.004>
- Figueredo, L., & Varnhagen, C. K. (2004). Detecting a problem is half the battle: the relation between error type and spelling performance. *Scientific Studies of Reading*, 8(4), 337–356.
<https://doi.org/10.1207/s1532799xssr0804>
- Figueredo, L., & Varnhagen, C. K. (2005). Didn't you run the spell checker? effects of type of spelling error and use of a spell checker on perceptions of the author. *Reading Psychology*, 26(4-5), 441–458. <https://doi.org/10.1080/02702710500400495>
- Figueredo, L., & Varnhagen, C. K. (2006). Spelling and grammar checkers: Are they intrusive? *British Journal of Educational Technology*, 37(5), 721–732. <https://doi.org/10.1111/j.1467-8535.2006.00562.x>
- Fitzgerald, J. (1987). Research on Revision in Writing. *Review of Educational Research*, 57(4), 481–506. <https://doi.org/10.3102/00346543057004481>
- Flower, L., & Hayes, J. R. (1980). The Cognition of Discovery : Defining a Rhetorical Problem. *College Composition and Communication*, 31(1), 21–32. <https://doi.org/10.2307/356630>
- Flower, L., & Hayes, J. R. (1981). A Cognitive Process Theory of Writing, *College Composition and Communication* 32(4), 365–387.
- Flower, L., Hayes, J. R., Carey, L., Schriver, K., & Stratan, J. (1986). Detection , Diagnosis , and the Strategies of Revision. *College Composition and Communication*, 37(1), 16–55.
<https://doi.org/10.2307/357381>
- Galbraith, D., & Torrance, M. (2004). Revision in the Context of Different Drafting Strategies. In L. Allal, L. Chanquoy, & P. Largy (Eds.), *Revision: Cognitive and Instructional Processes* (pp. 63–86). Kluwer Academic Publishers. <https://doi.org/10.1007/978-94-007-1048-1>
- Global AutoCorrect. (n.d.). LexAble. Retrieved from <https://www.lexable.com/>
- Golding, C., Sharmini, S., & Lazarovitch, A. (2014). What examiners do: what thesis students should know. *Assessment and Evaluation in Higher Education*, 39(5), 563–576.
<https://doi.org/10.1080/02602938.2013.859230>
- Goodwill Community Foundation (2019) Computer Basics – Using Accessibility Features. Retrieved April 2019, from <https://edu.gcfglobal.org/en/computerbasics/using-accessibility-features/1/>
- Graham, S., Harris, K., & Hebert, M. (2011). Informing writing: The benefits of formative assessment. *A Carnegie Corporation Time to Act report*. Washington, DC: Alliance for Excellent Education
- Grammarly. (n.d.). Grammarly Inc. Retrieved February 2019, from <https://www.grammarly.com>

- Guo, L., Crossley, S. A., & McNamara, D. S. (2013). Assessing Writing Predicting human judgments of essay quality in both integrated and independent second language writing samples : A comparison study. *Assessing Writing*, 18(3), 218–238.
<https://doi.org/10.1016/j.asw.2013.05.002>
- Hacker, D. J., Plumb, C., Butterfield, E. C., Quathamer, D., & Heineken, E. (1994). Text Revision : Detection and Correction of Errors, *Journal of Educational Psychology*, 86(1), 65–78.
- Hanov, S. (2011) Fast and Easy Levenshtein distance using a Trie. Retrieved from
<http://stevehanov.ca/blog/?id=114>
- Hari, R., & Renvall, H. (2001). Impaired processing of rapid stimulus sequences in dyslexia, *Trends in cognitive sciences*, 5(12), 525–532.
- Hari, R., Valta, M., & Uutela, K. (1999). Prolonged attentional dwell time in dyslexic adults. *Neuroscience Letters*, 271(3), 202–204.
- Hatcher, J., Snowling, M. J., & Griffiths, Y. M. (2002). Cognitive assessment of dyslexic students in higher education, *British Journal of Educational Psychology*, 72, 119–133.
- Hayes, J. R. (1996). A new framework for understanding cognition and affect in writing. In C. M. Levy & S. Ransdell (Eds.), *The science of writing: Theories, methods, individual differences, and applications* (pp. 1-27). Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc
- Hayes, J. R. (2004). What Triggers Revision? *Revision: Cognitive and Instructional Processes*, 13, 9–20. https://doi.org/10.1007/978-94-007-1048-1_2
- Hayes, J.R. (2009) From idea to text. In D.Myhill (Ed.), *The Sage handbook of writing development*. (65-79), London: SAGE Publications.
- Hayes, J. R. (2012). Evidence from language bursts, revision, and transcription for translation and its relation to other writing processes. In Michel Fayol, D. Alamargot, & V. W. Berninger (Eds.), *Translation of thought to written text while composing: Advancing theory, knowledge, research methods, tools, and applications*. New York: Psychology Press. (15–25). New York: Taylor & Francis.
- Hayes, J. R., & Berninger, V. W. (2014). Cognitive processes in writing. A framework. In B. Arfe, J. Dockrell, & V. W. Berninger (Eds.), *Writing development in children with hearing loss, dyslexia or oral language problems* (pp. 3–15). New York: Oxford University Press.
- Hayes, J. R., & Chenoweth, N. A. (2006). Is working memory involved in the transcribing and editing of texts? *Written Communication*, 23(2), 135–149.
<https://doi.org/10.1177/0741088306286283>
- Hayes, J. R., & Chenoweth, N. A. (2007). Working memory in an Editing Task. *Written Communication*, 24(4) <https://doi.org/10.1177/0741088307304826>
- Hayes, J. R., Flower, L., Schriver, K., Stratman, J., & Carey, L. (1987). Cognitive processes in

- revision. In S. Rosenberg (Ed.), *Reading, Writing, and language processes* (pp. 176–240). Cambridge: Cambridge.
- Henik, A., & Tzelgov, J. (1982). Is three greater than five: The relation between physical and semantic size in comparison tasks. *Memory & Cognition*, 10(4), 389–395.
<https://doi.org/10.3758/BF03202431>
- Higher Education Statistics Agency (2018) Higher Education Student Enrolments. Retrieved July 2019, from <https://www.hesa.ac.uk/data-and-analysis>
- Hiscox, L., Leonavičiute, E., & Humby, T. (2014). The effects of automatic spelling correction software on understanding and comprehension in compensated dyslexia: Improved recall following dictation. *Dyslexia*, 20(3), 208–224.
- Houghton, G., & Zorzi, M. (2003). Normal and Impaired Spelling in a Connectionist Dual-Route Architecture. *Cognitive Neuropsychology*, 20(2), 115–162.
<https://doi.org/10.1080/02643290242000871>
- Huck, S. W., & Bounds, W. G. (1972). Essay Grades: An Interaction Between Graders' Handwriting Clarity and the Neatness of Examination Papers. *American Educational Research Journal*, 9(2), 279–283. <https://doi.org/10.3102/00028312009002279>
- Hulme, C., & Snowling, M. J. (2009). *Developmental Disorders of Language Learning and Cognition*. Oxford: Blackwell Publishing.
- Jacobs, J. R. (1982). Finding words that sound alike. The Soundex algorithm. *Byte*, 7(3): 473–4.
- Jacobs, K., Foley, G., Punnet, L., Hall, V., Gore, R., Brownson, E.,...Ing, A. (2011). University students' notebook computer use: lessons learned using e-diaries to report musculoskeletal discomfort. *Ergonomics*, 54(4), 411–411. <https://doi.org/10.1080/00140139.2011.571432>
- Jeffries, S., & Everatt, J. (2004). Working memory: Its role in dyslexia and other specific learning difficulties. *Dyslexia*, 10(3), 196–214. <https://doi.org/10.1002/dys.278>
- Johansson, V. (2009). Lexical diversity and lexical density in speech and writing: a developmental perspective. *Working Papers in Linguistics*, 53(0), 61–79.
<https://doi.org/10.7820/vli.v01.1.koizumi>
- Johnson, A. C., Wilson, J., & Roscoe, R. D. (2017). College student perceptions of writing errors, text quality, and author characteristics. *Assessing Writing*, 34, 72–87.
<https://doi.org/10.1016/j.asw.2017.10.002>
- Kamil, M. L., Mosenthal, P. B., Pearson, P. D., Barr, R., Mosenthal, P. B., Pearson, P. D., & Barr, R. (2016). *Handbook of Reading Research, Volume III*. Routledge.
<https://doi.org/10.4324/9781315200613>
- Kandel, S., & Perret, C. (2015). How does the interaction between spelling and motor processes build up during writing acquisition? *Cognition*, 136.
<https://doi.org/10.1016/j.cognition.2014.11.014>
- Kearns, D., Roeland, H., Hoeft, F., Pugh, K., & Frost, S. (2019). Neurobiology of dyslexia.

