# The nature of the risk faced by pedestrians with neurodevelopmental disorders: A systematic review.

Kate Wilmut[1] and Catherine Purcell[2]

[1]Oxford Brookes University, Department of Psychology, Health and Professional Development, Faculty of Health and Life Sciences

[2]Cardiff University, School of Healthcare Sciences, College of Biomedical Life Sciences

Corresponding author: Dr Kate Wilmut, Reader, Oxford Brookes University, Department of Psychology, Health and Professional Development, Faculty of Health and Life Sciences, Headington Campus, Oxford, OX3 0BP. Tel: 01865 483781. Email: k.wilmut@brookes.ac.uk

## Abstract

Pedestrians represent one of the most vulnerable road user groups worldwide. Children and adult pedestrians with neurodevelopmental disorders may be at greater risk due to deficits in a range of domains, such as attention, social communication, motor control and executive function. According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (American Psychological Association, 2013), neurodevelopmental disorders include individuals with a diagnosis of Autism Spectrum Disorders, Attention Deficit Hyperactivity Disorder, Specific Learning Disorder, Motor Difficulties, Communication Disorders and Intellectual Disabilities. The purpose of this systematic review and meta-analysis was to explore existing literature relating to determine the nature of the risk faced by pedestrians with neurodevelopmental disorders. Relevant databases including Web of Science, PhysInfo and CINAHL were searched up to July 2019. All peer reviewed journals that presented data focusing on neurodevelopmental disorders and some aspect of road crossing or roadside behaviour that included a control or comparison group were included. A total of 149 abstracts were assessed and 17 met the inclusion criteria. The identified papers could be grouped into four areas: (1) rate of injury; (2) assessment of risk; (3) eye gaze and understanding of road layout and (4) gap choice. No papers exploring the risk factors at the roadside for individuals with Specific Learning Disorders or Communication Disorders were identified. Overall, the review provide evidence for an elevated risk of injury for individuals with ADHD at the roadside, potentially as a consequence of poor temporal gap choice, although there was evidence that this risk could be mediated by executive dysfunction rather than ADHD symptomology. Furthermore, poor temporal gap choice was found in children with DCD but it remains unclear as to whether this risk translates to the roadside. Finally, both children and adults with ASD and children with ID were found to demonstrate differences in behaviour /

understanding at the roadside. In general, co-occurrence between neurodevelopmental disorders has been largely ignored in the current literature relating to pedestrian risk and future research could consider this along with executive functioning.

Key Words: neurodevelopmental disorders; roadside; DCD; ADHD; ASD; ID

**Highlights**

- Children with Attention Deficit Hyperactivity Disorder and Developmental Coordination Disorder may make poor temporal gap choices at the roadside

- Individuals with Autism Spectrum Disorder show differences in terms of direction of gaze when crossing the road and in terms of ability of crossing safely at designated crossing places

- Children with Intellectual Disability and poor visual attention demonstrate a difficulty with making judgements regarding the comparative safety of crossing places compared to children with intellectual difficulties alone

- Co-occurrence of neurodevelopmental disorders has been largely ignored in this context

- Executive dysfunction may explain some of the risk seen in Attention Deficit Hyperactivity Disorder

# 1. Introduction

## 1.1. The Global Road Challenge

Globally, approximately 1.35 million people die each year as a result of preventable road traffic accidents, and road traffic injuries are the leading cause of death for children and young adults aged 5-29 years, suggesting an urgent need for a shift in the current health agenda, which has to date largely ignored road safety (World Health Organisation, 2018). Approximately 22% of these needless deaths are accounted for by pedestrians who remain one of our most vulnerable road users (World Health Organization, 2018). As well as the human cost, the economic cost borne from preventable road traffic accidents is estimated at 3% of countries gross domestic product (World Health Organization, 2018). Despite this, there remains a lack of attention in the research and in the planning, design and operation of roads to mitigate the risks associated with these road users. In many countries, roads still lack adequate crossings for pedestrians and allow motor vehicle speeds that are too high (Reynolds, Harris, Teschke, Cripton, & Winters, 2009). In addition, to these risks faced by all pedestrians, there are a group of individuals that may be even more vulnerable at the roadside, due to deficits in a range of domains that are considered essential for safe road crossing, such as attention, executive functioning, social communication and motor control. These road users can be classified as having neurodevelopmental disorders.

### 1.2. Neurodevelopmental disorders and the roadside

There is some existing evidence that leads us to believe that there is good reason to suspect that the nature of the difficulties characteristic of neurodevelopmental disorders might place them more at risk at the roadside. For example, in older adults visual processing and selective attention have been identified as being more important than age itself when considering crossing safety (Dommes & Cavallo, 2011; Dommes, Cavallo, & Oxley, 2013). These cognitive domains are also known to be implicated in at least some neurodevelopmental disorders such as Autism Spectrum Disorder, ASD (Cowan et al., 2018), specific learning difficulties (Varvara, Varuzza, Padovano Sorrentino, Vicari, & Menghini, 2014; Westby, 2019), communication disorders (Martin & Allen, 2008), Attention Deficit Hyperactivity Disorder (ADHD), Intellectual Disabilities (ID) (Alevriadou, Angelou, & Tsakiridou, 2006) and Developmental Coordination Disorder (Leonard, Bernardi, Hill, & Henry, 2015) which may therefore, put these individuals at risk at the roadside. Given these potential risk factors understanding the exact nature of risk at the roadside in a neurodevelopmental population is vital for remediation especially given the heterogeneous nature of these disorders. Despite the distinct diagnostic categories provided by the DSM-5 (American Psychiatric Association, 2013), neurodevelopmental disorders (for a full description see below) are often seen in combination, with co-occurrences of these disorders being the rule rather than the exception (Bishop & Rutter, 2008). It is therefore important to review the research across all of these neurodevelopmental disorders in order to determine risk factors and the nature of the risk.

### 1.3. Classification of Neurodevelopmental disorders

The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) (American Psychiatric Association, 2013) classify neurodevelopmental disorders as a group of conditions which manifest in the early developmental period whilst recognising the impact across the lifespan, and are characterised by developmental deficits that produce impairments of personal, social, academic or occupational functioning. The range of developmental deficits vary from specific limitations of learning or control of executive function to global impairments of social skills or intelligence. The DSM-5 (American Psychiatric Association, 2013) classifies neurodevelopmental disorders into the categories described below.

#### 1.3.1. Autism Spectrum Disorders

The DSM-5 (American Psychiatric Association, 2013) introduced substantial revisions to the diagnostic criteria for Autism in its latest edition. One key change included a shift from the triadic to dyadic symptom groupings, whereby (1) impaired social communication, (2) impaired social interaction and (3) restricted behaviour as previously described became (1) impaired social communication and interaction and (2) restricted behaviour. Furthermore, there was a consolidation of previously separate diagnostic subcategories for autistic disorder, Asperger's disorder, and pervasive developmental disorder not otherwise specified, into a single category of Autism Spectrum Disorder (ASD). It is estimated that the prevalence of ASD is between 1-1.5% and it is thought to be highly heritable, with both common and rare variants contributing to its aetiology (Grove et al., 2019). As a consequence of the revisions to the diagnostic categorisation of ASD, the clinical presentation is heterogeneous and includes individuals with severe impairment and intellectual disability as well as individuals with above average IQ and high levels of academic and occupational functioning (Grove et al., 2019).

