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The roles of anxiety, self-concept, self-efficacy, resilience and motor control in the perceptions and actions of adults with and without Developmental Coordination Disorder

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Abstract

Developmental coordination disorder (DCD) is characterised by impairment of motor skills with negative impacts on everyday life. Although it continues into adulthood in approximately 70% of cases, research on adults with DCD remains limited. This thesis investigated the roles of and relationships between anxiety, self-concept, self-efficacy, resilience and motor control in how adults with DCD perceive and act in everyday surroundings compared to adults with typically developing (TD) motor skills.

An initial study examined relationships between general and movement-specific anxiety, self-efficacy, general resilience and self-concept in 74 adults with diagnosed DCD, 26 adults with suspected DCD and 79 TD adults (18-60 years) using an online questionnaire including existent and novel measures. Anxiety, self-efficacy and resilience were poorer in the adults with diagnosed or suspected DCD, while higher resilience related to higher self-efficacy and lower anxiety in the combined DCD group. Those with suspected DCD whose self-concept focused on movement difficulties had lower movement-specific self-efficacy.

A second study investigated the roles of general and movement-specific anxiety, self-efficacy, general resilience and motor control in how 41 TD adults thought they would behave (perceptual judgement) and how they actually behaved (executed action). A final study investigated this in 17 adults with DCD and 17 age- and sex-matched TD adults. These involved a questionnaire including existent and novel scales, a perceptual judgement task with static and dynamic conditions, and an executed action task walking through different-sized gaps between doors.

Findings were discussed within an ecological framework drawing strongly on Newell's constraints-based approach (1986). Results indicated a relationship between higher movement-specific anxiety and bigger safety margins in TD adults only. Adults with DCD demonstrated significantly different turning behaviours to the TD adults and less consistent motor control related to bigger relative safety margins. Findings also showed notable differences in the point of behaviour change (critical ratio) between perceptual judgement and executed action, illustrating the importance of studying perception and action in tandem.

The findings contribute novel insights into the roles of these factors in how adults with and without DCD perceive and realise their intentions and abilities to act in the world. They offer a springboard for future research and could contribute to further development of strategies for adults with DCD to effectively manage motor skills difficulties.

Statement of Aims and Objectives

The research comprising this thesis aimed to investigate the roles of and potential interactions between anxiety, self-concept, self-efficacy, resilience and motor control in how adults with typically developing motor skills and adults with Developmental Coordination Disorder (DCD) think they will behave (their perceptual judgement), and how they actually behave (their executed action), when navigating obstacles in the everyday environment.

It aimed to do so by first describing elements of anxiety, confidence and self-concept within an action context among adults with and without DCD. It then aimed to build on the initial findings to investigate the influence of anxiety, self-efficacy, resilience, and movement variability (one's ability to move consistently) on the perceptions and actions of typically developing (TD) adults. Building further on the findings from this second study, the final aim was to investigate the comparative influence of these same elements on the perceptions and actions of adults with DCD as compared to their age and sex-matched peers.

To achieve these aims, the following objectives were set.

(i) Determine generalised anxiety, self-efficacy and self-concept in adults with and without DCD, as well as anxiety and self-efficacy specifically in relation to safe navigation of the environment on foot, in a sample of adults with and without DCD using existent psychometric measures and self-developed questionnaires.

(ii) Refine an anxiety and self-efficacy measure for navigating the environment on foot based on the information collected from measures in objective (i).

(iii) Determine the point at which behaviour changes for perceptual only and action tasks and examine the way in which this point relates to body size, movement consistency, anxiety, self-efficacy and/or resilience in a sample of typically developing adults.

(iv) Replicate objective (iii) in a sample of adults with DCD and their typically developing age- and sex-matched peers.

Please note, the research undertaken in the three studies comprising this thesis was approved by the University Research Ethics Committee, Oxford Brookes University (UREC reference numbers: 201396 (Study One); 201422 (Study Two and Study Three).

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Chapter One: Introduction

Movement is integral to how organisms experience the world. It is always guided by perception of the surrounding physical environment. In turn, perception is inevitably moulded by the possibilities for movement or action offered by the environment. Furthermore, both perception and action may be influenced by how an organism feels about itself, its environment, and its capacity to successfully navigate that environment. This thesis explores the nature of these relationships and how they may vary among adults with typically developing motor skills and adults with a condition called Developmental Coordination Disorder (DCD). In order to do this, the theoretical approaches underpinning the research undertaken to form this thesis will first be examined.

1.1 The relationship between perception and action: theoretical approaches

1.1.1 The ecological account of psychology

The ecological account of psychology is concerned with the unity of perception and action. It was first established and cultivated by J. J. Gibson in relation to perception (1977; 1979/2015) and subsequently E. J. Gibson with a focus on developmental psychology (1969; Gibson & Pick, 2000). Several key concepts underpin its theory, all of which hinge on the embedding of organisms in their physical environment. Ecological theory sees an organism plus its environment - an inseparable pair - as one unit of analysis. A related notion is that perception and action are inseparable from one another. Just as an organism cannot be separated from its environment, perception and action cannot be separated: they are interdependent. Ecological psychology sought to dissolve the ideas of perception and action, organism and environment, subjective and objective and even mind and body as dichotomies; theoretical assumptions that had previously always fuelled the debate between cognitivism and behaviourism. The ecological approach offered an alternative to this split between the entirely inferential, representational nature of cognitivism and behaviourism's commitment to the supremacy of physicalist stimuli. Ecological psychology offered a vision in which these schools of thought complemented one another as stages of a larger, united cognitive picture (Lobo, Heras-Escribano & Travieso, 2018).

Gibson (1979) theorised that visual perception of the information necessary to execute a movement is a *direct* process, i.e., it does not involve any cognition. He explained this using the idea of a symbiotic relationship between vision and action. So, vision supplies information about the environment and the organism's position within it while action (i.e. movement through the environment) serves as the source of the rich, nuanced information the visual system needs. In this way there is an uninterrupted cycle taking place between the two. For Gibson, the ecological validity - or real-world applicability- of research therefore depends on considering visual perception and movement *together*, along with mutual consideration of an individual organism and the environment within which it is perceiving and acting. The ecological approach is sometimes divided theoretically between dynamical systems theory on the one hand and the concept of a perception-action loop on the other. A brief explanation of both of these is given below.

1.1.2 Dynamical systems theory

A dynamical system is made up of various elements that are united and interdependent. The behaviour of the system changes over time due to this interdependence of the component parts shaping it. Dynamical systems theory describes this changing behaviour mathematically and posits that the system displays emergent and self-organising behaviour as a result (see e.g., Thelen, 1989; Richardson & Chemero, 2014). These aspects of dynamical systems theory have proven useful to ecological psychology overall and especially to the development of theories in relation to motor coordination dynamics (e.g., Stoffregen & Riccio, 1988; Turvey, 1990). The ideas at the heart of dynamical systems theory feed directly into the other key ideas about the relationship between perception and action discussed here, namely that movement emerges from a constant, ever-shifting process of underlying reciprocity between an organism, its environment and the continuously changing constraints manifesting within this system. However, as a theoretical framework this is more commonly referenced in relation to motor development and learning, as well as in thinking about the systems involved in the production of coordinated movement. As such, given the focus of this thesis, dynamical systems theory will not be specifically touched upon again.

1.1.3 The perception-action loop

The concept of a perception-action loop focuses on the fundamental reciprocity between a perceiver and its environment (see Richardson et al., 2008; Warren, 2006). Building on Gibson's theory, it posits that the systems of perception and action are intrinsically coupled in order to effectively interpret environmental opportunities and constraints, with the goal of producing skilled, adaptive movement. Distinctive features of this concept are the active nature of perception and the notion that perception and action are not simply interacting with or influencing one another, but that they are mutually and “symmetrically constraining” (Richardson et al., 2008, p. 174).

1.1.4 Affordances

Within the broader conceptual framework of the perception-action loop, Gibson (1977) developed the term ‘affordance’ to describe how the nature of objects in the environment interacts with an individual’s characteristics to provide possibilities for action. Key to this is the notion that an individual organism embedded in their environment knows and interprets their environment *because* they perceive affordances, i.e., the possibilities for action available specifically to them in that specific environment. Where an environment is the same, different individual characteristics make for different affordances. For example, a south-facing windowsill affords a person a surface to place a vase of sunflowers, but it affords their cat the perfect spot to sunbathe (as well as a conveniently placed vase for a refreshing drink). A coffee table affords an adult somewhere to put their cup, but for a small child it affords a place to climb up and reach that shelf of things that surely must be toys. It is important to note that affordances exist regardless of whether they are actually perceived since they are located in both the material properties of environment and perceiver, and although they are not always actively perceived they can be focused on and engaged with selectively (Warren, 1984).

The affordance relation therefore guides behaviour through an individual’s perception of the ‘fit’ between their body and the environment in the context of potential and executed action (Gibson, 1979). Indeed, Gibson saw the perception of affordances as perceiving “ecological meaning” in the sense of perceiving how one’s surroundings relate to one’s capacities (Gibson, 1979/2015, pp. 131-132). For example, when faced with a staircase a person does not perceive the height of each stair in centimetres, but whether or not they can step up onto it (Lobo et al., 2018).

Interestingly, in spite of being a central tenet of ecological psychology, a single definition of affordances remains elusive. Some authors base their definition on affordances being environmental properties which are complemented by the individual characteristics of organisms (e.g., Turvey et al., 1981; Turvey, 1992). In fact, Turvey (1992) goes so far as to argue that when these complementary properties of environment and organism are together under the right circumstances, affordances will *always* be realised - successfully or otherwise. Other authors, such as Stoffregen (2003) do not agree, preferring to conceptualise affordances as "*emergent* properties of the organism-environment system" (Stoffregen, 2003, p. 118).

1.1.5 The action-specific perception account

Rooted in Gibson's (1979) ecological approach, the action-specific perception approach is based on a mutual relationship between a perceiver's abilities and environmental properties, the interaction of which produces affordances. However, as has been established, an individual's characteristics are dynamic and they can change over time. The same environment - and potential for executing actions in that environment - may be perceived differently by the same individual depending on how they feel and what they are capable of at that moment. So, in a stable environment the affordance relation shifts in line with the perceiver's state and abilities, which may be influenced by myriad factors. This idea lies at the heart of the action-specific perception account (see e.g., Proffitt, 2006; Witt & Proffitt, 2008; Witt, 2011).

What is distinctive about the action-specific account of perception however is that it prioritises the abilities of a perceiver as the definitive feature of action perception, seeing perception as a direct function of behavioural abilities. As such it proposes that perceivers with different abilities and subject to different states will perceive similar environments differently while, as mentioned above, an individual's perception of the same environment is subject to change as their abilities and / or state change. Like Gibson's original ecological approach, this challenges traditional constructivist conceptions of perception as objectively representative of the environment and unconnected to behaviour (e.g., Marr, 1982; Norman, 2002; Rock, 1983; 1997). Witt (2011) conveys the essence of the action-specific account through the example of somebody coming across a tall wall in their path. One person perceives it as a barrier and looks for a way around it. For another person who is trained in parkour or urban climbing, that same wall *affords* climbing over. The same distinction could be made between the same person, at different times in their life - before and after taking up urban climbing for example.

Like the other related frameworks explored here, the action-specific account of perception shows its Gibsonian roots by considering motor action as subjective and by contextualising perception of action firmly within the relationship between perceiver and perceived. However, its prioritisation of the abilities and state of the perceiver differentiate it from related theoretical frameworks, such as the constraints-based approach which, as will be discussed subsequently in further detail, see the roles of environment, individual characteristics and task as equally influential on the perception of action (Newell, 1986).

Some critics have argued that nonvisual elements, including action capabilities, may affect judgements that derive not from perception itself, but from post-perceptual processes (see e.g., Loomis & Philbeck, 2008). Indeed, Witt (2011) acknowledges that the action-specific account of perception is susceptible to this given that current studies rely on perceptual judgements (e.g., Proffitt, 2006; Riener, Stefanucci, Proffitt & Clore, 2011; Stefanucci, Proffitt, Core & Parekh, 2008). As Witt (2011) notes, these perceptual judgments arise from both underlying perceptual *and* post-perceptual processes which are together involved in the generation of responses. Action capability could consequently impact on either one or both of these. However, as will subsequently be examined more closely, where studies involving perceptual judgements of affordances consider judgements of potential action directly alongside the associated executed action, this may enhance confidence that perceptual processes are indeed being captured.

1.1.6 The constraints-based approach

The notion of *constraint* has an important role in theories of the relationship between perception and action. Indeed, the constraints-based approach, which stemmed from Gibson's (1979) ecological approach, views the environment, the individual and the task as potential constraints on motor action within a perception-action context. Crucially, these three aspects are all considered equally influential (Newell, 1986). Constraints arising from within an individual include physical and emotional aspects such as body dimensions and how anxious or calm an individual is feeling in a given situation or moment. Task-based constraints are elements of a task that affect the way in which an emerging movement is perceived and realised, such as how hard or soft the surface you need to walk on to get from point A to B is. Finally, there are constraints based within the wider shared environment such as weather or lighting (Harris, Purcell & Wilmut, 2022). Newell (1986) draws additionally on ideas from dynamic systems theory which is discussed in further detail subsequently and according to which movement results from the interactions between various subsystems that make up an individual, the task and their environment (Thelen, 1989). With this in mind, for Newell (1986) the multitude of individual-, task-, and environment-based constraints at play in any given moment are constantly interacting and influencing one another. Following this reasoning, the nature and effect of any of these constraints can vary both between and within individual organisms, giving rise to the emergence of different perception-action cycles and therefore movements from one moment to another.

A concrete example from Harris et al. (2022) gives this some real-world context. An individual's leg length (individual-based constraint, physical) would be expected to influence their step length. However, if this individual is feeling particularly anxious today, it might make their step length shorter than it would be when they feel calm, or shorter than another individual with the same leg length who is feeling less anxious today (individual-based constraint, emotional). A soft sandy surface that this individual needs to walk over would likely shorten their step length further, compared to on a hard road surface (task-based constraint). What's more, it happens to be nighttime and step length also shortens in the dark (environment-based constraint). So, considering these constraints together we could see that short leg length, combined with high anxiety (of whichever kind - this will be returned to later in the chapter), coupled with a soft walking surface which needs to be navigated in the dark may lead to the shortest step length for this individual. Although this is a simplified example which cannot take account of all the possible constraints involved, it does illustrate how these three types of constraints can interact with one another and influence movement.

1.1.7 A note on information processing theory

Until the advent of ecological psychology motor development research was dominated by the information processing account. This is a constructivist view whose principal assumption is that representations are internally 'modelled' in the brain, a process involving both perception and action brain-based 'programs'. In this way, the brain constructs meaning internally from external environmental input that has no inherent meaning itself. This aligns with the traditional cognitive view of a 'sense-think-act' cycle in which information is received from the environment (sense), that information is then processed (think), and then action is executed (act). Supporters of ecological psychology have traditionally seen this information processing account as opposing the central tenets of their view explored in the previous sections, including affordances and the perception-action loop (see e.g. Wade & Kazeck, 2018).

However, some have argued that information processing accounts and constraints-based accounts (typically seen as an ecologically-based theory) in fact have more shared rather than opposing elements (see e.g. Anson, Elliot & Davids, 2005; Wilmut, 2017). Anson et al. (2005) draw particular attention to the fact that Bernstein's seminal body of work on motor control features both motor programmes (key to information processing) and organism-environment interactions (key to ecological psychology) (e..g., see Bongaardt & Meijer, 2000). Indeed, the notion that a more hybrid theoretical framework may offer the most potential in explaining the relationship between perception and action has steadily gained in force and evidence base in recent years, an aspect that will be returned to in the later section on perception and action in DCD (e.g., Wilson, Caeyenberghs, Dewey, Smits-Engelsman & Steenbergen, 2018).

1.1.8 Summary of theoretical approaches

The range of theoretical approaches and concepts described, as well as the rich debates they have generated, highlight that there is no comprehensive theory which can definitively explain the relationship between perception and action. However, these descriptions do highlight the interlinking nature of several approaches and concepts. This thesis therefore proceeds from an understanding of the integrated principles of the ecological account of psychology, with a particular focus on affordances (Gibson, 1979), the concept of the perception-action loop (Richardson et al., 2008), the constraints-based approach (Newell, 1986), and the action-specific perception account (e.g., Proffitt, 2006). Being rooted in their common theoretical ground, the research described in this thesis firmly embeds perception within the context of its related action.

1.2 Studies of perception and action

A few years after Gibson's theory of affordances (1977) and ecological approach to visual perception (1979) were published, Warren (1984) undertook what would become a seminal study of affordances in relation to the 'climbability' of stairs. Participants were divided into two groups according to height (short or tall) and then asked to judge whether they could climb onto steps of differing heights put in front of them. In line with expectations, participants in the 'tall' group judged higher steps to be more 'climbable' than the participants in the 'short' group, notably without taking any actual 'step-climbing' action. Warren worked out the point at which participants were reaching a 'critical step' in their judgements. This was the step height which was judged as climbable in 50% of cases and as 'non-climbable' in 50% of cases when presented multiple times. During analysis Warren noted that the height of the critical step related to participants' body size. In light of this he came up with a biomechanical model focused on body measures: $Rc = Leg + ULeg - Lleg$, where Rc is critical step, Leg is overall leg length, $ULeg$ is upper leg length and $Lleg$ is lower leg length. When critical step height was divided by leg length, the significant differences between the 'tall' and 'short' groups disappeared. In addition, he deduced that an individual estimates steps that are less than 0.88 times their leg length to be 'climbable'. This was the first study to propose such a mathematical formulation and it ushered in a range of subsequent studies aiming to identify action possibilities offered by a specific surface or object for a given organism in relation to their body dimensions. It is important to note that in this study Warren first looked at perceptual judgements of 'climbability', but that in the second and third experiments of the study he looked at the act of climbing these stairs of differing heights and found that visually preferred riser height of stairs can be predicted from measurements of minimum energy expenditure. In this way perceptual judgement was to a certain extent being examined in relation to the associated action, though his and other researchers' subsequent studies went on to unite these aspects more directly in methodological terms.

For example, a few years later Warren and Whang (1987) undertook another study with the same analytical approach, but this time focused on visually guided action while walking through apertures. In this study, perceptual judgement was more directly embedded within the context of the associated action. Participants with a range of narrow and broad shoulders were filmed walking through apertures of different widths and using this footage the 'critical point', i.e. the point at which participants changed from frontal walking to turning their shoulders to pass through, was established. These were compared with the participants' perceptual judgments of whether they could walk straight through the apertures without turning, in both a static (i.e. standing still) condition and a dynamic (i.e. moving towards the aperture) condition. The authors identified that the critical point fell at the shoulder-to-aperture-width ratio of 1.3. In other words, participants turned their shoulders for apertures less than 1.3 times their own shoulder width. They also found that standing still and looking towards an aperture led to lower critical ratio judgements in both a moving and a static viewing condition (ranging from 1.14 - 1.17). The authors concluded that static viewing information is sufficient for facilitating accurate perceptual judgments of the 'passability' of apertures. Warren and Whang (1987) were able to further conclude from this study that affordance perception and movement behaviour are influenced by body dimensions.

Research drawing on these initial findings and methodological frameworks has since explored affordance perception in terms of perceptual judgments and their associated executed actions in different populations (and with varying parameters). Van der meer (1997) sought to examine how speed of locomotion and motor ability might influence the use of body-scaled information during visual guidance when passing underneath barriers of different heights. This was considered in typically developing adults, nursery school children, children with cerebral palsy and infants with less than six weeks' experience of independent walking. Van der meer (1997) found that all participants, except for the infants, demonstrated a body-scaled critical point at which their behaviour changed from walking upright to ducking underneath the barrier. Interestingly the nursery schoolers showed more cautious approach speed, while the children with cerebral palsy allowed for a bigger safety margin seemingly in compensation for a poorer ability to control their vertical positioning. Van der meer concludes that movement speed and consistency - or level of motor control - also have an important role in the way in which body-scaled information is used in the affordance relation between organism and environment.

Other studies returned to the aperture-crossing paradigm initiated by Warren and Whang (1987) and considered the role of body-scaling and other factors. Higuchi, Cinelli, Greig and Patla (2006) built on Warren and Whang's work by exploring how shoulder rotation is adjusted in line with aperture size and under various kinds of task-based constraints. To do this, the aperture sizes they used were scaled according to each participant's shoulder width to all fall below the critical aperture ratio of 1.3, as identified by Warren and Whang (1987), consequently forcing participants to turn their shoulders to pass through. Participants were asked to walk through the apertures in four different locomotion conditions: walking normally, holding a long bar with shoulder rotation permitted and subsequently not permitted, and using a wheelchair. This built on previous findings demonstrating the ability to rapidly and accurately adapt to artificial extensions of different bodily dimensions when engaged with sensory motor tasks. For example, in judging reachable space accurately holding a long stick (e.g., Berti & Frassinetti, 2000), and in accurate judgement of action capabilities with 10 cm blocks strapped to feet (e.g., Hirose & Nishio, 2001).

Higuchi et al. (2006) found that participants were able to make quick and consistently accurate judgments to pass through the apertures successfully except where they had to avoid what would otherwise be the adaptive movement response of a shoulder rotation while walking or using a wheelchair. Otherwise, when they could rotate their shoulders while walking and under the task-based constraint of carrying a long bar, they found that the angle of shoulder rotation at the point of passing through doors increased proportionally as aperture size decreased. This calibration of shoulder rotation to aperture size indicates that instead of producing the maximum shoulder rotation every time, the visuo-motor system is set up to accurately judge the exact degree of shoulder rotation needed to pass through a specifically-sized aperture. The authors also identified a reduction in movement speed just before participants crossed through the apertures and propose that this gives the visuo-motor system the time it needs to process the relevant visual information and plan its most appropriate behavioural response. This chimes with subsequent studies that also observed a reduction in speed when approaching revolving doors (Cinelli & Patla, 2008), although other research has pointed out that reduction in speed is needed to maintain body control when changing direction or could simply be a protective preventative mechanism designed to minimise any potential injury while crossing any kind of threshold (Patla, Prentice, Robinson, Neufeld, 1991; Wilmut & Barnett, 2010).

Wilmut and Barnett (2010; 2011) extended the work of Higuchi et al. by looking further at how shoulder angle and movement speed are tailored according to aperture size. They considered this first in typically developing adults (2010) and subsequently in typically developing 8-to-10-year-old children (2011). In their first study, aperture sizes included two shoulder-to-aperture ratios (SA ratios) for which participants would definitely need to rotate their shoulders to pass through (0.9 and 1.1), and two SA ratios for which they would not need to rotate and could walk through frontally. They found that for the initial approach (the first three seconds) movement speed and shoulder rotation remained stable across the SA ratios, but that as movement towards the threshold progressed, shoulder rotation angle, as well as magnitude and timing of speed reduction, became proportional to SA ratio. What's more, as the SA ratio increased (i.e. the bigger the aperture size), speed started to reduce later in the movement. This suggests that in typically developing adults early adjustments of movement, such as the timing with which movement speed begins to reduce, are strongly attuned to the ratio between shoulder width and aperture size, whether any later adjustment of body position is necessary or not. This exemplifies a functional, adaptive perception-action loop in line with the ecological approach.

Wilmut and Barnett (2011) subsequently investigated how typically developing children aged 8-10 years old make action judgements and adapt their movement while navigating through apertures. This time five aperture sizes were used which corresponded with SA ratios of 0.9, 1.1, 1.3, 1.5 and 1.7 and the spatial and temporal characteristics of shoulder rotation and movement speed across the approach phase and doorway threshold-crossing phase were collected. Results revealed that children show a critical ratio of 1.61, suggesting that the process of making an action judgement - in this case the decision to rotate their shoulders - is scaled differently to adults. Results also showed that both shoulder angle variability and lateral trunk variability could be used to predict shoulder angle at the door for larger apertures. This indicates that children do spatially and temporally adapt their movements according to aperture size like adults do, and furthermore supports the notion that children are sensitive to the constraints and dynamics of their own developing perception-action system. In other words, they take into account the consistency of their own movement behaviour and are able to successfully scale their actions appropriately. This also links back to the findings from an earlier study undertaken by Savelsbergh, Douwes Dekker, Vermeer and Hopkins (1998) suggesting that children with and without cerebral palsy could more successfully take into account their own visual-spatial abilities in terms of body-scaling for aperture size when action was being used in conjunction with, and indeed in the service of, perception.

Wilmut and Barnett’s findings support the dynamical scaling model, based on evidence suggesting that in children affordance perception is not directly related to body geometry but involves the dynamics of their still-developing perception-action system (Snapp-Childs & Bingham, 2009). In their study, Snapp-Childs and Bingham illustrated this with a task that involved stepping over or onto three different barriers (a single step up, a foam obstacle and a gap). These were scaled to body size and placed in the walking path of a group of 4- and 6-year-olds and a group of adults. Results showed that age-related differences in how these actions were scaled correlated with levels of movement variability, demonstrating the sensitivity of the perceptual-motor system of children as young as 4-years-old in effectively responding to their own individual-based constraints.

This 'taking into account' of movement variability, defined as how consistently an organism is able to move, is also relevant for populations at other stages of development and those with motor difficulties including DCD. Looking first towards the other end of the age continuum, Hackney and Cinelli undertook several studies with older adults, aged sixty and above (2011; 2013). Using a similar aperture-crossing paradigm as previous studies (Warren & Whang, 1987; Higuchi et al., 2006; Wilmut & Barnett 2010; 2011), they first (2011) identified that older adults show a critical ratio of 1.6 when walking through the apertures which is closer to the critical ratio of 1.61 shown by children in Wilmut and Barnett's (2011) study and differs notably from the critical ratio of younger adults shown to fall at 1.3 (Warren & Whang, 1987). This finding suggests that older adults take a more cautious approach than younger adults, while high levels of variability in magnitudes of shoulder rotation across the SA ratios suggest that older adults may navigate through apertures based both on body-scaling and age-related locomotive stability and control factors.

Hackney and Cinelli (2013) subsequently undertook a study to compare young and older adults and to determine both whether any differences in their movement behaviour resulted from differences in perception and whether their actions were guided by perceptual judgement. Both groups completed a perceptual judgement task which involved judging the 'passability' of variously sized apertures during static (standing still) and dynamic (walking towards) conditions, as well as an executed action task where they walked through the apertures. Results from the executed action task supported previous related research (Grabiner, Biswas & Grabiner, 2001; Owings & Grabiner, 2004; Hackney & Cinelli, 2011) in confirming that older adults rotate their shoulders at wider relative aperture sizes than younger adults. The older adults also demonstrated comparatively more variability in their shoulder rotations across all of the aperture widths. Results from the perceptual judgement task suggested that the static perceptions of older adults were similar to those of younger adults, but that their dynamic perceptions - for example, their perception as they move towards a doorway they need to go through - differ. Specifically, in the older adults it was only their dynamic perceptions that matched their actual actions, suggesting that perceptions of action capabilities are a function of dynamic stability, and that where stability decreases - as it has been shown to do with age (Patla et al., 1993; Shumway-Cook & Woollacott, 2011) -

self-motion becomes increasingly important in the accurate judgement of one's own action capabilities. Hackney and Cinelli (2013) therefore concluded that the age-related differences they observed likely resulted from differences in levels of dynamic balance control.
So far, the studies discussed have included a focus on movement *behaviour* when engaging actively with the affordance relation in a way that necessarily brings movement ability and perceptual judgement ability together. While this unity in the study of perception and action is the most compatible with the theoretical underpinnings of this thesis, there are pertinent studies that have explored only the judgement of affordances, including but not exclusively focusing on the 'passability' of apertures.

1.2.1 Studies of perceptual judgement

Beginning with a look back at Warren and Whang's (1987) study, once they had established in one component that participants were able to make consistent 'passability' judgements when statically viewing the apertures of various sizes from a distance, the authors tested the effect of a disruption of the ratio between eye height and standing height, unbeknownst to participants. Results showed that this disruption impaired the ability to make accurate and consistent perceptual judgements of 'passability'. The authors therefore concluded that perceptual judgement of 'passability' under such conditions depends on body-scaled eye height information. This links back to Gibson's (1979) theory of direct perception in which he asserts that visual scene information is scaled to eye height (also see Sedwick, 1973).

As part of a later study looking at spatial requirement estimation for wheelchair users, Higuchi, Takada, Matsuura and Imanaka (2004) found that nondisabled adults actually tended to overestimate the space they would need to walk through variously sized apertures without rotating their shoulders. However, when considered in relation to Warren and Whang's (1987) findings, the 'overestimation' did not exceed what was observed when participants did actually walk through apertures. Participants may therefore have simply been judging by the space they would actually need to walk through, taking into account appropriate safety margins.

Taking a different approach, and being a proponent of the action-specific perception account discussed previously, Proffit (2006) describes a series of studies using visually guided and haptic measures that focused on the perception of slant under various individual-based constraints. Findings showed that participants who were more fatigued, burdened by carrying a rucksack, elderly or with less robust levels of overall health judged hills to be steeper to walk up than control groups for whom these factors were not constraints.

1.2.2 The role of affect

Other relevant studies that consider different affordance judgements both within and outside of a movement behaviour context also elicit the consideration of other potential influences and constraints on perception and action, including the role of affect. ‘Affect’ and ‘affective state’ are terms whose definitions generate rich debate. However, one definition is “any experience of feeling or emotion, ranging from suffering to elation, from the simplest to the most complex sensations of feeling, and from the most normal to the most pathological emotional reactions. Often described in terms of positive affect or negative affect, both mood and emotion are considered affective states” (APA Dictionary of Psychology, 2023). Looking at how mood or emotional state may influence affordance perceptions in everyday life, studies undertaken by Riener et al. (2003; 2011) found that a group of participants listening to ‘sad’ music judged hills to be steeper to walk up than participants in another group who were listening to ‘happy’ music.

One aspect of affect that has been a focus of various studies of perceptual judgement of affordances, alone or in combination with the associated action(s), is anxiety. Anxiety is often categorised in terms of being ‘state’ or ‘trait’. State anxiety fluctuates and exists in a given moment ‘characterised by subjective feelings of tension, apprehension, nervousness, and worry, and by activation or arousal of the autonomic nervous system’ (Spielberger, Gorsuch, Lushene, Vagg & Jacobs 1983, p. 4). State anxiety relates to but differs from trait anxiety as ‘relatively stable individual differences in anxiety-proneness as a personality trait’ (Spielberger et al., 1983, p. 4). Bootsma, Bakker, van Snippenberg and Tdlohreg (1992) first studied anxiety’s effects on perceptions of the ‘reachability’ of approaching objects. A group with high trait anxiety, a neutral trait anxiety group and a group with low trait anxiety judged whether a range of approaching balls were reachable under an induced anxiety condition and a control condition. Their findings showed that higher anxiety (shown to be highest in the participants with high trait anxiety subject to the anxiety induction) affected the accuracy with which the salient perceptual information was picked up. However, interestingly anxiety did not affect the critical ratio itself. The authors conclude from this that heightened anxiety can affect the perceiver's processing of relevant information without affecting the affordance itself.

A later study undertaken by Pijpers, Oudejans, Bakker and Beek (2006) showed that higher state anxiety, induced by placing participants at a height where they would have an increased fear of falling, decreased both their perceived and actual maximum reaching height while completing a wall-climbing task. The authors conclude that their findings call attention to the role emotional state plays in perceiving and realising affordances. They see their results as contributing to an evidence base showing that changes in emotional state coincide with changes to affordance and action perception.