- Teaching exceptional children*, 51(3), 175–188. <https://doi.org/10.1016/j.conb.2014.09.007>
- Kellogg, R. T. (2008). Training writing skills: A cognitive developmental perspective. *Journal of Writing Research*, 1(1), 1–26. <https://doi.org/10.17239/jowr-2008.01.01.1>
- Kellogg, R. T., Olive, T., & Piolat, A. (2007). Writing and cognition: Research and applications. *Acta Psychologica*, 20, 382–397.
- King, G., & Zeng, L. (2001). Logistic Regression in Rare events Data. *Political Analysis*, (9) 137–163
- Krause, M. B. (2015). Pay Attention!: Sluggish multisensory attentional shifting as a core deficit in developmental dyslexia. *Dyslexia*, 21(4), 285–303. <https://doi.org/10.1002/dys.1505>
- Leijten, M., De Maeyer, S., & Van Waes, L. (2011). Coordinating sentence composition with error correction: A multilevel analysis. *Journal of Writing Research*, 2(3), 331–363.
- Leijten, M., Ridder, I. De, Ransdell, S., & Waes, L. Van. (2007). *The effect of errors in the text produced so far. Strategy decisions based on error span, input mode, and lexicality*. University of Antwerp, Research paper D/2007/1169/009
- Levenshtein, V. I. (1966). Binary codes capable of correcting deletions, insertions, and reversals. *Cybernetics and control theory* 10(8). <https://doi.org/citeulike-article-id:311174>
- Levy, C. M., & Ransdell, S. (1995). Is writing as difficult as it seems? *Memory & Cognition*, 23(6), 767–779. <https://doi.org/10.3758/BF03200928>
- Lindstrom, J. H. (2018). Dyslexia in the Schools: Assessment and Identification. *Teaching Exceptional Children*, 51(3), 189–200. <https://doi.org/10.1177/0040059918763712>
- Logan, G. D., & Crump, M. J. C. (2010). Cognitive illusions of authorship reveal hierarchical error detection in skilled typists. *Science*, 330(6004), 683–686. <https://doi.org/10.1126/science.1190483>
- Lovett, B. J., Lewandowski, L. J., Berger, C., & Gathje, R. A. (2010). Effects of Response Mode and Time Allotment on College Students' Writing. *Journal of College Reading and Learning*, 40(2), 64–79.
- MacArthur, C. A. (2009). Reflections on Research on Writing and Technology for Struggling Writers, *Learning Disabilities Research & Practice*, 24(2), 93–103.
- MacArthur, C. A. (2006). The effects of New Technologies on Writing and Writing Processes. In C. a MacArthur, S. Graham, & J. Fitzgerald (Eds.), *Handbook of writing research* (1st ed., pp. 248–274). New York.
- MacArthur, C. A., Graham, S., Haynes, J. B., & DeLaPaz, S. (1996). Spelling Checkers and Students with Learning Disabilities: Performance Comparisons and Impact on Spelling. *The Journal Of Special Education*, 30(1), 35–57.
- MacArthur, C. A. (1996). Using technology to enhance the writing processes of students with learning disabilities. *Journal of Learning Disabilities*, 29, 344–354. <https://doi.org/10.1177/002221949602900403>

- Madraso, J. (1993). Proofreading : Proofreading: The Skill We've Neglected to Teach, *The English Journal* 82(2), 32–41.
- Maggio, S., Chenu, F., Berc, G. B. De, Pesci, B., Lété, B., Jisa, H., & Fayol, M. (2015). Producing written noun phrases in French, *Written Language & Literacy*, 18(1), 18-24.
- Maggio, S., Lété, B., Chenu, F., Jisa, H., & Fayol, M. (2012). Tracking the mind during writing: Immediacy, delayed, and anticipatory effects on pauses and writing rate. *Reading and Writing*, 25(9), 2131–2151. <https://doi.org/10.1007/s11145-011-9348-1>
- Mapou. (2008). Comprehensive evaluation of adults with learning disabilities. In L. E. Wolf, H. E. Schreiber, & J. Wasserstein (Eds.), *Adult learning disorders. Contemporary issues* (pp. 248–273). New York: Psychology Press.
- Margolin, D. I. (1984). The neuropsychology of writing and spelling: Semantic, phonological, motor, and perceptual processes. *The Quarterly Journal of Experimental Psychology Section A : Human Experimental Psychology*, 36(3), 459–489. <https://doi.org/10.1080/14640748408402172>
- Markanday, S., Brennan, S. L., Gould, H., & Pasco, J. a. (2013). Sex-differences in reasons for non-participation at recruitment: Geelong Osteoporosis Study. *BMC Research Notes*, 6(104). <https://doi.org/10.1186/1756-0500-6-104>
- Marshall, J., & Powers, J. (1969). Writing Neatness, Composition Errors, and Essay Grades. *Journal of Eudcational Measurement*, 6(2), 97–101.
- Maughan, B., Messer, J., Collishaw, S., Pickles, A., Snowling, M., Yule, W., & Rutter, M. (2009). Persistence of literacy problems: spelling in adolescence and at mid-life, *Journal of Child Psychology and Psychiatry* 8, 893–901. <https://doi.org/10.1111/j.1469-7610.2009.02079.x>
- McCarthy, P. M., & Jarvis, S. (2010). MTL-D, vocd-D, and HD-D: A validation study of sophisticated approaches to lexical diversity assessment. *Behavior Research Methods*, 42(2), 381–392. <https://doi.org/10.3758/BRM.42.2.381>
- McCutchen, D. (1986). Domain knowledge in development of writing ability. *Memory and Language*, (25), 431–444.
- McCutchen, D. (1996). A capacity theory of writing: Working memory in composition. *Educational Psychology Review*, 8(3), 299–325. <https://doi.org/10.1007/BF01464076>
- McNaughton, D., Hughes, C., & Clark, K. (1997). The effect of five proofreading with learning disabilities. *Journal of Learning Disabilities*, 30(6), 643–651.
- Medimorec, S., & Risko, E. (2017). Pauses in written composition : on the importance of where writers pause. *Reading and Writing*, 30(6), 1267–1285. <https://doi.org/10.1007/s11145-017-9723-7>
- Medincle Limited [software] <https://www.medincle.com/>
- Microsoft (no date) Turn spellcheck on or off. Retrieved March 2019, from

<https://support.office.com/en-GB/article/Turn-spell-check-on-or-off-e2805461-77d4-4832-b006-061163c8d01a>

- Mirault, J., Snell, J., & Grainger, J. (2019). Reading without spaces: The role of precise letter order. *Attention, Perception, & Psychophysics*, 81(3), 846–860.
<https://doi.org/10.3758/s13414-018-01648-6>
- Mishra, R. K. (2015). *Interaction between Attention and Language Systems in Humans*. Springer India. <https://doi.org/10.1007/978-81-322-2592-8>
- Mitton, R. (1987). Spelling checkers, spelling correctors and the misspellings of poor spellers. *Information Processing and Management*, 23(5), 495–505. [https://doi.org/10.1016/0306-4573\(87\)90116-6](https://doi.org/10.1016/0306-4573(87)90116-6)
- Mogey, N., Cowan, J., Paterson, J., & Purcell, M. (2012). Students' choices between typing and handwriting in examinations. *Active Learning in Higher Education*, 13 (2), 117–128
- Mogey, N., & Fluck, A. (2015). Factors influencing student preference when comparing handwriting and typing for essay style examinations. *British Journal of Educational Technology*, 46(4), 793–802. <https://doi.org/10.1111/bjet.12171>
- Mogey, N., Paterson, J., Burk, J., & Purcell, M. (2010). Typing compared with handwriting for essay examinations at university: letting the students choose. *Research in Learning Technology*, 18(1), 29–47. <https://doi.org/10.1080/09687761003657580>
- Mogey, N., Sarab, G., Haywood, J., Van Heyningen, S., Dewhurst, D., Hounsell, D., & Neilson, R. (2008). The end of handwriting? Using computers in traditional essay examinations. *Journal of Computer Assisted Learning*, 24(1), 39–46. <https://doi.org/10.1111/j.1365-2729.2007.00243.x>
- Morken, F., & Helland, T. (2013). Writing in dyslexia: Product and process. *Dyslexia*, 19(3), 131–148. <https://doi.org/10.1002/dys.1455>
- Morphy, P., & Graham, S. (2012). Word processing programs and weaker writers/readers: A meta-analysis of research findings. *Reading and Writing*, 25(3), 641–678.
<https://doi.org/10.1007/s11145-010-9292-5>
- Mortimore, T., & Crozier, W. R. (2006). Dyslexia and difficulties with study skills in higher education, *Studies in Higher Education* 31(2), 235–251.
<https://doi.org/10.1080/03075070600572173>
- Moss, G., & Washbrook, L. (2016). *Understanding the Gender Gap in Literacy and Language Development Language Development*. University of Bristol, Bristol working papers in education No. 01/2016. Retrieved February 2019, from
<https://www.bristol.ac.uk/education/research/publications>
- Myhill, D., & Jones, S. (2007). More Than Just Error Correction. *Written Communication*, 24(4), 323–343. <https://doi.org/10.1177/0741088307305976>
- Nergård-nilssen, T., & Hulme, C. (2014). Developmental Dyslexia in Adults : Behavioural