### 1.3.2. Attention Deficit Hyperactivity Disorder

Attention Deficit Hyperactivity Disorder (ADHD) is defined by impaired levels of inattention, disorganisation and / or hyperactivity – impulsivity (American Psychiatric Association, 2013). The diagnostic criteria identify three specific subtypes (predominantly Inattentive, predominantly Hyperactive-Impulsive, and Combined) and 18 core symptoms (American Psychiatric Association, 2013). The prevalence of ADHD varies but is thought to be approximately 5.29% (Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014). Individuals with ADHD experience significant impairments across a wide range of outcomes, for example academic, interpersonal, occupational, personal, substance use and driving (Barkley, 2006; Willcutt et al., 2012).

### 1.3.3. Specific Learning Disorder

The DSM-5 (American Psychiatric Association, 2013) groups together difficulties with reading, written expression, speech and mathematics under the diagnostic category of

Specific Learning Disorder. In terms of reading, Developmental Dyslexia has been defined as a hereditary temporal processing defect, associated with impaired magnocellular neuronal development, that impacts selectively on the ability to learn to read, leaving oral and non-verbal reasoning powers intact (Stein, 2018). The prevalence of Developmental Dyslexia is estimated at 6.3% (Roongpraiwan, Ruangdaraganon, Visudhiphan, & Santikul, 2002). In terms of written expression, Dysgraphia, closely related to Developmental Dyslexia, is a disorder characterized by difficulties in the acquisition of writing/spelling skills despite adequate schooling and IQ (Döhla, Willmes, & Heim, 2018). In terms of speech, Developmental Language Disorder (previously known as Specific Language Impairment or SLI) is estimated to affect 7% of the population (Bishop et al., 2017) and is considered the most prevalent of all neurodevelopmental disorders. Finally, in terms of mathematics, Dyscalculia is characterised by a marked persistent problem in applying the basic methods of arithmetic and knowledge of maths facts, in the absence of low intelligence or inadequate schooling (American Psychiatric Association, 2013). It is estimated that the prevalence of Dyscalculia is approximately 3-7% (Morsanyi, van Bers, McCormack, & McGourty, 2018).

#### 1.3.4. Motor disorders

Motor disorders can be grouped into: stereotypic movement disorder, tic disorders and Developmental Coordination Disorder (DCD). Stereotypic movement disorder is characterised by repetitive non-functional motor behaviour which infers with daily living (Valente et al., 2019). Tic disorders, the most commonly researched being Tourette’s syndrome, are also characterised by repetitive movements (tics) with at least one vocal (phonic) tic. Approximately 1% of school aged children present with Tourette’s syndrome (Stern, 2018). Developmental Coordination Disorder (DCD) is a neuromotor condition that is thought to affect approximately 5-6% of school-aged children (Blank et al., 2019). The DSM-

5 (American Psychiatric Association, 2013) describes DCD as occurring when motor coordination is below what might be expected given the child's chronological age and opportunity for motor skill development. Difficulties with coordination of either gross or fine motor movements, or both, interfere with academic achievement or activities of daily living. Coordination difficulties do not relate to a medical condition or disease (e.g., cerebral palsy, muscular dystrophy, visual impairment or intellectual disability). If intellectual disability is present, the motor difficulties are in excess of those expected for the child's IQ (American Psychiatric Association, 2013).

**1.3.5. Communication Disorders**

Communication disorders are often characterized by delays in speech, hearing, or language (Gregg, 2017). The DSM-5 (American Psychiatric Association, 2013) describes four main communication disorders that affect children including: language disorder; speech sound disorder; childhood-onset fluency disorder (stuttering) and social (pragmatic) communication disorder. Diagnoses are based on difficulties with language or speech production and use, as well as the absence of any known cause (American Psychiatric Association, 2013). A common criterion between all four communication disorders is age of onset, where symptoms must be present in the early developmental period (American Psychiatric Association, 2013). The main differences between the four communication disorders is in the primary difficulty the child will be experiencing (Peters & Matson, 2018). For example, a diagnosis of language disorder requires that an individual demonstrates difficulties in the acquisition and use of language (Peters & Matson, 2018). In contrast, the main difficulty in speech sound disorder will be with the production of intelligible speech (Peters & Matson, 2018). The only communication disorder currently listed in the DSM-5 that does not only apply to children is adult-onset fluency disorder (stuttering), where onset of symptoms can occur in adulthood as opposed to the early developmental period (American Psychiatric Association, 2013).

### 1.3.6. Intellectual Disability

Intellectual Disability (ID) is characterized by concurrent deficits in intellectual and adaptive functioning, with onset prior to adulthood (American Psychiatric Association, 2013). This category includes terms used previously such as mental retardation and global developmental delay. Prevalence rates for ID are generally estimated to be 1% of the population, with higher rates in middle and low income countries (Maulik, Mascarenhas, Mathers, Dua, & Saxena, 2011). Intellectual disability has been associated with deficits in selective attention (Neill, 1977; Neill & Westberry, 1987).

### 1.3.7. Other

According to the DSM-5 (American Psychiatric Association, 2013), this category applies to presentations in which symptoms characteristic of neurodevelopmental disorders, such as impaired social or occupational functioning are present, but do not meet the full criteria for any of the disorders in the neurodevelopmental disorders diagnostic class.

## 1.4. Objectives

The aim of this systematic review was to explore existing literature relating to neurodevelopmental disorders (as specified above) to determine the nature of the risk faced by these children and adults at the roadside.

### 1.4.1. Methods

This systematic review was conducted in line with principles outlined in the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Green, 2011) and is reported in accordance to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati, Tetzlaff, & Altman, 2009). This review has been registered on the open science framework (osf.io/z78kf)[1].

**2.1. Search strategy**

A literature search was conducted independently by both authors using 10 electronic databases: Web of Science; PsychInfo; Applied Social Sciences Index and Abstracts (ASSIA); Ovid Medline Scopus; Embase; CINAHL; Pubmed; ProQuest Public Health; Cochrane Library and AMED. These databases were selected as they represent a broad spectrum of disciplines, i.e. psychology, medicine, occupational therapy. The final search was performed on the 28th July 2019. As neurodevelopmental disorders have undergone a number of changes in terminology a wide variety of different terms were used to describe the population of interest. Neurodevelopmental disorders were defined using DSM-5 (American Psychiatric Association, 2013) whilst using both the terminology in this latest edition and in previous editions (e.g. both SLI and DLD were searched for). We combined terms to describe the population of interest with terms referring to road crossing, where possible MeSH terms and Boolean operators were used. Finally, hand searches were made of the reference lists of relevant reviews and included articles. A full description of the search strategy for PsycInfo is provided in Table 1.

[1] Please note, the registration on the Open Science Framework was not made prior to the searching and screening of papers. We initially pre-registered with PROSPERO in June 2019 but because this review does not have a direct health outcome it was rejected in December 2019. The details of the review are unchanged from those originally submitted.