Stefanucci et al. (2008) subsequently investigated the role of induced height anxiety specifically in relation to the perception of geographical slant in the context of looking down from the top of a hill. When participants stood on a skateboard at the top of the hill, the hill was judged to be steeper compared to the judgments of participants placed in the same position but on top of a stable wooden box of the same height as the skateboard. However, when participants were asked for a visually guided estimated measure of the hill's slant using a haptic palmboard, they gave accurate estimated measures across both the skateboard and wooden box conditions (also see Proffitt, Bhalla, Gossweiler & Midgett, 1995). These findings indicate that anxiety may have a different influence on explicit judgement than on other facets of action perception.

In a later study, Graydon, Linkenauger, Teachman and Proffitt (2012) considered the influence of induced state anxiety on the perceptual judgments of reaching and grasping ability which they then directly compared with actual action capabilities in these tasks. In this study Graydon et al. (2012) induced heightened state anxiety in one group of participants with an anxiety-provoking breathing task frequently used in previous research (e.g., Schmidt & Trakowski, 2004; Teachman, Marker & Clerkin, 2010). The authors used a series of tasks with which they measured perceived and actual reaching ability, grasping ability and the ability to move the hand through apertures. Their results showed that participants in the more anxious group underestimated their real action capabilities consistently in all of the tasks compared to participants in a control group. In other words, higher anxiety led to more cautious assessments of what participants thought they could do. Graydon et al. (2012)

concluded that state anxiety influences how affordances are perceived in near space and that higher anxiety leads to withdrawal behaviours.

Related to Pijpers et al.'s (2006) approach and in a return to the aperture-crossing paradigm, Hackney, Cinelli, Denomme and Frank (2015) later investigated the relationship between postural threat, action capabilities and identifying possibilities for action (in the context of the passability of apertures). They did so by challenging participants' ability to maintain their balance by asking them to walk along a narrow (20cm wide) and elevated pathway (raised 40cm from ground level) to pass through apertures ranging from 1.1 to 1.5 times their shoulder width. Compared to a 'normal' walking condition on a ground level path that was not narrowed in any way, the elevated walking condition gave rise to decreased walking speed, increased trunk sway and a larger average critical ratio (1.4 in the elevated condition (±0.02) as compared to 1.2 (±0.02) in the ground level condition). Anxiety provoked by a perceived and actual threat to physical balance therefore appears to influence movement behaviour, in this case illustrated by aperture-crossing behaviour.

Studies which have investigated the effect of state anxiety on perceptions of affordances and action perception, such as those discussed above, have tended to use induced high and low anxiety conditions. In a more recent previous study however, Harris and Wilmut (2020) aimed to address a lack of research into everyday state anxiety's impact on the perception of everyday actions in typically developing adults. State anxiety was measured using the State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1983). Using a similar methodological approach as previous aperture studies (e.g., Wilmut, Du & Barnett, 2016), participants were asked to make perceptual judgements and perform the associated action in relation to crossing over ground-based apertures of different sizes which represented puddles. The critical ratio in this case was the aperture size, relative to participants' leg length in cm, at which crossing behaviour (judgement or actual) switched from a step to a spring.

Interestingly it was found that perceptual judgement critical ratio could be predicted with state anxiety, whereas action critical ratio was not. These results suggest that everyday state anxiety may constrain perceptual judgement of action capabilities, but this may not be reflected in emergent movement behaviour. Despite methodological differences, this does recall Bootsma et al.'s (1992) earlier finding that anxiety state may affect perceptual information pickup without affecting an affordance per se. Once again, these findings illustrate the value of measuring movement behaviour instead of inferring it from perceptual judgements, even when these are embedded in a context of action.

Another more recent study undertaken by Vegas and Laurent (2022) built on previous work by Mark and Vogele (1987) as well as Riener et al.'s (2011; 2013) previous studies by looking at positive and negative mood inductions and their effects on affordance perceptions of sitting. Interestingly, Vegas and Laurent found that an induced 'happy' or 'sad' mood led to decreased accuracy in participants' perceptions of sitting affordances, while participants in another group with no mood induction perceived their sitting affordances accurately according to body-scaled intrinsic units. Reflecting on how their findings could relate to previous research and theory the authors concluded that this decrease in accuracy resulting from a spike in either positive or negative mood may be due to a mood-related modification of available energy levels (e.g., see Gaillot et al., 2007; Zadra, Weltman & Proffitt, 2015) or alternatively a disruption of attunement to optical variables with key roles in the guidance of action and/or calibration of the perceptual-motor system (e.g., see Fajen, 2005; Ruginski, Thomas, Guess & Stefanucci, 2019).

Subsequently and most recently, Bague and Laurent (2023) have considered the relationship between perception of affordances and symptoms of depression. The authors experimentally investigated suggestions from previous theoretical work that perception of action possibilities is influenced by depression, which interestingly has been conceived of by some as an action-related disorder (see e.g., Fuchs, 2005; Canbeyli, 2010; Kiverstein et al., 2020). They did so using a reachability task in which participants estimated their maximum capability of reaching a given target with their hand, without moving the rest of their body. This was then compared with their actual motor reachability capacity. In this study, the critical ratio related to participants' arm length and was converted to intrinsic body-scaled measurements. The Beck Depression Inventory-Fast Screen (BDI-FS) was used to allocate participants to a group with or without depressive symptoms (Beck, Steer & Brown, 2000).

Bague and Laurent (2023) found that participants with depressive symptoms made more conservative estimations than those without depressive symptoms. Those with depressive symptoms perceived reduced motor action possibilities compared to controls, indicating some impairment of the body-scaling of environmental properties at the perceptual level in this group. In relation to theoretical models of depression and affordances, the authors concluded that depressive symptoms are associated with altered, and even impaired, perception of reaching affordances. They suggest that this might be an embodied manifestation of the inhibitory regulation commonly shown in depression and that the ‘negative mood’ component of depressive symptoms is likely central to this alteration to affordance perception (e.g, Fuchs & Schlimme, 2009; Laborit, 1979; 1982; Schneider, 2006). They also suggest that this research could form the beginnings of a bridge between theoretical models of depression as a ‘pathology of action’, research into affordances and research into embodied perception.

In spite of the body of research discussed so far on mood, anxiety and depression in relation to perception of action, research on other potentially influential affective factors including self-efficacy, resilience and elements of self-concept in typically developing and other populations is currently lacking. This is something this thesis seeks to address and which will be detailed in the final section of this chapter.

1.3 Developmental Coordination Disorder

A principal focus of this thesis is to investigate the roles of the factors discussed in section 1.2, along with motor control, in the perceptions and actions of adults with DCD. In light of this, sections 1.3 and 1.4 will focus on several key elements of the condition itself and on studies to date which have considered the relationship between perception and action in individuals with DCD.

1.3.1 Definition

The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition Text Revision, (DSM-5-TR) (APA, 2022) classifies DCD within the Neurodevelopmental Disorders section. It is placed as the first condition listed in the ‘Motor Disorders’ subsection. The term DCD to describe this condition was approved in 1994 at the International Consensus Meeting in London, Ontario, Canada. DCD is defined by the four criteria described below according to the DSM-5-TR.

A. Acquisition and execution of coordinated motor skills is far below the expected level for an individual’s age, given the opportunity for skill learning.

B. Motor skill difficulties interfere significantly with activities of daily living and impact on productivity at school or work, prevocational and vocational activities, leisure and play.
C. Onset is in the early developmental period.
D. Motor skill difficulties cannot be better explained by intellectual delay, visual impairment, or other neurological conditions that affect movement.

DCD occurs across cultures, ethnic groups and socio-economic circumstances. Research is ongoing into the cause of DCD, yet the condition currently remains idiopathic. Evidence to date points towards DCD being a separate, unique neurodevelopmental disorder which may, and often does, co-occur with one or several other neurodevelopmental and neurobehavioural disorders (Blank et al., 2019). The details and implications of this will be discussed in a later section.

1.3.2 History and terminology

Orton (1937) first identified the significance of enhanced 'clumsiness' in certain children in an extensive range of studies into a range of developmental problems. However, this was not researched any further in the scientific literature until Walton, Ellis and Court (1962) undertook a study describing 'clumsy children' and which used the terms 'developmental apraxia and agnosia'. Since that point, a whole range of terminology has arisen in attempts to accurately describe children whose struggles with motor skills impact everyday life (Polatajko, Fox & Missiuna, 1995; Missiuna & Polatajko, 1995; Henderson & Henderson, 2003). These include 'clumsy child syndrome' (Gubbay, 1972), 'sensory integrative dysfunction' (Ayres, 1972), developmental dyspraxia (Cermak, 1985), perceptual motor dysfunction (Laszlo & Sainsbury, 1993) and physical awkwardness (Miyahara & Register, 2000). It is also notable that across Scandinavia the acronym DAMP has been used to describe children with attention, motor control and perception deficits (Gillberg, 2003).

As terminology around 'clumsiness' in children diversified, in 1994 clinicians and researchers came together in London, Ontario (Canada) to decide which terminology should consistently be used. At this consensus meeting the term 'developmental coordination disorder (DCD)' was agreed on (Polatajko et al., 1995). This term, along with its diagnostic criteria, had been added to the third edition of the DSM (APA, 1985) and these remain (in their updated versions) in the current edition (APA, 2022). Consensus on the term DCD was renewed by the Leeds Consensus Statement (Sugden, 2006) which underlined the agreement between international clinicians and researchers to maintain the term DCD in reference to this unique, distinct condition. Since then, the European Academy for Childhood Disability (EACD) has reaffirmed this, and the DSM-5 criteria for defining the condition, several times (Blank, Smits-Engelsman, Polatajko & Wilson, 2012; Blank et al., 2019). In the most recent international clinical practice recommendations on the definition, diagnosis, assessment, intervention, and psychosocial aspects of developmental coordination disorder, Blank et al. (2019) do however recognize that in various places debate and even some confusion remains regarding the different terminology and definitions that are still used in the field of developmental movement difficulties. An example of this is the widespread use of the term 'dyspraxia' in the UK context, which is used by the Dyspraxia Foundation who specify that this incorporates DCD, although their definition goes beyond DCD and includes several non-motor difficulties not covered by the DSM definition (Dyspraxia Foundation, 2023). Others specify a distinction between 'dyspraxia' and 'developmental dyspraxia'. However, use of the term 'dyspraxia' is not recommended by the international consensus.

More broadly, the literature includes several more general terms that often appear which include 'motor learning difficulty', 'movement difficulty' and 'physical awkwardness'. Although these refer to significant motor difficulty which is the principal feature of DCD, it is often ambiguous whether and/or how formal diagnostic criteria have been met.
It is important to note that the term DCD is drawn from the DSM-5-TR classification and that an alternative to this - the International Classification of Diseases (ICD-11) (World Health Organisation, 2019) - has legal status in several European countries. Formerly termed 'specific developmental disorder of motor functions' (ICD-10), the latest revised version has updated this to 'developmental motor coordination disorder'. Interestingly, the ICD-11's definition shares the DSM's focus on a serious impairment in the development of motor coordination not explicable by other neurological or other conditions, and it specifically includes orofacial motor coordination disorder, yet explicitly excludes abnormalities of gait and mobility. Throughout this thesis the term DCD will be used in line with the DSM-5-TR classification and criteria. Where the ICD-11's definition may be relevant, for example in reference to pertinent literature in the field, this will be specified.

1.3.3 Prevalence

Although its true prevalence across contexts is unknown, based on the literature to date it is estimated that 2% to 20% of children have DCD, percentages that depend greatly on the selection and identification criteria, as well as how stringently these are applied in each case or study (e.g., Wright & Sugden, 1996; Tsiotra et al., 2006; Lingam, Hunt, Golding, Jongmans & Emond, 2009). However, 5% to 6% is the percentage reported most often in the literature (Blank et al., 2012; 2019; APA, 2022). For example, in a population-based Swedish study of seven-year-old children, Kadesjö and Gillberg (1999) identified a 4.9% prevalence rate for severe DCD and 8.6% prevalence rate for moderate DCD. However, in a UK context the Avon Longitudinal Study of Parents and Children identified 1.8% of seven-year-old children in their study as having severe DCD, while finding that an additional 3% had 'probable' DCD that affected everyday life (Lingam et al., 2009). Literature considering prevalence generally recognizes that those children who meet the relevant DCD criteria have motor skill difficulties significant enough to affect functioning in both the academic and social spheres (Blank et al., 2019).

At both extremes, studies in other countries have reached very different estimations with a more recent study in Southern India detecting an estimated prevalence rate of only 0.8% using DSM-5 criteria in children aged 6-15 years in mainstream schools (Girish, Raja & Kamath, 2016). At the other end of the spectrum, Tsiotra et al. (2006) found a strikingly high estimated prevalence rate of 19% among Greek elementary children with an average age of eleven years, working to DSM-IV criteria. The most recent studies undertaken continue to reflect this diversity across a range of international and socio-economic contexts, and using DSM-5 criteria. For example, another recent study in India found a 3.8% overall prevalence rate in a large sample of elementary school children (average age, 11 years) (Sujatha, Alagesan, Lal & Rayna, 2020), while much higher rates were estimated from samples of elementary school-aged children (6-10 years) in Brazil (11.6%) (Rodrigues Vieira dos Santos & de Castro Ferracioli, 2020), Korea (10.94%) (Lee et al., 2019) and South Africa (9.9%) (Du Plessis, De Milander, Coetzee & Nel, 2020). It is notable however that the latter studies used the terms 'motor difficulties', 'probable DCD', and 'possible DCD' respectively.

This variance in reporting of prevalence rates may be due to several factors in relation to how DCD is identified. If only selected diagnostic criteria are applied, this may lead to higher prevalence rates. For example, some studies include children with motor coordination problems without considering intelligence or impact on everyday functioning (Geuze, Jongmans, Schoemaker & Smits-Engelsman, 2001). On the other hand, its prevalence can be underestimated as a result of a lack of awareness of the condition (Missiuna, Gaines & Soucie, 2006; Gaines, Missiuna, Egan & McLean, 2008). Other factors include the use of varying assessment tools and cut-off scores to indicate impairment in motor skills, socio-cultural differences in lifestyle, the impact of higher and lower socio-economic environments and even the wide range of terminology used to describe children with coordination challenges (Sugden, 2006; Tsiotra et al., 2006; Polatajko, Fox & Missiuna, 1995; Du Plessis et al., 2020).

DCD has generally been identified as more prevalent in males than females, though the male:female ratios vary from 2:1 up to 7:1 (e.g., Lingam et al., 2009; Gillberg & Kadesjö, 2003; Missiuna et al., 2008; Kadesjö & Gillberg, 1999). Although there is some evidence that the gender distribution of DCD prevalence may in certain contexts be almost equal (Missiuna, Cairney, Pollock, Cousins & MacDonald, 2009; Rodrigues Vieira dos Santos & de Castro Ferracioli, 2020; Du Plessis et al., 2020), Girish et al.'s (2016) is the only study to date which identified more females than males with DCD in their sample. However, another more recent study undertaken in India supported previous evidence of an almost 2:1 ratio of male:female prevalence (Sujatha et al., 2020), while Lee et al. (2019) found that 'probable DCD' was 1.61 times higher in boys than girls.

1.3.4 Aetiology

Although the mechanisms underlying DCD are not yet conclusively known, in recent years the integration of behavioural and neuroimaging data, as well as experimental research working across timescales and multiple analysis levels (neural, cognitive and behavioural) point towards several tentative conclusions (Blank et al., 2019; Licari, Rigoli & Piek, 2019; Subara-Zukic et al., 2022; Wilson et al., 2017). Behavioural data has illustrated wide-ranging deficits in motor control, basic motor learning processes and executive function. These include the planning and anticipatory control of movement as well as procedural motor learning. It is important to note however that performance in these areas was often moderated by task type and difficulty level. Emerging evidence also shows that children with DCD are able to compensate with strategies or actions that enable them to achieve a given task goal effectively but with less overall efficiency.

There has been an increase in neuroimaging studies over the last two decades, though these range in their quality, sample sizes and in some cases are hampered by missing data and/or the absence of concurrent behavioural measures (Wilson et al., 2017). While interpretations of these results should therefore be cautious, some initial converging evidence has suggested that individuals with DCD show decreased cortical thickness and hypoactivation in functional networks of the cerebellar, parietal and prefrontal regions (Langevin, MacMaster & Dewey, 2015; Debrabant, Gheyson, Caeyenberghs, Van Waelvelde & Vingerhoets, 2013; Licari et al., 2015; Pangelinan, Hatfield & Clark, 2013; Zwicker, Missiuna, Harris & Boyd, 2011). However, evidence to date has not been uniform, for example Licari et al. (2015) also identified increased activation in the right postcentral gyrus of children with DCD. In addition, structural diffusion magnetic resonance imaging studies have shown differences in the microstructural organisation of white matter, especially in sensorimotor tracts including the corticospinal tract, posterior thalamic radiation and the parietal sub-region of the corpus callosum (Debrabant et al., 2016; Langevin et al., 2014; Zwicker, Missiuna, Harris & Boyd, 2012). Other data from structural magnetic resonance imaging has indicated the involvement of sensorimotor structures in a poorly integrated neural network (Caeyenberghs et al., 2016).

Most recently, a combined systematic review and meta-analysis of recent behavioural and neuroimaging research on DCD concluded that in individuals with DCD serious deficits have consistently been identified in cognitive-motor integration, variability of movement kinetics, voluntary gaze control while moving, internal modelling, and context- or practice-dependent motor learning. Larger safety margins while navigating through and around obstacles, as well as atypical neural structure and function across sensori-motor and prefrontal brain regions were also consistently identified (Subara-Zukic et al., 2022). The latest thinking in the ongoing debate about DCD’s aetiology therefore centres on the identification of fundamental deficits in visual-motor mapping, cognitive-motor integration and the atypical maturation of motor networks as well as the pragmatic ways in which individuals compensate for these deficits.

Considered collectively, the results of these neuroimaging and behavioural studies offer support for the hypothesis that, compared with typically developing children, children with DCD demonstrate differences in neural structure and function. However, more conclusive confirmation of these findings will only be possible with larger and longitudinal studies. Linking back to the behavioural level, differences that have tentatively been identified so far could affect observational learning and anticipatory planning of movement as well as reduce the extent to which movement skill can become automatized. This could lead to increased reliance on feedback-based control, which is slower, and the aforementioned compensatory strategies (Blank et al., 2019).

Further initial evidence regarding biological and genetic factors in the aetiology of DCD, as well as the relationships of these with the aetiology of other neurodevelopmental disorders, will be discussed in the later section on co-occurrence.

1.3.5 Theoretical Framework

In recent years, researchers and clinicians working in the field have been moving towards a more unified - or hybrid - mechanistic and constraints-based account of DCD, the latter of which examines the interaction between individual, task and environmental constraints as discussed earlier in the chapter (Blank et al., 2019; Newell, 1986; 1991; Davids, 2010; Subara-Zukic et al., 2022, Wilson, Smits-Engelsman, Caeyenberghs & Steenbergen, 2017, Wilson et al., 2018). Building on previous hypotheses that DCD results from deficits in internal modelling and in the function of the mirror neuron system (MNS) (Wilson et al., 2013; Reynolds et al., 2015), this integrated framework sees individual constraints like these as able to affect performance variably, especially depending on task-type and difficulty level. This represents a shift from seeing the causal mechanisms of motor performance as linear - as in a traditional information processing framework - to seeing them as dynamic and interactive, fitting more with an ecological approach.

The most recent evidence collated and analysed by Subara-Zukic et al. (2022) has continued to support an ecological, constraints-based approach particularly to the issues of movement variability and compensations. Within this integrated framework further support is also offered by this evidence for the internal modelling deficit and associated MNS accounts, while incorporating the suggestion of atypical hemispheric connectivity from the most recent converging neuroimaging and behavioural data.

1.3.6 Characteristics and Impacts

(i) Motor development and performance

In typical development, as an infant grows and progresses through childhood they learn and acquire motor skills by means of spontaneous practice. However, this process does not take place in the same way for children with DCD, which is why it is referred to often as a motor learning disorder (e.g., Schoemaker & Smits-Engelsman, 2015; Wilmut & Barnett, 2019). This is also why the first criterion for identifying DCD in the Diagnostic and Statistical Manual of Mental Disorders is ‘the acquisition and execution of coordinated motor skills are substantially below that expected given the individual’s chronological age and opportunity for skill learning and use.’ (APA, 2022).

The characteristics of this atypical motor development manifest as significant interferences with activities of daily living and academic, vocational or professional performance. These can manifest in multiple ways in childhood and beyond (Zwicker, Missiuna, Harris & Boyd, 2012; Tal-Saban, Zarka, Grotto, Ornoy & Parush, 2012). Self-care is more challenging for individuals with DCD, for example dressing oneself, using buttons and zips, tying shoelaces, cooking a meal and using cutlery. The difficulty that atypical motor skills can lead to with school and school-related tasks such as handwriting, copying, drawing, cutting with scissors, keeping work and belongings organised, and meeting deadlines tend to have a negative impact on academic achievement and/or performance in the workplace. Physical education and overall engagement with sports is often a particular challenge for those with DCD as they likely struggle with throwing, catching or kicking balls, running, skipping, and climbing etc. It is striking to note that in spite of average or above average intelligence, evidence shows that children with DCD have lower educational attainment than their typically developing peers (see e.g., Cantell, Smyth & Ahonen, 2003).

Motor skills difficulties impact not only work, but also play. In children with DCD, for example, they can negatively affect the process of learning to ride a bike, the amount of practise and exposure to riding in ‘real world’ environments, and the confidence and enjoyment this process of skill development and activity affords as an important childhood rite of passage in many cultures and contexts (Dunford, Missiuna, Street & Sibert, 2005; Mandich, Polatajko & Rodger, 2003). Difficulties with sports-related skills can lead to less engagement with all kinds of physical and group activities in childhood, adolescence and adulthood (Missiuna, Moll, King, King & Law, 2007; Missiuna, Moll, King, Stewart & MacDonald, 2008), which in turn can inhibit the development of confident and competent social skills and lead to social isolation, the consequences of which are discussed below (e.g., Cantell et al., 2003; Skinner & Piek, 2001).

(ii) Psycho-social domains

The impact of motor skill difficulties beyond the movement domain is increasingly well documented, with growing evidence of DCD's psycho-social consequences in childhood and beyond (see e.g., Blank et al., 2019; Green, Baird & Sugden, 2006; Hill & Brown, 2013; Omer, Jijon & Leonard, 2018; Skinner & Piek, 2001; Zwicker, Harris & Klassen, 2013). Individuals with DCD are often at higher risk of experiencing emotional and mental health problems including low self-esteem (e.g., Piek, Baynam & Barrett, 2006), anxiety (e.g., Sigurdsson, Van Os & Fombonne, 2002), depression (e.g., Hill & Brown, 2013; Missiuna et al., 2006) and a range of emotional-behavioural disorders (Heath, Toste & Missiuna, 2005; Cairney, Veldhuizen & Szatmari, 2010). The implications of these, particularly in adulthood, will be explored in further detail in the later section focused on well-being and identity in adults with and without DCD.

(iii) Executive function

Executive function (EF) refers to a group of cognitive processes and abilities that facilitate goal-directed behaviour. This includes working memory, response inhibition, cognitive flexibility, problem-solving, reasoning, self-awareness and emotional regulation (Cristofori, Cohen-Zimerman & Grafman, 2019). EF difficulties are a common finding in DCD and are strongly associated with impairments in the planning and organisation of daily life (Fogel, Stuart, Joyce & Barnett, 2021; Sartori, Valentini & Fonseca, 2020; Wilson et al., 2020). It is important to note however that it is not yet known whether EF difficulties are a fundamental symptom of DCD or in fact a co-occurring condition (Blank et al., 2019). EF is however an aspect to consider in an interactive and dynamic constraints-based account of DCD in terms of whether and how it may relate to both the core motor performance and psycho-social elements of the condition.

1.3.7 Co-occurrence

Evidence shows that DCD often co-occurs with other developmental disorders and emotional, social and learning issues (e.g., Lingam et al., 2010). It most frequently co-occurs with attention deficit hyperactivity disorder (ADHD) with some studies indicating a co-occurence rate of 50% or higher (e.g., Kadesjö & Gillberg, 1998), which has been shown to lead to poorer psycho-social and educational outcomes in a longitudinal and community-based study (Rasmussen and Gillberg 2000). Autism spectrum disorder (ASD) is also reported to frequently co-occur with DCD (Green et al., 2002; 2009; Lingam et al., 2009; Wisdom, Dyck, Piek, Hay & Hallmayer, 2007). However, as Blank et al. (2019) note, these combined findings suggest that 90% of children with DCD do not have ASD and as such any notions of shared aetiology should be discussed tentatively and with considerable care. DCD has also been shown to frequently co-occur in children with language difficulties relating to speech, reading and writing (e.g., Hill, Bishop & Nimmo-Smith, 1998; Kaplan, Dewey, Crawford & Wilson, 2001; Scabar et al., 2006; Tseng, Howe, Chuan & Hsieh, 2007; Visscher, Houwen, Scherder, Moolenaar & Hartman, 2007). Studies in the last decade have additionally shown that children with DCD struggle significantly more with symbolic and non-symbolic number processing than their TD peers (Gomez et al., 2015; Pieters, Desoete, Van Waelvelde, Vanderswalmen & Roeyers, 2012).

In terms of the relationship between co-occurrence and the genetic aetiology of DCD, a large genetic study of twins showed that the motor symptoms of DCD are in the majority of cases distinct from behavioural features of co-existing disorders such as ADHD (Martin, Piek, Baynam, Levy & Hay, 2010). Other more recent studies offer growing evidence of a genetic basis for DCD (see e.g., Mosca et al., 2016). Most recently, a genome-wide association study undertaken by Mountford, Hill, Barnett & Newbury (2021) has opened up the first direct window into a potential underlying genetic mechanism of motor difficulties consistent specifically with DCD.

This growing evidence base highlights both the relevance of co-occurring disorders particularly with regard to outcomes, and also the fact that DCD does exist as a distinct disorder with its own underlying mechanisms and pathways that may interact with other conditions to varying extents, with varying manifestations and consequences (Blank et al., 2019). Indeed, Newbury (2019) and Licari et al. (2019) underline the complexity inherent in identifying the underlying genetic mechanisms of specific disorders where there may be considerable genetic overlap, as well as the importance of epigenetics - the influence of and interaction between biological and environmental influences - in attempts to understand aetiology.

1.3.8 Diagnosis

The European Academy of Childhood Disability (EACD) recommends that DCD should be diagnosed by a medical professional or a multidisciplinary professional team appropriately qualified to examine an individual according to specified criteria, which closely follow those in the DSM-5 (Blank et al., 2019). This team should in ideal circumstances include both a medical specialist such as a child psychologist, psychiatrist, neurologist or developmental paediatrician, as well as an occupational or physical therapist trained in using a standardised motor assessment used to evaluate individuals suspected of having DCD. Details of how each of these criteria should be assessed in the diagnosis process are described as part of the section 4.4 on participant screening in Chapter Four which covers the experimental methods used in the studies comprising this thesis. The latest EACD guidelines recognise that there are realistically multiple pathways towards the accurate diagnosis of DCD. The assessment and diagnosis processes are ultimately multi-faceted and nuanced, relying at various stages on the judgement of professionals, parents and individuals themselves, supported by the use of standardised, reliable and valid tools.

1.3.9 Intervention

Children who meet the diagnostic criteria for DCD generally need treatment in the form of intervention, the nature and extent of which can vary depending on context as well as the degree and impact of the motor problems experienced (Blank et al., 2019). It is the influence of these on activities of everyday living (self-care, academic life and productivity, leisure, play, connections with peers and everyday physical activity) that indicates what kind of intervention is needed. A systematic review and meta-analysis evaluating the evidence available to date on motor-based interventions for DCD, specifically undertaken for the latest EACD recommendations, found consistently that activity-oriented interventions can improve skill performance (Smits-Engelsman et al., 2018).

In planning a programme of intervention for children with DCD, the EACD recommends careful evaluation of an individual’s strengths and weaknesses within their environmental context (family, school, community, neighbourhood, type of urban or rural area etc.) to ensure the best chance of positively affecting motor function, activity and participation. They also recommend individualised goal-setting as a key aspect, addressing both activities and participation with the building of physical fitness in mind, as well as considering psychosocial factors and assessing a child's self-concept in order to helpfully incorporate these into the treatment planning process (see e.g., Cairney et al., 2007; Farhat et al., 2015; Ferguson, Naidoo & Smits-Engelsman, 2015). Both motor and non-motor aspects of an individual child's functioning are considered important in establishing intervention priorities.

1.3.10 Developmental trajectory: childhood and beyond

A small pool of studies has looked into the transition from childhood to adolescence in individuals with DCD, and these suggest that in 50-70% of cases motor difficulties do persist into adolescence and adulthood (APA, 2022). Although some children with DCD do seemingly 'grow out' of their movement and associated problems, there is limited but growing evidence showing that many do not and that the nature and impact of the problems they experience in daily life can change along with their developmental stage and associated changes in circumstances (Cantell & Kooistra, 2002; Cleaton, Tal-Saban, Hill & Kirby, 2021; Engel-Yeger, 2020; Harris, Wilmut & Rathbone, 2021; Harris, Purcell & Wilmut, 2022; Hill, Brown & Sorgardt, 2011; Kirby, Edwards & Sugden, 2011; Kirby, Williams, Thomas & Hill, 2013; Losse et al., 1991; Tal-Saban & Kirby, 2019).

It is important to note that the point at which the transition from childhood to adolescence and from adolescence to adulthood takes place varies between socio-cultural contexts, and that services aimed at supporting these groups can also vary from country to country, or even region to region within a given country. For example, a 16-year-old with DCD who is employed will face different challenges and have access to different types of resources to a peer who is in full-time education. Each individual's personal resources (resilience, self-esteem, self-confidence etc.) and social support network and wider community will also differ (and potentially fluctuate) depending on their circumstances, at what point, and to what extent these change as they move forward towards and into adulthood (Blank et al., 2019).

1.3.11 DCD in adulthood

Although there are no explicit diagnostic criteria, adults are now mentioned in the latest DSM-5-TR (APA, 2022) indicating that the criteria set out for children can be used with adaptations to the examples and daily activities described (Blank et al., 2019). Despite the comparative sparsity of research evidence beyond childhood, many of the recommendations for children with DCD are reasonably applicable to adolescents and adults with DCD. For example, those relating to history taking, clinical examination and motor assessment tools are all relevant across the age spectrum. However, there is a lack of standardised tests available for adults, and although some of the motor performance tests such as the BOT-2 and MABC-2 are currently being used in the identification and description of DCD in adolescents and adults, further work is necessary to properly establish their use with these populations. In terms of questionnaires, the Adult Developmental Coordination Disorders/Dyspraxia Checklist (ADC) has so far been the most widely used screening tool in research on adults with DCD, though shorter tools such as the Adolescents and Adults Coordination Questionnaire do exist. However, the latest EACD recommendations do note that further work is needed to fully ascertain their psychometric properties. The ADC will be discussed in further detail in Chapter Two.