- Manifestations and Cognitive Correlates, *Dyslexia*, 207, 191–207.
<https://doi.org/10.1002/dys.1477>
- Newell, A. F., Booth, L., & Beattie, W. (1991). Predictive text entry with PAL and children with learning difficulties. *British Journal of Educational Technology*, 22(1), 23–40.
<https://doi.org/10.1111/j.1467-8535.1991.tb00049.x>
- Niles-campbell, N., Tam, C., Mays, J., & Skidmore, G. (2008). Understanding the development of keyboarding skills in children with fine motor difficulties. *Occupational Therapy Now*, 10(august), 13–15.
- O'Rourke, L., Connelly, V., & Barnett, A. L. (2018). Understanding Writing Difficulties through a Model of the Cognitive Processes Involved in Writing. In B. Miller, P. McCardle, V. Connelly (Eds.) *Studies in writing, Writing Development in Struggling Writers* (pp.11–28).
- Olinghouse, N. G., & Wilson, J. (2013). The relationship between vocabulary and writing quality in three genres. *Reading and Writing*, 26(1), 45–65. <https://doi.org/10.1007/s11145-012-9392-5>
- Olive, T. (2014). Toward a parallel and cascading model of the writing system: A review of research on writing processes coordination. *Journal of Writing Research*, 6(2), 173–194.
<https://doi.org/10.17239/jowr-2014.06.02.4>
- Olive, T., Alves, R. A., & Castro, S. L. (2009). Cognitive processes in writing during pause and execution periods. *European Journal of Cognitive Psychology*, 21(5), 758–785.
<https://doi.org/10.1080/09541440802079850>
- Olive, T., Favart, M., Beauvais, C., & Beauvais, L. (2009). Children's cognitive effort and fluency in writing: Effects of genre and of handwriting automatisations. *Learning and Instruction*, 19(4), 299–308. <https://doi.org/10.1016/j.learninstruc.2008.05.005>
- Olive, T., & Kellogg, R. T. (2002). Concurrent activation of high- and low-level production processes in written composition. *Memory & Cognition*, 30(4), 594–600.
<https://doi.org/10.3758/BF03194960>
- Olive, T., & Passerault, J. M. J.-M. (2012). The Visuospatial Dimension of Writing. *Written Communication*, 29(3), 326–344. <https://doi.org/10.1177/0741088312451111>
- Oxford Brookes University (2019) Supporting Students with Dyslexia. Retrieved April 2019 from <https://www.brookes.ac.uk/staff/human-resources/equality-diversity-and-inclusion/guides-to-support-inclusive-teaching-and-learning/dyslexia/>
- Pallant, J. (2013). *SPSS survival manual* (1st ed.). Open University Press McGraw-hill Education.
- Parker, A. J., Slattery, T. J., & Kirkby, J. A. (2019). Return-sweep saccades during reading in adults and children. *Vision Research*, 155, 35–43.
<https://doi.org/10.1016/j.visres.2018.12.007>
- Payne, J. S., & Tainturier, M.-J. (2018). tDCS Facilitation of Picture Naming: Item-Specific, Task General, or Neither? *Frontiers in Neuroscience*, 12, 549.

<https://doi.org/10.3389/fnins.2018.00549>

- Pedler, J. (2001). Computer spellcheckers and dyslexics-a performance survey. *British Journal of Educational Technology*, 32(1), 23–37. <https://doi.org/10.1111/1467-8535.00174>
- Perry, C., Zorzi, M., & Ziegler, J. C. (2019). Understanding Dyslexia Through Personalized Large-Scale Computational Models. *Psychological Science*, 095679761882354. <https://doi.org/10.1177/0956797618823540>
- Pickering, S. J. (2006). Working memory in dyslexia. In T. Packiam Alloway & S. E. Gathercole (Eds.), *Working Memory and Neurodevelopmental Disorders* (1st ed., pp. 7–40). Sussex: Psychology Press.
- Pilotti, M., Maxwell, K., & Chodorow, M. (2006). Does the Effect of Familiarity on Proofreading Change With Encoding Task and Time ? *The Journal of General Psychology*, 3(133), 287–299. <https://doi.org/10.3200/GENP.133.3.287-299>
- Piolat, A. (1991). Effects of word processing on text revision. *Language and Education*, 5(4), 255–272. <https://doi.org/10.1080/09500789109541314>
- Piolat, A., Roussey, J.-Y., Olive, T., & Amada, M. (2004). Processing Time and Cognitive Effort in Revision : Effects of Error Type and of Working Memory Capacity. In *Linguistic forms at the writing process-product interface: discourse routines and cognitive entrenchment*. Kluwer Academic Publishers. <https://doi.org/10.1007/978-94-007-1048-1>
- Piolat, A., Roussey, J.-Y., & Thunin, O. (1997). Effect of screen presentation on text reading and revising. *International Journal of Human-Computer Studies*. *International Journal of Human-Computer Studies*, 47, 565–589.
- Pollock, J. J., & Zamora, A. (1983). Collection and characterization of spelling errors in scientific and scholarly text. *Journal of the American Society for Information Science*, 34(1), 51–58. <https://doi.org/10.1002/asi.4630340108>
- Prunty, M., & Barnett, A. L. (2017). Understanding handwriting difficulties: A comparison of children with and without motor impairment. *Cognitive Neuropsychology*, 34(3–4), 205–218. <https://doi.org/10.1080/02643294.2017.1376630>
- Prunty, M., Barnett, A. L., Wilmot, K., & Plumb, M. S. (2014). An examination of writing pauses in the handwriting of children with Developmental Coordination Disorder. *Research in Developmental Disabilities*, 35(11), 2894–2905. <https://doi.org/10.1016/j.ridd.2014.07.033>
- Quinlan, T., Loncke, M., Leijten, M., & Van Waes, L. (2012). Coordinating the cognitive processes of writing: The role of the monitor. *Written Communication*, 29(3), 345–368. <https://doi.org/10.1177/0741088312451112>
- Rapp, B., Epstein, C., & Tainturier, M. J. (2002). The integration of information across lexical and sublexical processes in spelling. *Cognitive Neuropsychology*, 19(1), 1–29. <https://doi.org/10.1080/0264329014300060>
- Rayner, K. (2009). The 35th Sir Frederick Bartlett Lecture: Eye movements and attention in

- reading , scene perception , and visual search. *The Quarterly Journal of Experimental Psychology*: <https://doi.org/10.1080/17470210902816461>
- Rezaei, A. R., & Lovorn, M. (2010). Reliability and validity of rubrics for assessment through writing. *Assessing Writing*, 15(1), 18–39. <https://doi.org/10.1016/j.asw.2010.01.003>
- Richardson, J. T. E. (2009). The academic attainment of students with disabilities in UK higher education. *Studies in Higher Education*, 34(2), 123–137. <https://doi.org/10.1080/03075070802596996>
- Richardson, J. T. E., & Wydell, T. N. (2003). The representation and attainment of students with a visual impairment in higher education. *Reading and Writing: An Interdisciplinary Journal*, 16, 475–503. <https://doi.org/10.1177/026461960202000107>
- Riddick, B., Sterling, C., Farmer, M., & Morgan, S. (1999). Self-esteem and anxiety in the educational histories of adult dyslexic students. *Dyslexia*, 5(4), 227–248.
- Ridsdale, J. (2005). Dyslexia and Self-Esteem. In Turner & Rack (Eds.), *The Study of Dyslexia* (pp. 249–279). New York: Kluwer Academic Publishers. https://doi.org/10.1007/0-306-48534-6_10
- Robertson, G., & Wilkinson, G. (2006). Wide Range Achievement Test, Fourth Edition (WRAT-4). Pearson Clinical.
- Ronneberg, V., Johansson, C., Mossige, M., Torrance, M., & Uppstad, P. H. (2018). Why bother with writers? Towards “good enough” technologies for supporting individuals with dyslexia. In B. Miller, P. McCardle, & V. Connelly (Eds.), *Studies in writing, Writing Development in Struggling Writers* (pp. 120–140). Brill.
- Rose, J. (2009). *Identifying and teaching children and young people with dyslexia and literacy difficulties: An independent report from Sir Jim Rose to the secretary of state for children, schools and families*. Department for Children, Schools and Families.
- Rosenblum, S., Epsztein, L., & Josman, N. (2008). Handwriting performance of children with attention deficit hyperactive disorders: A pilot study. *Physical and Occupational Therapy in Pediatrics*, 28(3), 219–234. <https://doi.org/10.1080/01942630802224934>
- Rumelhart, D. E., & McClelland, J. L. (1986). The appeal of parallel distributed processing. Parallel Distributed Processing. Explorations in the Microstructure of Cognition, in J.A.Feldman, P.J. Hayes & D.E. Rumelhart (Eds.). *Computational Models of Cognition and Perception*. (pp.110-146). The MIT Press
- Scardamalia, M., & Bereiter, C. (2006). Knowledge Building : Theory, Pedagogy , and Technology, In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences*. New York: Cambridge University Press. The MIT Press Cambridge.
- Seidenberg, M. S. (2005). Connectionist Models of Word Reading. *Current Directions in Psychological Science*, 14(5), 238–242. <https://doi.org/10.1007/978-1-4939-2993-1>
- Seidenberg, M. S. (2007). Connectionist models of reading. In G.Gaskell (Ed.) *The Oxford*