Table 1. Concept Table

| Search terms for Neuro-developmental disorders | Search terms for setting / task | Example of PsychInfo search |
| --- | --- | --- |
| Disorder* | Pedestrian* | [Disorder* OR Disab* OR |
| Disab* | Road* | Retardation OR Global |
| Retardation | Gap acceptance | developmental delay |
| Global developmental delay | Street | Asperger* OR Autism OR ASC |
| Asperger* | | OR ASD OR Dys* OR specific |
| Autism | | language impairment OR SLI |
| ASC | | OR DLD OR Clumsy OR DCD |
| ASD | | OR ADHD OR ADD] |
| Dys* | | **AND** |
| Specific Language Impairment | | [Pedestrians* OR Road* OR |
| SLI | | Gap acceptance OR Street] |
| DLD | | |
| Clumsy | | Limit = English language |
| DCD | | |
| ADHD / ADD | | |

**2.2. Inclusion and exclusion**

The inclusion criteria were studies that: (1) presented data focusing on neurodevelopmental disorders as defined by DSM-5 (American Psychiatric Association, 2013); (2) presented data focusing on some aspects of road crossing or roadside behaviour; (3) were published in peer reviewed journals and (3) were written in English. Exclusion criteria were: (1) studies which did not include either a control comparison group or a comparison across groups with different neurodevelopmental disorder[2]. Comparison groups potentially provide information regarding mediation and as such studies that did not include a comparison group were excluded. However, studies do differ on the types of comparison groups used and the findings from these studies have different implications. For example, a study comparing an atypical group with a typical group can inform us about the risk level of that atypical group as compared to the typical population, whereas a study considering two atypical populations (either with distinctly different atypicalities or with differing severity levels) tells us more about the risk levels within an atypical population. Although these are very different they still focus on comparative risk factors at the road side. No year of publication limit was imposed. PhD theses were not included but a search for published articles which arose from a thesis were searched for and, if they met the inclusion criteria were included.

After removing duplicates and papers which focused on non-neurodevelopmental disorder populations (e.g. ageing population, stroke, Parkinson's disease, Downs syndrome etc.) both authors independently screened titles, abstracts and finally full-text articles for eligibility. The authors reached a consensus of doubtful manuscripts through discussion.

### 2.3. Data extraction

For inclusion in the subset of studies for data extraction, the screened studies had to report outcomes for one or more of the following neurodevelopmental disorders: Intellectual Disabilities; Communication Disorders; Autism Spectrum Disorders; Attention Deficit Hyperactivity Disorder; Specific Learning Disorder; Motor Disorders and those classified as 'Other' according to the DSM-5 (American Psychiatric Association, 2013). In addition,

[2] Our question was specifically focused on whether individuals with neurodevelopmental disorders are more at risk at the roadside. To answer this question we needed a comparison group, i.e. to determine whether they are more at risk than another group. A number of studies focused on crossing training methods for children with neurodevelopmental disorders and were based on the assumption they were more at risk and so needed additional remediation. These studies were not included in the current systematic review.

screened studies had to focus on road crossing or some aspect of roadside behaviour. Extracted studies could be of any design, published at any time, and had to include a comparison group. All outcomes were extracted through the selection of means, medians and standard deviations. Both authors independently extracted data from each article using a data extraction form, which was adapted from the Cochrane Collaboration.

### 2.4. Quality assessment

Critical appraisal checklists provide a framework for scrutinising the quality of papers. The current systematic review used the Critical Appraisal Skills Programme (CASP) (Critical Appraisal Skills Programme, 2018). The CASP Cohort Study Checklist was adopted, which propagates a systematic process through which the strengths and weaknesses of each study could be identified. Section A of the CASP checklist deals with the validity of the results based on the cohorts and measures used (Qu1. Does the paper address a clearly focused issue? Qu2. Was the cohort recruited in an acceptable way? Qu3. Was exposure accurately measured? Qu4. Was outcome accurately measured? Qu5a. Were confounding factors identified? Qu5b. Were confounding factors controlled for? Qu6a. Was the follow up of subjects complete enough? Qu6b. Was the follow up of subjects long enough?). All of the questions are responded to with a yes, no or can’t tell. Section B focuses on the results (Qu7. What are the results of this study? Qu8. How precise are the results? Qu9. Do you believe the results?), two of these questions require the reviewers to provide free text and the final uses a yes, no, can’t tell response. Finally section C focuses on how the results can help locally (Qu10. Can the results be applied to the local population? Qu11. Do the results of this study fit with other available evidence? Qu12.What are the implications of this study for practice?), one of these questions require the reviewers to provide free text and the other two use a yes, no, can’t tell response. For the purposes of this review question 6 (section B) and question 10, 11 and 12 (section C) were excluded from our assessment as they either deal with issues not covered in the papers reviewed in this review or could not be determined due to the paucity of research in this area. Both authors independently assessed the full text articles and the outcomes of the separate CASP Checklist were compared to ensure agreement. Disagreements were discussed and resolved. We did not remove any papers from this review on the basis of assessed quality. We have provided the outcomes of these assessments for the yes, no, can’t tell questions at the end of the results section.

## 3. Results

The database search identified a total of 20,392 records. After removing duplicates, a total of 19,164 records were identified. All titles were independently screened by both authors and those clearly not focusing on a neurodevelopmental disorder population or on road crossing were excluded on the basis of the paper title. This left 149 papers which were screened on the basis of the abstract using the inclusion and exclusion criteria laid out above. From this 72 articles were selected and full texts sourced. At this stage studies were excluded either because they focused on road crossing training in children with neurodevelopmental disorders and did not include a control / comparison population, or because the study focused on driving rather than pedestrians, or the study did not focus on road crossing.

This left 17 articles for inclusion in this systematic review, 6 of these focused on individuals with Attention Deficit Hyperactivity Disorder (ADHD), 4 on individuals with Autism Spectrum Disorder (ASD), 4 with Developmental Coordination Disorder (DCD), 1 with Intellectual Disabilities (ID) and 2 which did not fully describe the nature of the developmental disabilities. These papers could be classified into four distinct subtypes: (1) studies considering rate of injury at the roadside; (2) studies considering assessment of risk;

(3) studies considering the understanding of road layout, eye-gaze and perception; and (4) studies considering gap choice when crossing the road. The latter three groups describe the road crossing process step-by step, one first needs to find a safe place to cross and understand safety / hazards, one then has to understanding the crossing process, look appropriately and perceive accurately, finally one needs to choose a temporal gap between cars which is appropriate for one's walking speed. Details of the identification process can be found in the PRIMSA flow chart in Figure 1.