In 2017 a scoping review was conducted in an effort to start bridging the evident ‘knowledge-to-practice’ gap in light of the scarcity of research evidence relating to DCD in adolescents and adults (Barnett, Kirby, van Waelvelde & Weintraub, 2017). Its findings, as well as those of more recent research, suggest that the motor difficulties and underlying constraints evident in children with DCD persist into adulthood. Co-occurring difficulties with executive function and attention among other things, as well as a range of secondary psychosocial impacts including anxiety, depression, low global self-esteem and challenges with social relationships were also reported repeatedly in the adult literature, reflecting both continuity from aspects of the childhood literature and the shifting impact and consequences of such challenges in the context of adult life (e.g., Cleaton et al., 2021; Engel-Yeger, 2020; Forde & Smyth, 2022). What’s more, as in the childhood literature, the adulthood literature so far indicates that adults with DCD show poorer physical health than their typically developing peers including higher obesity rates, lower endurance, strength, flexibility and general health and wellbeing (physical and mental). In light of this one important focus of interventions designed to support adults with DCD should be approaches to maintaining a physically active lifestyle (Barnett et al., 2017; Blank et al., 2019).

As individuals with DCD face emerging adulthood, they also tend to face more demands in relation to the independent organisation of aspects of everyday life such as money management, future planning, locating and keeping belongings appropriately arranged. Research to date suggests that these are areas in which adults with DCD often face real difficulties, and which as such can have serious consequences for their ability to cope with independent adult life (e.g., Hill & Brown, 2013; Kirby et al., 2011; 2013). Linked to this, research to date has also focused a lot on the ways in which their difficulties restrict the participation levels of adults with DCD in all kinds of everyday activities, with clear examples of how this negatively affects quality of life satisfaction, employment and work performance, leisure and physical activity, independent living and social functioning (e.g., Cleaton et al., 2021; Engel-Yeger, 2020; Gagnon-Roy, Jasmin & Camden, 2016; Sankar, Monisha, Doss & Palanivel, 2020; Forde & Smyth, 2022; Tal-Saban & Kirby, 2019).

Cleaton et al.'s (2021) study was the first to specifically consider how DCD may manifest differently in females with DCD and in different stages of adulthood, and their results showed that there are indeed gender- and age-related differences. In their study of 1,476 adults aged 16-60, women with at-risk or probable DCD reported significantly more gross and non-motor difficulties impacting significantly more on participation and activities in contrast to men with at-risk or probable DCD who reported more fine motor difficulties. Interestingly, across the sample the younger, emerging adults (16-25 years) reported facing significantly more non-motor challenges than those aged 26 and above. This points towards the added vulnerability of individuals with suspected DCD during that transitional 'emerging adulthood' stage to the multi-faceted secondary impacts of their motor difficulties.

Since Blank et al. (2019) identified an 'urgent need for further research with adults with DCD of all ages' (p. 36), as has been mentioned above several valuable additions have been made to the still emerging literature in this population. However there remains a lack of longitudinal work, and only one study to date has undertaken a 3-4-year follow-up with young adults (Tal-Saban, Ornoy & Parush, 2014). This will be an important aspect to address so that a better understanding of how DCD continues to develop through the lifespan can be gained in order to guide the effective practice of educational and health professionals, and to help guide employers, families and individuals with DCD themselves in navigating life with the condition (Blank et al., 2019). There also remains a limited body of research so far on the causal and consequential aspects involved in the poorer overall well-being and psychosocial functioning of adults with DCD, an element this thesis seeks to address.

1.4 Studies of perception and action in DCD

In light of the nature of DCD and its multifaceted impacts on individuals of all ages, gaining a thorough understanding of the relationship between perception and action - and how this might affect and be affected by different factors - is important in this population. Several studies to date have investigated this in both children and adults with DCD compared to TD peers using the aperture-crossing paradigm discussed previously and with a focus on the characteristics of walking on a level surface. In this section findings from relevant studies will be briefly summarised and further methodological detail will be described in Chapters Five (Study Two) and Six (Study Three).

Wilmut & Barnett (2011) showed that the extent to which a walking child with typically developing motor skills rotates their shoulders to pass through an aperture is based on that individual's level of movement variability: an increase in movement variability is accompanied by an increase in shoulder rotation. Building on this, Wilmut, Du & Barnett (2015) investigated how adults with DCD made action judgements and how they adapted their movement while navigating through a range of body size scaled apertures compared to TD adults. Results showed that while the TD adults accounted for body size only when deciding to rotate their shoulders, the adults with DCD tended to rotate their shoulders - i.e. to turn - for larger apertures. So, the adults with DCD showed a higher critical ratio than those in the TD group. Their findings also offered initial evidence that adults with DCD, like children with typically developing movement skills (Wilmut & Barnett, 2011), take into account elements of their own motor control (lateral trunk movement and movement variability) during action judgments. This can be interpreted as an adaptive strategy which accounts for movement difficulties in order to avoid collision.

Du, Wilmut & Barnett (2015) also undertook a study focused specifically on walking in adults with DCD. Compared to a group of TD adults, the DCD group showed greater variability across the board in foot placement and certain body movement measures, supporting the notion that adults with DCD are not able to produce consistent movement patterns in the same way or to the same extent as TD adults. This in turn supports previous findings that children with DCD demonstrate increased overall variability in leg movement patterns when walking than TD children (Rosengren et al., 2009). The authors link the increased variability seen in adults with DCD to the notion of reduced postural control and stability which may influence the consistency of their walking pattern, a link that has been explored in the literature on walking in elderly adults. However, the nature of the variability in movement is different in adults with DCD than in elderly adults, suggesting that the underlying mechanisms may differ.

Children with DCD have shown difficulties with postural control (Geuze, 2005) and previous research has used this to explain their differences in walking patterns (Deconinck et al., 2006). Du et al.'s (2015) findings therefore offer a potential springboard for future, more detailed research into postural control and stability specifically in adults with DCD to build on and broaden the age range of this evidence base. Indeed, Du et al. (2015) posit that certain neuromuscular deficits identified in children with DCD may persist into adulthood and therefore help explain aspects of postural and related gait control difficulties linked to movement variability (e.g., Johnston, Burns, Brauer & Richardson, 2002; Kane & Barden, 2012; Lundy-Ekman et al., 1991; Piek & Skinner, 1999; Raynor, 2001).

Overall, these results suggest increased levels of movement variability as a potential explanation for the anecdotal evidence of gait control problems with individuals of all ages with DCD which tend to manifest as a high rate of bumping into and tripping over things when navigating their environment. Movement variability is therefore shown to be an important factor when considering the relationship between perception and action in individuals with DCD.

In a return to the aperture-crossing paradigm, and to a focus on the relationship between perceptual judgement and executed action, Wilmut, Du & Barnett (2016) considered how children with DCD perceptually judge and move compared to TD children when looking at or walking through apertures of different sizes. Interestingly the perceptual critical ratio of children with DCD was significantly smaller in comparison with their TD peers (i.e. they thought they actually needed *less* of a safety margin). However, when the participants actually walked through the same apertures they displayed a significantly larger critical ratio than their TD peers, very similar to that found in adults with DCD (Wilmut et al., 2015).

While the TD group accounted only for body size, the children with DCD allowed for *more* of a safety margin than would be necessary when accounting only for their body size.

So, the children with DCD underestimated the space they would actually need when making the perceptual judgements in the first experiment. The authors concluded that their findings here indicate a difference between perception in a static context and perception in a dynamic context. Despite this difference however, Wilmut et al. (2016) did illustrate a clear relationship between perception and action in children with DCD through identifying positive relationships between the perceptual judgements in experiment one and their executed movement in experiment two. Where the participants demonstrated a high perceptual critical ratio, this was reflected in their movement behaviour with a high shoulder angle at the point of passing through the doors. In this way the children with DCD displayed a functional perception-action cycle in that what is perceived in the static condition is subsequently realised in the dynamic condition.

Strikingly however, the TD children did not demonstrate this relationship: their perceptual judgements were not related to their movement behaviour when passing through the apertures. This finding actually contrasts with what Chen, Tsai & Wu (2014) found when investigating perception of sitting height. In this study, perception of sitting height related to postural sway in the TD children but not in children with DCD. A series of studies undertaken by Johnson and Wade (2007; 2009) additionally showed that children at risk for DCD judge the limits of their action capabilities in reaching forwards horizontally while standing, and in relation to sitting height, less accurately than TD children. The varied nature of findings to date have offered valuable initial insights while also highlighting the need for further research into the relationship between perception and action in individuals with DCD. Indeed, Wilmut et al. (2016) use the constraints-based framework to actively promote the need for research to investigate perception both alone and in direct relation to movement so that the perception-action link, and how this may relate to the difficulties of individuals with DCD, can be more fully understood.

What is clear however is that the relationship between movement variability and degree of shoulder rotation appears to be a strategy which is adaptive in allowing individuals to modify the optimal safety margin (i.e. distance between the edges of the aperture and the shoulders) in line with their own movement ability (Wilmut et al., 2015; 2016). The research discussed so far in this section offers valuable insights into the role of movement variability in how individuals with DCD perceive and act to navigate their everyday environments. However, it remains to be explored whether other non-movement related factors may also have a role in the relationship between perception and action among individuals with DCD. This is a novel aspect this thesis will explore and is the focus of the following section.

1.5 The roles of self-concept and wellbeing in perception and action

As has been explored in the perception and action literature on individuals with typically developing motor skills, how we feel can influence how we perceive ourselves, our environment and our perceived ability to navigate that environment. In light of the challenges they face, these factors may be especially relevant for individuals with DCD. As discussed in the previous section, considering the increased demands for independent functioning that these individuals are likely to face as they approach and move through adulthood, adults with DCD may be especially affected. Although most of the literature to date considering elements of wellbeing and self-concept in DCD focuses on children, this thesis aims to contribute to the limited but growing body of research offering insights into the impacts of these factors on the functioning of adults with DCD.

1.5.1 Self-concept and DCD

The term ‘self-concept’ is defined as qualities which constitute individuals’ perceptions of long-term and enduring aspects of their identity. It is also closely linked to mood and wellbeing (Marsh & Shavelson, 1985; Rathbone, Holmes, Murphy & Ellis, 2015). To date, self-concept has only been considered in children with DCD compared to TD children. No studies have yet considered self-concept in adults with DCD compared to TD adults or in relation to the other wellbeing and movement factors under investigation in this thesis.

Peens and Pienaar (2006) found some initial evidence suggesting a negative influence of DCD on the self-concept of children aged 7-9 years. Cocks, Barton and Donelly (2009) later looked specifically at the self-concept of boys with DCD (aged 7-12 years) in relation to a range of academic and non-academic domains. Their results suggested that boys with DCD suffered from a significantly more negative self-concept in the domains of peer relations and physical abilities in general compared with normative values among age-matched TD children. Furthermore, severity of motor difficulties related significantly to aspects of self-concept regarding physical abilities. This was supported by Yu et al.'s (2016) finding that children with DCD (aged 7-10 years) had a more negative view of their self-concept in relation to physical coordination, sporting ability and physical health.

Peens, Pienaar & Nienaber (2008) undertook an intervention-based study with a group of 7-9-year-old children with DCD (N=58: 36 boys, 22 girls) which aimed to ascertain which method (motor intervention (MI), self-concept enhancing intervention (SC), psycho-motor intervention (P-MI) and a control group (CG)) may most effectively boost motor proficiency and self-concept. Motor proficiency and self-concept improved the most significantly in the P-MI intervention group, suggesting that these should be addressed together in an intervention context for optimal results.

Poulsen, Ziviani and Cuskelly (2006) found that in a large sample of boys aged 10-13 years (N=173), those with physical coordination difficulties in the moderate to severe range reported significantly lower general self-concept and self-concept perceptions in relation to their physical ability, appearance, and peer and parent relations. Results from this study also showed that relationships between their physical coordination, general self-concept and also self-perceptions of life satisfaction were influenced significantly by the boys' individual self-concept evaluations of physical ability, appearance, peer and parent relations. Encouragingly, the authors found that the adoption of task-oriented goals led to a positive change in these relationships.

In a later study focused on fostering the active participation of boys with DCD in health-enhancing leisure activities, the same authors identified lower peer relations self-concept in particular as a significant mechanism which mediates the relationship between low energy expenditure (due to less physical activity) and physical coordination ability (Poulsen, Ziviani & Cuskelly, 2008). They highlighted the potential clinical implications of tapping into peer relations self-concept as a 'change mechanism' to weaken the link between physical coordination ability and sedentary behaviour. This finding was later supported by Poulsen, Johnson & Ziviani's (2011) use of a classification and regression tree approach to detect patterns of relationships between motor performance factors, participation and psycho-social adjustment of boys with DCD in the same age range (10-13 years). They once again identified peer relations self-concept as a significant grouping factor alongside low levels of participation in informal out-of-school social-physical activities.

In a recent review, Hands et al. (2020) considered self-concept in both children and adolescents with DCD and identified that, by adolescence, if individuals with DCD did not believe physical aptitude to be important, even if their self-perceptions in relation to physical ability were low, this did not necessarily lead to diminished self-concept since they were able to disregard domains that were unimportant to their own self-related belief system. There is currently however a striking lack of research on self-concept in adults with DCD, an avenue that this thesis seeks to begin opening up.

1.5.2 Anxiety and DCD

Previous research suggests that anxiety is heightened in individuals with DCD compared to their TD peers, and that this seems to be linked to motor skills. There is a lot more evidence of this in younger populations (see e.g., Harrowell, Hollén, Lingam & Emond, 2017; Omer, Jijon & Leonard, 2019; Missiuna, 2003; Sigurdsson, Van Os & Fombonne, 2002). However, there is some evidence to suggest that anxiety in individuals with DCD may increase with age. Skinner and Piek (2001), for example, found higher anxiety levels among adolescents with DCD (aged 12-14 years) than among younger children with DCD (aged 8-10 years). Looking beyond early adolescence, Doering et al. (2019) have illustrated that anxiety in adolescence, specifically at age 15 years, comprises an important risk factor in the development of psychiatric issues in later adolescence and young adulthood.

Hill and Brown (2013) carried out one of the first investigations into mood disorders (symptoms of anxiety and depression at a clinical level) among adults with DCD. They found significantly higher symptoms of state and trait anxiety in the DCD group compared to their TD peers. This initial evidence supports the notion that higher anxiety rates continue from childhood into adulthood in this population. Kirby, Williams, Thomas and Hill (2013) took a different angle and considered the effect of employment status on psychosocial wellbeing in adults with DCD. Results showed high levels of self-reported anxiety in both the employed and unemployed adults with DCD, with most falling outside the 'normal' range according to the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983).

Most recently, Harris, Purcell and Wilmut (2022) undertook a review of studies to date that have investigated anxiety's influence on movement behaviour in individuals with DCD. Although many studies have highlighted the influence of anxiety on movement in non-DCD populations, the authors identified only two studies that have explicitly looked at this in a DCD population. In the first study Parr, Foster, Wood and Hollands (2020) used a stepping task in which participants with and without DCD were asked to step into a target box along a walkway with either no, one or two obstacles. Anxiety was measured at baseline and at each task difficulty level. Although movement-related group differences were shown in the form of increased step length variability and decreased anterior-posterior foot placement accuracy in the children with DCD, no group differences were identified in task-specific anxiety. The authors do note however that the anxiety measurement used in this study (a single question on a 10-point 'fear thermometer' scale) may not have been nuanced enough to detect group differences.

Parr, Foster, Wood, Thomas and Hollands (2020) subsequently used a more ecologically valid task - that of negotiating stairs - where the natural risk of falling is greater. Children with and without DCD either ascended or descended a seven-step staircase built to imitate domestic stairs. As in the stepping task in the previous study, group differences in movement behaviour were illustrated. The children with DCD showed increased use of the handrail, movement time, step duration and more toe/heel clearance variability than those without DCD. No task-specific anxiety differences were found in the stair ascent condition, but clear group differences were identified in the stair descent condition. The children with DCD reported higher task-specific anxiety (using the same 'fear thermometer' measure as in the previous study) than the children without DCD. Consequently, the authors chose to explore how the movement-related differences related to state anxiety and significant positive relationships were detected. Across both groups higher task-specific anxiety related to longer and more variable movement times and gaze behaviours which were interpreted as a strategy for sampling further ahead of one's current position.

This second study by Parr et al. (2020) is the only research so far to explicitly consider the influence of task-specific anxiety on emerging movements in individuals with DCD. Interestingly, in elderly adults direct relationships have been established between higher anxiety about falling and gait adaptations which in fact make falling more likely (Young, Wing & Hollands, 2012). Although Parr et al.'s (2020) findings are not so clear, they do offer initial support for the idea that higher anxiety during stair descent is related to adaptations (such as looking away from your feet in order to see what is coming next) which could actually increase the likelihood of tripping or falling. Harris et al. (2022) make a link here with self-reports by adults with DCD indicating that higher anxiety might negatively impact their perceived safety during walking (Scott-Roberts & Purcell, 2018). In light of these combined findings, it could therefore be inferred that these group differences between individuals with and without DCD may partly be due to attempted compensations for their higher anxiety which may unfortunately end up being maladaptive rather than adaptive, in that they may increase the risk of tripping or falling. This can be seen as emerging evidence that task-specific anxiety and movement behaviour may indeed be related in DCD (Harris et al. 2022).

However, given the small number of previous studies that have considered anxiety specifically in adults with DCD, the extent to which heightened anxiety persists in adulthood, why this may be and what else it may link to, remains unclear and warrants further research.

1.5.3 Self-efficacy and DCD

The concept of self-efficacy can be general or domain-specific. General self- efficacy is an individual's judgement in relation to themselves of how well they can enact courses of action needed to successfully navigate and deal with prospective situations (Bandura, 1982). However, the founding author of the concept Bandura (1982) emphasises that self-efficacy is ultimately domain-specific and that as such it forms an attitude towards a specific task in a specific context. General self-efficacy is therefore made up of a set of domain-specific attitudes which an individual extrapolates to their overall ability to perform the necessary actions that life generally entails.

Bandura (1997; 2006) emphasises that a 'one size fits all' approach has limited value since the self-efficacy belief system relates to specific and sometimes discrete domains of functioning. An effective self-efficacy scale must therefore be intricately linked to the specific circumstances and demands of the situation of interest. He does however note that certain efficacy beliefs may co-vary across even distinct realms of functioning, particularly when governed by similar sub-skills including certain higher order self-regulatory skills comprising elements of executive functioning. In light of this, Bandura (2006) encourages the construction of bespoke self-efficacy scales for a researcher's domain of interest with its specific task demands and context. He details the relevance of and advises how to build appropriate domain specification within the scale to ensure it is tailored properly to assess the multifaceted ways in which efficacy beliefs operate in that domain.

Previous research that has considered self-efficacy and DCD has only done so only amongst children. Cairney et al. (2005) used a cross-sectional investigation of elementary school children in Canada and found that the effect of DCD on physical activity was mediated by generalised self-efficacy. Their model showed that 28% of the variance in children's physical activity was predicted by generalised self-efficacy and DCD. However, in direct contrast to this a subsequent study by Batey et al. (2014) found that although children with DCD have lower task (perception of confidence in performing a given task) and barrier (perception of confidence in performing a given activity in the presence of common barriers that may interfere) self-efficacy in relation to physical activity than typically developing children, neither task nor barrier self-efficacy was shown to mediate the relationship between DCD and physical activity. Interestingly, this later study used more domain specific efficacy scales. Batey et al. (2013) suggest that this difference may indicate that generalised self-efficacy, as a different construct, may impact the physical activity of children with DCD more than the more domain-specific measures of task and barrier efficacy.

Another recent study by Nobre, Valentini, Ramalho and Sartori (2019) suggested that DCD in children leads to lower perceived self-efficacy in relation to daily activities, and most prominently regarding leisure activities and global self-efficacy. The authors conclude that the motor skill difficulties experienced by these children influence how effective they perceive themselves to be at performing all kinds of daily actions successfully. Interestingly, Rodger et al. (2007) found somewhat in contrast to this that children with DCD showed perceived self-efficacy of their physical and cognitive functioning within the average normative range of scores at the ages of 5-6. However, another study Engel-Yeger and Kasis (2010) found that children with DCD (aged 5-10) had significantly lower self-efficacy scores across all domains measured by the Perceived Efficacy and Goal Setting System than their age-matched TD peers (PEGS, Missiuna, Pollock & Law, 2004). What's more, lower self-efficacy correlated with both lower motor performance and lower preference to participate in leisure activities. The authors concluded that while motor difficulties may limit participation preference in children with DCD, low self-efficacy could act as a further hindrance to participation. Another recent study of a sample of female children aged 9-12 years looked at the effects of implementing a daily programme of either competitive or participatory games over several weeks (Khanjani, Bagherli, Nasiri, Namazizadeh & Namazizadeh, 2021). It is interesting to note that among girls of this age range with DCD, results showed that the participatory games increased their self-reported self-efficacy more than the competitive games, although both programmes had a positive effect.

In a recent qualitative study based on interviews with 13-15-year-old teenagers with DCD, self-efficacy showed itself to be a recurring theme (Payne & Ward, 2019). According to the participants themselves, this influenced their motivation and participation in daily activities as well as affecting how resilient they felt, among other aspects of their lived experience. The authors conclude that this highlights the need for interventions with a focus on building self-efficacy in teenagers with DCD as an important contribution to fostering positive futures for them. In the only study to date that has considered self-efficacy as a factor relevant to the functioning of adults with DCD, Medeiros et al. (2023) most recently found self-efficacy to be a mediating factor between motor proficiency and internalizing problems (such as anxiety and depression) in young adults with DCD (18-30 years), along with self-esteem and social support. This finding reinforces the idea that interventions involving the boosting of self-efficacy could contribute to protecting the mental health of adults with motor difficulties.

The varied nature of findings to date and the fact that all but one previous study in this area has considered only children starkly highlights the need for research into generalised and domain-specific self-efficacy's potential role in the profile of adults with DCD. This is especially important given that their physical activity profile likely differs notably from that of children due to the different demands, possible loopholes and barriers they face as individuals expected by society at large to function independently.

1.5.4 Resilience and DCD

In an exploration of the relationship between self-efficacy and resilience - defined as the ability to adapt positively and "bounce back" in the face of adverse experiences (Southwick, Bonanno, Masten, Panter-Brick & Yehuda, 2014) - Schwarzer and Warner (2013) make the point that having high self-efficacy may help an individual show resilience when facing adversity. Given the mechanisms related to mood, motivation and behaviour that self-efficacy beliefs activate, these beliefs can encourage the development of resilience, as illustrated by self-reports from tennagers with DCD in the aforementioned study by Payne and Ward (2019). In this way, self-efficacy has been conceptualised by some as one of the components of resilience (e.g., Rutter, 1990). Indeed, resilience has been shown to closely relate empirically to self-efficacy though theoretically it is distinct in that self-efficacy can exist even in the absence of stressors (Hinz, Schumacher, Albani, Schmid & Brähler, 2006).

In terms of research specifically into resilience in DCD populations, most studies have flagged up the positive role it can play in coping strategies individuals with DCD use to mitigate the negative impact of their motor skills difficulties on their physical and psychosocial wellbeing (e.g., Tamplain & Miller, 2021; Zwicker, Suto, Harris, Vlasakova & Missiuna, 2018). Several studies focusing on late adolescence and young adulthood found that higher resilience related strongly to the effective employment of behavioural and cognitive strategies to manage motor differences, and that an important focus for interventions should be promotion of resilience to boost, among other factors, self-esteem (Harrowell et al., 2017; Missiuna, Moll, King, Stewart & Macdonald, 2008; Payne & Ward, 2019). Considering it from another angle, Morris, Ogden and Gentle (2021) undertook a qualitative study based on interviews with adult siblings of individuals with DCD. A recurring theme in this study was the increased resilience of both the individuals with DCD and their family members as a result of living with a diagnosis of DCD. To date there has however been relatively little research into how resilience is related to other variables in DCD, especially in adulthood.

1.6 Summary and aims

This thesis is composed of three research studies. Building on the base of existing evidence discussed throughout this chapter, together these aimed to investigate the influence of and relationships between anxiety, resilience, self-efficacy, self-concept and movement variability in relation to the perceptual judgements and executed actions of adults with and without DCD.

The first study (Chapter Three) used an online questionnaire composed of three existent psychometric measures and two novel scales. It aimed to explore the relationships between anxiety, self-efficacy, resilience and self-concept both generally and specifically in relation to movement among adults with and without DCD. The novel scales developed in this study were subsequently refined into a measure for anxiety and self-efficacy specifically in relation to movement for use in the two following studies. The sample for this study comprised 79 typically developing adults, 74 adults with formally diagnosed DCD and 26 adults with self-reported suspected DCD.

The second study (Chapter Five) was lab-based and involved three stages: an online questionnaire completed in the lab, a perceptual judgement task and an executed action task based on the aperture paradigm used by several of the studies discussed previously in this chapter. This study aimed to investigate the influence of anxiety, self-efficacy, resilience and movement variability (how consistently one is able to move) on the perceptions and actions of typically developing adults. It did so by determining the point at which behaviour changed for perceptual only and action tasks and exploring the way in which this point related to body size, movement consistency, anxiety, self-efficacy and resilience in a sample of 41 typically developing adults.

The third study (Chapter Six) was also lab-based and involved three (for the TD group) or four (for the DCD group) stages: a movement assessment (the MABC-2 (Henderson et al., 2007)), an online questionnaire completed in the lab, a perceptual judgement task and an executed action task based on the aperture paradigm used by several of the studies discussed previously in this chapter. This study aimed to investigate the influence of anxiety, self-efficacy, resilience and movement variability (how consistently one is able to move) on the perceptions and actions of adults with DCD. It did so by determining the point at which behaviour changed for perceptual only and action tasks and exploring the way in which this point related to body size, movement consistency, anxiety, self-efficacy and resilience in a sample of 17 adults with DCD (confirmed by the MABC-2) and 17 age- and sex-matched typically developing controls.

Please note, the participants who took part in the second (Chapter Five) and third (Chapter Six) studies were different subjects. As the first study (Chapter Three) used an anonymous online questionnaire, it is impossible to know whether any of the participants who took part in the first study also took part in the second or third studies.

The research comprising this thesis offers an original contribution to the emerging literature on DCD in adulthood in terms of understanding the disorder's impact on individuals' lived experience. It furthermore contributes new, in-depth insight into the roles of and relationships between anxiety, self-efficacy, resilience and movement consistency in how adults with DCD perceive their intentions and abilities to act, and how they realise those actions compared with TD adults. As discussed earlier in this chapter, only two studies have explored elements of this so far in children with DCD, while none have yet done so in adults. Practical implications include the potential to inform interventions helping adults with DCD safely navigate their environment with more confidence and less anxiety. These can contribute to improving the quality of functional and emotional life for individuals with DCD, for whom moving around their world can present significant physical and psychosocial challenges.

1.6.1 Note on chapter structure

Chapter Two describes the questionnaire measures used in all three studies. Chapter Three describes and discusses study one. Chapter Four describes the experimental methods involved in studies two and three, along with the movement assessment tool used for the purposes of grouping participants with and without DCD. Chapters Five and Six describe and discuss studies two and three respectively. Finally, chapter Seven contains the general discussion and conclusions.

Chapter Two: Questionnaire Measures

This chapter describes and discusses the measures chosen and developed for use in studies one, two and three. Some of the measures were used across all three studies in the same format, while others were used only in certain studies or adapted for use in studies two and three from their original format in study one. It will be explicitly noted which category each measure falls into and exactly what adaptations were made where this was the case. Please note that this chapter will focus solely on questionnaire measures and measures for the purpose of participant grouping. Measures of experimental variables will be described and discussed in Chapter Four.

2.1 Six 'I am' Statements

'I am…' statements are an open-ended measure of self-concept, as defined in Chapter One, and their format is based on the widely used Twenty Statements Test (TST) (Kuhn & McPartland, 1954). These were only included in study one and for this section of the questionnaire participants were asked to complete up to six statements, each beginning with 'I am…', by describing long-term and enduring aspects of their identity. Each statement was subsequently coded in relation to whether they referenced motor difficulties. The total number of statements generated per participant was also calculated. This task has previously been used to examine self-concept in other developmental disorders in adults (e.g., autism; Tanweer, Rathbone & Souchay, 2010) but until now has not been used in relation specifically to DCD.

2.2 The Brief Resilience Scale (BRS)

Smith et al.'s (2008) six-item scale defines resilience as "the ability to bounce back or recover from stress" (p. 194). It aims to assess the original, essential meaning of the construct, tapping into the root of the word 'resilience' from its Latin base of "re", meaning "back" and "salire" meaning "to jump or leap" (Agnes, 2005). According to Smith et al. (2008), the BRS differs from previous measures that focused on the resources and factors facilitating resilience. For example, popular measures such as the Resilience Scale by Wagnild and Young (1993) and the Connor-Davidson Resilience Scale (Connor & Davidson, 2003) both assessed protective factors or resources involving coping styles and personal characteristics, including self-efficacy. Smith et al. (2008) argue that previous measures, reviewed by Ahern et al. (2006), seem to offer a summary score relating to the resources that broadly support positive adaptation, without necessarily assessing the fundamental, underlying construct of resilience.

The BRS consists of three positively worded (1, 3, 5) and three negatively worded (2, 4, 6) items to curtail positive response bias and social desirability effects. The scale is scored through reverse coding items 2, 4 and 6 before then finding the mean score of the six items. The items are rated using a five-point scale with “strongly disagree” at one end and “strongly agree” at the other. Example items are: “I tend to bounce back quickly after hard times” (item 1) and “It is hard for me to snap back when something bad happens” (item 4, reverse coded).

During its development the BRS was tested using four separate samples to examine its psychometric characteristics. Samples one and two were undergraduate students, three consisted of cardiac patients, and the fourth of chronic pain patients. The scale showed good internal consistency, with Cronbach’s alpha values between .80 and .91 (samples 1-4 respectively: .84, .87, .80, .91). During development, the BRS was administered twice in two of the samples, offering a test-retest reliability value (ICC) of .69 for one month in 48 individuals from sample two and .62 for three months in 61 individuals from sample three. It also demonstrated convergent and predictive discriminant validity, while its one-factor solution illustrated that it measures resilience as a unitary construct.

Overall, the BRS therefore appears to be a reliable instrument for specifically assessing resilience as the ability to bounce back or recover from stress. The authors conclude that in doing so it could offer important and unique information about individuals dealing with stressors in their lives, particularly health-related stressors.

Interestingly, during the development of the scale, Smith et al. (2008) found that, as predicted, resilience was related to a range of factors including personal characteristics, social relations, coping styles and aspects of health across all four samples. Of particular interest for its use in this research is that resilience correlated negatively with anxiety. This was assessed using the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983), one of the instruments also chosen to measure general anxiety in studies one, two and three.

Although Windle, Bennett and Noyes (2011) claim to have been unable to identify a 'gold standard' among 15 measures of resilience reviewed for psychometric rigour, they did identify the BRS as receiving among the top three best psychometric ratings alongside the Connor-Davidson Resilience Scale (Connor & Davidson, 2003) and the Resilience Scale for Adults (Friborg et al. 2003). Out of these three measures, the BRS appears to be the best suited to the current study in terms of its definition of resilience for the purposes of investigating whether the ability to bounce back or recover from stress relates to general and movement-specific self-efficacy, elements of self-concept and general, state, trait and movement-specific anxiety. It was also designed specifically using samples of adults almost exactly within the current studies' age ranges (mean age range: 19-62).