- Handbook of Psycholinguistics*, (pp.235–250). Oxford University Press.
- Shanahan, T. (2017). Relationships between reading and writing development. In C. A. MacArthur, S. Graham, & J. Fitzgerald (Eds.), *Handbook of writing research* (2nd ed., pp. 194–210). London: The Guilford Press.
- Shelton, J., & Weinrich, M. (1997). Further evidence of a dissociation between output phonological and orthographic lexicons: A case study. *Cognitive Neuropsychology*, 14(1), 105–129. <https://doi.org/10.1080/026432997381637>
- Smith-Spark, J. H., Henry, L. A., Messer, D. J., Edvardsdottir, E., & Ziecik, A. P. (2016). Executive functions in adults with developmental dyslexia. *Research in Developmental Disabilities*, 53–54, 323–341. <https://doi.org/10.1016/j.ridd.2016.03.001>
- Smith, W. G. (2008). Does gender influence online survey participation? A record-linkage analysis of university faculty online survey response behavior. *Eric Ed501717*, 1–21. <https://doi.org/10.1017/CBO9781107415324.004>
- Snell, J., & Grainger, J. (2017). The sentence superiority effect revisited spatial attention and reading view project parallel orthographic processing and sentence reading *Cognition*. 168, 217-221
- Snowling, M. J. (2012). Early identification and interventions for dyslexia: A contemporary view. *Journal of Research in Special Educational Needs*, 13(1), 7–14. <https://doi.org/10.1111/j.1471-3802.2012.01262.x>
- Snowling, M. J., Nash, H. M., Gooch, D. C., Hayiou-Thomas, M. E., & Hulme, C. (2019). Developmental outcomes for children at high risk of dyslexia and children with developmental language disorder. *Child Development*, 00(0), 1–17. <https://doi.org/10.1111/cdev.13216>
- Sommers, N. (1980). Revision strategies of student writers and experienced adult writers. *College Composition and Communication*, 31(4), 378–388.
- Strömquist, S., Johansson, V., Kriz, S., Ragnarsdóttir, H., Aisenman, R., & Ravid, D. (2002). Toward a cross-linguistic comparison of lexical quanta in speech and writing. *Written Language & Literacy*, 5(1), 45–67. <https://doi.org/10.1075/wll.5.1.03str>
- Stroop, J. R. (1935). Studies of interference. *Journal of Experimental Psychology*, 18(6), 643–662. <https://doi.org/10.1037/h0054651>
- Sumner, E., & Connelly, V. (2020). Writing and revision strategies of students with and without dyslexia. *Journal of Learning Disabilities*. <https://doi.org/10.1177/0022219419899090>
- Sumner, E., Connelly, V., & Barnett, A. L. (2012). Children with dyslexia are slow writers because they pause more often and not because they are slow at handwriting execution. *Reading and Writing*, <https://doi.org/10.1007/s11145-012-9403-6>
- Sumner, E., Connelly, V., & Barnett, A. L. (2014). The influence of spelling ability on handwriting production: children with and without dyslexia. *Journal of Experimental*

Psychology: Learning, Memory , and Cognition, 40(5), 1441–1447.

- Sumner, E., Connelly, V., & Barnett, A. L. (2016). The Influence of Spelling Ability on Vocabulary Choices When Writing for Children With Dyslexia. *Journal of Learning Disabilities*, 49(3), 293–304. <https://doi.org/10.1177/0022219414552018>
- Swanson, L. (2006). Working memory and reading disabilities Both phonological and executive processing deficits are important. In T. Alloway & S. Gathercole (Eds.), *Working Memory and Neurodevelopmental Disorders* (1st ed., pp. 59–88). New York: Psychology Press.
- Tainturier, M. J., & Rapp, B. (2003). Is a single graphemic buffer used in reading and spelling? *Aphasiology*, 17(6–7), 537–562. <https://doi.org/10.1080/02687030344000021>
- The British Dyslexia Association New Technologies Committee (2015) BDA Technology, Spell checkers. Retrieved March 2019, from. <https://bdatech.org/what-technology/spell-checkers/>
- The Dyslexia Association (2019) Adults with Dyslexia. Retrieved April 2019, from <https://www.dyslexia.uk.net/adults-with-dyslexia/>
- Tops, W., Callens, C., van Cauwenberghe, E., Adriaens, J., & Brysbaert, M. (2013). Beyond spelling: The writing skills of students with dyslexia in higher education. *Reading and Writing*, 26(5), 705–720. <https://doi.org/10.1007/s11145-012-9387-2>
- Tops, W., Callens, M., Lammertyn, J., van Hees, V., & Brysbaert, M. (2012). Identifying students with dyslexia in higher education. *Annals of Dyslexia*, 62(3), 186–203. <https://doi.org/10.1007/s11881-012-0072-6>
- Torrance, M. (2017). Understanding planning in text production. In C. A. MacArthur, S. Graham, & J. Fitzgerald (Eds.), *Handbook of writing research* (2nd ed., pp. 72–87). London: The Guilford Press.
- Torrance, M., Rønneberg, V., Johansson, C., & Uppstad, P. H. (2016). Adolescent Weak Decoders Writing in a Shallow Orthography: Process and Product. *Scientific Studies of Reading*, 20(5), 375–388. <https://doi.org/10.1080/10888438.2016.1205071>
- Torrance, M., Thomas, G., & Robinson, E. (2000). Individual differences in undergraduate essay-writing strategies: a longitudinal study. *Higher Education*, 39(2), 181–200.
- Torruella, J., & Capsada, R. (2013). Lexical Statistics and Tipological Structures: A Measure of Lexical Richness. *Procedia - Social and Behavioral Sciences*, 95, 447–454. <https://doi.org/10.1016/j.sbspro.2013.10.668>
- Treiman, R., & Kessler, B. (2006). Spelling as statistical learning: Using Consonantal context to Spell Vowels. *Journal of Educational Psychology* 98(3) 642-652
- Valdois, S., Bosse, M. L., & Tainturier, M.-J. (2004). The cognitive deficits responsible for developmental dyslexia: review of evidence for a selective visual attention disorder. *Dyslexia*, 339–363. <https://doi.org/10.1002/dys.284>
- van Galen, G. P. (1991). Handwriting: Psychomotor issues for a theory. *Human Movement Science*, 10, 165–191.

- van Heuven, W. J. B., Mandera, P., Keuleers, E., & Brysbaert, M. (2013). SUBTLEX-UK: A new and improved word frequency database for British English. *The Quarterly Journal of Experimental Psychology*, 67(6), 1–36.
<https://doi.org/https://doi.org/10.1080/17470218.2013.850521>
- van Waes, L., Leijten, M., & Quinlan, T. (2010). Reading during sentence composing and error correction: A multilevel analysis of the influences of task complexity. *Reading and Writing*, 23(7), 803–834. <https://doi.org/10.1007/s11145-009-9190-x>
- VeritySpell [Computer software]. (n.d.). Oribi. Retrieved from
<https://oribisoftware.com/en/verityspell/>
- Warmington, M., Stothard, S. E., & Snowling, M. J. (2012). Assessing dyslexia in higher education: The York adult assessment battery-revised. *Journal of Research in Special Educational Needs*, 13(1), 48–56. <https://doi.org/10.1111/j.1471-3802.2012.01264.x>
- Wengelin, Å. (2002). Text production in adults with reading and writing difficulties *Gothenburg Monographs of Linguistics*, 20, 6–8.
- Wengelin, Å. (2007). The word-level focus in text production by adults with reading and writing difficulties. In *Writing and cognition : Research and applications* (pp. 67–82). Elsevier.
- Wengelin, Å., Torrance, M., Holmqvist, K., Simpson, S., Galbraith, D., Johansson, V., & Johansson, R. (2009). Combined eyetracking and keystroke-logging methods for studying cognitive processes in text production. *Behavior Research Methods*, 41(2), 337–351.
<https://doi.org/10.3758/BRM.41.2.337>
- Wiseheart, R., & Altmann, L. J. P. (2018). Spoken sentence production in college students with dyslexia: working memory and vocabulary effects. *International Journal of Language and Communication Disorders*, 53(2), 355–369. <https://doi.org/10.1111/1460-6984.12353>
- Wolman, D. (2010). Spelling Fixers: Meet the inventors of spellcheck. Retrieved July 2018, from
<https://schwafire.atavist.com/spellcheck>
- World Health Organisation. (2013). *The ICD-10 Classification of Mental and Behavioural Disorders. IACAPAP e-Textbook of child and adolescent Mental health* (Vol. 55).
- Yannakoudakis, E. J., & Fawthrop, D. (1983). The rules of spelling errors. *Information Processing and Management*, 19(2), 87–99.

9 Appendices

List of appendices

Appendix A: Part of the marking criteria used at Oxford Brookes University.....	241
Appendix B: The full questionnaire.....	242
Appendix C: UREC approval letter.....	257
Appendix D: Participant information text for the questionnaire study.....	258
Appendix E: Participant information sheet for study one in chapter 5 and chapter 6.....	261
Appendix F: Consent form for studies 1 and 2 in chapter 5 and for chapter 6.....	264
Appendix G: The writing prompt from YAA-R.....	265
Appendix H: Common spelling error sources (websites).....	267
Appendix I: Tables of misspellings and difficult to spell words for studies in Chapter 5.....	268
Appendix J: Participant information sheet for study 2 chapter 5.....	269
Appendix K: Essay scoring rubric.....	272

Appendix A: Part of the marking criteria used at Oxford Brookes University

Degree Class	%	Overall presentation and writing style
First	74-95	Minimal errors in spelling, punctuation and/or grammar.
and Upper Second	62-68	
Lower Second	52-58	Contains a number of errors in spelling, punctuation and/or grammar.
and Third	42-48	
Resit	35	Contains a significant number of errors in spelling, punctuation and/or grammar, some of which undermine the intended meaning.
Fail	5-25	Contains excessive spelling, punctuation and/or grammar errors that undermine the intended meaning.