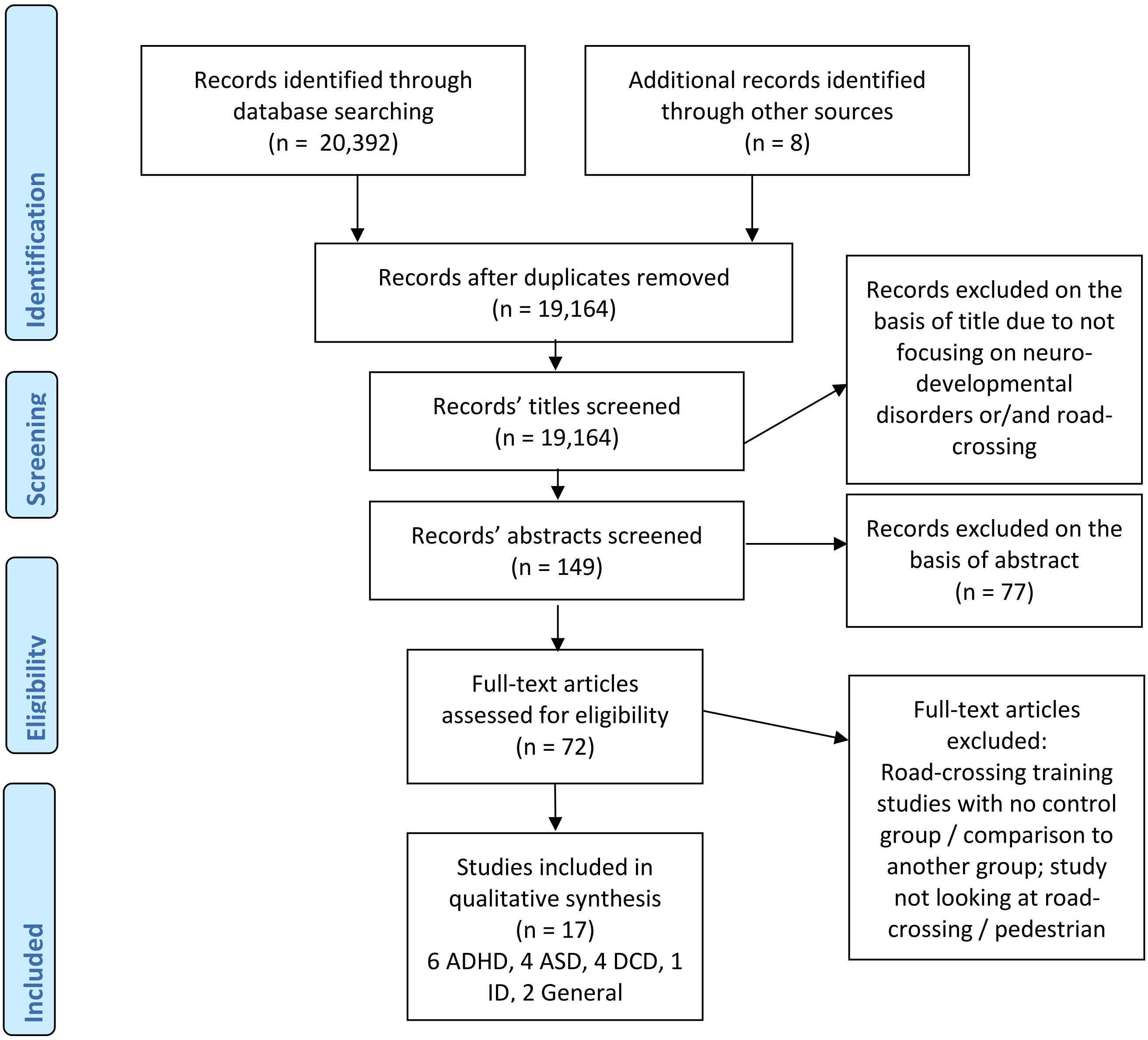


Figure 1. PRISMA Flow Chart

### 3.1. Summary of papers

The 17 papers are grouped into the categories given above and are summarised in text and in table form below.

#### 3.1.1. Rate of injury at the roadside

The first four papers focus on the rate of injury at the roadside in individuals with neurodevelopmental disorders, these studies are summarised in Table 2. The first study obtained data from a sample of 240 cases of paediatric trauma in children with pre-existing ADHD aged between 5-14 years and 21,902 children with no pre-existing diagnosis (DiScala, Lescohier, Barthel, & Li, 1998). In total 48 children in this sample were on medication and 26 had an additional comorbidity commonly associated with ADHD, such as learning disability. The authors found that external causes of injury differed across groups, with pedestrian injury the leading cause of hospital admission in the ADHD group (27.5%) compared to 18.3% in the non-ADHD group. More recently and on a bigger scale a second study conducted a similar study, again based in the US, looking at rates of injury across a large sample of children with ADHD, children with other developmental disabilities[3], children with physical disabilities and children with none of these disabilities (Pastor & Reuben, 2006). General rate of injury was highest in the children with ADHD, twice as high compared to the typical group, with 204 accidents per 1000 children for the ADHD group and 115 per 1000 for the non ADHD group. More specifically if we look at the breakdown of those accidents injury on roads was higher in the children with ADHD (accounting for 14% of accidents or 28 accidents per 1000) compared to typical children (accounting for 8% of accidents or 9 accidents per 1000). It is worth noting at this point that injury on a road in this study included injury as a pedestrian, a cyclist and a passenger with no way to separate these.

[3] The data from this group is not reported as this included individuals with and without neuro-developmental disorders as classified by the DSM-5, i.e. Pervasive Developmental Delay, Down's syndrome, Autism and Cerebral Palsy

On a smaller scale Brook and colleagues (Brook, Boaz, Brook, & Boaz, 2006) aimed to determine the rate of and parent beliefs regarding accidents in children aged between 15 and 18 years with ADHD and co-occurring learning disability[4] (ADHD-LD). A questionnaire was distributed to 108 parents of children with ADHD-LD and 87 parents of children with no such diagnosis. The authors found that children with ADHD-LD were involved in more accidents in general, but no significant differences between groups were found for roadside accidents. Despite this lack of difference parents of children with ADHD-LD were more concerned about their children being involved in roadside accidents compared to the control group.

Two further studies used US government held databases to determine the frequency of different external causes of death within a population with a learning disability (Strauss, Shavelle, Anderson, & Baumeister, 1998) and consider the association between learning disability and risk as a pedestrian (Xiang et al., 2006). Strauss et al., (1998) extracted data from a database of all individuals with learning disabilities and details regarding cause of death, this resulted in 520 cases which they compared to a typical population. Data showed that individuals with learning disabilities were much more likely than the typical population to have external causes of death due to pedestrian accidents. For a typical population the rate of pedestrian accidents was 3 per 100,000, for the population with learning disabilities this was 8.04 per 100,000. Xiang et al., (2006) extracted data from the national transportation database and looked at children aged 5-17 years with and without any long lasting sensory, physical, mental or emotional condition, the data set comprised 299 children with disabilities and 388 children without. They considered data that asked the children (or their parents) whether they had been hit by a car while walking or riding a bike (yes/no) and also asked

[4] This is the term used by the authors to indicate children with ADHD who also had a learning disability as determined by a teacher.

them to complete a 20 item checklist regarding difficulties with traffic based environments. Participants in the disability group reported a greater number of traffic collisions as a pedestrian (5.2% for those with disabilities versus 0.7% for those without) and over a third (39%) of children with disabilities reported traffic based difficulties compared to under a quarter of the children without disabilities (22.6%). The most commonly reported traffic challenges were “Too few or missing sidewalks/paths,” “Do not know when it’s safe to cross,” “Insensitive/unaware drivers,” and “surface problems.”

Table 2. A summary of the papers focusing on the rate of injury at the roadside

| Authors | Group (N) | Country | Age | Gender ratio (% male) | Findings |
|---|---|---|---|---|---|
| Brook et al. (2006) | ADHD and LD (108), TD (87) | Israel | 15-17 yrs | ADHD 56%, TD 56% | Rate of accidents, ADHD/LD = TD group, parents of ADHD/LD more worried about accidents |
| DiScala et al. (1998) | ADHD (240), TD (240) | US | 5-14 yrs. | ADHD 88% TD 67% | Pedestrian injury leading cause of hospital admission in the ADHD group, higher than the control group. |
| Pastor et al. (2006)* | ADHD = 3753, TD = 28961 | US | 6-17 yrs. | ADHD 74% TD 50% | Street / highway injury higher in ADHD vs. TD. |
| Strauss et al. (1998) | Individuals with developmental disability vs. national average (520) | US | 15-59 yrs | Developmental disability 56% | Externally caused deaths due to pedestrian accidents > in group with developmental disabilities |
| Xiang et al. (2006)* | N=299 dev. disabilities, N=388 without | US | 5-17 yrs. | Disability 67%, Without 49% | Developmental disabilities group had a higher incidence of pedestrian accidents compared to those without. |

*The number of individual involved in accidents had to be extracted using the reported percentage of participants involved in accidents and includes road users other than pedestrians.