What's more, although its authors do examine the relationship with social factors, the BRS' items focus predominantly on resilience as a sense of personal agency. This aligns with the current study's focus on *self*-efficacy and *self*-concept, honing in on the individual's sense of personal agency both generally and specifically in relation to moving around their everyday environment.

The BRS was also used consistently across the three studies comprising this thesis as part of the online questionnaire mentioned previously.

2.3 New General Self-Efficacy Scale (NGSE)

Chen, Gully and Eden's (2001) eight-item scale uses a five-point rating scale with "strongly disagree" at one end and "strongly agree" at the other. An example item is "I am confident that I can perform effectively on many different tasks." Higher scores imply higher general self-efficacy (GSE) levels. Developed and used with adults, it shows evidence of being a psychometrically sound instrument with adequate reliability and validity for measuring and differentiating between individuals with different levels of GSE (Chen, Gully & Eden, 2004; Scherbaum, Cohen-Charash & Kern, 2006). It was designed in line with Eden's (2001) definition of GSE as "one's belief in one's overall competence to effect requisite performance across a wide variety of achievement situations" (p. 75).

Item responses showed internal consistency ranging from .85 to .90, exceeding the generally accepted .70 cut-off for exploratory research (Henson, 2001; Nunnally & Bernstein, 1994).

Having ranged from r = .62 to r = .65, this scale's stability coefficients are moderately high for variables relating to trait-like individual differences (Crocker & Angina, 1986; Chen et al., 2001; 2004). Regarding construct validity, evidence to date suggests a single-factor structure, supported by replication studies using confirmatory and exploratory factor analysis techniques (Chen et al., 2001; 2004).

The NGSE showed the most desirable psychometric properties when compared by Scherbaum et al. (2006) with two other existing and widely used GSE scales (the General Self-Efficacy Scale by Sherer et al., 1982 and the General Perceived Self-Efficacy Scale by Schwarzer and Jerusalem, 1995). This was done using an Item Response Theory approach[1]. In particular, it outperformed the other two measures in terms of item discrimination, item information and the test information functions' comparative efficiency. Scherbaum et al.'s (2006) findings also bolster existing validity evidence supporting the construct of GSE overall. Not only do the NGSE's items demonstrate strong relationships with the latent trait of GSE, they are also capable of effectively discriminating between those with similar yet differing levels of the trait. This also serves to help differentiate GSE from related constructs, such as self-esteem, with patterns of covariance, such as confirmatory factor analysis correlations.

It should be noted that the strength of the NGSE lies in discerning between individuals with lower levels of GSE. Within the higher range of GSE it appears to be less precise, though still capable of detecting differences (Chen et al., 2001; Scherbaum et al., 2006). However, for the purposes of this research this is appropriate given its focus on whether a relationship may exist between lower self-efficacy levels and the other variables under investigation.

The NGSE was used consistently across the three studies comprising this thesis as part of an online questionnaire consisting of several standardised and self-developed scales all detailed in this chapter.

2.4 Movement-Specific Self-Efficacy

These ten items were developed by the researchers using guidance from Bandura (2006) on constructing self-efficacy scales for specific domains; in this case, in relation to moving around an everyday environment on foot, something that can present challenges for

[1] based on a model for examining nonlinear relationships between response patterns, characteristics of items and individual-based characteristics like traits.

individuals with DCD in light of their motor difficulties. Five items were couched in terms of a quiet environment and five in terms of a busy environment since this difference may act as a constraint on individuals' perceptions of how effectively they are able to negotiate movement on foot through their surroundings. Participants were asked to rate their ability to carry out five kinds of everyday actions in:

A quiet environment, with the example of a path with no other or very few other people around explicitly given in the instructions.

A busy environment, with the example of a path crowded with people, bicycles and / or dogs being walked explicitly given in the instructions.

They were asked to rate this by recording a number from zero to 100 using a visual sliding scale, where the lower end (over 0) had 'cannot do at all' written above, the middle (over 50) had 'can do fairly well' written above, and the higher end (over 100) had 'can do very well' written above. Using this visual sliding scale, participants were only able to choose a response that rounded to the nearest 10 (i.e., 0, 10, 20, 30 etc.), limiting them to 11 possible responses. In each item, a concrete example was given in brackets to help participants visualise the action or kind of action they were being asked to consider. These five items consisted of the following:

(i) Moving past objects without bumping into them (for example, past displays in shops)
(ii) Estimating the space needed when walking between two objects (for example, between tables in a restaurant or two parked cars)
(iii) Being able to move from A to B without tripping / falling / bumping into things along the way (for example, from the entrance in a café to the table you wish to sit at)
(iv) Walking on an uneven surface without tripping (for example, a rocky path or a broken pavement)
(v) Avoiding an obstacle that appears in your path (for example, a dog running out in front of you)

2.5 Movement-Specific Anxiety

These were then used to inform the development of ten complementary items designed to tap into anxiety in relation to moving around an everyday environment on foot. Participants were asked to rate the degree of anxiety they generally feel regarding their ability to carry out the same five everyday actions, as stated in section 2.4, in both a quiet and busy environment (identical description of environments as in the movement-specific self-efficacy scale). They were asked to rate their anxiety by recording a number from zero to 100 where the lower end (over 0) corresponded to 'not at all anxious', the middle (over 50) to 'anxious', and the higher end (over 100) to 'highly anxious'. As previously, using this visual sliding scale participants could only choose a response rounding to the nearest 10 (i.e., 0, 10, 20, 30 etc.), limiting them to 11 possible responses.

Both the movement-specific self-efficacy and the movement-specific anxiety scales were included in the online questionnaire components of all three studies. However, adaptations were made after completion of study one to mitigate any further loss of potential data as some participants in study one had seemingly accidentally skipped over certain items on the scale due to the set-up of the visual sliding scale. This was adapted to have clearer instructions and with the aim of becoming more user-friendly. Changes were also made to the settings on the Qualtrics(™) platform to point out where answers were missing and remind participants to complete any missing items before moving on. Please see Appendix 1 for a copy of both movement-specific scales as they appeared in the online questionnaire.

2.6 The Hospital Anxiety and Depression Scale (HADS)

This 14-item scale developed by Zigmond and Snaith (1983) is designed to measure general anxiety and depression. While depression is not under investigation here, the scale is appropriate for measuring general anxiety levels in these studies given its well-established ability to reliably assess the presence and severity of anxiety above and below a clinically significant threshold. The depression items were included in accordance with licensing rules. Asking individuals to choose their answers based on how they have felt during the past week, Zigmond and Snaith (1983) attempted to reduce response bias by alternating response order. By framing the questions in this way, the authors aimed to mitigate the impact of any heightened anxiety experienced due to a clinical setting, while ensuring that the score reflects recent and present mood state. Four responses for each item were decided on to prevent anybody consistently opting for the middle answer. To one item the first response implies maximum severity and on the following item the last response indicates maximum severity. An example item is: “I can sit at ease and feel relaxed” 0 = Definitely, 1 = Usually, 2 = Not often and 3 = Not at all. Zigmond and Snaith (1983) emphasise the care taken while developing the scale to successfully separate the concepts of anxiety and depression. Its score ranges are designed to minimise the amount of potential false positives or false negatives.

The HADS was developed with adults aged between 16 and 65 years, aligning with the age range of the participants in studies one, two and three (18-60 years). The anxiety subscale’s internal consistency is good, with positive Spearman correlations between individual items and the total score of other subscale items ranging from rho = .76 to rho = .41 and a significance level of $p<.01$. Spearman correlations of the anxiety subscale scores, and psychiatric ratings calculated from interviews (0-1 considered non-cases of clinical anxiety, 2 considered doubtful cases and 3-4 considered definite cases) were also determined to ascertain whether the anxiety subscale score could signal the severity, as well as the presence, of anxiety (rho = .74, $p <.001$). The authors concluded that the anxiety subscale score could effectively measure severity of anxiety.

The sample used to develop the scale were adults in general medical outpatient clinics, and no research has yet been done to specifically validate its use in individuals with DCD. However, some research has been undertaken to validate its use in populations with other neurodevelopmental disorders with which anxiety and depression symptoms can frequently co-occur, such as autism spectrum disorder (e.g., Uljarević et al., 2018). At the time of its development the authors concluded the HADS would likely prove an efficient tool for screening and assessing presence, severity and changes in clinically significant anxiety levels. Their prediction was correct and, although it was developed with and principally for clinical use, this scale has been used extensively to consider mental health aspects of non-clinical populations due to its reliable ability to assess anxiety above and below a clinically significant level (see e.g., Djukanovic, Carlsson & Årestedt, 2017; Gupta et al., 2020; Hinz et al., 2014).

The HADS was also used consistently across the three studies comprising this thesis as part of the online questionnaire mentioned previously.

2.7 The State-Trait Anxiety Inventory (STAI)

Developed by Spielberger, Gorsuch, Lushene, Vagg & Jacobs (1983), the STAI is a highly reliable and valid measure of state and trait anxiety in adults, concepts defined in Chapter One. This is supported by studies across diverse research and clinical contexts (e.g., Ortuño-Sierra et al., 2016; Segenreich et al., 2009).

The STAI consists of two separate self-report scales, the S-Anxiety scale to measure state anxiety and the T-Anxiety scale to measure trait anxiety, each of which comprise twenty statements. In the S-Anxiety scale, these evaluate how respondents feel "*right now*, at this moment", while in the T-Anxiety scale they evaluate how respondents *generally* feel. These two scales are printed on opposite sides of a test form. This instrument is always completed in its printed format. The authors recommend that where both scales are administered together, the S-Anxiety should always be completed first, followed by the T-Anxiety scale. This is due to the design of the S-Anxiety scale which renders it sensitive to the conditions under which it is completed; scores could be affected by the emotional climate fostered if the T-Anxiety scale were completed first. Conversely, and interestingly in terms of construct validity, the T-Anxiety scale has shown relative insusceptibility to the conditions under which it is completed (see e.g., Auerbach, 1973; Lamb, 1969; Spielberger et al., 1973).

In line with the definition of state anxiety discussed in Chapter One, the S-Anxiety scale assesses how apprehensive, worried, nervous and tense individuals feel in the present moment. Example statements are 'I feel calm' (item 1) and 'I am presently worrying over possible misfortunes (item 7). Respondents are asked to read each statement and then circle the number to the right of the statement indicating to what extent they feel this way *'right now*' on the following four-point scale: 1. 'not at all'; 2. 'somewhat'; 3 'moderately so' or 4. 'very much so'. It is clearly explained in the instructions that there is no right or wrong answer and respondents are asked not to spend too much time on any one statement but to give the answer which seems to best describe their present feelings.

The T-Anxiety scale evaluates how individuals generally describe themselves, aiming to assess an individual's level of trait anxiety in line with the definition discussed in Chapter One. Example statements are 'I am "calm, cool and collected"' (Item 27) and 'I get in a state of tension or turmoil as I think over my recent concerns and interests' (Item 40). Respondents are asked to read each statement and then circle the number to the right of the statement indicating how frequently they feel like this on the following four-point scale: 1. 'almost never'; 2. 'sometimes'; 3. 'often'; or 4. 'almost always'. It is clearly explained in the instructions that there is no right or wrong answer and respondents are asked not to spend too much time on any one statement but to give the answer which seems to best describe how they generally feel.

Each STAI item receives a weighted score of 1 to 4. In ten of the S-Anxiety and eleven of the T-Anxiety items, 4 indicates the presence of high anxiety (for example, "I feel nervous", "I have disturbing thoughts"). For the remaining items, 4 indicates the absence of anxiety (for example, "I feel steady", "I am content"). For these 'anxiety-absent' items scoring weights are reversed. For each scale, the weighted scores for the twenty items are added together to make a total score, taking into careful account that scores are reversed for the 'anxiety-absent' items. Scores for both scales range from a minimum of 20 to a maximum of 80.

As expected regarding a measure designed to assess changeable, circumstantial anxiety levels, stability is relatively low for the state anxiety (S-Anxiety) scale. Test-retest coefficients ranged from .16 to .62, with a median reliability coefficient of just .33. However, internal consistency as measured by alpha coefficients (median of .93) and by item remainder correlations is good, demonstrated by consistently high item-remainder correlations for S-Anxiety items across the normative groups comprising working adults (.63), high school students (.55), university students (.59) and military recruits (.61). This is further supported by the overall median alpha coefficient of .92 across the normative samples (Spielberger et al., 1983). The S-Anxiety scale also met robust construct, concurrent, convergent and divergent validity criteria at each step of the development process as detailed by Spielberger et al. (1983).

Stability for the trait anxiety (T-Anxiety) scale was shown to be relatively high as measured by test-retest coefficients ranging from .73 to .86 among normative samples of college students and from .65 to .75 among normative samples of high school students. The T-Anxiety's median reliability coefficients were .765 for the college students and .695 for the high school students. Internal consistency was also high for the T-Anxiety scale as measured by alpha coefficients (median of .90) and item-remainder correlations (.56, .57, .54 and .52 respectively in the normative samples of working adults, university students, high school students and military recruits). As with the S-Anxiety scale, the T-Anxiety scale met robust construct, concurrent, convergent and divergent validity criteria at each step of the development process as detailed by Spielberger et al. (1983). It is important to note that across both scales individual items had to meet specific validity criteria at each phase of the scale's development process in order to remain included for further evaluation and final validation. These processes are described in full by Spielberger and Gorsuch (1966), Spielberger et al. (1970) and in the appendices of the updated STAI Manual (Spielberger et al., 1983).

The STAI was incorporated into the questionnaire components of studies two (Chapter Five) and three (Chapter Six) of this thesis. For copyright reasons, and since it could not be completed in a digital format, it was not possible to include it in the online questionnaire for the first study (Chapter Three).

2.7.1 Reflection on the Use of Several Anxiety Measures

As explored in detail in Chapter One, anxiety is a complex construct with multiple facets. In study one, general anxiety was measured using the HADS (1983) and the self-developed movement-specific anxiety scale. This was done in order to gain insight into respondents' 'global' anxiety level and also their anxiety specifically in relation to motor skill when executing certain actions while navigating everyday environments on foot. However, the snapshot of 'global' anxiety captured by the HADS and of this movement-specific anxiety may also be influenced by other subtypes of anxiety including 'state' and 'trait' anxiety, also examined in Chapter One and in the previous section. For copyright reasons it was not possible to incorporate the STAI (Spielberger et al., 1983) into the online questionnaire for study one, however it was possible to include it in its hard copy format as part of the questionnaires component of studies two and three, both of which were laboratory-based. This was done for the latter two studies to gain a more nuanced understanding of participants' anxiety to then facilitate greater insight into the interaction between anxiety, perceptual judgement of movement and the execution of that movement.

2.8 The Adult DCD/Dyspraxia Checklist (ADC)

This questionnaire is the first, and currently only, screening tool for DCD in adults. It was developed and tested in both the United Kingdom and Israel by Kirby, Edwards, Sugden and Rosenblum (2010). The authors developed this instrument in recognition of and response to increasing numbers of children growing up and presenting with DCD into adulthood. At the time of development, the ADC aimed to specifically target criterion B of the DSM-IV criteria for DCD, to consider how and where difficulties with motor functioning impact on an adult's life. In the current project, it was incorporated into the questionnaire component of studies two and three to contribute to the accurate grouping of participants and to ensure that participants in the DCD group met criteria B and C of the updated DSM-5 criteria for DCD, all of which are detailed in Chapter One. The authors of the ADC focused on criterion B of the DSM-IV since other tools are able to measure the actual motor function of adults with amendments to make them age appropriate, for example the Movement Assessment Battery for Children, Second Edition (MABC-2), whose upper age band is currently 11-16 years (Henderson, Sugden & Barnett, 2007). However, Kirby et al. (2010) aimed to develop a tool able to effectively describe the patterns of DCD presentation and impact in adulthood, which can differ to those in childhood. The explicit objective of the ADC is to identify youth and adults *at risk* for DCD in a valid and reliable way, since in its format as a questionnaire it cannot explicitly measure motor functioning. It can therefore be used most usefully in tandem with tests that do so, such as the MABC-2.

The ADC is a self-report questionnaire about the adult's ability to function across various contexts including academic, working, home and social environments both currently and when they were a child. Its items include a focus on organisation in time and space when performing daily living activities and self-care skills, common vocational and academic tasks such as driving and writing, and abilities in relation to hobbies and social participation. The choice of items is based on current knowledge about the underlying mechanisms of DCD and problematic areas of functioning for both children and adults with DCD.

The questionnaire comprises three subscales. Subscale A (10 items) focuses on difficulties experienced as a child which offers a history of childhood difficulties that can be distinguished from any acquired motor functioning problems in adulthood potentially caused by other factors, such as multiple sclerosis. Subscale B (10 items) focuses on current difficulties and specifically the influence of DCD on an individual's own perception of their performance. Subscale C (20 items) also focuses on current difficulties but specifically on current feelings an individual has about their performance as reflected upon by others. Every item describes a difficulty an individual may experience or have previously experienced. They are asked to respond with a Likert scale as to whether this difficulty occurred or occurs 'Never' [0], 'Sometimes' [1], 'Frequently' [2] or 'Always' [3]. The lower the score, the better the performance. An example item from each scale is:

A: As a child did you… Have difficulties eating without getting dirty (Item 2)
B: Do you have difficulties currently with the following items… Self-care tasks such as shaving or make-up? (Item 1)
C: Currently… Do you have difficulties with sitting still or appearing fidgety?

The questionnaire was developed with a sample of 107 students aged 17-42 years, 62 of whom were from Israel and 42 of whom were from Wales, UK. In the overall sample, 49 participants had previously been diagnosed with DCD or Dyspraxia, or self-reported symptoms in keeping with DCD/Dyspraxia. The remaining 58 participants served as controls, matched to the DCD group. Mean age between the groups showed no significant difference (control: 23.5 years, S.D. = 4.52; DCD: 23.67 years; S.D. = 4.7; $t(102) = 1.88$, $p < .08$). In line with criterion D of the DSM-5 diagnostic criteria for DCD, participants with conditions that could better explain their motor skills deficits including neurological diseases, physical disabilities, autism spectrum disorders, other serious illnesses or injuries were excluded from the sample. All participants were native speakers of either Hebrew in the Israeli sample or English in the UK sample.

Based on results from these 107 questionnaires, the ADC was found to have high levels of internal reliability. Chronbach's coefficient alpha was calculated for each of the three subscales as well as for all of the items. The overall alpha coefficient was calculated to be 0.953, well above the generally acceptable level of 0.70. The values for each subscale were also high (subscale A: as a child; □ =.914, subscale B: current symptoms; □ =.873, subscale C: current symptoms manifested by others; □ =.900). Internal reliability was also examined using Pearson correlation analysis to consider correlations between each of the 40 items and the final score of the ADC which showed significant correlations ($r = 0.44–0.79$, $p < .001$).

The ADC's construct validity was examined by determining its ability to discern between the group with and without DCD. This was done by applying a MANOVA to the mean scores of the three subscales before applying a *t*-test to analyse the group differences for the mean overall ADC score. The mean overall score showed significant differences between the DCD and non-DCD groups (DCD = 99.41, S.D. = 19.9; control = 60.36, S.D. = 12.5; $t(103) = 11.85$, $p < .001$ and the MANOVA indicated significant differences between the groups for the three subscales ($F(3,101) = 52.061$, $p < .001$). These results illustrated that those participants in the DCD group experienced significantly greater difficulties with performing activities of daily living compared to those in the control group.

The authors established concurrent validity by comparing the means of subscales A, B and C of the ADC with the mean overall score of the Handwriting Proficiency Screening Questionnaire (HPSQ; Rosenblum, 2008). They based this on the fact that handwriting difficulties in children with DCD were formally recognised as part of Criteria A and B of the DSM-IV (Barnett, 2006) and that among school-aged children these difficulties can limit academic participation (Dunford et al., 2001). In light of this, they found a significant moderate correlation between the ADC subscales and the mean overall scores of the HPSQ (ADC A: $r = 0.68$; ADC B: $r = 0.754$; ADC C: $r = 0.707$; $p < .001$).

Additionally, a discriminant analysis was undertaken to determine to what extent the mean scores of the ADC subscales differentiated between participants with DCD and control participants. A discriminant function was found for classifying all participants by group (Wilks' lambda = 0.393, p <.001). As for the subscales A (as a child; loading of 0.91) and C (currently - as manifested by others; loading of 0.90) could strongly differentiate between the two groups, while B loaded as 0.70. As such, 88% of overall participants, 91% of control participants and 84% of DCD participants were accurately classified based on this function. It was shown that group classification had not occurred by chance with the calculation of a Kappa value (0.733, p <.001). A Chi-square test of independence, performed to explore between-group differences regarding individual items of the ADC, showed large differences with a higher percentage of the DCD group marking that they 'usually' or 'always' experienced difficulties in comparison to the control group.

In 2011 the scoring system was revised from the initial study (Kirby et al., 2010). In the section on childhood difficulties (subscale A), an individual is required to score at least 17 to meet the criteria of having past difficulties likely related to DCD in childhood. If this is the case, a combined overall score can be calculated and a score of 56 or over indicates that an individual is at risk of DCD, while a score of 65 or over indicates that an individual has probable DCD. As discussed in Chapter One, the terminology of 'probable DCD' is often used in the research literature about both children and adults with DCD due to the variable nature of and often limited access to the full range of appropriate diagnostic tools and resources needed to gain a true diagnosis, especially in adulthood. These factors also vary widely across contexts in practical, linguistic and cultural terms.

Reflecting on the insights gained from the results of the study to develop this tool, the authors noted the marked difference in functioning illustrated by specific questions where large between-group differences were shown. They draw particular attention to the finding that 71.4% of the participants with DCD struggled with ‘writing neatly when having to write fast’ in comparison with 17.9% of the control group; 55.1% of the participants with DCD struggling with ‘organising/finding things in your room’ in comparison with only 7.1% of the control group; and 68.8% of the participants with DCD avoiding ‘clubs or dancing’ in comparison with only 9.6% in the control group. They further note that these specific differences in response patterns call attention both to the continuation from childhood into adulthood of motor difficulties for tasks like writing and the accurate execution of actions, and also the way DCD can permeate other important and pervasive aspects specifically of adult life. These include organisation, planning and engagement with certain socio-culturally conventional activities and behaviours where adults meet and interact.

So, the ADC was developed as the first screening tool able to distinguish between adults with DCD and typically developing adults. Its authors note that the study used to develop the questionnaire took place across two culturally different contexts, yet it remained sensitive and was able to differentiate between the two groups in a similar way. What drove the work to develop this tool was above all a pragmatic need as increasing numbers of young people were growing up and presenting with difficulties in higher education contexts, especially salient in places like the UK where a diagnosis is the only way to access the practical support required. A key strength of the ADC lies in its ability to tap into the wide-ranging difficulties adults with DCD deal with and whose impact on their lives is holistic, rather than limited only to difficulties with motor functioning. For example, it can identify executive functioning difficulties - usually associated more with ADHD - which also impact adults with DCD far more than typically developing adults. In light of this comprehensive, integrative view of individuals with DCD, Kirby et al. (2010) have called for further research to add to their initial data which can assist, clinically and otherwise, in considering each adult with DCD holistically and in determining the exact support that will most benefit them.

The use of the ADC in studies two and three engages with this call by examining how the emotional factors of anxiety, self-efficacy and resilience may interact with everyday motor functioning to impact holistically on an adult with DCD's experience in navigating their environment, as compared to typically developing adults. This tool is unique in relation to the other standardised measures used in studies one, two and three in that it is the only assessment aimed specifically at adults with DCD. More than a decade after its development, and in light of Blank et al.'s (2019) identification of an urgent need for further research into DCD in adulthood, the ADC is hopefully the pioneering component of a future range of motor and other assessment tools aimed specifically at evaluating DCD in adults which together could address the full set of DSM-5 criteria for the condition.

It is important to note here that two minor changes were made to the ADC to allow for participants to indicate whether they drove a car or not, and if not, a text box to optionally give their reason for this. This was to facilitate more accurate grouping of participants by placing their score for the adulthood section into fuller context.

Specifically, for question C5 (If you drive, did it take you longer than others to learn to drive?), an additional check box was added which stated 'I do not drive'. An additional question was then added which asked: 'If you do not drive, please indicate why you choose not to drive.' A text box was then offered for the participant to freely write their reason for this. In terms of scoring, for those who ticked the 'I do not drive' option, where they wrote a reason in the subsequent text box that related to their perception of their motor skills, the previous question (C5) was given a score of 3. In question C12 (If you are a driver, do you have difficulty parking a car?), this same scoring approach was used (i.e., those who had stated they did not drive in question C5 and had given a reason related to perceived motor skills were given a score of 3).

It was decided to make these adaptations to facilitate as accurate an insight as possible, within the context of the ADC questions, into the participants' perceived motor skills in adulthood and the impact of these. This then allowed for more accurate grouping of participants, especially ensuring that those participants in studies two and three who were allocated as having TD motor skills were not showing up as having ADC scores above the threshold deeming them to be 'at risk for DCD' or to have 'probable DCD'.

2.9 Demographic Questions

Studies one, two and three included several demographic questions in the final section of the online questionnaire. These aimed to gather information about demographic variables that may interact with the emotional, perceptual and movement variables under examination and which were relevant for matching and grouping purposes in study three.

In study one respondents were asked about their gender and to tick the box next to one of four options: woman, man, non-binary or prefer to self-describe. Underneath the 'prefer to self-describe' option a text box was given to allow for an optional additional free text response. They were subsequently asked their age in years and their nationality. They were then asked whether they had received a confirmed diagnosis of DCD or Dyspraxia with a 'yes' or 'no' option to tick. Below this, they were asked whether they suspected they had a difficulty with motor control and coordination that they have had since childhood and that is not due to a physical or visual issue, but which has not been formally diagnosed. Likewise, there was a 'yes' or 'no' option to tick. Finally, they were asked to indicate any other developmental difficulties, with a free text box beneath.

In studies two (Chapter Five) and three (Chapter Six), the questions about gender, age and nationality were the same as in study one (Chapter Three), except for the addition of age 'in years and months' to facilitate more accurate age-matching of participants in the DCD and TD groups. In light of the incorporation of both the MABC-2 and the ADC, no further questions were included in this section about a diagnosis or suspicion of DCD / Dyspraxia specifically. However, the final question asked participants to indicate any developmental difficulties (diagnosed or suspected), with a free text box for their response beneath.

In all three studies participants were provided with links to the MIND website and the Dyspraxia Foundation UK website as potentially helpful resources in the event that any of the questions they answered or tasks they completed brought up negative emotions or memories and / or if they wished to seek out further information about DCD / Dyspraxia.

Chapter Three

Study One: Anxiety, Confidence and Self-Concept in Adults with and without Developmental Coordination Disorder

Please note, this study is published:

Harris, S., Wilmut, K., & Rathbone, C. (2021). Anxiety, confidence and self-concept in adults with and without developmental coordination disorder. *Research in Developmental Disabilities*, *119*. https://doi.org/10.1016/j.ridd.2021.104119

A copy of the paper is included as Appendix 2.

For inclusion here, changes were only made to the introduction and methods sections to ensure the flow of information within the wider structure of the thesis.

3.1 Background

As has been discussed in detail in Chapter One, the potential influence of how anxious or confident individuals feel on how they perceive and interact with the world round them may be particularly pertinent for those with DCD. While, as also detailed fully in Chapter One, most of the related literature focuses only on children and adolescents with DCD, the demands of navigating adult life with DCD render the potential influences of anxiety and confidence levels even more salient (see e.g., Omer et al., 2019; Blank et al., 2019).

Indeed, in terms of overall wellbeing, a study by Engel-Yeger (2020) concluded that some of the negative effects of life with DCD may be linked with lower levels of health-related quality of life in adulthood. In an earlier study, Tal-Saban, Ornoy and Parush (2014) found that young adults aged 22–29 years with DCD reported lower levels of quality of life and life satisfaction. Their analyses showed that psychological health was the domain that most significantly predicted life satisfaction in this group. In addition, Hill, Brown and Sorgardt (2011) had previously found that a group of young adults (aged 18-27 years) with DCD self-reported significantly lower quality of life satisfaction in every domain compared to TD adults.

In terms of anxiety specifically, the limited studies to date with a focus on anxiety in adults with DCD have suggested that this population experiences increased anxiety levels, with links to lower wellbeing in other aspects, compared to adults with typically developing motor skills (Hill & Brown, 2013; Kirby et al., 2013). Yet the exact nature of the anxiety experienced, the reasons for it and what else it may be connected to remain to be further explored.

Turning to consider the role of confidence, in the current study confidence is conceptualised as consisting of general self-efficacy, domain-specific self-efficacy and resilience. Each of these concepts, and the type of scales needed to effectively measure them, has been defined and discussed in chapters one and two. What's more, the limited research that has focused on the role of self-efficacy in individuals – and so far, specifically only children – with DCD has been described and discussed in chapter one. It is pertinent to note here however that the contrasting findings of Cairney et al. (2005) and Batey et al.'s (2013) studies support Bandura's (2006) ideas regarding the multifaceted patterning of self-efficacy beliefs across different domains of functioning.

Indeed, the varied nature of previous findings, which have been discussed fully in chapter one, support Bandura's (2006) assertions that self-efficacy is ultimately domain-specific and that, as such, it forms an attitude towards a specific task in a specific context. Taking a novel approach, the current study therefore sought to measure both general and domain-specific (i.e., movement-specific) self-efficacy to try and tease apart the nuances of which facets may mediate the relationship between DCD and movement. As noted previously, this may be particularly important in adults with DCD given their different opportunities for and barriers to physically activity they need or want to engage in.

Regarding resilience, both its relationship with and distinctiveness from self-efficacy as a construct have been discussed in chapter one. As has also been discussed, the limited research into resilience among individuals with DCD, and especially among adolescents and young adults with DCD, has linked higher resilience with the successful use of behavioural and cognitive strategies to manage motor differences and promote wellbeing (e.g. Harrowell et al., 2017; Missiuna et al., 2008; Zwicker et al., 2018). In light of these initial findings, the current study was interested to explore whether and how resilience may relate to anxiety and self-efficacy, both generally and specifically in relation to movement on foot around everyday environments, in adults with DCD.

The final component of the current study was to explore how self-concept may relate to how anxious or confident individuals feel about navigating their everyday environments. Self-concept has been defined and discussed in relation to research on children and adolescents with DCD in chapter one (see Cocks et al., 2009; Hands et al., 2020; Marsh & Shavelson, 1985; Rathbone et al., 2015; Yu et al., 2016). However, it is worth noting that in the current study, in contrast to studies by Cocks et al., (2009) and Yu et al. (2016), we did not measure the positive/negative valence of self-concept, but rather the presence or absence of self-concepts related to movement or motor ability. We were interested in whether the presence of movement-related self-concepts in people with DCD were related to the other factors under investigation. Previous studies that have explored self-concept in people with DCD have used self-description questionnaires which offer domain- specific and composite scores resulting from closed-ended questions with, for example, Likert scale scoring across a range of subscales, including those relating specifically to physical self-concept. The current study however purposely used open-ended 'I am…' statements (based on the Twenty Statements Task; Kuhn & McPartland, 1954), which were subsequently coded to examine how adults with DCD define themselves in their own words.

Please note, this study was pre-registered on the Open Science Framework (Registration DOI: 10.17605/OSF.IO/ZPHV7).