Note: Marking criteria from September 2018

Appendix B: The full questionnaire.

Investigating the use of spellcheck in writing.

You are being invited to take part in a questionnaire study. To help you decide whether or not to take part, please read the following information about why the research is being done.

What is the purpose of the study?

The purpose of this study is to collect information about the use of spellcheck in writing. This study is part of a larger project investigating the impact of spellcheck on writing for writers with and without dyslexia.

Who is eligible to take part in this study?

Anyone aged 18 or over, with English as a first language is invited to take part.

Do I have to take part?

No. It is up to you to decide whether or not to take part. If you do decide to take part, please be aware that by submitting this questionnaire you are providing consent to collect this information. No information will be recorded until you submit your responses, once your responses have been submitted, it will not be possible to change or delete your response.

What will happen to me if I take part?

You will be presented with a series of questions about your academic writing practices (such as whether you use word processing or not, whether you produce drafts or not). For each of these you will need to tick the answers that most closely match your writing practices. This should take no more than 10 minutes.

What are the possible benefits and risks of taking part?

There are no specific benefits to you in taking part. However, the research will contribute to our understanding of the impact of spellcheck for writers with and without dyslexia.

If you are a student of Oxford Brookes University, either taking part or declining to do so, will have no effect on any current or future programme of studies, including assessments.

Your responses to the questions in this questionnaire do not, in any way, indicate good or bad writing practices. However, if you become concerned about your writing performance after answering the questions in the questionnaire, and you would like to talk to someone, you may contact the dyslexia and specific learning difficulties team at the Oxford Brookes University Student Centre. Their details are available from the researcher and will be provided at the end of the questionnaire. For more information about dyslexia, the websites of some UK wide dyslexia associations are also available from the researcher and will be shown on screen at the end of the questionnaire.

Will what I write in this study be kept confidential?

Yes. You will not be asked to give your name or any personal identification on any of the materials used during this questionnaire, so all the information stored will be anonymous. No personal information will be recorded by qualtrics (IP address, email address or any other identification details).

What will happen to the results of the research?

The data will be used for a PhD thesis and may form part of a published article or conference/seminar paper. They may also be used for future research on this topic. All the data collected from this research will be kept in accordance with the University's policy of Academic Integrity. This means that all data will be securely stored in paper or electronic form for a period of 10 years.

If you would like to receive a summary of the research findings then please email the principal investigator (contact details are at the end of this page) and you will be added to a mailing list. An email will be sent out at the end of this project in 2017 with a summary of the findings.

What should I do if I want to take part?

If you wish to take part, please tick the box at the end of this page to indicate that you have read and understood this information, then click on the green rectangle at the bottom right hand side of the screen.

Who is organising and funding the research?

The research is being conducted in part fulfilment of a PhD at Oxford Brookes University.

Who has reviewed the study?

This study has been approved by the University Research Ethics Committee (UREC) at Oxford Brookes University (approval number: **150958**). If you have any concerns about the way in which the study has been conducted, you can contact UREC on ethics@brookes.ac.uk.

Contact for Further Information

For further information regarding this study please contact the principal investigator or supervisor, contact details can be found below.

Principal investigator: Lynsey O'Rourke
Email: 14029556@brookes.ac.uk

Supervisor: Vince Connelly
Email vconnelly@brookes.ac.uk
Phone: 01865 484257

Supervisor: Anna Barnett
Email abarnett@brookes.ac.uk
Phone: 01865 48 3680

Department of Psychology, Social Work and Public Health,
Faculty of Health and Life Sciences

Oxford Brookes University
OX3 0BP

Thank you for taking time to read this information.

If you would like to take part in this questionnaire, please tick the box to indicate that you have read and understood this information, then click on the green rectangle at the bottom right hand side of the screen.

☐ I have read and understood this information

End of Block:

Start of Block:

By submitting this questionnaire you are providing consent for your responses to be collected. If at any point you no longer wish to take part you may leave the questionnaire and no information will be recorded unless you submit your responses. In order to record your responses you must

press submit at the end of the questionnaire. Once your responses have been submitted it will not be possible to change them.

☐

I have read and understand the above statement

For the purposes of carrying out this Survey, Oxford Brookes University uses the survey tools provided by Qualtrics with whom the University's Faculty of Health and Life Sciences holds an agreement. There is always a certain element of risk of data loss when data is collected and processed in an internet environment. This risk cannot be eliminated entirely and participants consenting to take part in the survey need to be aware of this risk. However, personal data will be minimised to the extent possible for the survey and the University believes that Qualtrics offers sufficient guarantees to keep the data secure while it is being processed. These security obligations are set out in the agreement between Qualtrics and the University.

Further information about Qualtrics can be found on the following web site: <http://qualtrics.com/>

☐

I consent to participate in this survey

End of Block:

Start of Block:

Writing with a computer typically involves using a word processor (such as Microsoft Word or Apple Pages).

When using a word processor to produce formal pieces of text (over a paragraph in length), how often do you use each of the following programs?

	Never	Occasionally	Often	Most of the time	Always
Microsoft Word	☐	☐	☐	☐	☐
Apple Pages	☐	☐	☐	☐	☐
Google Documents	☐	☐	☐	☐	☐
Lotus WordPro	☐	☐	☐	☐	☐
Adobe InCopy	☐	☐	☐	☐	☐
Other (please specify) 	☐	☐	☐	☐	☐

End of Block:

Start of Block:

‘Please think about when you construct important pieces of writing (e.g. essays, reports, proposals, formal letters, long emails) for the following questions:’

	Never	Occasionally	Often	Most of the time	Always
When writing, how often do you write a plan (short notes or bullet points) of what you will include in the text?	☐	☐	☐	☐	☐
If you write plans, how often do you write a plan using a pen and paper?	☐	☐	☐	☐	☐
If you write plans, how often do you write a plan using a word processor?	☐	☐	☐	☐	☐
How often do you write a draft (a rough version of the whole text) before writing the final text?	☐	☐	☐	☐	☐
If you write a draft, how often do you write a draft with a pen and paper?	☐	☐	☐	☐	☐
If you write a draft, how often do you write a draft with a word processor?	☐	☐	☐	☐	☐

End of Block:

Start of Block:

When you write using a word processor, why do you choose to do so rather than write using a pen and paper?

Please select all reasons which apply to you.

- ☐ The writing is expected to be produced with word a processor
- ☐ Typing is quicker than handwriting
- ☐ Typing is easier than handwriting
- ☐ Text appears neater than handwriting
- ☐ The tools in word processor are helpful (e.g. thesaurus or spellcheck)
- ☐ Text is easier to edit (e.g. it is easy to delete, move and copy text)
- ☐ The document can be accessed from different devices and locations
- ☐ The document can be shared virtually
- ☐ Other (please specify) _____

Display This Question If: "When you write using a word processor, why do you choose to do so rather than write using a pen and paper? Please select all reasons which apply to you." **Selected Choices Count Is Greater Than 1 Carry Forward Selected Choices.**

Please click and drag each of the reasons that you use a word processor and arrange them from most important at the top to least important at the bottom (1 = most important).

- _____ The writing is expected to be produced with word a processor
- _____ Typing is quicker than handwriting
- _____ Typing is easier than handwriting
- _____ Text appears neater than handwriting
- _____ The tools in word processor are helpful (e.g. thesaurus or spellcheck)

- _____ Text is easier to edit (e.g. it is easy to delete, move and copy text)
- _____ The document can be accessed from different devices and locations
- _____ The document can be shared virtually
- _____ Other (please specify) _____

End of Block:

Start of Block:

Word processors have a number of tools to aid writing. Please indicate which tools you find useful.

- ☐ Spellcheck
- ☐ Grammar check
- ☐ Synonyms/thesaurus
- ☐ Dictionary
- ☐ Tools which effect aesthetics (font, style, layout)
- ☐ Ability to insert items (images, graphs, tables)
- ☐ Other (please specify) _____

End of Block:

Start of Block:

The spellcheck function is usually active (switched on) as part of a word processor's default settings.

How often do you use spellcheck in its default settings?

	Never	Occasionally	Often	Most of the time	Always
	☐	☐	☐	☐	☐

The spellcheck settings can be altered.

Have you ever altered the spellcheck settings?

☐ Yes

☐ No

Display This Question If: “The spellcheck settings can be altered. Have you ever altered the spellcheck settings?” = Yes

Please describe the alterations that you have made to spellcheck

Display This Question If: “The spellcheck settings can be altered. Have you ever altered the spellcheck settings?” = Yes

When writing with a word processor, how often do you use these altered spellcheck settings?

	Never	Occasionally	Often	Most of the time	Always
	☐	☐	☐	☐	☐

If spellcheck is not active then spelling errors will not be recognised (underlined or highlighted) until spellcheck is activated by clicking on the spellcheck symbol.

How often do you use spellcheck so that spelling errors are only underlined/highlighted when you click the spellcheck symbol?

- ☐ Never
- ☐ Occasionally
- ☐ Often
- ☐ Most of the time
- ☐ Always

End of Block:

Start of Block:

When a spelling mistake occurs, how often do you correct it by selecting a word from the list of

When spellcheck is used in its default setting (so that spelling errors are underlined as you type), how often do you spot a spelling mistake before it becomes underlined or highlighted?