### 3.2. Assessment of risk

The next four papers focus on the ability to detect and judge risk in relation to finding a safe place to cross the road. These studies are summarised in Table 3. The first study investigated whether boys with ADHD aged between 5-6 years, 7-8 years and 10-11 years, with high versus low inattention recognise hazards, evaluate risk and describe preventative strategies differently (Mori & Peterson, 1995). Coppens Test of Safety and Prevention (Coppens, 1985) was used to measure children's understanding of safety and ability to generate preventative strategies. This test considers risk in a variety of situations which include road crossing, participants are shown photographs in Paris, one depicting a safe and one a risky situation, the participant is asked to identify the risky situation. Mori et al. (1995) reported no differences on the Coppens Test of Safety and Prevention between children with high versus low inattention, although some age differences were noted whereby the 7-8 year-olds and 10-11 year-olds scored significantly better than the youngest children. On a similar theme Farmer and Peterson (1995) examined the ability of a male sample of 30 children aged between 7-11 years, 14 with clinically diagnosed ADHD and 16 in a control group, to recognise hazards, evaluate risk and define preventative strategies. Children completed a risk of injury scale, which included a 10 min hazard identification video followed by questions to assess children’s cognitions about the process of injury and their knowledge of safety and prevention. Although children with ADHD recognised the hazards and reported similar levels of compliance with safety rules as did the control children, they anticipated fewer negative consequences. They expected to sustain less severe injury, anticipated less distress of injury, and described a greater likelihood of engaging in risky activities. The authors conclude that new approaches to child-based preventative interventions, such as role-playing, may prove useful for boys with ADHD (Farmer & Peterson, 1995).

Anastasia (2010) considered the importance of attentional abilities in children with intellectual disability to judge the safety of crossing places. They took a group of children with intellectual disability and divided them into a group with associated attentional difficulties and a group without. A play mat of a road scene with toy cars placed in specific locations provided an allocentric / birds-eye view and participants were asked to determine whether a given crossing place was safe to cross. The task could be made more complex by adding additional, but irrelevant, factors (additional cars etc). The ability to judge the safety of given crossing points was influenced by visual attention with those children with poor visual attention demonstrating a lower level of accuracy than those with a higher level of accuracy (Anastasia, 2010).

Purcell and Romijn (2017) using a computerised environment which required participants to navigate an avatar around pavements to find a safe place to cross. The findings demonstrated that children with DCD chose fewer safe road crossing places than their non-DCD peers when faced with an egocentric view of the road crossing game. However, when presented with an allocentric view point no group differences were found. Children also completed a questionnaire regarding their experiences with both road crossing and road crossing training. No group differences were found in any of the measures, including confidence in crossing the road, perceived crossing ability or access to training (Purcell & Romijn, 2017).

Table 3. A summary of the papers focusing on the detection of hazards

| Authors | Group (N) | Country | Age | Gender (% male) | Findings |
|---|---|---|---|---|---|
| Anastasia (2010) | ID with poor visual attention (20), ID with good visual attention (20) | Greece | 10-12 yrs | All 100% | Ability to accurately judge safe and unsafe crossing places was influenced by visual attention, those children with low visual attention and ID did less well |
| Farmer et al. (1995) | ADHD (14), TD (16) | US | 7-11 yrs | All 100% | No group differences for ability to identify hazards, but the ADHD group less concerned about risk |
| Mori et al. (1995) | ADHD high impulsivity (46), ADHD low impulsivity (50) | US | 5-11 yrs | All 100% | ADHD=TD on Coppen's test of safety and prevention. |
| Purcell and Romijn (2017) | DCD (21), TD (21) | UK | 6-12 yrs | DCD 57%, TD 57% | Ability to find safe crossing place: DCD=TD for allocentric view, TD>DCD for egocentric view. No group differences in road crossing exposure / training |

### 3.3. Understanding road layout, Eye-gaze and Perception

The first three papers in this group focused on a comparison between pedestrian shared zones and zebra crossings in Australia (Cowan et al., 2018; Earl et al., 2016; Earl, Falkmer, Girdler, Morris, & Falkmer, 2018), these studies are summarised in Table 4. Firstly, Earl et al., (2016) considered fixation duration and the number of fixations in a single adult with Asperger's syndrome and compared this to typical adults (this study also included a stroke patient and an individual with cognitive impairment, however, the findings from these individuals are not reported here). A clear difference was seen in the distribution of fixations on traffic relevant and traffic non-relevant objects in both types of road layout. The participant with Asperger's syndrome had more fixations focused on traffic non-relevant (60% of fixations) compared to traffic relevant (40% fixations) objects. This is in contrast to the typical participants who had approximately 62% of fixations focused on traffic relevant objects and the rest on traffic non-relevant objects. Cowan et al., (2018) expanded upon this work using a group of adults with and without ASD. Adults with ASD made no eye contact and as such no comparison could be made. Although no differences were found in the number of fixations made to traffic related or non-traffic related objects fixation duration was shorter in the individuals with ASD compared to typical peers, however, this was driven by a shorter duration in the non-traffic related objects not the traffic related objects.

Earl et al. (2018) looked at knowledge / understanding of these different types of road layouts in a group of typically developing adults, a group of adults with mild to moderate ASD and a group of high functioning adults with Asperger's syndrome (AS). The authors conducted a Q sort task whereby participants rated 44 statements regarding pedestrian crossing situations. Data was subject to a factor analysis and two factors or viewpoints were extracted. The 39 individuals who loaded onto the first viewpoint (I am confident at using shared zones and zebra crossings) came from all three groups, with 46% from the typical group, 39% from the ASD group and 15% from the AS group. The second viewpoint (I know the rules but drivers might not) was defined by 12 participants, 17% were typically developing, 33% were from the ASD group and 50% from the AS group. This study demonstrates no clear differences in viewpoints across these groups, however, only 12/20 of the AS group loaded on one of these two factors which suggests that their viewpoints differ from these and this might pose a barrier for these individuals.

The forth paper has a different focus, with a virtual reality programme for teaching children with ASD road crossing skills, specifically crossing at a pedestrian crossing (Josman, Ben-Chaim, Friedrich, & Weiss, 2008). Initially, all children were observed crossing the street and their performance was measured using a pedestrian safety scale. All participants then completed a virtual environment intervention for eight sessions either once or twice weekly. This involved the children deciding when to cross whilst at a set of traffic lights which was presented as a game with levels of difficulty; children progressed onto the next level of difficulty once they had successfully completed the previous level (i.e. crossed the road). Safe crossing of the road was linked to looking to the left and right and waiting for the ‘green man’ to appear and so this is essentially measuring one’s understanding of crossing at a pedestrian crossing. As difficulty increased, the number of cars and car speed increased. Unfortunately, this paper does not provide details of all of the data collected, for example no data is given for the initial ratings of safety nor on the behaviour of the typical children in the crossing game. However, it is clear that the children with ASD were not as competent at the road crossing game prior to training as they only progressed to level 1-4 while the typical group progressed to level 9.

Finally, a single study has considered the perceptual abilities and judgements of children with Developmental Coordination Disorder (DCD) within a road crossing environment (Purcell, Wann, Wilmut, & Poulter, 2012). Once you are in a safe position and directing your gaze appropriately what do you perceive? Purcell et al. (2012) demonstrated that the perceptual abilities of children with DCD may be less refined than those of their typically developing counterparts which might impact on road crossing decisions. Furthermore, children with DCD were unable to detect a vehicle as approaching if it was 5 sec away when it travelled above 20-30 mph and this ability was less refined than their non-DCD peers.