3.2 Aims and Hypotheses

The first aim was to first describe and compare general and movement-specific anxiety, self-efficacy, general resilience, and movement-related self-concept among adults with DCD and TD adults. A subsequent aim was to explore the relationships between these factors in adults with DCD. Based on the literature to date, it was first hypothesised that anxiety (both general and movement-specific) would be higher in adults with DCD than in TD adults. Secondly, it was hypothesised that movement-specific self-efficacy would be lower in adults with DCD than in TD adults. It was also of interest to identify whether this effect may also extend to general self-efficacy. It was thirdly hypothesised that adults with DCD with lower self-efficacy (both general and movement-specific) would have higher anxiety levels (see e.g., Bandura, 1988). It is notable that the relationships between resilience and the other factors remain underexplored in relation specifically to movement and in a DCD population. However, based on previous research in other contexts and populations, it was hypothesised that individuals with higher resilience might experience lower anxiety levels and higher self-efficacy (Schwarzer & Warner, 2013; Zwicker et al., 2018). However, this investigation into resilience and its relationships with the other factors was predominantly exploratory.

Similarly, the investigation into potential relationships between self-concept and the other factors was exploratory.

3.3 Methods

3.3.1 Participants

Although DCD is the official term for the condition used in the DSM-5 (American Psychiatric Association, 2013) many adult individuals in the UK self-identify as having Dyspraxia as this is the terminology often used in many educational and clinical settings (Purcell, Scott-Roberts & Kirby, 2015). Therefore, to ensure the best chance of accessing a larger sample from this population, both terms were used during the recruitment process. 79 TD adults, 74 adults with formally diagnosed DCD / Dyspraxia and 26 adults with self-reported suspected DCD / Dyspraxia between the ages of 18 and 60 years completed the questionnaire. It was elected to include both formally diagnosed and suspected DCD so that the current work may be usefully comparable with other studies in the field. Many of these use the terms ‘probable DCD’ or ‘suspected DCD’, given that formal diagnosis is not always feasible in the context of samples from certain populations, particularly in the case of large samples (e.g., Cairney et al., 2005). Data from individuals who suspect they may have DCD / Dyspraxia without a formal diagnosis can also offer valuable insights, particularly in the case of this questionnaire study in which self-perception has an important role. For the purposes of the current study, the TD group could include individuals with other neuro-developmental disorders such as Dyslexia. This is because the developmental aspect of interest here relates specifically to difficulties with movement. As such ‘typically developing’ throughout the current and subsequent studies in this thesis refers specifically to motor development.

The sample was opportunistic and participants were recruited via social media, a voluntary research participation panel at Oxford Brookes University and a database of individuals with DCD who had previously taken part in research studies at the university. Table 3.1 shows the demographic details of the participants.

Although it is beyond the scope of this thesis to consider this aspect further, the following information offers insight into the broader developmental profile of the samples across groups.

42% of participants in the combined DCD group also self-reported having ADHD, ASD, dyslexia and / or a sensory processing disorder. In the TD group, one participant self-reported having dyslexia and one participant self-reported having ASD.

Table 3.1

Demographic details of participants across the three groups

Group	N	Age range (years)	Mean age (years)	% Female	% Male	% Non-binary	% Prefer to self-describe gender
Diagnosed DCD	74	18 - 60	33.7 (SD: 11.0)	77% (N=57)	20% (N=15)	1% (N=1)	1% (N=1)
Suspected DCD	26	18 - 60	37.8 (SD: 12.1)	77% (N=20)	15% (N=4)	8% (N=2)	None
TD	79	20 - 60	40.5 (SD: 11.5)	75.9% (N=60)	22.8% (N=18)	1.3% (N=1)	None

3.3.2 Measures

Having been invited to complete an anonymous online questionnaire, participants completed an eight-section questionnaire generated using the software Qualtrics^{TM}. This included an opening section to provide informed consent and a closing section to provide demographic information. The remaining six sections comprised the standardised scales and self-developed movement-specific scales described in detail in Chapter Two. Namely, the New General Self-Efficacy Scale (NGSE) (Chen et al., 2001), the Brief Resilience Scale (BRS) (Smith et al., 2008), the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983), six 'I am' statements based on the widely used Twenty Statements Test (Kuhn & McPartland, 1954), a movement-specific self-efficacy scale and a movement-specific anxiety scale. These were presented in counterbalanced order.

Data collection began in August 2020 and was completed in October 2020. A preview copy of the full questionnaire is available on the OSF pre-registration document via a hyperlink. As noted previously, the movement-specific scales are also available to see in see Appendix 1.

3.4 Data Processing and Statistical Analysis

A priori sample size target was set at 100 participants with DCD and 100 TD participants. This was met for the pooled DCD sample but fell slightly short for the TD sample. However, the sample size here greatly exceeds that seen in similar previous studies and sufficient power was present throughout. Some participants were missing data in the movement-specific measures. These participants were removed from the analyses involving the movement-specific measures. This resulted in sample sizes for these analyses of N = 64 (DCD diagnosed group), N=23 (DCD suspected group) and N = 63 (TD group). For analyses which did not involve the movement-specific measures, the whole sample was used, i.e., N = 74 (diagnosed DCD), N=26 (suspected DCD) and N=79 (TD).

The open-source computer software jamovi was used to conduct statistical analyses on the data (The jamovi project, 2021).

A principal component analysis (PCA), using oblimin rotation, was performed on all the data from the movement-specific scales, i.e. from the DCD and TD groups together. This was done to reduce the data and to verify whether the data were reliably capturing the dimensions the scale was aiming to measure, namely movement-specific self-efficacy and movement-specific anxiety. Using parallel analysis (the scree plot alongside eigenvalues), the data (N=150) loaded freely onto two components which in total explained 78.3% of the overall variance in the data. Sample size was confirmed to be sufficient using the MKO sampling adequacy measure with all values sitting above .885 and an overall value of .908. The assumption of sphericity was met using Bartlett's test of sphericity (X2=4333(190), p<.001), and as might be expected the two components were moderately negatively correlated (rs = -0.526). The way in which the questions loaded onto the components is shown in Table 3.2. The first component represents all of the questions focusing on movement-specific self-efficacy while the second on movement specific anxiety. Following this, mean values were calculated for each component.

Table 3.2

Results of principal component analysis showing question loading onto components representing movement-specific self-efficacy and anxiety across quiet and busy environments

Environment	Focus	Question	Component 1	Component 2
Quiet	Self-Efficacy	Moving past objects	0.908	
		Estimating space	0.904	
		Not tripping / falling / bumping	0.892	
		Uneven surface without tripping	0.780	
		Avoiding obstacle	0.836	
	Anxiety	Moving past objects		0.942
		Estimating space		0.930
		Not tripping / falling / bumping		0.928
		Uneven surface without tripping		0.860
		Avoiding obstacle		0.910
Busy	Self-Efficacy	Moving past objects	0.980	
		Estimating space	0.924	
		Not tripping / falling / bumping	0.940	
		Uneven surface without tripping	0.780	
		Avoiding obstacle	0.862	
	Anxiety	Moving past objects		0.803
		Estimating space		0.846
		Not tripping / falling / bumping		0.825
		Uneven surface without tripping		0.728
		Avoiding obstacle		0.757

Kruskal Wallis tests were conducted to compare general self-efficacy, general anxiety, and general resilience levels across group (diagnosed DCD, suspected DCD and TD). These were also conducted to compare self-efficacy and anxiety specifically in relation to movement across group. Non-parametric tests were undertaken due to violation of the assumptions of normality and equal variances. Dwass-Steel-Critchlow-Fligner pairwise comparisons were used where appropriate. Effect size was reported as epsilon squared which is equivalent to R2. Spearman correlations were used to determine relationships between the various measures, and this was done for the TD group as compared to the DCD group (with the DCD suspected and DCD diagnosed combined). Fisher's z transformation was used to determine levels of significance across correlation coefficients which showed differences in the patterns across the groups. For self-concept analysis chi- squared was used to determine differences in frequency of explicit mention of motor skills difficulties / dyspraxia and Kruskal-Wallis tests followed up whether differences in the general and specific measures existed between those who did explicitly mention motor skills difficulties / dyspraxia and those who did not. Alpha level for significance was set at 0.05 throughout.

3.5 Results

3.5.1 General and Movement-Specific Measures: Anxiety, Self-Efficacy and Resilience in Adults with DCD and TD adults

With regard to the descriptive data, a main effect of group was found for all three general measures, general anxiety $H(2) = 30.3$, $p < .001$, $\varepsilon 2 = .17$, general resilience $H(2) = 28.0$, $p < .001$, $\varepsilon 2 = .16$ and general self-efficacy $H(2) = 43.8$, $p < .001$, $\varepsilon 2 = .25$. Differences were demonstrated between the TD group and the two DCD groups (diagnosed DCD and suspected DCD), but no differences were observed between the diagnosed DCD and suspected DCD group. General anxiety was significantly higher in both DCD groups compared to the TD group and resilience and self-efficacy were lower. The group data for each of these measures are summarised in Table 3.3.

For the movement-specific measures both anxiety and self-efficacy demonstrated a significant effect of group, $H(2) = 80.3$, $p < .001$, $\varepsilon 2 = .54$ and $H(2) = 40.8$, $p < .001$, $\varepsilon 2 = .27$ respectively. These differences were due to significantly higher anxiety and significantly lower self-efficacy in both DCD groups compared to the TD group. No differences were observed between the DCD groups (diagnosed DCD and suspected DCD).

Table 3. 3

Mean and median scores for general and movement-specific measures with standard deviation (SD) and inter-quartile range (IQR) shown in brackets

		Diagnosed DCD Mean (SD) Median (IQR)	Suspected DCD Mean (SD) Median (IQR)	TD Mean (SD) Median (IQR)
		N = 74	N = 26	N = 79
General	Anxiety	12.8 (3.8)	11.2 (4.23)	8.1 (3.8)
		13.0 (5.0)	11.0 (7.0)	8.0 (5.0)
	Resilience	2.45 (.75)	2.49 (.92)	3.19 (.85)
		2.42 (1.0)	2.50 (1.2)	3.33 (1.3)
	Self-efficacy	3.00 (.79)	3.17 (.82)	3.69 (.71)
		3.00 (1.13)	3.13 (1.13)	3.81 (.75)
		N = 64	N = 23	N = 63
Movement-specific	Anxiety	46.7 (22.1)	41.9 (24.4)	19.0 (22.4)
		48.5 (30.3)	44.0 (36.0)	11.0 (24.0)
	Self-efficacy	43.2 (17.1)	51.8 (22.5)	83.1 (15.5)
		40.5 (25.5)	48.0 (37.0)	86.0 (15.5)

3.5.2 Relationships between the measures

Correlation coefficients and p values are given in Table 3.4 for the DCD group and Table 3.5 for the TD group. For these analyses, unlike those described previously, the diagnosed and suspected DCD group were combined due to low numbers in the suspected group and a lack of difference between the groups up to this point. In terms of the general measures, in the DCD group the results indicated a significant positive association between self- efficacy and resilience, and significant negative associations between self-efficacy and anxiety and between resilience and anxiety. As shown in Table 3.4, within the DCD group there was a significant positive association between general self-efficacy and movement- specific self-efficacy, and a significant negative association between resilience and movement-specific anxiety. A significant positive association was also shown between general anxiety and movement-specific anxiety. Interestingly, no significant association was found between movement-specific anxiety and movement-specific self-efficacy, ($p = .061$).

Table 3. 4

Spearman correlations between measures in the DCD group (diagnosed and suspected combined)

	General Anxiety	General Self-Efficacy	Resilience	Movement-Specific Anxiety
General Self-Efficacy	*rs*(87) = -.295 *p* = .005	-	-	-
Resilience	*rs*(87) = -.412 *p* <.001	*rs*(87) = .327 *p* = .002*	-	-
Movement-Specific Anxiety	*rs*(87) = .264 *p* = .014	*rs*(87) = -.209 *p* = .052*	*rs*(87) = -.222 *p* = .039	-
Movement-Specific Self-Efficacy	*rs*(87) = -.140 *p* = .196*	*rs*(87) = .261 *p* = .015*	*rs*(87) = .060 *p* = .582	*rs*(87) = -.202 *p* = .061*

Please note: Grey shading indicates non-significant correlations. *Indicates relationships where there was a difference in pattern of significance shown between DCD and TD groups

Table 3. 5

Spearman correlations between measures in the TD group

	General Anxiety	General Self-Efficacy	Resilience	Movement-Specific Anxiety
General Self-Efficacy	rs(63) = -.427 p < .001	-	-	-
Resilience	rs(63) = -.427 p <.001	rs(63) = .247 p = .051*	-	-
Movement-Specific Anxiety	rs(63) = -.184 p = .148	rs(63) = -.324 p = .009*	rs(63) = -.324 p = .001	-
Movement-Specific Self-Efficacy	rs(63) = .356 p = .004*	rs(63) = .121 p = .346*	rs(63) = .247 p = .051	rs(63) = -.611 p <.001*

Please note: Grey shading indicates non-significant correlations. *Indicates relationships where there was a difference in pattern of significance shown between DCD and TD groups

Five of the correlations followed different patterns across the DCD and TD group, i.e., they were significant in one group but not the other. Of the correlations which showed differences in significance across groups, only two (the relationships between movement-specific self-efficacy and movement-specific anxiety and movement-specific self-efficacy and general anxiety both of which are significant in the TD group but not the DCD group) were actually significantly different across the groups. In this case, Fischer's z transformation resulted in a z difference of 3.72 p = .002 and 2.99 p = .003 respectively. The Fischer's z transformation scores for the five correlations with different significance patterns across DCD and TD groups are given in Table 3.6.

Table 3. 6

Fisher z transformations and z differences for the DCD and TD groups, given for the correlation coefficients which differed in terms of significance between the two groups. Two-tailed p values are provided

Variables	DCD Details	DCD Fisher z	TD Details	TD Fisher z	Difference in z	P value
Resilience GSE	*rs* = .327 N = 87	.339	*rs* = .247 N = 63	.252	.516	.610
MSA GSE	*rs* = -.209 N = 87	-.212	*rs* = -.324 N = 63	-.336	.734	.465
MSSE General Anxiety	*rs* = -.140 N = 87	-.141	*rs* = .356 N = 63	.372	-3.036	.002*
MSSE GSE	*rs* = .261 N = 87	.267	*rs* = .121 N = 63	.142	.741	.459
MSSE MSA	*rs* = -.202 N = 87	-.205	*rs* = -.611 N = 63	-.711	2.99	.003*

Please note: For formatting purposes, GSE = General self-efficacy; MSSE = Movement-specific self-efficacy; MSA = Movement-specific anxiety.

*Denotes significance at $p<.05$

3.5.3 Self-concept in adults with DCD and TD adults

There was no significant difference in the number of identity statements (up to six in total for each participant) across groups; $H(2) = 2.39$, $p = .303$, diagnosed DCD (Mean = 5.35, Mdn = 6), suspected DCD (Mean = 5.54, Mdn = 6) and TD groups (Mean = 5.76, Mdn = 6). Of 74 participants with diagnosed DCD, 25 directly mentioned motor skills difficulties and / or referred to being ‘dyspraxic’ in their six ‘I am’ statements (34%), while of 26 participants with suspected DCD, 8 directly mentioned motor skills difficulties and / or being ‘dyspraxic’ (31%). Chi-squared indicated no greater frequency of mentions of motor skills difficulties in one group over another $\chi2(1,100) = .0791$, $p = .779$. For the diagnosed DCD group, we found no difference in either the general or the movement-specific measures for those who did mention motor skills difficulties and / or dyspraxia compared to those who did not (all *p*>.05). For the suspected DCD group, it was found that movement-specific self-efficacy was significantly lower in those individuals who mentioned motor skills difficulties and / or dyspraxia, $H(1) = 5.88$, $p = .015$ (Mention Mean = 37.4, SD = 20.6, Mdn = 31.0, IQR = 21.5, No Mention Mean = 59.5, SD = 19.9, Mdn = 53.0, IQR = 25.0). No other differences were found, $p > .05$.

3.6 Discussion

The results of this first study are multifaceted. They indicate that general and movement-specific anxiety, self-efficacy, and general resilience are all poorer in adults with DCD compared to TD adults. These findings support our hypotheses that anxiety (both general and movement-specific) would be higher, and that movement-specific self-efficacy would be lower in adults with DCD than in TD adults. This supports what has been found in previous studies among adults with DCD in relation to general anxiety (e.g., Hill & Brown, 2013), and extends previous findings among children with DCD to adults with DCD in relation to movement-specific self-efficacy (e.g., Batey et al., 2013). The results also suggest that adults with DCD have lower general self-efficacy compared with TD adults, a novel aspect we aimed to explore, and an effect already identified in children with DCD (e.g., Cairney et al., 2005). This is further strengthened by the finding that movement-specific self- efficacy was significantly positively associated with general self-efficacy in adults with DCD, the potential implications of which are discussed further below.

The fact that no differences were found between the diagnosed and suspected DCD groups in any of the general or movement-specific measures suggests that a diagnosis for DCD may not make a difference to these as standalone measures, or – given the size of the smaller suspected DCD sample – that no difference was able to be detected in this case. Our initial findings offer novel insights while adding further evidence to the preliminary and emerging literature focusing specifically on adults with DCD, whether suspected or diagnosed. This also contributes to reducing the reliance on extrapolating findings about children to apply to an adult population.

Another novel aspect has been the identification of significant relationships in the combined suspected and diagnosed DCD group. Our prediction that adults with DCD who had lower general self-efficacy would show higher general anxiety was supported by a significant negative association between these factors. This effect has not been identified in adults with DCD until now, but further adds to evidence of a relationship between self-efficacy and anxiety, at least in their general forms. In the DCD group, this makes sense in line with Bandura's (1988) assertion that the level of perceived control over potential threats in the surrounding environment has a key role in anxiety arousal. If, as according to social cognitive theory, the interpretation of threat reflects the connection between perceived competence and potentially threatening aspects of the surrounding environment, then this could help explain the relationship between self-efficacy and anxiety in people with DCD. Thus, people with motor skill difficulties may be more likely, due to this connection between perceived competence and potential threat, to interpret their environment in more threatening terms.

Clear associations between movement-specific anxiety and general anxiety and between movement-specific self-efficacy and general self-efficacy were found in the DCD group as we would perhaps expect in a population in which motor skill difficulties can permeate most aspects of everyday life. Notably no significant association was found between movement-specific self-efficacy and movement-specific anxiety in the DCD group. We suggest that the lack of relationship here may relate to the fact that living with motor skills difficulties leads to both a realistic appraisal of one's movement-related self-efficacy, as well as a kind of 'normalisation' of this in terms of its impact on everyday life, so that it may not affect anxiety in the domain of movement specifically. Interestingly, however, no significant association was found between general self-efficacy and movement-specific anxiety or between general anxiety and movement-specific self-efficacy in the DCD group. These findings support that the differences between the general and domain-specific constructs may influence their interactions, and particularly in this population and in relation to the domain of movement. This links with suggestions from Batey et al. (2013) and Bandura (2006) that general self-efficacy and domain-specific self-efficacy, as distinct constructs, may relate to and impact upon other variables – be it physical activity or anxiety levels – in different ways.

As for resilience, a significant negative association was evident between resilience and general anxiety, while a significant positive association was evident between resilience and general self-efficacy in the DCD group. These findings support our hypothesis that higher resilience would be linked with lower anxiety and higher self-efficacy (e.g., Schwarzer & Warner, 2013; Zwicker et al., 2018). In terms of the movement-specific measures, in the DCD group there was a significant negative association between resilience and movement-specific anxiety, while no significant association was identified with movement-specific self-efficacy. This difference further supports the notion that general and movement-specific self-efficacy differ both in their composition as constructs, and in how they interact with other psychological variables such as anxiety and resilience. However, the relationship between resilience and movement-specific anxiety does suggest that movement-specific anxiety may be more closely related to general anxiety than movement-specific self-efficacy is to general self-efficacy.

These results offer further evidence, and this time in an adult population, in support of Zwicker et al.'s (2018) findings regarding the effectiveness of resilience as a protective mechanism and to foster coping abilities to mitigate the negative impacts of DCD. These may be particularly pertinent for adults with DCD, especially given the increased and well-documented challenges they face in living life with motor skills difficulties. As an individual with these challenges, a more developed ability to recover from stress, linked with the connection between self-efficacy and anxiety noted previously, may positively impact how threatening that individual interprets the environment to be and, in turn, how capable they feel navigating it. As such, this could be a worthwhile avenue for future research in this field to pursue further.

Finally, the results relating to self-concept suggest that individuals with suspected DCD for whom motor skills difficulties are a dominant component of their self-concept have lower movement-specific self-efficacy. It is notable that this effect was only present in the suspected DCD group – for participants with a formal diagnosis there was no significant difference in movement-specific self-efficacy in those who referred to movement-related self-concepts compared to those who did not. Future research will be needed to explore the potential reasons for these findings, but one possibility is that people who self-report having undiagnosed DCD - and for whom motor skills difficulties are a key part of their self-concept- may be particularly conscious of their movement-related problems.

Indeed, the finding that a focus on motor skills difficulties in self-concept statements is linked solely to movement-specific self-efficacy leaves it difficult to ascertain how positively or negatively those individuals view their movement-related self-concepts. The fact that a focus on movement lowered movement-specific but not general self-efficacy may mean that these individuals do not view this aspect of their self-concept negatively, but perhaps just realistically given the impact of DCD on motor skills and movement abilities. For some individuals, recognition of their clumsiness could be a source of unhappiness or anxiety and therefore they might rate this as a negative aspect of their identity, while for other individuals, recognition of their clumsiness might be just that – recognition – and they may feel fine about that aspect of their identity.

An interesting area for future research to delve into could build on the initial finding in the current study to investigate whether the emotional valence of self-concepts – rather than the presence or absence of a specific type of self-concept (e.g., in this case movement-related) – might relate significantly to factors such as anxiety, resilience and self-efficacy in adults with DCD.

3.6.1 Limitations

The DCD group comprised participants with both formally diagnosed and suspected DCD. Whilst this is an established approach (e.g., Batey et al., 2014; Kirby et al., 2013) and no group differences were found between diagnosed and suspected DCD - apart from in relation to movement-related self-concept statements - it is important to note that inclusion in the DCD group was based on self-report. As such, we cannot be certain, for example, that participants in the diagnosed DCD group had a formal diagnosis. Second, the assessments developed to target movement-specific anxiety did not target movement as a whole but focused only on mobility on foot (a sub-category of motor skills). As the motor implications of DCD extend far beyond mobility on foot, it is important not to generalise the findings of the present study beyond this domain. Future work assessing a more comprehensive overview of motor skills in relation to anxiety and self-efficacy will be needed to examine whether these results can be extended more broadly. Finally, it is unsurprising that many of the DCD group (both diagnosed and suspected) included statements about motor skills difficulties in their self-concept, as they were aware they were taking part in a study about movement disorders, and this is likely to have primed this aspect of their identity. However, this does not affect the interpretation of our analyses (within the DCD groups) into whether those with DCD who did define themselves in relation to motor skills difficulties differed in their responses to the self-efficacy, resilience and anxiety measures compared to those with DCD who did not define themselves in this way.

As discussed earlier, the current study did not measure the emotional valence of participants' self-concept (i.e., whether the 'I am' statements were positive or negative). Considering this, a limitation of the current study is the consequent inability to compare its findings in this domain with previous studies on DCD and self-concept, which not only sampled children and adolescents rather than adults, but which all also directly measured and discussed the positivity and negativity of self-perceptions (Cocks et al, 2009; Hands et al., 2020; Yu et al., 2016).

3.7 Conclusion

This first study offers novel insights into the nature of and relationships between general and movement-specific anxiety, self-efficacy, and resilience among adults with suspected and diagnosed DCD compared with TD adults, factors which have been under or unexplored in this population. Its findings indicate that general and movement-specific anxiety, self-efficacy, and general resilience are all poorer in adults with DCD compared to TD adults. It is striking that higher resilience was related to higher self-efficacy and lower anxiety in adults with DCD. Results also show that where motor skills difficulties featured in the self-concept of adults with suspected (but not diagnosed) DCD, movement-specific self-efficacy was lower. This final aspect of the findings opens a new conversation about self-concept and DCD in adulthood, suggesting further pathways for research to explore.

Taken together, these findings contribute to the growing body of evidence showing that DCD continues to significantly challenge psychosocial wellbeing into adulthood. They highlight the important role of resilience as a potentially protective factor that could be harnessed in managing some of the secondary impacts of DCD in adulthood. In light of the results explored here, interventions to improve the psychosocial wellbeing of adults with DCD may indeed benefit from a focus on building resilience and self-efficacy while lowering anxiety, especially in light of the relationships observed, and with a particular focus on movement-related domains. The relationships explored here illustrate the importance of addressing all the aspects of an individual's perception and experience, especially considering how they are linked and can potentially therefore affect one another. These approaches could contribute to the development of effective strategies to manage the multifaceted, interrelated impacts that motor skills difficulties have on everyday life for adults with DCD.

This first study not only offers valuable evidence which stands alone (see Appendix 2: Harris, Wilmut & Rathbone, 2021), it also acts as a foundation for the second and third studies described and discussed in subsequent chapters.

Chapter Four: Experimental Methods

This chapter describes the apparatus, participant screening, procedures and data processing used and undertaken in the experimental components of studies two and three (described in Chapters Five and Six). These took place in the Perception and Motion Analysis Laboratory at Oxford Brookes University.

4.1 Apparatus

4.1.1 Motion capture system

A VICON 3D motion capture system (Oxford Metrics Ltd, Oxford, UK) was used to track movement in the executed action task. It consists of a computer data station and six infrared cameras. The VICON system is identified widely in diverse biomechanical research areas as a ‘gold standard’ for motion analysis (e.g., Barker, Craik, Freedman, Herrmann & Hillstrom, 2006; Pfister, West, Bronner & Noah, 2014). The cameras use non-invasive infrared technology and run at a sampling frequency of 120 Hz in order to measure precise changes in 3D movement and capture streamed movement data. They do this by capturing the movement of small spherical reflective markers with a diameter of 14mm. These are attached using double-sided tape to the relevant landmarks on a participant depending on the range of motion to be captured.

In this case, three reflective markers were placed on bony landmarks on the shoulders, one on the left acromion process (LAP), one on the right acromion process (RAP) and one at the top of the spine on top of the seventh cervical vertebra (C7). The VICON cameras only capture the movement of the markers, and no physical footage of the individual. The cameras were positioned to capture maximum coverage of the markers within a 6.5m x 3.5m area where participants would walk straight towards and through an aperture between the two wooden doors, before stopping in front of a blank wall (see Figures 4.2 and 4.3 in subsequent procedure section for illustrations of the task set-ups). To ascertain the point at which a participant passed through the aperture, three additional markers were placed on the inner edges of the moveable doors. One was placed on the left door and two were placed on the right door to facilitate identification of each side.

Data were collected in this direction only, with participants walking toward the aperture and with the markers on the tops of their shoulders and back of their neck detectable to the cameras along with the markers on the moveable doors. Data collection began as soon as the markers crossed the threshold of the area covered by the cameras and finished as soon as the participant had passed through the aperture created by the wooden doors. Collection of data along the x-axis tracked medio-lateral movement, along the y-axis anterior-posterior movement and along the z-axis vertical movement. The nature and processing of the data extracted from the VICON system is described subsequently.

4.1.2 Task equipment

Tape measures were used to record the shoulder width and height in centimetres of participants. As illustrated in Figure 4.2, two doors on moveable bases were used to create apertures of different sizes for perceptual judgement and executed action tasks which will be fully described in the subsequent section. These doors were two metres by one metre in size and consisted of a single piece of wood attached to a triangular base supported by castor wheels for manoeuvrability. A laminated ruler showing metres and centimetres was taped to the floor area underneath the door bases. This was used to mark in non-permanent marker pen six shoulder-to-aperture (SA) ratios between 0.9 and 1.9, rising by increments of 0.2, for each participant. The doors could then be wheeled back and forth along the ruler line to form the different aperture sizes in line with the appropriate SA ratios of each participant.

Two paper forms recorded the non-motion-capture data for the different tasks. For the perceptual judgement task, the form comprised a table to record participants' judgements (in relation to whether they would need to turn or not) for the different SA ratios for a static and a dynamic condition, as well as participant number and the order in which the two conditions were presented. For the executed action task, the form comprised two tables. The first recorded participant number, shoulder width and height (in cm) and calculations of the SA ratios, the method for which is described subsequently. The second table listed the order of the six different aperture sizes (dictated by each participant's SA ratios) which was pseudo-randomised over the course of 30 trials along with a space to record completed trials.

4.2 Procedure

All participants completed three tasks: a set of questionnaires (online and paper-based), a perceptual judgement task (i.e., judging the space you think you would need to walk through different sized gaps between doors without bumping into the sides) and an executed action task (i.e., actually walking through different sized gaps between the doors). Overall task order - whether participants completed the perceptual judgement or executed actions task first - was alternated in an effort to counterbalance any potential effect of task order on actions and / or judgements.

On arrival, shoulder width (i.e., the distance between the right and left acromion process) was measured in cm. This was then used to calculate six shoulder-to-aperture (SA) ratios between 0.9 and 1.9 to be used in the perceptual judgement and executed action tasks. Once calculated to the nearest round cm, these were marked on the laminated floor ruler underneath the moveable doors using non-permanent marker pen. Height in cm was also measured and recorded.

Participants who were recruited specifically for inclusion in the ‘adults with DCD’ group completed the Movement Assessment Battery for Children, second edition (MABC-2) (Henderson, Sugden & Barnett, 2007) and in all instances this was completed before anything else. The MABC-2 will be described in further detail in section 4.4.2.

4.2.1 Questionnaires

A paper copy of the State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1983) was presented along with an online questionnaire on a laptop using the software Qualtrics XM™. All participants completed the paper questionnaire first, followed immediately by the online questionnaire. As detailed fully in Chapter Two, the online questionnaire included a range of standardised scales measuring aspects of movement skill in childhood and adulthood, anxiety, resilience and self-efficacy which were presented in counterbalanced order. It also incorporated items developed specifically to focus on anxiety and self-efficacy in the domain of movement on foot around the everyday environment. In addition, an opening section provided online informed consent and a closing section provided demographic information to fully describe the sample and screen responses for the necessary inclusion criteria.

4.2.2 Perceptual Judgement Task

For the perceptual judgement task, participants began standing 6.5m from an aperture created between the two moveable doors described previously. The backdrop to this was a blank white wall between two windows with blinds fully closed. This standing distance ensured that the experiment set-up aligned, as far as was practically possible, with previous studies on adults with DCD in which they have been asked to judge and walk through apertures (e.g., Hackney, Cinelli, Denomme & Frank, 2015; Wilmut, Du & Barnett, 2016). The order of the static and dynamic conditions was alternated in an effort to counterbalance any potential effect of task order on participants' judgements.