- ☐ Never
 - ☐ Occasionally
 - ☐ Often
 - ☐ Most of the time
 - ☐ Always
-
- ☐ Never
 - ☐ Occasionally
 - ☐ Often
 - ☐ Most of the time
 - ☐ Always

End of Block:

Start of Block:

For the following questions please think about when you construct important pieces of writing (e.g. essays, reports, proposals, formal letters) using spellcheck in its default settings (so that spelling errors are underlined or highlighted as you type).

Does the notification of a spelling error (e.g. the appearance of a red line) ever cause you to stop typing?

- ☐ Yes
- ☐ No
- ☐ It depends (please specify) _____

Does the notification of a spelling error (e.g. the appearance of a red line) ever disrupt your train of thought when writing?

- ☐ Yes
- ☐ No
- ☐ It depends (please specify) _____

When a spelling error occurs in your writing, how often do you correct the error as soon as you notice it?

- ☐ Never
- ☐ Occasionally
- ☐ Often
- ☐ Most of the time
- ☐ Always

After noticing a spelling error, some people continue to write before choosing to correct the error. When you notice a spelling error, how far do you usually continue to write before stopping to correct the error?

- ☐ To the end of the word
- ☐ To the end of the sentence
- ☐ To the end of the paragraph

- ☐ To the end of the whole text
- ☐ I continue to write until the thought held in my head is down in writing.
- ☐ Other (please specify) _____

End of Block:

Start of Block:

Sometimes words may be spelled correctly but become underlined as if they are wrong (this often happens for proper nouns, names, or specialist vocabulary).

Do you ever add words into the spelling dictionary so that they are recognised in the future?

- ☐ Yes
- ☐ No

End of Block:

Start of Block:

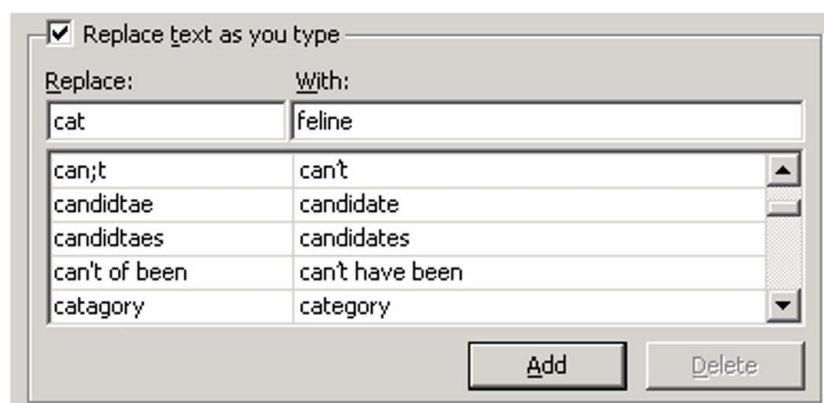
Word processors also include some AutoCorrect as standard.

For example:

teh ---> AutoCorrect ---> **the**

This is theh ouse -->AutoCorrect --->**This is the house.**

These replacements are stored in a dictionary:



This function can replace words which are mistyped (**can;t** --> **can't**) or misspelled (**catagory** --> **category**).

Writers can add their own frequently made mistakes and the replacements.

Writers can add replacements for words even when there is no mistake (**cat --> feline**).

Have you ever added any words into the AutoCorrect list of words?

☐ Yes

☐ No

Do you ever switch AutoCorrect off?

☐ Yes

☐ No

End of Block:

Start of Block:

Do you use any specialised writing software (such as text to speech software)?

☐ Yes

☐ No

Display This Question If: Do you use any specialised writing software (such as text to speech software)? = Yes

What software do you use?

End of Block:

Start of Block:

Please provide the following information about yourself.

Age

Gender

☐ Male

☐ Female

Do you consider yourself to have any disabilities which impact your reading or writing? (e.g. dyslexia or specific language impairment)

☐ Yes

☐ No

Display This Question If: Do you consider yourself to have any disabilities which impact your reading or writing? (e.g. dys... = Yes

Please specify this disability

End of Block:

Start of Block:

Are you currently a student?

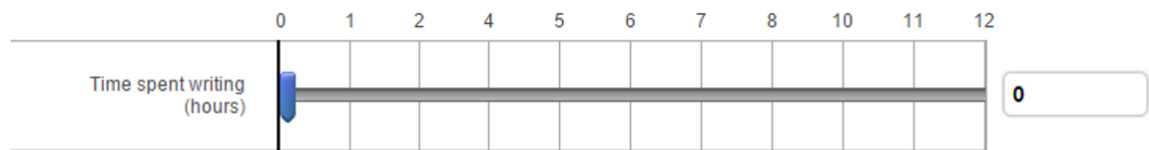
☐ Yes

☐ No

End of Block:

Start of Block:

On average, how many hours a day do you spend on tasks that include writing?
(please click drag the bar to indicate your answer)



End of Block:

Start of Block:

Display This Question If: Are you currently a student? = yes

In which course are you currently enrolled?

Display This Question If: Are you currently a student? = yes

What academic year are you currently in?

▼ 1 ... 6+

Display This Question If: Are you currently a student? = yes

Part time or full time study?

☐ Full time

☐ Part time

There are no further questions in this questionnaire.

No information will be recorded until you submit your responses, once your responses have been submitted it will not be possible to change or delete your response. If you do not wish to submit your data simply exit the questionnaire.

To submit your responses please press the green continue button in the bottom right of the screen.

When your responses have been recorded a thank you message will appear.

End of Block:

Thank you for taking part in this survey. Your contribution to this research is valued and appreciated.

If you would like more information, a summary of the findings from this research or if you wish to take part in further studies about the impact of spellcheck, please contact Lynsey O'Rourke at 14029556@brookes.ac.uk

Or visit this website: <https://sites.google.com/a/brookes.ac.uk/writing-and-dyslexia-research/home>

Your responses to the questions in this questionnaire do not, in any way, indicate good or bad writing practices. However, if you feel concerned about your writing performance, and you would like to talk to someone, you may contact the dyslexia and specific learning difficulties team at the Oxford Brookes Student Centre. Their details are below:

Disability and Dyslexia Service
Oxford Brookes University
Helena Kennedy Student Centre
Headington Hill Campus
Oxford OX3 0BP

9.00am - 5.00pm Monday to Thursday
9.00am - 4.30pm on Friday

Tel: 01865 484653
Email: dyslexiaspld@brookes.ac.uk

Alternatively please visit their website:
<https://www.brookes.ac.uk/students/wellbeing/disability-and-dyslexia-service/>

For further information about dyslexia please visit these websites of UK based dyslexia services:
The British Dyslexia Association: <http://www.bdadyslexia.org.uk>
Dyslexia Action: <http://www.dyslexiaaction.org.uk>

Appendix C: UREC approval letter



Professor Vince Connelly
Director of Studies
Department of Psychology
Faculty of Health and Life Sciences
Oxford Brookes University
Gipsy Lane
Headington

5 November 2015

Dear Professor Connelly

UREC Registration No: 150958
Programme application investigating writing behaviour in students with and without dyslexia

Thank you for the email of 26 October 2015 outlining the response to the points raised in my previous letter about the PhD study of your research student Lynsey O'Rourke and attaching the revised documents. I am pleased to inform you that, on this basis, I have given Chair's Approval for the study to begin.

The UREC approval period for this programme study is five years from the date of this letter, so 5 November 2020. If you need the approval to be extended please do contact me nearer the time of expiry.

As new sub-studies commence, please forward any updated documentation to Louise Wood for the UREC files.

Should the recruitment, methodology or data storage change from your original plans, or should any study participants experience adverse physical, psychological, social, legal or economic effects from the research, please inform me with full details as soon as possible.

Yours sincerely

A handwritten signature in blue ink, appearing to read "S Quinton", with a long horizontal flourish extending to the right.

Dr Sarah Quinton
Chair of the University Research Ethics Committee

cc Anna Barnett, Supervisory Team
Lynsey O'Rourke, Research Student
Morag MacLean, Research Ethics Officer
Jill Organ, Research Degrees Team
Louise Wood, UREC Administrator



www.brookes.ac.uk

Appendix D: Participant information text for the questionnaire study.

Investigating the use of spellcheck in writing.

You are being invited to take part in a questionnaire study. To help you decide whether or not to take part, please read the following information about why the research is being done.

What is the purpose of the study?

The purpose of this study is to collect information about the use of spellcheck in writing. This study is part of a larger project investigating the impact of spellcheck on writing for writers with and without dyslexia.

Who is eligible to take part in this study?

This study is open to adults (aged 18+) with or without dyslexia. Please note that the study is open only to individuals who speak English as their first language.

Do I have to take part?

No. It is up to you to decide whether or not to take part. If you do decide to take part you will be directed to an anonymous web-based questionnaire. By submitting this questionnaire you are providing consent to collect this information. No information will be recorded until you submit your responses, once your responses have been submitted it will not be possible to change or delete your response.

What will happen to me if I take part?

You will be presented with a series of questions about your academic writing practices (such as whether you use word processing or not, whether you produce drafts or not). For each of these you will need to select the answers that most closely match your writing practices. This should take no more than 10 minutes.

What are the possible benefits and risks of taking part?

There are no specific benefits to you in taking part. However, the research will contribute to our understanding of the impact of spellcheck for writers with and without dyslexia.