Table 4. A summary of the papers focusing on eye gaze and the understanding of road layout (AS = Asperger's syndrome)

| Author | Participants (N) | Country | Age | Gender (% male) | Findings |
|---|---|---|---|---|---|
| Cowan et al. (2018) | ASD (19), TD (21) | Australia | 18-68yrs | ASD 84%, TD 24% | ASD = no eye contact fixations. ASD=TD for number of fixations between traffic relevant and traffic non-relevant. Fixation duration shorter in ASD vs. TD |
| Earl et al. (2016) | TD (2), AS (1), other non-NDD participants | Australia | Adults | TD not stated, AS 0% | AS: number of fixations greater for non-traffic relevant objects (~40%) vs. traffic relevant (~60%). Opposite way for TD (62% traffic relevant, 38% non-traffic relevant). |
| Earl et al. (2018) | TD (21), mild to moderate ASD (21), AS (20) | Australia | TD x̄ 38yrs, ASD x̄ 25yrs, AS x̄ 36yrs | TD (33%), ASD (85%), AS (33%) | Participants grouped into 1. 'Confident users', N=39, 46% TD, 39% ASD, 15% AS and 2. 'I know the rules but drivers might not', N=12, 17% TD, 33% ASD, 50% AS. Only 50% of AS were represented |
| Josman et al. (2008) | ASD (6), TD (6) | Israel | 8-16yrs | Both groups 83%, | Before training TD group were better at road crossing game, reaching level 9 while ASD participants reached level 1-4. |
| Purcell et al. (2012) | DCD (11), TD (11) | UK | 9yrs | Both groups 64% | Children with DCD less able to judge when vehicle was approaching, when >30 mph it appeared stationary to DCD group. |

### 3.4. Perceptual abilities and gap choice

The final group of papers considered actual road crossing behaviour. These four papers are summarised in Table 5. The first aimed to investigate the pedestrian behaviour of 39 children aged between 7-10 years with ADHD combined type (ADHD-C) and explore whether inattention, oppositionality and executive dysfunction can explain increased pedestrian injury risk in children with ADHD-C (Stavrinos et al., 2011). They compared the results with 39 typically developing children. Children were presented with a virtual road crossing task where they simply had to indicate when they would cross. The authors measured missed opportunities, wait times, attention to traffic, gap size used, hits and close calls, time left to spare and start delay. Children in the ADHD-C group displayed greater executive dysfunction, greater inattention and more oppositionality compared to the control group. However, there were no significant differences between groups for behaviour before the road crossing. Still, the ADHD-C group crossed when it was less safe to do so in terms of gap size and time left to spare. Using a mediation analysis the authors demonstrate that executive dysfunction mediates the association between ADHD-C and unsafe crossing behaviour (while inattention and opposionality do not). Similarly, Clancy and colleagues measured road crossing safety margins of 48 children aged between 13-17 years with and without ADHD using a head mounted display (Clancy, Rucklidge, & Owen, 2006). Participants were required to safely cross a near side lane of a virtual road in front of an approaching van. Three vehicle distances were used (40, 50 or 60 m) which were repeated twice in a block design of 7 blocks. Van velocity was varied based on distance and time to arrival and 42 trials were presented. Margin of safety, walking speed, time to cross, unsafe crossings and percentage of gap used were measured. The authors reported that the ADHD group left shorter margins of safety, were slower in crossing the road, made more unsafe crossings and used less of the available gap in comparison to the control group. Furthermore, the crossing decisions of the ADHD group resulted in collision twice as often as the control group. However, across all findings some learning was seen with improvement in both groups across the 7 blocks.

A series of studies focusing on DCD have also considered gap choice within a simulated environment while crossing one lane (Purcell, Wann, Wilmut, & Poulter, 2011) and two lanes (Purcell, Wilmut, & Wann, 2017) of traffic. In both of these studies children appeared to be free of attentional difficulties as confirmed by a screening tool in Purcell et al (2011) and by teacher report in Purcell et al. (2017). Both studies measured the traffic gaps that children with DCD and their typically developing peers choose and compared these to individual walking times. When considering one-lane traffic it seemed that children with DCD left longer safety margins than their typically developing counterparts, however, when this was extended to a two-lane more immersive environment this finding was reversed and the gaps left by the children with DCD were not long enough for them to cross at a normal walking speed.

552 Table 5. A summary of the four papers considering perceptual abilities and gap choice.

| Author | Group (N) | Country | Age | Gender (% male) | Findings |
|---|---|---|---|---|---|
| Clancy et al. (2006) | ADHD (24), TD (24) | New Zealand | 13-17 yrs | Both groups 50% | ADHD = smaller safety margins than TD. TD collisions on 5.7% of trials vs. 12% for ADHD group. For both groups an effect of learning, with collisions decreasing over time. |
| Purcell et al. (2011) | At risk of DCD (6), DCD (9), TD (11) | UK | 9 yrs | At risk (64%), DCD (83%), TD (71%) | Exp 2. DCD group left longer temporal gaps and hence larger safety margins at all car speeds compared to TD children (considered four car speeds from 32-80km/h. |
| Purcell et al. (2017) | DCD (25), TD (25) | UK | 6-11 yrs | Both groups 72% | Children with DCD = shorter gaps than TD group. None of the gaps left by the children with DCD were sufficient for crossing at a normal walking speed (considered one- and two-lane crossing and three speeds from 20mph-40mph) |
| Stavrinos et al. 2011 | ADHD-C (39), TD (39) | US | 7-10 yrs | Both groups 71% | ADHD-C crossed with smaller gaps and had less time to spare. Executive dysfunction mediated relationship between ADHD-C and safety of the cross. |

### 3.5. Quality assessment outcome

Responses to the yes, no, can't tell questions from section A, B and C of the CASP are provided in Table 6. From this table it is clear that the most common quality issue was a lack of controlling for confounding variables, even when those were identified. In fact 10/16 of the studies which conducted quantitative analyses did not account for confounding variables. Furthermore, five of the studies did not provide sufficient evidence for us to determine whether the cohorts were selected appropriately.

## 4. Discussion

The aim of this review was to determine the nature of the risk that children and adults with neurodevelopmental disorders may face at the roadside. We found 17 papers which met our criteria for inclusion, and which considered risk in ASD, ADHD, DCD and ID. We found no papers looking at risk factors at the roadside for individuals with Specific Learning Disorders or Communication Disorders. The papers we found could be grouped into four different areas of risk at the roadside: (1) Rate of Injury; (2) Assessment of Risk; (3) Eye Gaze and Understanding of Road Layout and (4) Perception and Gap choice. Findings will be discussed using these four groupings and then common themes discussed.