(i) Static Condition

Participants began by facing away from the aperture. On turning around, they were presented with an aperture between 0.9 and 1.9 times their shoulder width (arranged in increments of 0.2, so the apertures were either 0.9, 1.1, 1.3, 1.5, 1.7 or 1.9 times the participant's shoulder width). They were asked to judge whether they thought they could walk through the presented aperture with or without turning their shoulders by stating either 'turn' or 'no turn'. After each judgement, participants turned around to face away from the aperture while the researcher changed the size of the aperture according to the SA ratios between 0.9 and 1.9. This component of the experiment consisted of 18 trials which were presented in the same pseudo-randomised order to each participant, with each SA ratio (0.9, 1.1, 1.3, 1.5, 1.7, 1.9) appearing three times. This was done so that the same SA ratio would not appear in consecutive trials and to avoid any predictable increase or decrease in SA ratio

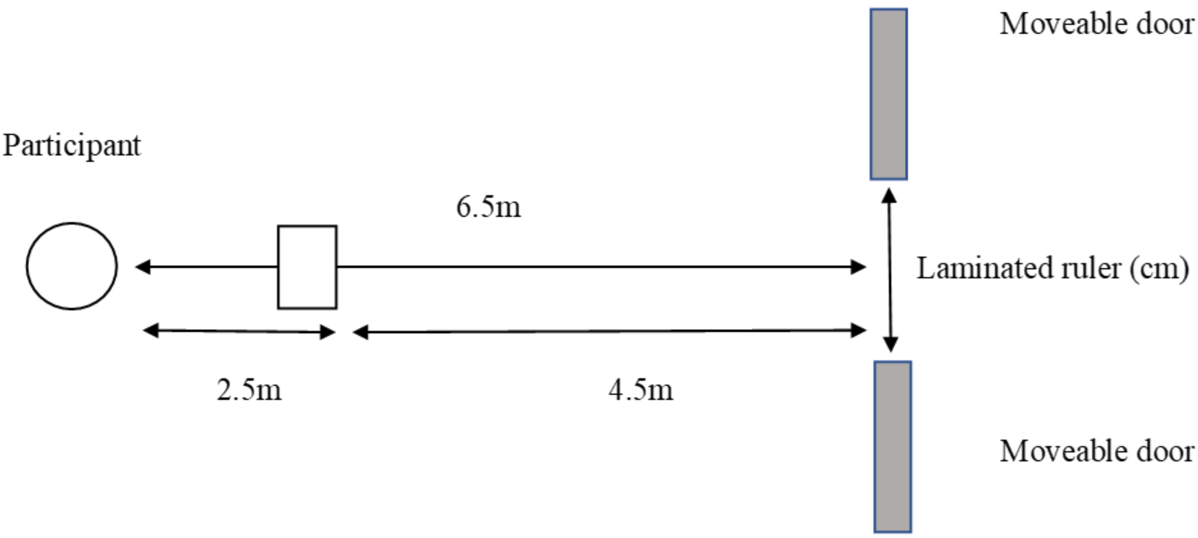
(ii) Dynamic Condition

Participants began by facing away from the aperture. On turning around, they were presented with an aperture of 0.9, 1.1, 1.3, 1.5, 1.7 or 1.9 times their shoulder width. They were asked to walk forward 2.5m in a straight line from their starting point at a natural pace onto a square blue sports mat (45cm by 38cm) placed 4m from the aperture. As soon as they arrived on the blue mat, participants were asked to judge whether they thought they could walk through the presented aperture with or without turning their shoulders by stating either 'turn' or 'no turn'. After making the judgement, participants turned around and walked back to their original starting point, facing away from the aperture while the researcher changed the size of the aperture as described previously. This condition also consisted of 18 trials which were presented in the same pseudo-randomised order to each participant, with each SA ratio (0.9, 1.1, 1.3, 1.5, 1.7, 1.9) appearing three times. As in the static condition, this was done so that the same SA ratio would not appear in consecutive trials and to avoid any predictable increase or decrease in SA ratio.

The set-up for both the static and dynamic conditions is illustrated in Figure 4.1.

Figure 4. 1

Illustration of apparatus and set-up for static and dynamic perceptual judgement task conditions



4.2.3 Executed Action Task

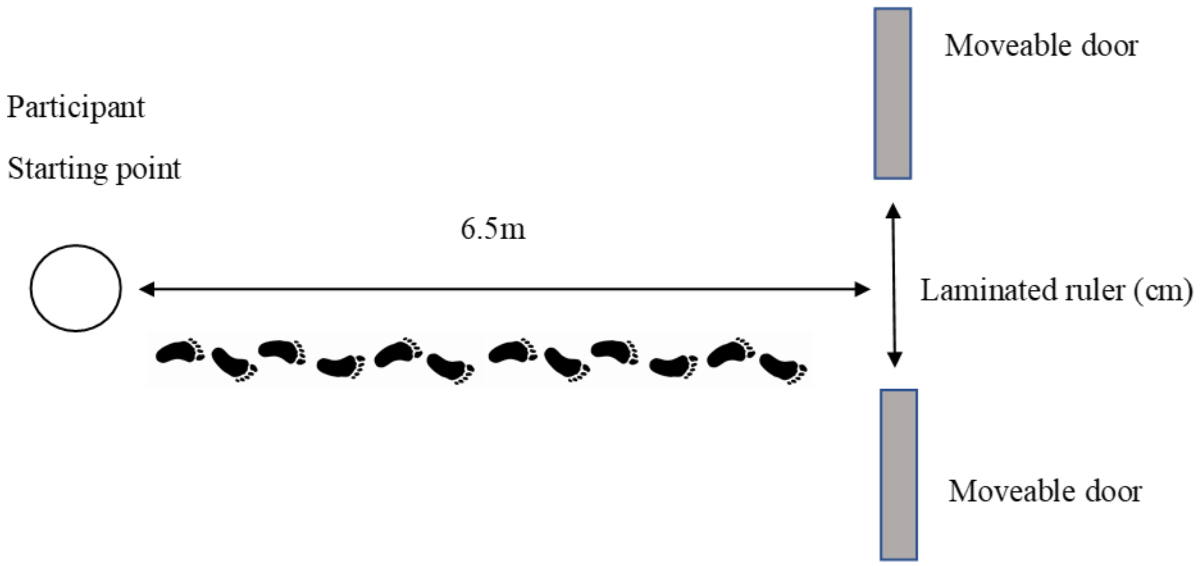
The executed action task consisted of 30 trials presented in the same pseudo-randomised order to each participant, with each SA ratio (0.9, 1.1, 1.3, 1.5, 1.7, 1.9) appearing five times. As in the perceptual judgement tasks, this was done so that the same SA ratio would not appear in consecutive trials and to avoid any predictable increase or decrease in SA ratio. For each trial, participants stood 6.5m away from an aperture created by the same moveable doors as described previously. They began by facing away from the aperture. Upon the initiation of a trial, participants were asked to turn around and walk towards and through the aperture to a stop-point in front of the wall behind the doors. Movement was captured from the point at which participants were within 4m of the aperture up to the point of passing the aperture's threshold. Participants stayed at the stop-point, facing the wall behind the aperture, until the researcher signalled for them to walk back through the doors to their starting point. While they were walking back to the starting point and remained facing away from the aperture, the researcher changed the size of the aperture ready for the next trial.

The researcher made clear that to walk through some of the apertures participants would need to turn their shoulders, while for others they would not. The researcher stated that there was no right or wrong way to walk through, and that the participant should simply walk through in a way that felt natural to them.

The set-up for the executed action task is illustrated in Figure 4.2.

Figure 4. 2

Illustration of apparatus and set-up for executed action task condition



4.3 Data Processing

4.3.1 Motion capture data

The cameras collected 2-D kinematic data which was reconstructed into 3-D trajectories and then labelled using the VICON computer data station. Any gaps in the data were filled using the VICON software to render the filling as accurate as possible. These data were then filtered using an optimised low pass Woltring filter with a 12 Hz cut off point to screen any noise and smooth the data. This is a commonly used method in motion analysis which filters out noise appropriately without compromising the capture of relevant movement variability (Wilmut & Barnett, 2010; 2011; Woltring, 1985).

The data were then exported into Microsoft Excel and tailored MATLAB™ (MathWorks) routines were used to extract the movement variables of interest. Aperture and shoulder width were calculated with the *x* and *y* position of the door markers and the RAP and LAP markers. The position of the door markers also allowed identification of any deviation between desired and actual aperture width which could then be taken into account during data analysis in studies two and three (see Chapter Five and Chapter Six). The movement data was split into two phases: the approach phase (defined as the first two seconds of movement captured) and the passing phase (defined as the point at which the C7 marker came level with the doors).

The following variables were extracted by the MATLAB programme during the approach phase. **Baseline sway (°)**, calculated in degrees using the mean angle rotation of the shoulders across the approach phase. This refers specifically to the first four steps captured by the VICON cameras. For each of these steps the maximum angles between the two relevant shoulder points (the RAP and the LAP) with respect to the frontal plane were calculated in radians and this was then converted to degrees (°).

Approach speed (mm ms^{-1}), which describes average movement speed during the first two seconds of movement captured. For this the derivative of displacement data was taken before applying a least-squares approximation method to determine a trend line of C7's movement with a speed-time profile for each trial. This followed the method used by Higuchi et al., 2006 and Wilmut and Barnett, 2011. All measures of movement speed were subsequently taken from the aforementioned trend line that was fitted.[2] Finally, lateral trunk movement (mm) was determined to ascertain the relationship, on those trials where shoulder rotation occurred, between a decision to rotate the shoulders, the magnitude of this shoulder rotation at the door, and how controlled this movement was (i.e. the level of movement variability). For this, the average and standard deviation of the cumulative lateral movement of C7 across the approach phase for each SA ratio were calculated, giving lateral trunk movement variability. During the passing phase the MATLAB programme extracted the variable of

[2] Although approach speed (mm ms^{-1}) was extracted as a prospective variable of interest, this was not subsequently used in the analyses that were undertaken with the data.

shoulder angle at the door. This was the angle between the shoulders, with respect to the initial frontal plane, as C7 passed through the aperture, calculated the same way as the baseline sway variable. The MATLAB programme also determined whether participants turned or did not turn their shoulders on each trial. A turn was identified if the shoulder angle at the door was greater than one standard deviation above baseline sway (in line with Wilmut & Barnett, 2011; Wilmut et al., 2015; 2016).

This also allowed for the extraction of **mean relative safety margin (mm) (RSM)** (i.e. how much relative space beyond their own body dimensions participants were allowing for). To calculate this, at the point of passing through the doors the medio-lateral distance between the shoulders (i.e. shoulder width) was calculated using the **shoulder angle at the doo**r (°). From this, RSM was calculated by subtracting shoulder width (mm) from actual aperture size (mm). This gave the proportion of an individual's shoulder width that they choose to leave as a 'safety margin' between their body and the door edges. For example, a value of 0.5 indicates that the individual has left the equivalent of 50% of their own shoulder width between the edge of their shoulder(s) and the door edges. This could be 25% on each side or a different distribution. As such, a higher value for RSM indicates a more cautious approach.

Results produced from MATLAB were then exported via Microsoft Excel to the open-source computer software jamovi for statistical analysis (The jamovi project, 2021).

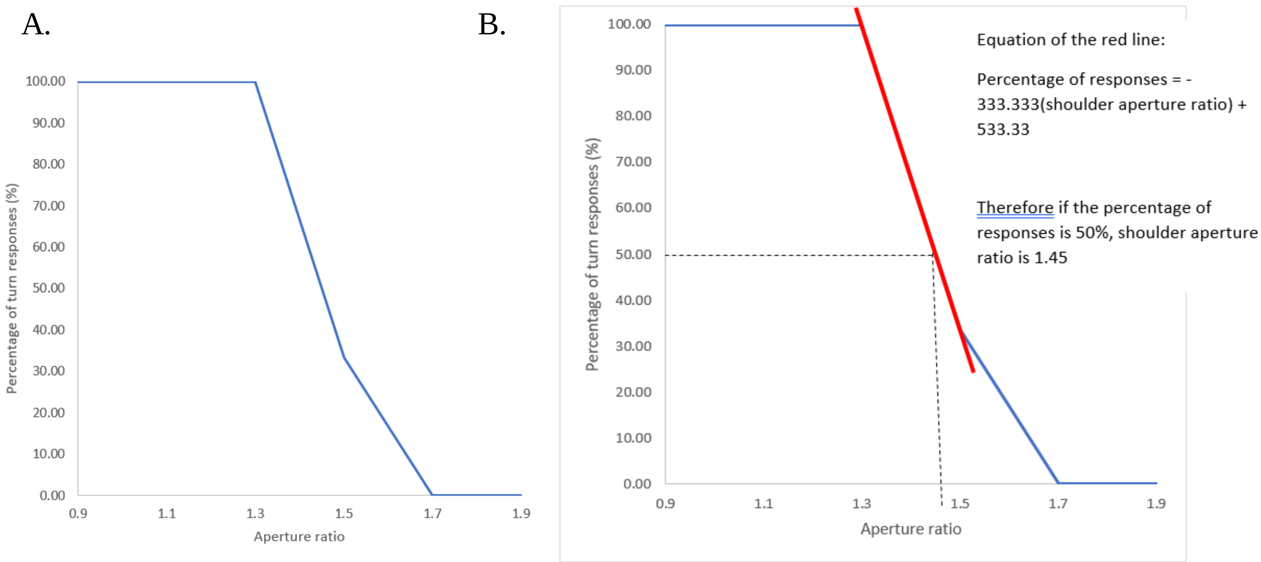
4.3.2 Critical ratio

The point at which behaviour changes is called the critical ratio (as explained in section 1.2 in Chapter One). So, for example, in the context of these studies the critical ratio is the SA ratio at which a participant's behaviour (whether a judgement or execution of an action) changes from *not turning* their shoulders to pass through an aperture, to *turning* their shoulders to pass through an aperture. The statistical analyses undertaken in studies two and three aim to explore the relationships and differences between the critical ratios across three conditions: static perceptual judgement, dynamic perceptual judgement and executed action. In both of the perceptual judgement conditions, 'turn' or 'no turn' was determined with a verbal judgement on each trial. In the executed action condition, the MATLAB programme identified a 'turn' on trials where the shoulder angle at the door exceeded baseline sway plus one standard deviation, as described in the previous section.

The critical ratios for the static and dynamic perceptual judgement conditions were calculated following the method taken in a previous study (Harris & Wilmut, 2020) and by other previous research into perceptual judgements of affordances (e.g., Warren, 1984). This described the critical ratio as the aperture ratio at which the participant judged that they 'would turn' on 50% of the trials. This 50% mark therefore demonstrates the point at which the participant is unsure of the appropriate response and as such the point at which behaviour is subject to change. For both the static and dynamic conditions, the ratio at which this 50% mark fell was calculated using excel. The percentage of 'turn' responses for each SA ratio was calculated for each participant across both conditions. Then, the largest aperture width at which participants stated they would 'turn' for more than 50% of the time (i.e. a 66% or 100% turn response) and the smallest aperture width at which participants stated that they would 'turn' for less than 50% of the time (i.e. 33% or 0% turn responses) were graphed. This created a straight line, the formula for this was derived and the aperture width at which 50% turn responses would be expected was calculated. To illustrate, an example of this from the dynamic condition is shown below in Figure 4.3. This example shows data from an individual who gave 100% turn responses for 0.9, 1.1 and 1.3 aperture ratios, 33.33% turn responses for the 1.5 aperture ratio and 0% turn responses for the 1.7 and 1.9 aperture ratios. A. illustrates this raw data, B. illustrates the plotting of the data between the largest aperture ratio giving >50% turn responses and the smallest giving <50% turn responses, this is illustrated by the red line. The horizontal and vertical dotted line on the graph indicates where a theoretical 50% turn responses would fall. Using the formula of a straight line the critical ratio for this individual for the dynamic condition is 1.45, as shown in the text box.

Figure 4.3

Graphs illustrating where the 50% response rate fell for a participant in the dynamic perceptual judgement condition. Graph A shows the raw data while graph B shows the fitted line crossing the data



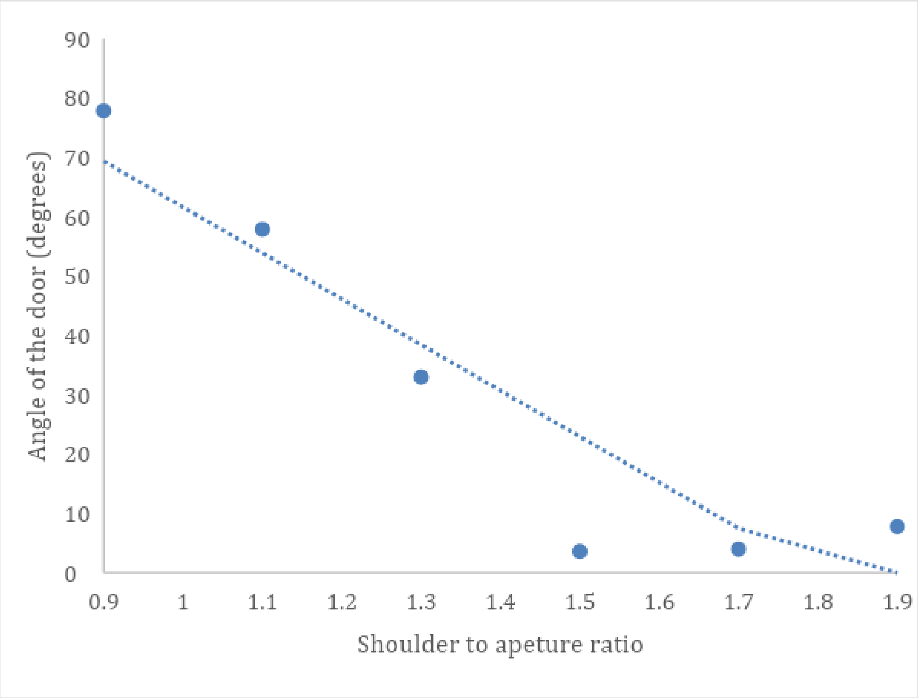
Critical ratios calculated using this method will from this point be referred to as using the '50% method'.

In the executed action condition, an additional method was used to calculate the critical ratio using the actual angle (with respect to the frontal plane) that the participant passed through the aperture as described by Wilmut, Du and Barnett (2016). This method was chosen to facilitate comparison with related previous experimental research (Wilmut & Barnett, 2011; Wilmut, Du & Barnett, 2015; 2016) and provides a more accurate depiction of the critical ratio than can be extracted using a dichotomous 'turn' or 'not turn' category. The calculation involved fitting a third-order polynomial curve to the profile of each participant's shoulder angle at the point of crossing the aperture across all the SA ratios. The SA critical ratio was subsequently determined from this curve as the shoulder-to-aperture ratio at which the shoulder angle at the door first lay at one standard deviation above baseline sway (side-to-side movement).

Raw data points are illustrated in Figure 4.4 by blue circles which denotes the average angle at the door for each shoulder to aperture ratio. The dotted line illustrates the fitted polynomial curve, the equation of which is stated along with the fit. In this instance baseline sway was 8.9 degrees with a standard deviation of 1. Therefore, the critical ratio is the smallest shoulder to aperture ratio at which the angle of the door falls above 9.9 degrees, in this example that was calculated to be 1.5.

Figure 4. 4

Graph illustrating the calculation of executed action critical ratio using a fitted polynomial curve



Critical ratios calculated using this method will from this point be referred to as using the ‘polynomial method’.

4.3.3 Summary of statistical analyses

Following processing, the data were statistically analysed to explore relationships between the variables of interest: body dimensions, movement variability, anxiety, self-efficacy, resilience, perceived and actual behaviour. Specifically, the analyses aimed to examine how critical ratio (the point at which behaviour changes) in perceptual-only and executed action tasks relates to body dimensions, movement variability, anxiety, self-efficacy and resilience. These analyses and their results are described and discussed in detail in the subsequent chapters.

4.4 Participant Screening

4.4.1 Background to the diagnosis process

This section offers detail of the diagnosis process for DCD to contextualise the approaches to participant screening taken in study three (Chapter Six), of which the Movement Assessment Battery for Children, second edition (MABC-2) (Henderson, Sugden & Barnett, 2007) formed a principal component. To assess criterion A (the acquisition and execution of coordinated motor skills is substantially below that expected given the individual's chronological age and sufficient opportunities to acquire age-appropriate motor skills), the first and second most widely used standardised motor assessments used in the diagnosis process for DCD are the MABC-2 and the Bruininks–Oseretsky Test of Motor Proficiency, second edition (BOT-2) (Bruininks & Bruininks, 2005). Both tests are norm-referenced with good levels of reliability and validity for helping diagnose DCD.

To assess criterion B (the motor skills deficit described in criterion I significantly and persistently interferes with the activities of everyday living appropriate to chronological age (e.g. self-care and self-maintenance and mobility) and impacts upon academic/school productivity, prevocational and vocational activities, leisure, and play), the approach depends on the age of the individual being assessed. In the case of children, parents may be asked directly about their child's motor skills, performance, timings of motor learning processes in relation to activities like getting dressed, brushing teeth, tying shoelaces, using cutlery, and handwriting. Additionally, questionnaires and/or checklists such as the latest revised version of the Developmental Coordination Disorder Parent Questionnaire (DCDQ-R) (Wilson et al., 2009) and the MABC-2 Checklist (Henderson et al., 2007), designed to be completed by teachers, can be used. The DCDQ-R has now been extended in the form of the Little DCD Questionnaire, or Little DCDQ, to be used to help detect DCD in children of three and four years of age (Rihtman, Wilson & Parush, 2011; Wilson et al., 2015; Venter, Pienaar & Coetzee, 2015). In the case of adults, the only tool to date available for this purpose is the Adult Developmental Coordination Disorder/Dyspraxia Checklist (ADC) (Kirby, Edwards, Sugden & Rosenblum, 2010) which includes a section on both childhood and adulthood.

To assess criterion C (the motor skills deficits are not better accounted for by any other medical, neurodevelopmental, psychological, social condition, or cultural background), the approach is necessarily multi-faceted. A standardised IQ assessment can rule out an intellectual disorder, a neurological examination is recommended to rule out conditions that may otherwise explain motor development impairments and an eye examination by an optometrist is recommended to rule out other visual impairments. Additionally, a relevant, trained professional or team of professionals should be able to establish whether other psychological or socio-cultural factors may account for movement difficulties which present as similar to DCD.

To assess criterion D (onset of symptoms in childhood (although not always identified until adolescence or adulthood)), depending again on the age of the individual being assessed, parents/caregivers or the individual themselves should be asked about the pattern and trajectory of their child's or their own motor development in an attempt to identify as clearly as possible in the individual circumstance whether a delay in typical motor development was evident in early life.

As mentioned in Chapter One, it is recognised that multiple pathways exist towards the accurate diagnosis of DCD and that the order in which each criterion may be suitably met can vary (Blank et al., 2019). For example, if a child's movement difficulties are picked up first within the school system, they may first be assessed by an educational psychologist with a focus on criteria A, B and D before being referred to a medical doctor to exclude other relevant conditions or factors as referenced in criterion C.

4.4.2 The Movement Assessment Battery for Children - Second Edition (MABC-2)

In light of the above, the MABC-2 (Henderson, Sugden & Barnett, 2007) was undertaken in advance of the questionnaires, perceptual judgement and executed action tasks with participants who would prospectively be assigned to the 'adults with DCD' group for study three. The MABC-2 includes both a standardised test (involving the individual directly) and a checklist (rated by an adult) both of which aim to identify and describe impairments of motor function in children. In this research project only the MABC-2 Test was used since this component has a higher age band (age band 3: 11 to 16 years) and since either the test or the checklist can be used to identify an individual with motor difficulties by comparing the score to normative data. As the examiner's manual clearly states, this is a well-established research tool that is used widely to select participants for experimental study to ensure that the relevant participants qualify as having impaired motor function consistent with DCD. It is for this purpose the MABC-2 was used in study three. It is important to note that there is currently no standardised test with UK based normative data for individuals above the age of 16 and this is why the MABC-2 was chosen as the most appropriate tool available.

The test for age band 3 includes three manual dexterity tasks (1. Turning pegs the opposite way around and placing them accurately in the holes on a pegboard using one hand, both right and left hand are tested; 2. Building a triangle made of three plastic yellow strips, three loose nuts and three loose bolts; 3. Completing a drawing trail in a single continuous line without crossing the boundary lines, using the dominant hand), two aiming and catching tasks (1. Throwing a ball at a wall from a marked distance of 2 m and catching it with one hand, both right and left hand are tested; 2. Throwing a ball at a wall target from a marked distance of 2.5 m), and three balance tasks, the first of which is static and the latter two of which are dynamic (1. Standing heel-to-toe on the keels (narrow raised strips) of two joined balance boards for up to 30 seconds; 2. Walking toe-to-heel backwards along a 4.5 m line; 3. Five continuous diagonal hops on six mats set out in a zig-zag pattern).

In terms of the test's scoring processes relevant to study three, on the record form for age band 3 raw scores for individual items are calculated and summarised, followed by the calculation and recording of their equivalent standard scores. Three component scores are calculated for manual dexterity, aiming and catching, and balance respectively, and the equivalent standard scores for these are also recorded. Total test score is then calculated and its equivalent standard score is finally calculated and recorded. Additionally, percentile ranks are offered for both the total test score and the three component scores. For the purposes of allocating participants to the DCD or TD group in study three, the total test score, its equivalent standard score and corresponding percentile rank are key. In this study, any individual whose standard score fell on or below 7 (i.e. one standard deviation below the mean) and whose corresponding percentile rank fell below the 16th percentile was regarded as having movement difficulties consistent with DCD.

The MABC-2 norms detailed in its manual stem from a validation sample representative of the UK child population between the ages of 3:0 to 16:11 years inclusive. In this sample of 1172, 566 (48.3%) were boys and 606 (51.7%) were girls. The demographic characteristics of this standardisation sample are detailed further in the manual (Henderson et al., 2007, pp 129-130). Regarding the development of Age Band 3 specifically, a study by Chow, Chan,

Chan and Lau (2002) involving 31 teenagers showed good to excellent inter-rater and test-retest reliability estimates for seven items that were retained in the finalised Movement ABC-2 Test (see Henderson et al., 2007, Table 7, p. 135). Particularly relevant to the use of the MABC-2 in this research is another study by Faber and Nijhuis-Van der Sanden (2004) that involved 64 young adults aged 18 to 28 where the authors were especially interested in the test's appropriateness for individuals above the age of 16, the normative sample's upper limit. Given the timeframe of that study, the young adults were tested using the experimental version of Age Band 3 used in the aforementioned study by Chow et al (2002). Faber and Nijhuis-Van der Sanden (2004) obtained an intra-rater intra-class correlation (ICC) of 0.79 and also an equivalent inter-rater ICC of 0.79. In this study also, intra-rater stability values of scores above and below the 15th percentile point for each item ranged from 79 to 100% agreement, while the equivalent inter-rater values ranged from 88 to 100% agreement. In another small study (60 children, 20 in each age band) which focused on the stability of scores on the finalised version of the MABC-2 Test and which ran parallel to the principal UK standardisation study, for the total test scores a reliability coefficient of 0.80 was established, with the coefficients exceeding the generally acceptable criterion of >0.70 for all individual component scores. The standard errors of measurement along with the 90% and 95% confidence intervals are detailed in the examiner's manual (Henderson et al., 2007, table 8, p. 136).

The original Movement ABC (MABC) Test (Henderson & Sugden, 1992) demonstrated good criterion-related validity as illustrated by correlations of the test scores with those on other motor tests composed of items relating to both fine and gross motor skills and also with those on motor tests that focus only on fine or gross motor skills. For example, Croce, Horvat and McCarthy (2001) explored its concurrent validity with both the long and short form of the Bruininks-Oseretsky Test of Motor Proficiency (BOT) (1978), which seeks to examine the entire range of motor ability, using percentile ranks as the measure of interest on both. The correlation with the long form of the BOT was 0.76 (p<.001) and with the short form it was 0.71 (p<.001). In terms of more focused tests that assess a more restricted range of skills, for example the German Korperkoordinationstest für Kinders (KTK) (Kiphard & Schilling, 1974) is composed of items examining only dynamic balance and locomotor agility. Smits-Engelsman et al. (1998) conducted a study with a large sample of 208 Dutch children which examined the MABC Test's relationship with the KTK. 134 of the children were selected randomly from mainstream schools, while 74 were referred due to suspected movement difficulties. Overall, the correlation between the MABC and the KTK for the randomly selected group was 0.62 ($p<.0001$) while for the referred group it was 0.65 ($p<.001$).

Since its publication in 1992, over 100 studies have published data relevant to the MABC Test's ability to differentiate between children who may be expected to have movement difficulties and those with typical motor development for their age (e.g., Wilson et al., 2000; Hill, 2001; Piek & Pitcher, 2004). There is in summary a wealth of evidence of the validity of the Movement ABC Test. When developing the MABC-2 Test, its developers gathered an expert panel to discuss the revisions in relation to content validity as compared to the original MABC Test. The members of this group of experts unanimously judged the revised test content to be representative of the motor domain as detailed by the test developers and to have sufficient coverage across the areas of motor skills. Additionally, professionals across a wide range of relevant disciplines have provided published feedback about the strong face validity of the MABC-2 Test. Also, correlations between the scores on the three MABC-2 Test components were considered to be satisfactory by its developers. They were further reassured by the fact that each component correlates well with the Total Test Score (see Henderson et al., 2007, table 9, p. 142).

Finally, in terms of criterion-related validity, three particular studies carried out alongside the standardisation programme for the MABC-2 Test offer evidence of strong criterion-related and discriminative validity (see Kavazi, 2006; Barnett, Henderson & Sugden, 2007 and Siaperas, Holland & Ring, 2006). Since its publication in 2007, a wide range of studies have gone on to reinforce the evidence base showing the strong reliability and validity of this tool (see e.g., Griffiths, Toovey, Morgan & Spittle, 2018; Lane & Brown, 2014).

Chapter Five

Study Two: The influence of anxiety, self-efficacy, resilience, and motor control on the perceptual judgements and executed actions of typically developing adults

5.1 Background

As explored in Chapter One, various studies have investigated factors other than body dimensions which may vary between individuals and constrain how they perceive and execute movements. To re-summarise here, previous findings regarding the influence of emotional state on the perceptions and actions of typically developing individuals have been mixed. For example, looking only at the perceptual judgments of an affordance, Reiner et al. (2003; 2011) found that listening to 'sad' music led to TD participants judging a hill to be steeper than another group listening to 'happy' music.

Most research in this area has focused on the effect of anxiety in its various forms on the perceptual judgements of affordances alone or in combination with the associated action(s). For example, Steffanucci et al. (2008) found that TD participants standing on a skateboard at the top of a hill rather than a stable wooden box judged the slant of the hill as steeper. So induced height anxiety in this situation led to judgements of the hill as steeper, which could be interpreted as a more cautious mindset. However, interestingly when a visually guided measure in the form of a haptic palm board was introduced, participants made accurate slant estimations across both the skateboard and wooden box conditions. This finding suggests that heightened anxiety may influence perceptual judgements that are entirely divorced from the associated action - a more heuristic perceptual perspective. However, when elements of the associated action are introduced, in this case via the haptic palm board, the effect may not carry through. This notion is supported by other research that has more explicitly studied the influence of anxiety - induced or otherwise - on perceptual judgements and their associated executed actions.

Although in one study Pijpers et al. (2006) found that inducing higher state anxiety decreased both perceived and actual maximum reaching height during a wall-climbing task, a range of other studies have found that higher anxiety affects perceptual judgements without influencing the associated executed actions. For example, Graydon et al. (2012) found that higher anxiety led to underestimations of actual action capabilities during a reaching and grasping task. So more anxious TD participants made more cautious judgements about what they thought they could reach and grab hold of, but this cautiousness was not reflected when they actually undertook the reaching and grasping action task. However, Graydon et al. (2012) made the point that the increased cautiousness in perceptual judgement due to higher anxiety may lead to avoidant or withdrawal behaviours in a movement context.