If you are a student of Oxford Brookes University, either taking part or declining to do so, will have no effect on any current or future programme of studies, including assessments.

Your responses to the questions in this questionnaire do not, in any way, indicate good or bad writing practices. However, if you become concerned about your writing performance after answering the questions in the questionnaire, and you would like to talk to someone, you may contact the dyslexia and specific learning difficulties team at the Oxford Brookes University Student Centre. Their details are available from the researcher and will be provided at the end of the questionnaire. For support or for more information about dyslexia please visit these websites of some UK wide dyslexia associations:

The British Dyslexia Association: <http://www.bdadyslexia.org.uk>

Dyslexia Action: <http://www.dyslexiaaction.org.uk>

Will what I write in this study be kept confidential?

Yes. You will not be asked to give your name or any personal identification on any of the materials used during this questionnaire, so all the information stored will be anonymous. No personal information will be recorded (IP address, email address or any other identification details).

What will happen to the results of the research?

The data will be used for a PhD thesis and may form part of a published article or conference/seminar paper. They may also be used for future research on this topic. All the data collected from this research will be kept in accordance with the University's policy of Academic Integrity. This means that all data will be securely stored in paper or electronic form for a period of 10 years.

If you would like to receive a summary of the research findings then please email the principal investigator (contact details are at the end of this page) and you will be added to a mailing list. An email will be sent out at the end of this project in 2017 with a summary of the findings.

What should I do if I want to take part?

If you wish to take part, please click the link provided in the email that this information sheet was sent with.

Who is organising and funding the research?

The research is being conducted in part fulfilment of a PhD at Oxford Brookes University.

Who has reviewed the study?

This study has been approved by the University Research Ethics Committee (UREC) at Oxford Brookes University (approval number: **150958**). If you have any concerns about the way in which the study has been conducted, you can contact UREC on ethics@brookes.ac.uk.

Contact for further information

For further information regarding this study please contact the principal investigator or supervisor, contact details can be found above.

Thank you for taking time to read this information.

Principal investigator: Lynsey O'Rourke

Email: 14029556@brookes.ac.uk



Supervisors: Vince Connelly, Email vconnelly@brookes.ac.uk, Tel: 01865 484257

Anna Barnett, Email abarnett@brookes.ac.uk, Tel: 01865 48 3680

Department of Psychology, Social Work and Public Health,

Faculty of Health and Life Sciences

Oxford Brookes University

OX3 0BP

Investigating the impact of spellcheck on writing behaviour in writers with and without dyslexia.

You are being invited to take part in a research study. To help you decide whether or not to take part, please read the following information about why the research is being done.

What is the purpose of the study?

Writing is an important skill in education and employment, yet some students struggle with this complex skill. A range of tools are available to assist writers but the way in which these are used and the extent to which they improve writing has not been well investigated. The purpose of this study is to determine the impact of spellcheck on writing behaviour and the quality of writing produced by writers with and without dyslexia.

Who is eligible to take part in this study?

This study is open to undergraduate students with dyslexia aged between 18 and 22. You have been invited to take part because you have expressed an interest in being a participant via email or via the Oxford Brookes University Psychology Participant Panel. Please note that the study is open only to individuals who speak English as their first language and without any difficulties which impact their reading or writing abilities other than dyslexia.

Do I have to take part?

No. It is up to you to decide whether or not to take part. If you do decide to take part you will be asked to sign a consent form and you are still free to withdraw any unprocessed data without giving a reason.

What will happen to me if I take part?

You will be invited to the Psychology rooms at Oxford Brookes University. The data collection is expected to take 75 minutes.

You will then be asked to take part in a few tasks: reading, spoonerisms, and a non-verbal ability test. These tasks are designed to indicate whether a participant shows behaviours associated with dyslexia. The scores for this will not be calculated during the experiment and so no individual feedback will be available. You will also be presented with partial sentences which need to be completed. Finally, you will be asked to write two short pieces of text using Microsoft Word expected to take 15 minutes per text.

What are the possible benefits and risks of taking part?

Either taking part or declining to do so, will have no effect on any current or future programme of studies, including assessments. The tasks involved in this study are not diagnostic tools for dyslexia. However, should you feel concerned about your performance, and you would like to talk to someone, then please contact the dyslexia and specific learning difficulties team at Oxford Brookes University Student Centre. Their details are available from the researcher and will be provided at the end of the experiment. Alternatively, to find out about national support services, or for more information about dyslexia, please visit the following websites:

The British Dyslexia Association: <http://www.bdadyslexia.org.uk>

Dyslexia Action: <http://www.dyslexiaaction.org.uk>

Please be aware that should you decide to be assessed for a dyslexia diagnosis within 3 months of taking part in this study then you may wish to make the assessor aware of which tasks you have completed as part of this study. This is just in case the assessor plans to use tests for a diagnostic assessment which are similar to the tasks completed as part of this study. You will be provided with a list of the tasks that you complete during this study which can be given to any future assessors. This research will contribute to our understanding of the impact of spellcheck for writers with and without dyslexia.

Will what I say/write in this study be kept confidential?

You will not be asked to give your name on any of the materials used during this experiment. Only the researcher and supervisors will have access to the data, which will be stored in accordance with the University's policy on Academic Integrity.

The data will be used for a PhD thesis and may form part of a published article or conference/seminar paper. The data generated in the course of the research will be kept securely. If the data is likely to be used for a publication or conference paper it may be kept for a period of ten years after the completion of the research project. Any contact details will be deleted as soon as you have taken part in the research.

What should I do if I want to take part?

If you wish to take part, please email the researcher using the contact details above. Appointments can be made for a time that suits you. If you are unable to attend an appointment it would be helpful if you could give the researcher 24 hours' notice.

Who is organising and funding the research?

The research is being conducted in part fulfilment of a PhD at Oxford Brookes University.

Who has reviewed the study?

This study has been approved by the Department of Psychology Research Ethics Committee at Oxford Brookes University. If you have any concerns about the way in which the study has been conducted, you can contact the Psychology Research Ethics Officer, Morag MacLean, at mmaclean@brookes.ac.uk.

Contact for further information

For further information regarding this study please contact the experimenter or supervisor, their contact details can be found above.

Thank you for taking time to read this information.

Lynsey O'Rourke

CONSENT FORM



Investigating the use of spellcheck in writing.

Lynsey O'Rourke, PhD Student
Oxford Brookes University
Gipsy Lane,
Headington,
Oxford.
OX3 0BP

Please initial box

I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.

☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.

☐

I agree to take part in the above study.

☐

I agree that my data gathered in this study may be stored (after it has been anonymised) in a specialist data centre and may be used for future research.

☐

Please tick box

Yes

No

I agree to the writing tasks being recorded

☐☐

Name of Participant

Date

Signature

Name of Researcher

Date

Signature

The History of Chocolate

Chocolate is now enjoyed all over the world but until the late sixteenth century it was only found in Central and South America. For years the indigenous people of Central and South America, the Aztecs and the Mayans, had been making chocolate from cacao beans and consuming it as a drink. Cacao beans carried great importance for both cultures: the Mayans considered them to be a gift from the gods and the Aztecs associated them with fertility. Both societies even used them as currency. Cacao beans were made into a chocolate drink by roasting them and adding water and chilli spice. The mixture also had medicinal purposes and was an important part of many traditional ceremonies.

Christopher Columbus was introduced to cacao and chocolate on his last journey to the Americas in 1502. He took some beans back to Spain to show the king and queen, however, they were viewed with apathy. Chocolate didn't truly arrive in Europe until 1585, when a shipment of beans came from Mexico to Spain. At this stage chocolate was still served as a drink but the Spaniards replaced the chilli with milk and sugar to sweeten the bitter taste. Cacao beans were in short supply and Spain guarded the secret of chocolate jealously. However, the luxury began to spread across the rest of Europe during the 17th century. Italy was next to appreciate chocolate and it finally arrived in England in 1650. Chocolate was only available to the wealthiest, who consumed it in fashionable 'chocolate houses', much like today's coffee shops. The first chocolate house opened in London in 1657.

Chocolate remained a beverage for almost two hundred more years. It wasn't until 1847 that Joseph Fry created the first solid chocolate bar for eating. Others followed soon after, with John Cadbury adding a chocolate bar to his range. The solid chocolate bar was based on cocoa butter, extracted from cacao beans in a method developed by the Dutch chocolate maker, Casparus van Houten in 1828. Chocolate was still dark at this point and there was not quite the selection that we have today. In 1875 Daniel Peter produced the first milk chocolate bar using powdered milk; he was assisted in his work by Henri Nestle, a name still affiliated with chocolate today.

The world continues to be obsessed with chocolate. We still love to eat chocolate, and Switzerland currently consumes the most at 10kg per person each year. Contemporary chefs not only produce chocolate based deserts and puddings but also combine sweet and savoury by adding chocolate to main course dishes, to stews, meat pies and even brussel sprouts. Modern society has also found other uses for chocolate. Chocolate face masks and chocolate massages are just some of the

inventive ways in which chocolate has been used in health spas and beauty salons! It seems that chocolate, though now far removed from that known to the Aztecs, is as relished now as it was then.

Appendix H: Common spelling error sources (websites)

Lists of commonly misspelled words (all accessed December 2015).