Table 6. A summary of the quality assessment for questions with a yes (Y), no (N) or can’t tell (C) answer. Blank cells indicate the question was not appropriate for the given paper

| Author | Section A | | | | | | Section B |
|---|---|---|---|---|---|---|---|
| | Qu. 1 | Qu. 2 | Qu. 3 | Qu. 4 | Qu. 5a | Qu. 5b | Qu. 9 |
| Anastasia 2010 | Y | Y | Y | Y | Y | N | Y |
| Brook et al. 2006 | Y | Y | Y | Y | N | N | Y |
| Clancy et al. 2006 | Y | Y | Y | Y | Y | Y | Y |
| Cowan et al. 2018 | Y | C | Y | Y | Y | N | Y |
| DiScala et al. 1998 | Y | Y | Y | Y | Y | N | Y |
| Earl et al. 2016 | Y | Y | Y | Y | | | Y |
| Earl et al. 2018 | Y | C | Y | Y | N | N | Y |
| Farmer et al. 1995 | Y | Y | Y | Y | Y | Y | Y |
| Josman et al. 2008 | Y | C | C | N | N | N | Y |
| Mori et al. 1995 | Y | Y | Y | Y | Y | Y | Y |
| Pastor et al. 2006 | Y | Y | Y | Y | Y | Y | Y |
| Purcell et al. 2011 | Y | Y | Y | Y | Y | N | Y |
| Purcell et al. 2012 | Y | Y | Y | Y | Y | Y | Y |
| Purcell et al. 2017 | Y | Y | Y | Y | Y | N | Y |
| Purcell and Romijn 2017 | Y | Y | Y | Y | Y | N | Y |
| Stavrinos et al. 2011 | Y | Y | Y | Y | Y | Y | Y |
| Strauss et al. 1998 | Y | C | Y | Y | Y | Y | Y |
| Xiang et al. 2006 | Y | C | Y | Y | Y | N | Y |

Summary of the questions: Qu 1. Does the paper address a clearly focused issue? Qu 2. Was the cohort recruited in an acceptable way? Qu 3. Was exposure accurately measured? Qu. 4. Was outcome accurately measured? Qu. 5a. Were confounding factors identified? Qu. 5b. Were confounding factors controlled for? Qu. 9. Do you believe the results?

**4.1. Rate of Injury at the roadside**

Five papers considered the prevalence of injury at the roadside with three focusing on ADHD and two on general neurodevelopmental disorders. The meta-analysis demonstrated that in combination these studies provide a grouped confidence interval which indicates a higher prevalence of injury at the roadside in these populations compared to typical populations. So it would seem that individuals with ADHD and generalised developmental disabilities are more at risk of being injured at the roadside compared to their typical peers. The nature of these studies is that they provide a broad population overview of risk, however, for some of them the exact nature of the neurodevelopmental disorder is hard to determine. The Strauss et al., (1998) and Xiang et al., (2006) studies describe their populations as having 'developmental disabilities' (having sensory, physical, emotional or mental difficulties). Clearly these children may have neurodevelopmental disorders as defined by DSM-5 (APA, 2013) but this broad term may also include children with Downs Syndrome, Cerebral Palsy, Physical Disability etc. which are not neurodevelopmental disorders. As such, some caution is needed when drawing conclusions regarding the risk of injury at the roadside from these papers.

Two of the three papers (DiScala et al., 1998; Pastor et al., 2006) which focused solely on individuals with ADHD found an elevated risk of injury in the ADHD group. However, the third, (Brook et al., 2006) found no group differences regarding injury at the roadside. Brook et al., (2006) looked at an ADHD-LD population while DiScala et al., (1998) and Pastor et al., (2006) considered an ADHD only population. Although one might expect that an ADHD-LD population will be more at risk than an ADHD only population it is important to consider exposure to risk of injury. It may be that an ADHD-LD population, due to the nature of their difficulties, are less exposed to independent road crossing and so have less exposure to the risk of injury. This is somewhat supported by Brook et al's (2006) additional finding that the parents of their ADHD-LD group were more concerned about injury than parents of the typical children, although this is not a direct comparison between an ADHD-LD and an ADHD-only group it does indicate that measuring exposure alongside injury is important for us to fully understand risk of injury.

Finally, an important consideration in all of these population studies is that of generalisability. All of these studies, aside from Brook et al., (2006), were population studies carried out in the US. This may in part explain the difference in findings, but may also lead us to question whether similar findings would extend to different countries which have different road layouts etc.

### 4.2. Assessment of Risk

We grouped five papers under this heading, two which focus on a general ability to notice hazardous situations (including choice of crossing places) and three which more directly measure ability to choose a safe crossing place. These covered four of the neurodevelopmental disorders, namely ADHD, ASD, DCD and ID. A meta-analysis was not conducted on these data due to the disparate nature of the methods used and the tendency to report median and IQR data.

In terms of hazard perception, it would seem that children with attention difficulties are equally able to detect risky situations and propose preventative strategies (Mori et al., 1995 and Farmer et al., 1995). However, it is worth noting that this does not necessarily mean that these children are able to act on this knowledge, being able to recognise an external threat is potentially a different mechanism to being able to detect threat to oneself and then act upon that. Furthermore, both studies focus on general hazard perception and although this did include at least one instance of a road hazard neither were focused specifically on crossing nor do they present a breakdown. Therefore, these findings do not comprehensively consider understanding of risk at the roadside.

Anastasia (2010) and Purcell and Romijn (2017) both considered the ability of children to determine how safe a specific crossing place was. Both studies presented children with an allocentric ‘birds-eye view’ of a road crossing scene and asked children to indicate the safety of a specific crossing place. Anastasia (2010) demonstrated that children with ID alongside poor visual attention were much less able to determine the safety of a crossing position compared to children with ID and good visual attention. This finding suggests that visual attention maybe key in children with ID’s ability to judge safety. However, interpretation is difficult when trying to link this to potential behaviour at the roadside. An allocentric frame of reference is equivalent to detecting a hazardous situation in a photo / video, i.e. it is external to one’s actions (Zaehle et al., 2007) so whether children with ID and poor visual attention skills would be poorer at judging safety at the roadside is unclear. Using slightly different tools, Purcell and Romijn (2017) actively compared two viewing points (one an allocentric birds eye view and one an egocentric view) and found that children with DCD were as accurate as their peers when presented with an allocentric viewpoint but were much less accurate than their peers when presented with an egocentric frame. In this study visual attention was not directly measured but none had overt attention difficulties. The discordance between judgements in an allocentric frame versus an egocentric one is demonstrated here by the children with DCD, who can apply their understanding in an external or allocentric view but not in an internal one. Purcell and Romijn (2017)’s findings more directly suggest that children with DCD may struggle to identify safe crossing places and so these children might be more at risk at the roadside.

**4.3. Understanding of road layout, eye-gaze and perception**

Three of the papers in this section focused very specifically on shared pedestrian zones as compared to zebra crossings in Australia. Two of these looked at eye-gaze behaviour during crossing and the third on understanding of road layout in a group of adults with ASD vs. their peers. In terms of the eye gaze behaviour, one of the hypotheses of these papers was that given the marked social difficulties in ASD these individuals may fail to make direct eye contact with drivers and essentially this was found in both of the papers with the individual(s) with ASD making no eye contact saccades (Earl et al., 2016; Cowan et al., 2018). Further differences in the way adults with ASD direct gaze compared to their peers were also found. However, these seemed to be due to a greater number of fixations on traffic unrelated objects in the ASD group versus the typical group, but no differences for traffic related objects. Although these studies do point towards differences in gaze behaviour it is not clear whether these differences lead to a greater number of accidents / near collisions at the roadside.