Interestingly however, Hackney et al.'s (2015) study based around the aperture-crossing paradigm that will be used in the current study, found that increased anxiety induced by perceived and actual threat to physical balance at a height *did* lead to more cautious perceptual *and* movement behaviour when TD adult participants were approaching and navigating through apertures of a range of sizes.

The studies described so far all used induced higher and lower anxiety conditions. When everyday state anxiety among TD adults was considered by Harris and Wilmut (2020) with a task based around crossing over ground-based 'apertures' representing puddles, higher everyday state anxiety led to more cautious perceptual judgements, but not more cautious executed actions. So, in this case anxiety influenced what TD adults thought they would do when judging a potential action (i.e. their perceptual judgement), but not how they actually behave (i.e., their executed action). Looking through the lens of the constraints-based approach, this finding suggests that affective factors - including anxiety - may constrain perception of potential action (where no actual movement is involved) differently, compared to perception during the execution of the same action, where movement is involved.

As discussed in chapter one, as well as building on these previous findings, the current study sought to address a present lack of research into other potentially influential affective factors relevant to the relationship between perception and action in TD adults, namely in this case self-efficacy and resilience.

Furthermore, a range of other previous studies undertaken with TD children have highlighted the ability to move consistently as an important factor in executing action. Wilmut and Barnett (2011) found that although the decision to rotate shoulders when passing through an aperture is not body-scaled in exactly the same way as adults (see e.g., Higuchi et al., 2006; Warren & Whang, 1987), in terms of adapting their movements appropriately by taking into account their more variable - or in other words less consistent - movement, TD children do also spatially and temporally tailor their movements to aperture size. However, the role of how consistently individuals control their movement might relate to experience, developmental stage, and other factors including anxiety, self-efficacy (general and domain- or task-specific), and resilience, rather than movement ability alone. The current study therefore sought to explore the role of motor control alongside and in relation to the other factors discussed here among TD adults.

Please note, this study was pre-registered on the Open Science Framework (Registration DOI: 10.17605/OSF.IO/YN9FM).

5.2 Aims and hypotheses

To build on previous research, the current study aimed to investigate the roles of anxiety, self-efficacy, resilience, and motor control (one's ability to move consistently) in how TD adults think they will behave (their perceptual judgement) and how they actually behave (their executed action). In doing so it aimed to contribute new, in-depth understanding of the roles of anxiety, self-efficacy, resilience, and motor control in the relationship between how adults with typical motor development perceive their intentions and abilities to act in the world, and how they realise those actions. Another aim of the current study was to inform and offer useful comparisons with the subsequent and final study comprising this thesis which will investigate these relationships in adults with and without Developmental Coordination Disorder. The specific hypotheses related to each component are described in the following subsections.

5.2.1 Perceptual judgements

Based on previous findings it was hypothesised that higher anxiety, lower self-efficacy and lower resilience would correspond with more cautious perceptual judgements of action capabilities in both static and dynamic task contexts (i.e. judgments relating to a higher critical ratio and bigger relative safety margin). Additionally, it was hypothesised that more consistent movement control (i.e. lower movement variability) would correspond with perceptual judgements relating to smaller relative safety margins and lower critical ratios in both static and dynamic task contexts.

5.2.2 Executed actions

The hypotheses regarding executed action are based on previous findings from studies involving similar aperture-crossing tasks. In spite of Harris and Wilmut's (2020) finding, due to the increase in sample size in the current study and the use of several nuanced measures of anxiety and the other affective factors, it was hypothesised that higher anxiety, lower self-efficacy and lower resilience would correspond with more cautious executed actions (i.e. higher critical ratio and relative safety margin). Additionally, it was hypothesised that more consistent movement control (i.e. lower movement variability) would correspond with less cautious executed actions, in the form of lower critical ratios and smaller relative safety margins.

5.2.3 Critical ratios

It was hypothesised that critical ratio may vary across the three task conditions: static perceptual judgement, dynamic perceptual judgement and executed action. In light of the increased perceptual information on offer as the perception-action cycle progresses/develops through the three conditions, it was expected that critical ratio would be lowest in the static perceptual judgement condition, then higher in the dynamic perceptual judgement condition and then highest in the executed action condition.

5.3 Methods

5.3.1 Participants

41 adults with typically developing motor skills (33 female: 8 male)[3] aged 18-55 years participated in this study (see Table 1 for full demographic details). Participants were recruited via the Oxford Brookes Research Participation Portal and Psychology Participant Panel, social media advertising, as well as personal and professional contacts of the researcher. Participants self-reported no movement difficulties and also had to score below 56 on the total scale and below 17 on section A of the ADC to ensure their inclusion (i.e. below the cut-off scores indicating movement difficulties during childhood and being 'at risk for DCD' in activities for daily living during adulthood). In line with this, two prospective participants who scored above the aforementioned cut-off point on the ADC had to be excluded from the final sample (N = 41).

Table 5.1 shows the demographic details of participants.

[3] Although the questionnaire asked about gender, no participants stated that their gender differed from their biological sex. For consistency with the approach taken in study three (Chapter Six) in which participants across groups were sex-matched, in the current study participants were described in terms of sex rather than gender, as shown in Table 5.1.

Table 5. 1

Demographic details of participants

N	Age Range (years)	Mean Age (years)	% Female (sex)	% Male (sex)
41	18 - 55	27.7	80.49	19.51

Of the 41 participants with TD motor skills, five self-reported having dyslexia, one self-reported having diagnosed ADHD, one self-reported having suspected ADHD, one self-reported having ADHD and dyslexia, one self-reported having ADHD and ASD. Although it is beyond the scope of this thesis to consider this aspect further, this information offers insight into the broader developmental profile of the TD sample in the current study.

5.3.2 Apparatus and procedure

Both the apparatus and procedure for the current study have been described and explained in detail in Chapter Four. This section will therefore summarise the key components.

A six infrared-camera VICON 3D motion capture system (Oxford Metrics Ltd, Oxford, UK) tracked movement in the executed action task. Reflective markers were placed on the left acromion process (LAP), the right acromion process (RAP) and the seventh cervical vertebra (C7) as illustrated in figure 4.1 in the previous chapter. The cameras captured a 5.5m x 3.5m area where participants walked towards and through apertures between two wooden doors (2m x 1m) on moveable bases (shown in figure 4.2 in the previous chapter). A further three reflective markers were placed on the inner edges of these doors to facilitate identification during data processing. The VICON system tracked medio-lateral movement along the x-axis, anterior-posterior movement along the y-axis and vertical movement along the z-axis. The doors were wheeled back and forth along a ruler line (cm) placed on the floor to form six shoulder-to-aperture (SA) ratios between 0.9 and 1.9, rising by increments of 0.2, for each participant.

The first task was a questionnaire comprising a paper copy of the State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1983) and a digitalised questionnaire presented on a laptop with the software Qualtrics XM™. The digital component included three standardised scales. These were the New General Self-Efficacy Scale (NGSE) (Chen et al., 2001), the

Brief Resilience Scale (BRS) (Smith et al., 2008), and the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983). It also included two ten-item scales developed by the researchers to measure movement-specific self-efficacy and movement-specific anxiety, as described in chapter two (also see Harris et al., 2021). The Adult DCD/Dyspraxia Checklist (ADC) (Kirby et al., 2010) was additionally included to further screen participants, along with an informal interview, for the necessary inclusion criteria to qualify as adults with typically developing motor skills. Informal questions were also asked to establish the absence of any motor skill difficulties resulting from other conditions that could affect movement such as visual impairments of neurological conditions. All scales included in the digital component were presented in counterbalanced order. All of these questionnaire measures have been described and evaluated in detail in Chapter Two.

Following this, participants completed a perceptual judgement task and an executed action task. The order of these was alternated to counterbalance any potential effect on judgements and/or actions. Shoulder width (the distance between the right and left acromion process) was measured in cm. This was used to calculate the six SA ratios between 0.9 and 1.9.

The perceptual judgement task involved participants judging the space they thought they would need to walk through different sized gaps between doors - the aforementioned SA ratios between 0.9 and 1.9 - without bumping into the sides. As mentioned in the previous section, there was a static condition and a dynamic condition. In the static condition participants judged whether they would need to turn their shoulders or not to walk through the aperture from a standing position of 6.5m away. In the dynamic condition, they walked 2.5m forwards towards a small floor mat and then immediately made the judgement on arrival on the mat. The executed action task involved actually walking through different sized gaps between the doors. In both tasks the aperture sizes were presented in a pseudorandomized order to avoid any potential effect of incremental change on judgements and/or actions.

5.4 Data Processing

Sum scores from the NGSE, BRS, HADS, STAI and the ADC were calculated according to the instructions for each scale. The ADC scores were not used as part of subsequent statistical analyses but only to ensure that participants met the aforementioned inclusion criteria. Mean values were calculated for each movement-specific component: movement-specific anxiety and movement-specific self-efficacy. Scores from the ‘quiet environment’ and ‘busy environment' questions were combined in line with a principal component analysis that showed the data loading onto these two components only. This was undertaken using the method used in Chapter Three (and Harris et al., 2021).

One aim of the statistical analyses was to explore the relationship between the critical ratios (the point at which behaviour changes) across the three task conditions (static perceptual judgement, dynamic perceptual judgement and executed action) and the differences between them. As described and explained in full detail in Chapter Four, section 4.3.2, in the executed action condition, critical ratio was calculated in two ways: using the '50% method' and the 'polynomial method'

The processing of the motion capture data and extraction of relevant variables is described in detail in Chapter Four, section 4.3.1.

5.5 Statistical Analysis

The MATLAB results were exported via Microsoft Excel into the open-source computer software jamovi to conduct statistical analyses on the data (The jamovi project, 2021).

Pearson correlations were first examined between all relevant variables. This was done to take into account multicollinearity and subsequently decide which variables to use in regression analyses.

Two hierarchical multiple regression analyses were performed to examine whether and to what extent the variables chosen for inclusion predicted static or dynamic perceptual judgement critical ratio (50% method). Theoretically-driven choices were made relating to the order and composition of the three models included in the hierarchical multiple regressions. General anxiety and movement-specific anxiety were added to the first model. These were chosen to be entered into model one in light of previous findings suggesting that higher anxiety is linked to higher perceptual critical ratios during perceptual judgements of affordances in TD populations, as described in section 5.1 Since the effect of self-efficacy in this regard remains unexplored, but it is an affective construct that may relate to anxiety, general self-efficacy and movement-specific self-efficacy were added in a second model. A third and final model involved the addition of movement variability, added last because in adults with typical motor skills this is likely to be comparatively lower than in populations with atypical motor skills, and less likely than the wellbeing variables to impact turning behaviour in this population.

In relation to executed actions, Pearson correlations between executed action critical ratio (polynomial curve method) and mean relative safety margin were examined and two further hierarchical multiple regressions were performed, following the same theoretically-driven model structures, to examine whether and to what extent general anxiety, movement-specific anxiety, general self-efficacy, movement-specific self-efficacy and movement variability may predict executed action critical ratio and/or mean relative safety margin.

In relation to comparing the critical ratios (50% method) across all task conditions, Pearson correlations were performed to examine the relationships between these in the static perceptual judgement condition, the dynamic perceptual judgement condition and the executed action condition. Following this, a repeated measures Analysis of Variance (ANOVA) was performed to analyse the effect of condition (i.e. static perceptual judgement, dynamic perceptual judgement or executed action) on critical ratios.

5.6 Results

Initial Pearson correlation analyses indicated highly significant multicollinearity between data from the BRS (representing resilience) and data from the HADS (representing general anxiety), $r(39) = -.627$, $p < .001$, and the NGSE (representing general self-efficacy), $r(39) = .605$, $p < .001$. Significant multicollinearity was also evident between data from the STAI-S (representing state anxiety), the STAI-T (representing trait anxiety) and the HADS, $r(39) = .423$, $p = .006$; $r(39) = .765$, $p < .001$. In light of this, to mitigate the possible effect of multicollinearity affecting subsequent regression analyses, it was decided to include only data from the following wellbeing variables in all subsequent regression analyses: general anxiety (as measured by the HADS), general self-efficacy (as measured by the NGSE), movement-specific anxiety and movement-specific self-efficacy.[4]

It was notable that data from the movement-specific anxiety scale also correlated significantly with data from the HADS and the NGSE ($r(39) = .451$, $p = .003$; $r(39) = -.409$, $p = .008$ respectively), as did data from the movement-specific self-efficacy scale ($r(39) = -$

[4] Due to missing data from the STAI in the data set for the study described in the following chapter, it was chosen to use only data from the HADS in the regression analyses in the current study to facilitate consistency and useful comparison in terms of the anxiety measures across data analyses in both studies.

.487, $p = .001$; $r(39) = .418$, $p = .007$). However, it was decided to enter these into the regression analyses as separate variables since these correlations were moderate in strength and due to interest across the current and subsequent study of adults with both typical and atypical motor skills in the potentially different nuances of anxiety and self-efficacy as they relate specifically to movement. Descriptive details of the data from the wellbeing variables chosen for inclusion in subsequent regression analyses are shown in Table 5.2.

Table 5. 2

Descriptive details of data from anxiety and self-efficacy variables chosen for inclusion in regression analyses

	HADS	NGSE	MS Anxiety	MS Self-efficacy
Mean	8.54	3.67	22.07	77.72
Standard deviation	3.78	0.48	19.55	14.42
Range	16	2.25	64.5	60.6
Minimum	1	2.50	0	39.4
Maximum	17	4.75	64.5	100
Possible range	0 – 21	1 - 5	0 - 100	0 - 100

The differences between the mean critical ratio values across these three conditions is shown in Table 5.3. The values resulting from both the 50% method and the polynomial method for calculating executed action critical ratio are shown to illustrate the difference.

Table 5. 3

Estimated marginal means of critical ratios across task conditions

			95% Confidence Interval	
Condition	Mean	SE	Lower	Upper
Static Perceptual Judgement Critical Ratio	1.19	.02	1.15	1.23
Dynamic Perceptual Judgement Critical Ratio	1.21	.02	1.17	1.26
Executed Action Critical Ratio (50% method)	1.26	.02	1.22	1.30
Executed Action Critical Ratio (polynomial method)	1.44	.02	1.39	1.49

5.6.1 Perceptual judgments

It was notable that there were no significant correlations between any of the wellbeing variables, or indeed between movement variability in the executed action condition, and the critical ratios in either the static or dynamic perceptual judgement conditions.

Two hierarchical multiple regressions were performed to determine whether and to what extent static perceptual judgement critical ratio and dynamic perceptual judgement critical ratio may be predicted by general anxiety, movement-specific anxiety, general self-efficacy, movement-specific self-efficacy and / or movement variability.

In the first hierarchical multiple regression, none of the variables across models one, two or three significantly explained any variance in static perceptual judgement critical ratio. In terms of the overall results, in the first model general anxiety and movement-specific anxiety did not significantly explain any variance in static perceptual judgement critical ratio, R^2 = .03, $F(2, 38) = .66$, $p = .522$. When added to the second model, general self-efficacy and movement-specific self-efficacy jointly did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .05$, *Fchange* (2, 36) = 1.04, $p = .362$. When subsequently added to the third model, movement variability did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .01$, *Fchange* (1, 35) = .28, $p = .601$.The results for each individual predictor within the regression models are shown in Table 5.4. In summary, none of the variables across any of the three models significantly predicted static perceptual judgement critical ratio.

Table 5. 4

Hierarchical multiple regression results for the prediction of static perceptual judgement critical ratio

	β	95% C I for *β*		*B*	*p*
		LL	UL		
Model 1					
General anxiety	.18	-.18	.54	.01	.323
Movement-specific anxiety	.01	-.35	.37	.00	.959
Model 2					
General anxiety	.14	-.28	.56	.00	.511
Movement-specific anxiety	-.18	-.64	.28	-.00	.433
General self-efficacy	.06	-.34	.47	.02	.758
Movement-specific self-efficacy	-.33	-.81	.14	-.00	.160
Model 3					
General anxiety	.13	-.29	.56	.00	.524
Movement-specific anxiety	-.16	-.64	.32	-.00	.501
General self-efficacy	.04	-.37	.46	.01	.840
Movement-specific self-efficacy	-.32	-.80	.16	-.00	.179
Movement variability	.09	-.25	.43	.08	.601

In the second hierarchical multiple regression, none of the variables across models one, two or three significantly explained any variance in dynamic perceptual judgement critical ratio. In terms of the overall results, in the first model general anxiety and movement-specific anxiety did not significantly explain any variance in dynamic perceptual judgement critical ratio, $R^2 = .01$, $F(2, 38) = .17$, $p = .843$. When added to the second model, general self-efficacy and movement-specific self-efficacy jointly did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .06$, *Fchange* (2, 36) = 1.20, $p = .312$. When subsequently added to the third model, movement variability did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .01$, *Fchange* (1, 35) = .36, $p = .552$.The results for each individual predictor within the regression models are shown in Table 5.5. In summary, none of the variables across any of the three models significantly predicted dynamic perceptual judgement critical ratio.

Table 5. 5
Hierarchical multiple regression results for the prediction of dynamic perceptual judgement critical ratio

	β	95% C I for *β*		*B*	*p*
		LL	UL		
Model 1					
General anxiety	-.05	-.42	.31	-.00	.767
Movement-specific anxiety	.11	-.26	.47	.00	.563
Model 2					
General anxiety	-.07	-.50	.35	-.00	.729
Movement-specific anxiety	-.08	-.55	.38	-.00	.719
General self-efficacy	.12	-.29	.52	.03	.570
Movement-specific self-efficacy	-.35	-.83	.13	-.00	.146
Model 3					
General anxiety	-.08	-.50	.35	-.00	.720
Movement-specific anxiety	-.06	-.54	.42	-.00	.805
General self-efficacy	.09	-.33	.51	.03	.657
Movement-specific self-efficacy	-.34	-.82	.15	-.00	.165
Movement variability	.10	-.24	.45	.11	.552

5.6.2 Executed actions

Initial correlations were examined between the wellbeing variables, mean standard deviation (SD) of lateral trunk movement (representing movement variability) and both mean relative safety margin and critical ratio in the executed action condition (polynomial method).

None of the wellbeing variables of interest correlated significantly with critical ratio. Movement variability did not correlate significantly with either critical ratio or mean relative safety margin. However, there were significant correlations between mean relative safety margin and the following wellbeing variables: general self-efficacy, $r(39) = -.362$, $p = .02$, general anxiety, $r(39) = .379$, $p = .015$, movement-specific self-efficacy, $r(39) = -.422$, $p = .006$, and movement-specific anxiety, $r(39) = .441$, $p = .004$.

Although mean relative safety margin and executed action critical ratio correlated moderately and significantly with one another, $r(39) = .537$, $p < .001$, it was decided that separate regression analyses should be performed with these as the dependent variables given that they do measure different aspects of movement and turning behaviour during the aperture-crossing task. To reiterate, the mean relative safety margin measures how much space beyond their own body width participants left between themselves and the door edges, indicating the degree to which an individual has turned or not. Critical ratio measures the point at which the movement behaviour changes from walking straight ahead to turning the shoulders to pass through the aperture.

A first hierarchical multiple regression was performed following the model order described previously to determine the extent to which executed action critical ratio (polynomial curve method) was predicted by general anxiety and movement-specific anxiety (model one), followed by the additions of general self-efficacy and movement-specific self-efficacy (model two), and finally by the addition of movement variability (model three).

None of the variables across models one, two or three significantly explained any variance in executed action critical ratio. In terms of the overall results, in the first model general anxiety and movement-specific anxiety did not significantly explain any variance in dynamic perceptual judgement critical ratio, $R^2 = .07$, $F(2, 38) = 1.50$, $p = .235$. When added to the second model, general self-efficacy and movement-specific self-efficacy jointly did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .03$, *Fchange* $(2, 36) = .57$, $p = .573$. When subsequently added to the third model, movement variability did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .06$, *Fchange* (1, 35) = 2.46, $p = .125$.The results for each individual predictor within the regression models are shown in Table 5.6.

Table 5. 6
Hierarchical multiple regression results for the prediction of executed action critical ratio

	β	95% C I for *β*		*B*	*p*
		LL	UL		
Model 1					
General anxiety	.22	-.13	.58	.01	.214
Movement-specific anxiety	.09	-.27	.44	.00	.626
Model 2					
General anxiety	.19	-.23	.61	.01	.362
Movement-specific anxiety	-.05	-.51	.41	-.00	.815
General self-efficacy	.04	-.36	.44	.01	.827
Movement-specific self-efficacy	-.24	-.71	.22	-.00	.298
Model 3					
General anxiety	.18	-.23	.59	.01	.373
Movement-specific anxiety	.01	-.45	.47	.00	.970
General self-efficacy	-.01	-.41	.39	-.00	.945
Movement-specific self-efficacy	-.22	-.68	.25	-.00	.349
Movement variability	.26	-.07	.59	.28	.125

A second hierarchical multiple regression was performed following the same model order to determine the extent to which mean relative safety margin was predicted by general anxiety and movement-specific anxiety (model one), followed by the additions of general self-efficacy and movement-specific self-efficacy (model two), and finally by the addition of movement variability (model three).

In terms of the overall results, in the first model, general anxiety and movement-specific anxiety were found to (significantly) explain 23.5% of variance in mean relative safety margin, $R^2 = .235$, $F(2, 38) = 5.84$, $p = .006$. When added to the second model, general self-efficacy and movement-specific self-efficacy jointly did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .0233$, *Fchange* (2, 36) = .57, $p = .573$. When subsequently added to the third model, movement variability did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = 1.42e\text{-}4$, *Fchange* (1, 35) = .007, $p = .935$.

The results for each individual predictor within the regression model are shown in Table 5.7. In model one, movement-specific anxiety significantly predicted mean relative safety margin, $p = .04$. However general anxiety was not significantly related to mean relative safety margin in model one. Neither general nor movement-specific anxiety were subsequently significantly related to mean relative safety margin in models two or three. In model two, neither general nor movement-specific self-efficacy made a significant unique contribution to the model. Finally, in model three movement variability did not make a significant unique contribution to the model.

Table 5. 7
Hierarchical multiple regression results for the prediction of mean relative safety margin

	β	95% C I for *β*		*B*	*p*
		LL	UL		
Model 1					
General anxiety	.23	-.00	.01	.01	.163
Movement-specific anxiety	.34	.00	.00	.00	.040*
Model 2					
General anxiety	.13	-.01	.01	.00	.491
Movement-specific anxiety	.23	-.00	.00	.00	.279
General self-efficacy	-.14	-.10	.05	-.03	.455
Movement-specific self-efficacy	-.14	-.00	.00	-.00	.500
Model 3					
General anxiety	.13	-.01	.01	.00	.498
Movement-specific anxiety	.23	-.00	.00	.00	.287
General self-efficacy	-.14	-.11	.05	-.03	.460
Movement-specific self-efficacy	-.14	-.00	.00	-.00	.511
Movement variability	.01	-.22	.23	.01	.935

*Denotes significance at $p < .05$

5.6.3 Critical ratios

The critical ratios across all three task conditions correlated significantly with one another. There was a strong, positive and highly significant correlation between critical ratio in the static perceptual judgement condition and critical ratio in the dynamic perceptual judgement condition, $r(39) = .767$, $p < .001$. There was a moderate, positive and highly significant correlation between the critical ratio in the static perceptual judgement condition and the critical ratio in the executed action condition (50% method), $r(39) = .506$, $p < .001$. There was also a weaker positive, but still significant correlation between the critical ratio in the dynamic perceptual judgement condition and the critical ratio in the executed action condition (50% method), $r(39) = .333$, $p < .033$. A correlation was also run between the 50% method critical ratio and the polynomial method critical ratio in the executed action condition which illustrated that although they are different (as illustrated by the values shown in Table 5.2 in section 5.6.1), they are significantly related, , $r(39) = .75$, $p < .001$.

A repeated measures Analysis of Variance (ANOVA) was performed to examine the effect of condition (i.e. static perceptual judgement, dynamic perceptual judgement or executed action (50% method)) on critical ratio. Mauchly's test of sphericity showed this assumption to be violated by the data and for this reason the Greenhouse-Geisser correction was used. The repeated measures ANOVA revealed a statistically significant effect of condition on critical ratio, $F(1.54) = 7.35$, $p = .003$, effect size calculated with partial η^2 was .14. Post-hoc pairwise comparisons with a Tukey correction indicated that there was no significant difference between the critical ratios in the static and dynamic perceptual judgement conditions, $p$tukey = .269. Neither was there a significant difference between the critical ratio in the dynamic perceptual judgement condition and the critical ratio in the executed action condition, $p$tukey = .104. However, the critical ratio in the executed action condition was significantly higher than the critical ratio in the static perceptual judgement condition, $p$tukey = .001. As specified in section 5.6.1, this difference is illustrated in Table 5.2 which shows the values themselves.

5.7 Discussion

Considering first the results relating to perceptual judgements, the lack of significance in the correlation analyses, and in both of the regression analyses pertaining to static and dynamic perceptual judgement critical ratios is striking. These results did not align with what was hypothesised and are contrary to previous findings, especially those in relation to anxiety. As detailed in the opening section of this chapter, higher anxiety has previously been shown to relate to more cautious perceptual judgements in a range of affordance judgement tasks, including the aperture-crossing paradigm used in the current study (for example, see Graydon et al., 2012; Hackney et al., 2015; Harris & Wilmut, 2020). The hypotheses regarding anxiety and the related factor of self-efficacy were therefore based on these previous findings. However, in the current study the results from the perceptual judgement tasks suggest that higher general and movement-specific anxiety and self-efficacy do not lead to more cautious perceptual judgements of the 'passability' of apertures in either a static or a dynamic context.

One reason for this contrast with previous findings may relate to the measurement of 'baseline' or everyday anxiety and self-efficacy in the current study. Most previous related studies were based around induced 'high' and 'low' anxiety conditions, which may relate to their detection of significant effects. An exception to this is the previous finding by Harris and Wilmut (2020) that higher everyday anxiety state anxiety, as measured by the STAI (Spielberger et al, 1983), led to more cautious perceptual judgements, but not to more cautious executed actions, among TD adults. This contrasting finding may relate to the use of different anxiety measures, since in the current study the HADS and a movement-specific anxiety scale were used.

The difference could also be task related. Although Harris and Wilmut (2020) used a similar methodology and paradigm, the judgements were about ground-based apertures designed to represent puddles. In both the static and dynamic perceptual judgement conditions participants judged whether they would 'step' or 'spring' over the 'puddle' from a position directly in front of it. In the current study however, perceptual judgements in static and dynamic conditions were made at a distance of either 6.5 m or 4.5 m respectively from the apertures between the moveable doors. Moreover, given the differing natures of the task, there is potentially less of an inherent need for cautious judgements about the act of passing between two doors where the biggest risk is bumping gently into the side, as opposed to when judging the need to step or jump over a puddle which is not only a less common everyday action but also implies more risk in terms of possibly getting wet as well as the pressure a jumping action may place on the body.

Feeding into a broader view of the relationship between anxiety and perception, these differences in findings, alongside the potential roles of measurement and task type, imply that any effect of anxiety on perception is dependent on its nature and intensity. This is therefore a relationship or even set of relationships that are highly nuanced. As discussed by Harris et al. (2022) and linking to the constraints-based approach (Newell, 1986), different types of anxiety – for example baseline trait anxiety versus anxiety related to a specific task – both constrain perception differently and are constrained by differing individual-, task- and / or environment-based factors.

Turning to consider the fact that no significant relationship was detected between movement variability and the perceptual judgement critical ratios, this is not necessarily surprising in adults with typical motor skills. Wilmut and Barnett's (2011) study highlighted the relationship between movement variability and executed actions, but this study did not involve perceptual judgements made outside of the associated executed actions and was also undertaken with children who had typically developing motor skills. Throughout childhood the consistency of movement is still developing and as such, by adulthood this may no longer be a significant factor in relation to the perceptual judgements of affordances in individuals with typical motor skills.

Moving on to consider the results relating to executed actions, analyses undertaken with data from the current study suggest that there are certain significant relationships between wellbeing and mean relative safety margin: so between how anxious or confident in their ability somebody feels and how much space they leave between their own body width and the edges of the doors by turning to a greater or lesser degree to pass through the gaps between the doors without bumping into the sides.

Considering first the correlational evidence, it is notable that no significant relationships were detected between any wellbeing or movement variables and executed action critical ratio. However, significant correlations between several wellbeing variables and mean relative safety margin supported what was hypothesised in relation to anxiety and self-efficacy. Specifically, higher general and movement-specific anxiety, as well as lower general and movement-specific self-efficacy correlated with bigger relative safety margins, which could be interpreted as more cautious executed actions, i.e. movement behaviour. It is notable however that movement variability showed no significant correlations with either executed action critical ratio or mean relative safety margin, likely for similar reasons as discussed regarding the perceptual judgement tasks in that for adults with typical motor skills this may not be a significant factor in their execution of low-risk, everyday actions such as this.

Correlational evidence alone however offers limited insight, and turning to look at the results from the regression analyses offers a more nuanced insight into both the detection and nature of such relationships. It is once again striking that no significant relationship was detected between anxiety, self-efficacy and/or movement variability and executed action critical ratio (polynomial method). This is likely for similar reasons as discussed above in relation to the static and dynamic perceptual judgement critical ratios. Although this does not align with what was hypothesised, in the case of executed action critical ratios it does align with Harris and Wilmut's (2020) previous finding that higher every day or baseline anxiety - as opposed to induced anxiety - does not impact action perception during the actual execution of movement behaviour in terms of critical ratio. However, it is interesting that when the movement behaviour - i.e. shoulder turning - was considered through the lens of mean relative safety margin the results showed that higher movement-specific anxiety was significantly related to bigger mean relative safety margin. In other words, those participants who were more anxious about their movement ability left a significantly bigger safety margin for themselves relative to their own shoulder width by turning to a greater degree to get through the gaps between the doors without bumping into the sides.

This finding offers a novel insight into the nature of a potential relationship between anxiety and movement behaviour in typically developing adults. It suggests that to detect such a relationship, the nature of the anxiety measurement is important. Where scales which measure generalised anxiety, such as the STAI or HADS may not detect a relationship, a scale such as the novel one used in the current study designed to measure anxiety specifically in relation to the type of task under experimental study was able to detect this more nuanced relationship that may otherwise have gone undetected. It also indicates that even if they are related, the nuanced differences between what 'critical ratio' can detect and what another measure of movement behaviour - in the case of this task paradigm the mean relative safety margin - are essential to take into consideration. Although this finding in relation to relative safety margin is more difficult to compare with previous research that has focused on critical ratio as the key measure of changes in movement behaviour, it is interesting nonetheless. It illustrates the potential benefit in future of considering the measurement of movement behaviour from more than just the perspective of critical ratio which can arguably offer less of a nuanced view as, by its nature, it offers more of a categorical view of behaviour change rather than the more graded or continuous view offered by a variable such as mean relative safety margin in this case.

This perspective shifts the focus towards *how* behaviour may be different in relation to factors such as anxiety rather than simply *whether* it is different. Indeed, except for Harris and Wilmut's study (2020) and Hackney et al.'s study (2015) (see section 5.1), previous studies that have explored how anxiety might shape or change behaviour have illustrated this by measuring accuracy rather than the 'switch' from one behaviour (i.e., critical ratio) (see e.g., Graydon et al., 2012; Pijpers et al, 2006; Stefanucci et al., 2008).