<https://www.tes.com/teaching-resource/commonly-misspelled-words-worksheet-6155505>

<http://grammar.yourdictionary.com/spelling-and-word-lists/misspelled.html>

<http://www.oxforddictionaries.com/words/common-misspellings>

<https://www.vocabulary.com/lists/191545>

<http://www.3plearning.com/top-10-hardest-words-spell/#>

<https://howtospell.co.uk/quizzone.php>

<http://marvin.cs.uidaho.edu/correctspell.html>

<http://blog.oxforddictionaries.com/2015/08/words-everyone-spells-wrong/>

<http://www2.sharonherald.com/herald/nie/spellb/spelllist2.html>

<http://grammar.yourdictionary.com/spelling-and-word-lists/misspelled.html>

Appendix I: Tables of misspellings and difficult to spell words for studies in Chapter 5.

Table A.1 Target word and misspellings used in Chapter 5, experiment 1 and 2.

Target Word	Misspelling
consciousness	consseousnesss
neighbourhood	neighbouthood
suspicious	suspitsous
conscientious	consciencious
successful	succeesful
occurrence	occurraace
committee	comiittee
glamorous	glammrous
necessarily	necesarily
resistant	ressitant
minuscule	minnscule
consensus	consencius
completely	compeltely
obscuring	obserring
accidentally	aciddentially
practising	practciing
beneficial	benefital
existence	exsitence
guarantee	gurrantee
politician	polittcian

Table A.2 Difficult to spell words used in Chapter 5 experiment 2.

Difficult to spell words		
anaesthetic	inoculations	Chandelier
possessions	immediately	coincidence
mischievous	Reconvene	camouflage
Equipment	Exhausted	silhouette
Ratatouille	miscellaneous	nutritious
manageable	Vinaigrette	kaleidoscope
perseverance	manoeuvres	precious
sophisticated	foreseeable	fortuitous
Playwright	mysteriously	marvellous
rhythmic	endeavour	fluorescent

Principal investigator: Lynsey O'Rourke,
lynsey.orourke-2014@brookes.ac.uk



Supervisors: Vince Connelly, Email vconnelly@brookes.ac.uk, Tel: 01865 484257
Anna Barnett, Email abarnett@brookes.ac.uk, Tel: 01865 48 3680

Department of Psychology, Social Work and Public Health,
Faculty of Health and Life Sciences
Oxford Brookes University
OX3 0BP

Investigating the impact of spellcheck on writing behaviour in writers with and without dyslexia.

You are being invited to take part in a research study. To help you decide whether or not to take part, please read the following information about why the research is being done.

What is the purpose of the study?

Writing is an important ability in education and employment. However, some students struggle with this complex skill. A range of tools are available to assist writers, but the way in which these are used and the extent to which they improve writing has not been well investigated. The purpose of this study is to determine the impact of spellcheck on writing behaviour and the quality of writing produced by writers with and without dyslexia.

Who is eligible to take part in this study?

This study is open to undergraduate students with dyslexia aged between 18 and 22. Please note that the study is open only to individuals who speak English as their first language and without any difficulties which impact their reading or writing abilities (other than dyslexia).

Due to use of the eye tracker, this study is not suitable for people with conditions which make it difficult to track the eye (such as an irregularly shaped cornea). It will not be possible to wear glasses, hard contact lenses or tinted contact lenses during the eye tracking experiment. Thus, this experiment is not suitable for those who require glasses/hard contact lenses to read from a computer screen (soft contact lenses are OK). If you are unsure whether a condition would interfere with eye tracking please contact Lynsey via email (lynsey-orourke2014@brookes.ac.uk)

and she will let you know whether this is the case. In addition, on the day of the study, please do not wear false eyelashes or heavy eye makeup as this can distort imaging of the eye. Please also be aware that in order to track the eye, a small paper sticker will be placed on the forehead, and so you must be prepared to expose your forehead (eg clip back hair if necessary).

Do I have to take part?

No. It is up to you to decide whether or not to take part. If you do decide to take part you will be asked to sign a consent form and you are still free to withdraw any unprocessed data without giving a reason.

What will happen to me if I take part?

You will be invited to the Psychology rooms at Oxford Brookes University. The data collection is expected to take 90 minutes. You will be asked to take part in a few tasks: reading, spoonerisms, and a non-verbal ability test. These tasks are designed to indicate to what extent a participant shows behaviours associated with dyslexia. Then the eye tracker will be calibrated to follow your eye movements. After this you will be presented with a series of partial sentences which need to be completed. Please note that the scores for all tasks will not be calculated during the experiment and so no individual feedback will be available.

What are the possible benefits and risks of taking part?

To compensate for your time and effort you will receive £20. This research will contribute to our understanding of the impact of spellcheck for writers with and without dyslexia.

The tasks involved in this study are not diagnostic tools for dyslexia. However, should you feel concerned about your performance and would like to talk to someone, then please contact the dyslexia and specific learning difficulties team at Oxford Brookes University Student Centre. Their details are available from the researcher and will be provided at the end of the experiment. Alternatively, to find out about national support services, or for more information about dyslexia, please visit the following websites:

The British Dyslexia Association: <http://www.bdadyslexia.org.uk>

Dyslexia Action: <http://www.dyslexiaaction.org.uk>

Please be aware that should you decide to be assessed for a dyslexia diagnosis within 3 months of taking part in this study then you may wish to make the assessor aware of which tasks you have completed as part of this study. This is just in case the assessor plans to use tests for a diagnostic assessment which are similar to the tasks completed as part of this study. You will be provided

with a list of the tasks that you complete during this study which can be given to any future assessors.

Will what I say/write in this study be kept confidential?

You will not be asked to give your name on any of the materials used during this experiment. Only the researcher and supervisors will have access to the data, which will be stored in accordance with the University's policy on Academic Integrity. The data will be used for a PhD thesis and may form part of a published article or conference/seminar paper. The data generated in the course of the research will be kept securely. If the data is likely to be used for a publication or conference paper it may be kept for a period of ten years after the completion of the research project. Any contact details will be deleted as soon as you have taken part in the research.

What should I do if I want to take part?

If you wish to take part, please email the researcher using the contact details above. Appointments can be made for a time that suits you. If you are unable to attend an appointment it would be helpful if you could give the researcher 24 hours' notice.

Who is organising and funding the research?

The research is being conducted in part fulfilment of a PhD at Oxford Brookes University.

Who has reviewed the study?

This study has been approved by the Oxford Brookes University Research Ethics Committee. If you have any concerns about the way in which the study has been conducted, you can contact the Chair of the University Research Ethics Committee who may be contacted at: ethics@brookes.ac.uk.

Contact for further information

For further information regarding this study please contact the experimenter or supervisor, their contact details can be found above.

Thank you for taking time to read this information.

Lynsey O'Rourke

Appendix K: Essay scoring rubric

Although the GRE Analytical Writing measure contains two discrete analytical writing tasks, a single combined score is reported because it is more reliable than a score for either task alone. The reported score ranges from 0 to 6, in half-point increments.

The statements below describe, for each score level, the overall quality of analytical writing demonstrated across both the Issue and Argument tasks. The test assesses "analytical writing," so critical thinking skills (the ability to reason, assemble evidence to develop a position and communicate complex ideas) are assessed along with the writer's control of grammar and the mechanics of writing (e.g., spelling).

The reliability estimate was calculated using performance of all individuals who tested between July 1 2014 and June 30 2017. Test takers completed two analytical writing tasks and two ratings for each were in agreement about 85% of the time, differed by 1 point 14% of the time and different by more than one point about 1% of the time.

Score Level Descriptions for the Analytical Writing Measure

Scores 6 and 5.5

Sustains insightful, in-depth analysis of complex ideas; develops and supports main points with logically compelling reasons and/or highly persuasive examples; is well focused and well organized; skillfully uses sentence variety and precise vocabulary to convey meaning effectively; demonstrates superior facility with sentence structure and language usage, but may have minor errors that do not interfere with meaning.

Scores 5 and 4.5

Provides generally thoughtful analysis of complex ideas; develops and supports main points with logically sound reasons and/or well-chosen examples; is generally focused and well organized; uses sentence variety and vocabulary to convey meaning clearly; demonstrates good control of sentence structure and language usage, but may have minor errors that do not interfere with meaning.

Scores 4 and 3.5

Provides competent analysis of ideas; develops and supports main points with relevant reasons and/or examples; is adequately organized; conveys meaning with

reasonable clarity; demonstrates satisfactory control of sentence structure and language usage, but may have some errors that affect clarity.

Scores 3 and 2.5

Displays some competence in analytical writing, although the writing is flawed in at least one of the following ways: limited analysis or development; weak organization; weak control of sentence structure or language usage, with errors that often result in vagueness or lack of clarity.

Scores 2 and 1.5

Displays serious weaknesses in analytical writing. The writing is seriously flawed in at least one of the following ways: serious lack of analysis or development; lack of organization; serious and frequent problems in sentence structure or language usage, with errors that obscure meaning.

Scores 1 and 0.5

Displays fundamental deficiencies in analytical writing. The writing is fundamentally flawed in at least one of the following ways: content that is extremely confusing or mostly irrelevant to the assigned tasks; little or no development; severe and pervasive errors that result in incoherence.

Score Level 0

The examinee's analytical writing skills cannot be evaluated because the responses do not address any part of the assigned tasks, are merely attempts to copy the assignments, are in a foreign language or display only indecipherable text.

Score NS

The examinee produced no text whatsoever.