Earl et al., (2018), looked at understanding of the right of way and rules of road within these different zones again across an ASD and a typical population. This study used the Q-sort task to group participants into two groups based on their understanding of these rules, the findings seem to point towards poor representation of individuals with Asperger's syndrome within these two groups. However, once again it is unclear whether these differences result in actual risk. It is also worth noting that in this later study gender, age and driving ability differences were apparent across the groups and so the limiting factor to understanding may not be the neurodevelopmental disorder per se but could instead be about one's driving experience or age. In a related study Josman et al's (2008) measured how able children with ASD were at using light controlled crossings. They found a better baseline performance at their road crossing game in typical children compared to a group with ASD which demonstrates that prior to training the ASD group are far less competent users of light-controlled crossing and so may be more at risk. In this latter study many of the children had ASD and diagnosed PDD which may indicate that the severity of their difficulties were higher than the adults in the Earl et al., (2018) study although little information was presented in either paper regarding diagnoses.

The final paper in this group was, Purcell et al., (2012) who considered the basic perceptual ability of children with DCD to detect when something is approaching. Findings suggest that children with DCD struggle to detect a vehicle as approaching once it exceeds 30 mph under certain viewing conditions. These findings point towards a potential perceptual limitation in children with DCD, whereby they may simply not realise that the car / vehicle is approaching. Such a perceptual limitation could put these children at risk at the roadside.

### 4.4. Perceptual abilities and gap choice

The final grouping of studies were much more homogenous in terms of the measures and methods used, they all measured the size of the temporal gap chosen between cars when crossing and they all compared this to the child's walking speed. This allowed a comparison of a measure of 'sufficiency of temporal gap', i.e. whether the gap chosen was temporally longer than the time needed to cross the road, using this measure we can see that the majority of studies found a difference between children with neurodevelopmental disorders (specifically ADHD and DCD) and their peers, whereby the temporal gap was shorter in the children with neurodevelopmental disorders putting them more at risk of collision.

Interestingly, Stravinos et al., (2011) considered temporal gap and executive function in ADHD. This paper found that executive dysfunction mediated the relationship between ADHD-C symptoms and how safe the cross was. Given that we see many studies reporting executive function deficits across neurodevelopmental disorders this mediating relationship might be important in terms of our understanding of risk at the roadside and neurodevelopmental disorders. For example, executive function is thought to be impacted in ASD (Pennington & Ozonoff, 1996), Specific Learning Disorders (Varvara et al. 2014; Westby, 2019), communication disorders (Martin and Allen 2008) and in DCD (Leonard et al., 2015.). However, executive function is not a single concept and differences are seen in the types of executive dysfunctions across neurodevelopmental disorders. It is not clear from the battery of executive function tasks used in Stravinos et al., (2011) whether a single or multiple executive functions mediated this relationship.

Interestingly, in the two studies considering children with DCD (Purcell et al., 2011 and Purcell et al., 2017) contrasting results were presented, with one showing no difference in the DCD and TD groups for one-lane crossing and the other showing more prevalent dangerous crossing decisions for the children with DCD compared to their peers in both one- and two-lane crossing tasks. In fact, the Purcell et al., (2011) study refers to the children with DCD being more cautious. An important distinction to make across these studies is the reported severity of the DCD symptoms, the children with DCD in the Purcell et al., (2011) study fell below the 5$^{th}$ percentile on the test component of the Movement Assessment Battery for Children, second edition) (Henderson, Sugden, & Barnett, 2007) while for the Purcell et al., (2017) study they were below the 15$^{th}$ percentile. So the children more affected by their motor difficulties had a better outcome, this could however be due to these children understanding their profound crossing difficulties and so rejecting any crossing gap whenever they saw a vehicle approaching in the distance. This type of overly-cautious behaviour, although seemingly safe, can result in frustration and then impulsive decisions (Purcell et al., 2011).

## 5. Summary

The papers summarised in this review provide evidence of an elevated risk of injury in individuals with ADHD at the roadside which may be due to poor choice of temporal gap. In the ADHD group this elevated risk may be a consequence of poor road-crossing choices which one study demonstrate was mediated by executive dysfunction rather than the symptoms most commonly associated with ADHD. Further evidence is given regarding poor choice of temporal gap in children with DCD but whether this results in greater risk of injury is currently not known, furthermore, the role of visual attention / executive function is unclear here. Other evidence has been reviewed which demonstrates differences in behaviour / understanding at the roadside in individuals with ASD (children and adults) and children with ID, however, it is not clear whether this translates into a greater risk or indeed a greater rate of injury in these individuals. This review is limited in the conclusions that can be drawn due to the paucity of the research carried out in this area and the hugely varied methods and groups that have been used. More research considering the abilities of individuals with neuro-developmental disorders is urgently needed.

## 6. Common issues

It is well documented that neurodevelopmental disorders are heterogeneous in nature and also that co-occurrences of these disorders is generally considered the rule and not the exception (Bishop and Rutter, 2008). Therefore, in order to be able to fully interpret findings from studies it is important that samples are fully described, that we take severity and co-occurrences into account when interpreting findings. A limitation in our interpretation of the data is that not all studies described their populations fully / did not measure co-occurrences. For example, we see many similarities between the children with ADHD and the children with DCD in terms of gap choice and although attention was measured in studies focusing on DCD (Purcell et al., 2011; Purcell et al., 2017), motor control was not mentioned in the studies focusing on ADHD and so we cannot be confident that these studies were not, in part, focusing on the same population. This point extends into the other papers as well, even with the population studies, we can be sure that some of the participants had additional difficulties that were either un-diagnosed, un-reported or un-checked for. A final, common issue with these studies which make interpretation difficult is that some of them do not control for confounding variables such as age and gender of groups and as the results may be biased. This indicates the need to careful consideration of potential confounding factors and then appropriate statistical of methodological adjustments to account for these.

## 7. Recommendations for practice

Based on the paucity of research studies reviewed here it is difficult to make specific recommendations for practice. However, one key element of safety is recognition of a potential issue. This research has highlighted a vulnerability of children with some neurodevelopmental disorders at the roadside; as such practitioners should be encouraged to explore with families whether road crossing is an issue or risk that needs to be addressed as a functional goal. As far as we are aware, there are currently no specific evidence based general recommendations to improve road crossing amongst children with neurodevelopmental disorders, but advice could be provided by health or education practitioners to parents and the rules of the road, such as crossing at designated crossing sites, extended road crossing practise and continued supervision for longer than might be expected with typically developing children. A body of research has focused on remedial training for teaching road crossing skills in children with ASD / very low IQ, however, this is not necessarily appropriate for all children with neurodevelopmental disorders, especially those who may appear to understand the rules of crossing the road but who are still, as shown by this review, at a greater risk at the roadside. Road crossing is often over-looked during development of functional goals in favour of more academic / scholastic based skills such as reading and writing, however, it is a key skill for independence throughout life and this review has clearly highlighted the importance of supporting children with neurodevelopmental disorders in this area.

## 8. Conclusion

Given the prevalence rate and heterogeneous nature of neurodevelopmental disorders there is surprisingly little evidence regarding the nature of the risk to these individuals as pedestrians at the roadside. That could of course lead us to believe these individuals are not more vulnerable at the roadside. However, the evidence which does exist and which we have reviewed here, although difficult to interpret in places, does indicate an elevated risk and differences in behaviour and understanding within the context of road crossing. It would seem that individuals with ADHD and DCD are prone to choose unsafe crossing gaps, that individuals with ASD use gaze behaviour differently at the roadside and may understand or perceive aspects of road layout differently than their typical counterparts and that children with ID may struggle to find safe crossing places. Further research is needed to qualify these statements and to investigate the role that executive function may play in these behaviours, but this is clearly an area of research which is in needed of further scrutiny.

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