Turning finally to consider the results which compared the critical ratios across task conditions (static perceptual judgement, dynamic perceptual judgement and executed action (50% method)), a significant difference was detected between static perceptual judgement and executed action critical ratio. Post hoc tests revealed that critical ratios in the executed action condition were significantly higher than those in the static perceptual judgement condition. Although estimated marginal means illustrated that critical ratios in the dynamic perceptual judgement condition followed the trend that was hypothesised, it was not significantly higher than critical ratio in the static perceptual judgement condition. These findings add further support to the notion highlighted in previous related studies that although perception and action are linked as part of a cycle, what somebody says they 'would do' should not be taken as a proxy for what they would *actually* do (Harris & Wilmut, 2020; Wilmut et al., 2017). Linking this finding back to the constraints-based approach, the difference detected here between perceptual judgement and executed action highlights and adds to the evidence base that these elements of the perception-action cycle are affected differently by individual-, task- and environmental-based constraints including those explored in the current study.

5.7.1 Limitations

Limitations in the current study related principally to the nature of measurement in the case of certain wellbeing and movement variables. As discussed, both previously in this chapter and in Chapter Four, there are several methods for calculating critical ratio, each of which have strengths and drawbacks. One issue in the current study was the tension between obtaining the most accurate measurement of critical ratio in the different task conditions and the need to be able to compare critical ratios, measured in a consistent way, across those different task conditions. As discussed previously, it was decided to use two methods for calculating critical ratio. The 50% method allowed comparison of the perceptual judgement and executed action critical ratios, while the polynomial method could only be used for the executed action data given the richer nature of the movement data compared to the binary nature of the spoken perceptual judgements. The reason this latter method was also used was that it allowed a more accurate calculation of the critical ratio values in the executed action condition. The disparity between executed action critical ratio values calculated using the different methods however does arguably undermine the validity of the method used to facilitate comparison across the task conditions, however it was decided that the insight offered by facilitating such a comparison in this way would still be of interest despite this limitation. This is also a broader issue in the field of perception and action research in terms of comparing critical ratio findings across studies, which will be discussed in further detail in Chapter Seven. The debate surrounding methods for calculating critical ratio also highlights the further clarity afforded by the measurement of relative safety margin as a complementary or alternative measure of movement behaviour within the context of this task paradigm.

Another measurement-related limitation was the nature of using questionnaire-based measures of anxiety. In light of the earlier point regarding the detection of a relationship between movement-specific anxiety and movement behaviour, a physiological measure of anxiety could be a more sensitive and accurate tool to detect and offer greater insight into the relationship between anxiety and movement behaviour. This idea will also be examined and discussed further in the general discussion (Chapter Seven).

5.8 Conclusion

In conclusion, the results of the current study suggest that within a typically developing adult population, higher anxiety related specifically to movement on foot around an everyday environment leads to individuals leaving more space beyond their own body width when navigating through apertures. Although this relationship was evident in the movement behaviour itself, it was not evident in perceptual judgements about this same movement behaviour. The results also indicate that the point at which behaviour changes, the critical ratio, differs significantly between perceptual judgement when standing still (what individuals said they ‘would’ do) and executed action (the movement behaviour individuals actually performed). Together these findings further illustrate that perception and action must be studied together before drawing conclusions based on one or the other alone since they may be influenced by differing constraints. They additionally reveal the importance of measurement tool specificity in being able to capture specific and nuanced relationships between wellbeing factors and the perception-action cycle that may go undetected with the use of more generalised measures.

These findings offer a springboard from which to explore whether the same relationships or others exist in adults with atypically developing motor skills, and specifically DCD, in comparison with typically developing adults. This will be the focus of the following chapter.

Chapter Six

Study Three: The influence of anxiety, self-efficacy, resilience, and motor control on the perceptual judgements and executed actions of adults with and without DCD

6.1 Background

This study aims to build on the findings of study two, described and discussed in the previous chapter. The roles of anxiety, self-efficacy, resilience, and motor control - specifically one's ability to move consistently - in how individuals think they will behave (their perceptual judgement) and how they actually behave (their executed action) may be particularly pertinent for individuals with DCD. The growing body of evidence suggesting that these elements of well-being tend to be poorer in adults with DCD (Harris, Wilmut & Rathbone, 2021; Hill & Brown, 2013) lead to the question of whether, in line with this, the effect of these on perception and action may be different or more evident in adults with DCD as compared to adults with typically developing motor skills.

As was discussed in Chapter One, several studies to date have shown movement variability to be an important factor when considering the relationship between perception and action in individuals with DCD. For example, findings from Du et al.'s (2015) study suggested that adults with DCD are not able to produce consistent movement patterns while walking on a level surface in the same way or to the same extent as TD adults. Although the adults with DCD displayed similarities to the TD controls in terms of step length, width and stride time, they showed greater variability of velocity in the anterior-posterior and vertical directions, as well as greater variability of acceleration in the vertical direction.

In another study, after examining spatial and temporal characteristics collected over both the approach and passing phases, Wilmut et al. (2015) found adults with DCD to have a higher critical ratio when walking through apertures scaled to their body size ranging from 0.9 up to 2.1 times their shoulder width (i.e. they turned for larger apertures). They also showed greater lateral trunk movement and movement variability than TD adults, and this influenced how they adapted their movement to achieve the desired result of passing through the apertures without bumping into the sides: they started to turn sooner, more often, and to a greater degree than their TD peers. As discussed in Chapter One, these findings suggest that adults incorporate awareness of their own motor control (lateral trunk movement and movement variability) when making action judgements during movement, potentially an adaptive strategy to avoid bumping into things. The authors do point out that although no collisions took place in their study, it was a controlled lab environment. As such, they note that in more complex environments with various stimuli and where slower movement is not possible this strategy may not work as effectively and collisions may therefore be more likely to occur.

Wilmut et al.'s (2016) study subsequently examined how children and young people (aged 7-17 years) with DCD make perceptual judgements and executed actions when navigating through apertures compared to TD controls. The participants were first asked to make 'passability' judgements (i.e. would you need to turn your shoulders to walk through this aperture?) about apertures ranging from 0.9 incrementally up to 2.1 the ratio of each participant's shoulder width. The results interestingly showed that the children with DCD underestimated the space they would need when making perceptual judgements - they actually thought they would need less of a safety margin than the TD children. Conversely when the children with DCD actually walked through the apertures they showed a significantly greater critical ratio than the TD children, allowing a greater safety margin than would be needed if only accounting for their body size. These findings indicated that perception in a static context differs from perception in a dynamic context. In spite of this, the authors were able to identify a relationship between perception and action in children with DCD: high perceptual critical ratios were subsequently reflected in high shoulder angles at the point of passing through the doors. This illustrates a functional perception-action cycle in children with DCD: what is perceived from a static position is realised in a dynamic context.

Interestingly the TD children did not show the same relationship, although this contrasts with Chen et al.'s (2014) finding that perception of sitting height was linked to postural sway in TD children but not children with DCD. While the evidence to date does offer promising insights, given how the findings have varied further research is necessary to elucidate the relationship between perception and action in DCD. Indeed, Wilmut et al. (2016) promoted the constraints-based approach as a useful framework for investigating perception in its own right and directly as it relates to movement to shed further light on the relationship between the perception-action cycle and the characteristics of individuals with DCD. While research to date in populations with DCD has offered insights into the influence of aspects of motor control on perceptual judgements and executed actions, perception and action have not yet been examined together in adults with DCD, a novel element this study sought to address. Furthermore, no studies have yet explored the influence of the wellbeing factors under investigation in this thesis on both the perceptions and actions of individuals - and in this case adults - with DCD.

The current study therefore considered how anxiety, self-efficacy, resilience and movement variability constrain the ways in which adults with DCD perceive and act compared to their TD peers. The standalone influence, and potential interactions, of these factors remains unexplored in adults with DCD, a population in which an urgent need for further research has been identified, as discussed previously (Blank et al., 2019). Indeed, previous research has suggested a link between motor control, anxiety and elements of self-efficacy including self-concept (Cairney, Rigoli & Piek, 2013). The nature of this relationship needs further exploration, yet the suggested link speaks to the notion that these, and related factors such as resilience (see e.g., Schwarzer & Warner, 2013), are of particular relevance to movement planning and execution in adults with DCD. Given the still limited understanding of DCD's aetiology, adults with the condition are a unique population who have poor motor control for relatively unknown reasons. It is therefore vital to investigate the perception of individuals with DCD directly in relation to movement planning and execution since that relationship lies at the crux of the condition.

Please note, this study was pre-registered on the Open Science Framework (Registration DOI: 10.17605/OSF.IO/YN9FM).

6.2 Aims and hypotheses

6.2.1 Perceptual judgments

In terms of perceptual judgments, this study aimed to investigate how anxiety, self-efficacy, resilience and movement variability constrain how adults with DCD perceive their action capabilities in a static and a dynamic perceptual task as compared to TD adults.

In terms of anxiety (general, state, trait and movement-specific), higher anxiety was expected to correspond with more cautious perceptual judgments (i.e. a higher critical ratio) of action capabilities in adults with DCD in both a static and a dynamic task context. Based on the synthesis of different branches of previous evidence, it was expected that this relationship may be more statistically evident in adults with DCD as compared to TD adults (e.g., Harris et al., 2021; Wilmut, Du & Barnett, 2015).

In terms of self-efficacy (general and movement-specific) lower self-efficacy was expected to correspond with more cautious perceptual judgments of action capabilities in adults with

DCD in both a static and a dynamic task context. For the same reasons as stated previously, it was expected that this relationship may be more statistically evident in adults with DCD as compared to TD adults.

Lower resilience was also expected to correspond with more cautious perceptual judgments of action capabilities in adults with DCD in both a static and a dynamic task context. This effect was once again expected to be more statistically evident in adults with DCD as compared to TD adults.

In terms of movement variability, more consistent motor control was expected to lead to less cautious perceptual judgments of actual action capabilities with smaller prospective safety margins and lower critical ratios in adults with DCD in both a static and a dynamic task context (see Wilmut et al., 2015; Wilmut et al., 2016). Based on previous research, it is expected that this relationship will be statistically evident in adults with DCD as compared to TD adults.

6.2.2 Executed actions

In terms of executed actions, this study aimed to investigate how anxiety, self-efficacy, resilience and movement variability constrain how adults with DCD execute their actions as compared to TD adults.

In terms of anxiety (general, state, trait and movement-specific), higher anxiety was expected to correspond with more cautious executed actions (in terms of critical ratio and relative safety margin) in adults with DCD. As indicated above, based on previous evidence it was expected that this relationship may be more statistically evident in adults with DCD as compared to TD adults. Critical ratio and relative safety margin were both examined because, although they relate to one another, they measure different aspects of turning behaviour. A participant's critical ratio is the size of the aperture relative to their own shoulder width at which they decided to turn rather than walk through facing forwards: it is the point at which the movement behaviour changes from 'no turn' to 'turn'. However, a participant's relative safety margin is calculated using shoulder angle at the door to measure the degree to which a participant turned, and shows how much space, beyond their own body width, they left between themselves and the doors.

Lower self-efficacy (general and movement-specific) was expected to correspond with more cautious executed actions in adults with DCD. As indicated above, based on previous evidence it was expected that this relationship may be more statistically evident in adults with DCD as compared to TD adults.

Lower resilience was expected to correspond with more cautious executed actions in adults with DCD as compared to TD adults. Likewise, based on previous evidence it is expected that this effect may be stronger in adults with DCD as compared to TD adults.

In terms of movement variability, more consistent motor control was expected to lead to less cautious and smaller safety margins with a lower critical ratio during executed actions in adults with DCD (see Wilmut et al., 2015; Wilmut et al., 2016). In light of previous evidence, this relationship was expected to be more statistically evident in adults with DCD as compared to TD adults.

6.2.3 Critical ratios

This study additionally aimed to investigate whether the critical ratio would differ across the static perceptual judgment, dynamic perceptual judgment and executed action tasks between the adults with DCD and the TD adults.

In line with previous findings, the critical ratio was expected to be lowest in the static perceptual judgment task, then higher in the dynamic perceptual judgment task and then highest in the executed action task (Wilmut et al., 2015;2016).[5] Prior to undertaking this study directional hypotheses regarding differences between the groups across the task conditions could not be made due to a lack of previous evidence suggesting any directive effect.

6.3 Methods

6.3.1 Participants

17 adults with DCD (10 female: 7 male) and 17 TD adults (10 female: 7 male) aged 18-60 years participated in this study (see Table 6.1 for full demographic details). The participants were sex- and age-matched as closely as possible between the groups. It was originally planned to age-match the adults with DCD and their TD counterparts to within 12 months. However, this was not possible in all cases due to unexpectedly high scores on the Adult Developmental Coordination Disorders / Dyspraxia Checklist (ADC) (Kirby et al., 2010) in

[5] Please note: on the Open Science Framework registration document the order of these is reversed due to a typographic error.

some of the adults without DCD and due to limitations on recruitment. Participants were therefore sex-matched[6] and matched as closely as possible by age and it was shown that there was no significant difference in age across the groups ($t(34) = -0.0566$, $p = 0.955$).

TD participants were recruited via the Oxford Brookes Research Participation Portal and Psychology Participant Panel, social media advertising, personal and professional contacts of the researcher. TD participants self-reported no movement difficulties and also had to score below 56 on the total scale and below 17 on section A of the ADC to ensure their inclusion (i.e. below the cut-off scores indicating movement difficulties during childhood and being 'at risk for DCD' in activities for daily living during adulthood). In line with this, three prospective TD participants had to be excluded from the final sample for the age- and sex-matched TD group (N=17) and other appropriate age- and sex-matched TD participants were recruited.

Steps were taken to ensure that participants assigned to the group 'adults with DCD' met the criteria for Developmental Coordination Disorder as described in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition Text Revision (DSM-5-TR, APA 2022). To satisfy criterion A all participants in the DCD group were assessed using the Movement Assessment Battery for Children, second edition (MABC-2, Henderson et al., 2007). There is currently no standardised assessment tool going beyond the upper age band of the MABC-2 (age band 3: 11-16 years old). To be included in the DCD group participants scored below the 16th percentile. To satisfy criterion B and C participants with DCD scored above 17 on section A of the ADC to demonstrate difficulties during childhood, and above 65 on the total scale to demonstrate difficulties with daily living in adulthood. In terms of criterion D participants in the DCD group took part in an informal interview about other conditions which could have better explained their motor difficulties. In order to meet criterion D they had to clearly report the absence of any known neurological or other medical conditions that may affect their movement.

Participants with DCD were recruited in the first instance via a database of individuals with DCD who agreed to be contacted about participating in research studies, held by the Perception and Motion Analysis Research Group at Oxford Brookes University. Participants

[6] As mentioned in section 5.3.1, although the questionnaire asked participants about their gender, it was decided to sex-match since information about the biological sex of the participants in the DCD group was already known from a research participation database they had joined during childhood. None of their TD 'matches' described their gender as differing from their biological sex.

were also recruited through advertising the study through several channels of the Dyspraxia Foundation, a national charity and support network for individuals with DCD. Professional and personal contacts were also invited to take part.

The initial aim was to recruit up to 25 adults with DCD and 25 age- and sex-matched TD adults aged 18-60 years. However, due to recruitment and data capture challenges a sample of 17 adults in each group was used. The motion capture data for two prospective participants for the DCD group was not clear enough to include, resulting in the exclusion of these and their prospective TD age- and sex-matched controls. Despite these limitations, this sample size is similar to or exceeds those of several previous studies with similar methodologies and samples of adults with DCD (Hackney & Cinelli, 2013; Wilmut, Du & Barnett, 2015).

Table 6.1 below shows the demographic details of participants in the two groups.

Table 6. 1

Demographic details of participants in both groups

Group	N	Age Range (years)	Mean Age (years)	% Female (sex)	% Male (sex)
DCD	17	18 - 56	32.41	58.82	41.18
TD	17	18 - 55	32.53	58.82	41.18

As noted in section 5.3.1 of the previous chapter, although it is beyond the scope of this thesis to consider this aspect further, the following information aims to offer useful insight into the broader developmental profile of participants across both groups.

Of the 17 participants with TD motor skills, one self-reported having an auditory processing disorder and one self-reported having ADHD. Of the 17 participants with DCD, four self-reported having ADHD, two self-reported having ASD, three others self-reported having both ASD and ADHD, one self-reported having dyslexia, one other self-reported having both dyslexia and ADHD, one other self-reported having both ASD and a sensory processing disorder, one other self-reported having a sensory processing disorder, and one other self-reported having a learning difficulty specifically in mathematics.

6.3.2 Apparatus and procedure

As noted in the previous chapter, both the apparatus and procedure for this study have been described and explained in detail in Chapter Four. For conciseness, this detail is not repeated here. The only change in procedure from study two (Chapter Five) was that prospective participants for the 'adults with DCD' group undertook the MABC-2 (Henderson et al., 2007) on arrival and before the tasks began.

6.4 Data processing

All data were processed in the same way as described in section 4.3 in Chapter Four and section 5.1 in Chapter Five, incorporating the additional variable of 'group'. The ADC scores were not used as part of subsequent statistical analyses but only to assign participants to the correct group. One participant in the DCD group was missing data from the STAI-S (state anxiety) scale, and as such their data along with that of their matched TD counterpart was excluded from analyses involving the STAI-S score.

6.5 Statistical Analysis

The MATLAB results were exported via Microsoft Excel into the open-source computer software jamovi to conduct statistical analyses on the data (The jamovi project, 2021).

Pearson correlations were first examined between all relevant variables. This was done to take into account multicollinearity and subsequently decide which variables to use in regression analyses.

Two hierarchical multiple regression analyses were performed to examine whether and to what extent the variables chosen for inclusion predicted static or dynamic perceptual judgement critical ratio, and whether this differed according to movement ability. Theoretically-driven choices were made in relation to the order and composition of the three models included in the hierarchical multiple regressions. ADC score and Lateral Trunk Movement were added to the first model. ADC score was used as the most sensitive measure of movement ability between the two groups (adults with DCD / TD adults) and was therefore used as a proxy for group membership. As described above, Lateral Trunk Movement represents participants' level of movement variability. These were chosen to be entered in this order into model one in light of Wilmut et al.'s (2016) previous findings suggesting a link between movement variability and perceptual critical ratios in individuals with DCD (i.e., higher movement variability leading to children with DCD underestimating the amount of space they *thought* they would need to pass through apertures without bumping into the sides). Unlike in the previous chapter which focused on TD adults only, in the current study movement variability was seen as more likely to show a predictive effect due to the higher levels of movement variability shown by individuals with DCD and previous findings mentioned above. Based on the previous findings in TD populations suggesting a link between higher anxiety and higher perceptual critical ratios during judgements about affordances, general anxiety and movement-specific anxiety were added to the second model. General self-efficacy and movement-specific self-efficacy were then added to the third model since the effect of self-efficacy as a distinct variable has not been explored to date. The order and composition of the three models remained the same for both regressions, the first with static perceptual judgement critical ratio as its dependent variable and the second with dynamic perceptual judgement critical ratio as its dependent variable.

In relation to executed actions, Pearson correlations between executed action critical ratio (polynomial method) and mean relative safety margin were examined and two further hierarchical multiple regressions were performed, following the same theoretically-driven model structures as described above, to examine whether and to what extent these same variables may predict executed action critical ratio and/or mean relative safety margin.

To compare the critical ratios (50% method) across task conditions, Pearson correlations were first performed to examine relationships between these in the static perceptual judgement condition, the dynamic perceptual judgement condition, and the executed action condition. This was examined separately for each group: adults with DCD and TD adults. Following this, a two-way repeated measures Analysis of Variance (ANOVA) was performed to analyse the effect of condition (i.e. static perceptual judgement, dynamic perceptual judgement or executed action) and group (adults with DCD or TD adults) on critical ratios.

6.6 Results

Pearson correlation analyses revealed several highly significant correlations between wellbeing variables. Data from the BRS (representing resilience) was not included in subsequent regression analyses due the strength of its multicollinearity with both the HADS (representing general anxiety) ($r(32) = -.642$, $p < .001$) and the NGSE (representing general self-efficacy) ($r(32) = .646$, $p < .001$). Additionally data from the STAI-S and STAI-T scales, representing state and trait anxiety respectively, were also not included in subsequent regression analyses due to the strength of their multicollinearity with the HADS (STAI-S:

r(31) = .685, p <.001, STAI-T: r(32) = .679, p <.001), and multicollinearity between data from the STAI-T and the NGSE (r(32) = -.564, p <.001).[7] In addition to multicollinearity, and as mentioned in the previous chapter, missing data from the STAI-S scale in the adults with DCD group contributed to the HADS being chosen as the only measure of generalised anxiety for inclusion in the regression analyses.

As such, in light of the above and in line with analyses from the study of TD adults only described in the previous chapter, only data from the HADS (representing general anxiety), the NGSE (representing general self-efficacy), the movement-specific anxiety scale and the movement-specific self-efficacy scale were chosen to be included as variables in subsequent regression analyses to examine which of these may predict critical ratio and / or relative safety margin in the static and dynamic perceptual judgement conditions (50% method) and in the executed action condition (polynomial method) respectively.

Although the correlations differ, as was also the case in data from the study described in chapter five, in the current study data from the movement-specific scales did significantly correlate with data from the generalised anxiety and self-efficacy scales (the HADS and the NGSE). Specifically, data from the movement-specific anxiety scale correlated significantly and moderately positively with data from the HADS, $r(32) = .419$, $p = .014$. Data from the movement-specific self-efficacy scale correlated significantly and moderately negatively with data from the HADS, $r(32) = -.530$, $p = .001$, and also significantly and moderately positively with data from the NGSE, $r(32) = .566$, $p < .001$. As in the previous study, in spite of these correlations it was decided to enter these into the regression analyses as separate variables since they were moderate in strength and given the specific interest in the current study in the nuances of anxiety and self-efficacy as they relate specifically to movement among adults with typical and atypical motor skills.

Descriptive details of the data across both groups from the wellbeing variables are shown in Table 6.2.

[7] Please note, data from the STAI-S scale only has 31 degrees of freedom due to missing data from one participant.

Table 6. 2

Mean and median scores for all wellbeing measures with standard deviation (SD) and interquartile range (IQR) shown in brackets

		DCD Mean (SD) Median (IQR)	TD Mean (SD) Median (IQR)
General	Anxiety (HADS)	9.88 (4.28) 9.0 (4.0)	5.88 (3.90) 6.0 (5.0)
	Anxiety (STAI-S)	34.6 (11.3) 30.0 (13.3)	28.4 (4.95) 28.0 (8.0)
	Anxiety (STAI-T)	44.1 (11.9) 39.0 (18.0)	37.2 (9.20) 37.0 (13.0)
	Resilience (BRS)	2.78 (.827) 2.50 (.833)	3.76 (.719) 3.83 (.500)
	Self-efficacy (NGSE)	3.49 (.815) 3.75 (1.38)	3.98 (.635) 4.00 (.750)
Movement-specific	Anxiety	26.8 (19.9) 19.3 (33.7)	16.9 (20.0) 11.0 (17.3)
	Self-efficacy	50.2 (23.5) 43.4 (30.3)	80.3 (14.8) 81.8 (10.1)

*With regard to the variables chosen for inclusion in subsequent regression analyses, using Welch's t test due to unequal variance, movement-specific self efficacy (*p*<.001) and HADS (*p*=.008) scores were shown to be significantly different across groups, while movement-specific anxiety (*p*=.062) and NGSE scores were not (*p*=.157).

6.6.1 Perceptual judgements

Pearson correlation analyses performed on all of the data together revealed only one significant correlation, which was negative and relatively weak, between general self-efficacy, represented by the NGSE, and perceptual judgement critical ratio in the static condition only, r(32) = -.347, p = .044.

When the data from each group (adults with DCD and TD adults) was examined separately, a correlation of similar strength and significance level was also evident in the TD group between general self-efficacy and perceptual judgement critical ratio in the static condition, but there were no significant correlations evident between any of the other variables chosen for inclusion in the subsequent regression analyses and perceptual judgement critical ratios in either the static or dynamic condition in the DCD group.

Two hierarchical multiple regression analyses were performed to determine whether and to what extent first static perceptual judgement critical ratio and then dynamic perceptual judgement critical ratio may be predicted by ADC score (as a proxy for group, being the most sensitive measure of movement ability in this data set), movement variability, general anxiety, movement-specific anxiety, general self-efficacy and / or movement-specific self-efficacy. The model orders and compositions for both of these have been described and explained in the previous section.

The first hierarchical multiple regression showed that none of the variables across models one, two, or three significantly explained any of the variance in static perceptual judgement critical ratio. In terms of results regarding the overall model fit and model comparisons, in the first model ADC score and movement variability did not significantly explain any variance in static perceptual judgement critical ratio, $R^2 = .002$, $F(2, 31) = .033$, $p = .968$. When added to the second model, general anxiety and movement-specific anxiety jointly did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .012$, Fchange $(2, 29) = .169$, $p = .845$. When subsequently added to the third model, general self-efficacy and movement-specific self-efficacy jointly did not contribute any significant increment in the percentage of variance explained (either), $\Delta R^2 = .142$, Fchange $(2, 27) = 2.28$, $p = .122$. The results for each individual predictor within the regression models are shown in Table 6.3. The only individual variable reaching statistical significance is general self-efficacy ($p = .044$), yet this is not reflected in the overall model fit.

Table 6. 3
Hierarchical multiple regression results for the prediction of static perceptual judgement critical ratio

	β	95% C I for β		*B*	*p*
		LL	UL		
Model 1					
ADC score	.0338	-.349	.417	2.09e-4	.858
Movement variability	.0226	-.360	.405	.0203	.905
Model 2					
ADC score	.101	-.374	.577	6.25e-4	.667
Movement variability	.0212	-.373	.416	.019	.913
General anxiety	-.0473	-.508	.414	-.00186	.835
Movement-specific anxiety	-.0990	-.529	.331	-8.66e-4	.641
Model 3					
ADC score	.00503	-.602	.5919	-3.12e-5	.986
Movement variability	-.02815	-.439	.3830	-.02522	.889
General anxiety	-.08100	-.545	.3826	-.00319	.723
Movement-specific anxiety	-.06203	-.485	.3606	-5.43e-4	.766
General self-efficacy	-.45491	-.897	-.0126	-.10628	.044*
Movement-specific self-efficacy	.11364	-.539	.7663	8.19e-4	.724

* indicates statistical significance, at p <.05

The second hierarchical multiple regression showed that none of the variables across models one, two, or three significantly explained any of the variance in dynamic perceptual judgement critical ratio. In terms of results regarding the overall model fit and model comparisons, in the first model ADC score and movement variability did not significantly explain any variance in dynamic perceptual judgement critical ratio, $R^2 = .006$, $F(2, 31) = .092$, $p = .912$. When added to the second model, general anxiety and movement-specific anxiety jointly did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .002$, $F\text{change}\ (2, 29) = .022$, $p = .978$. When subsequently added to the third model, general self-efficacy and movement-specific self-efficacy jointly did not contribute any significant increment in the percentage of variance explained either, $\Delta R^2 = .116$, $F\text{change}\ (2, 27) = 1.79$, $p = .187$. The results for each individual predictor within the regression models are shown in Table 6.4. In summary, none of the variables across any of the three models significantly predicted perceptual judgement critical ratios in the dynamic condition.

Table 6. 4
Hierarchical multiple regression results for the prediction of dynamic perceptual judgement critical ratio

	β	95% C I for *β*		*B*	*P*
		LL	UL		
Model 1					
ADC score	-.0418	-.424	.340	-2.34e-4	.825
Movement variability	-.0535	-.435	.329	-.0434	.777
Model 2					
ADC score	-.0223	-.499	.455	-1.25e-4	.925
Movement variability	-.0527	-.449	.343	-.04279	.787
General anxiety	-.0477	-.510	.415	-.00170	.834
Movement-specific anxiety	.0135	-.418	.445	1.07e-4	.949
Model 3					
ADC score	-.1154	-.724	.4929	-6.47e-4	.700
Movement variability	-.0962	-.515	.3228	-.07808	.641
General anxiety	-.0772	-.550	.3953	-.00275	.740
Movement-specific anxiety	.0462	-.384	.4770	3.67e-4	.827
General self-efficacy	-.4111	-.862	-.0397	-.08702	.072
Movement-specific self-efficacy	.1070	-.558	.7722	6.99e-4	.744

6.6.2 Executed actions

An independent samples t-test indicated a significant difference in critical ratio in the executed action condition (polynomial curve method) between the adults with DCD and the TD adults, $t(32) = 2.94$. $p = .006$. Descriptive details of this difference are shown in Table 6.5 below. These results showed that the executed action critical ratios of adults in the DCD group were significantly higher than those in the TD group. This indicated that the adults with DCD were choosing to turn for bigger apertures than the TD adults, relative to their own shoulder width.

Table 6. 5

Descriptive details of difference in critical ratio between groups in the executed action condition

Group	N	Mean	Median	SD	SE
DCD	17	1.54	1.50	.152	.0368
TD	17	1.38	1.42	.150	.0365

Another independent samples t-test indicated a significant difference in mean relative safety margin between the adults with DCD and the TD adults, $t(32) = 3.44$, $p = .002$. Descriptive details of this difference are shown in Table 6.6. Once again, these results showed that the mean relative safety margins left by adults in the DCD group were significantly bigger than those left by the TD group. This indicated that the adults with DCD were leaving more space beyond their own body size to pass through apertures than the TD adults.

Table 6. 6

Descriptive details of difference in mean relative safety margin between groups in the executed action condition

Group	N	Mean	Median	SD	SE
DCD	17	.877	.838	.111	.0270
TD	17	.766	.753	.0747	.0181

A Pearson correlation analysis of all the data together suggested the following significant correlations. There was a moderate and significant negative correlation found between movement-specific self-efficacy and mean relative safety margin, $r(32) = -.64$, $p<.001$. There was additionally a weaker but significant negative correlation found between general self-efficacy and mean relative safety margin, $r(32) = -.34$, $p = .049$.

Moderate and significant negative correlations were also found between movement-specific self-efficacy and executed action critical ratio (polynomial method), $r(32) = -.42$, $p = .013$, as well as between movement-specific self-efficacy and movement variability (mean standard deviation (SD) of lateral trunk movement), $r(32) = -.45$, $p = .007$.

A moderate and significant positive correlation was additionally found between general anxiety and mean relative safety margin, $r(32) = .40$, $p = .019$.

In terms of relationships between the movement variables, it is also notable that a moderate and significant positive correlation was found between movement variability (mean SD lateral trunk movement) and mean relative safety margin, $r(32) = .50$, $p = .003$.

Pearson correlation analyses were also performed on the data for each group separately (adults with DCD and TD adults). In the adults with DCD a moderate and significant negative correlation was found between movement-specific anxiety and mean relative safety margin, $r(15) = -.56$, $p = .02$. This relationship was not found in the TD adults.

Similarly to those analyses performed on the perceptual judgement data described previously, two hierarchical multiple regression analyses were subsequently performed to determine the extent to which 1. executed action critical ratio (polynomial method) and 2. mean relative safety margin were predicted by ADC score (once again used as a proxy for group, being the most sensitive measure of movement ability in this data set), movement variability, general anxiety, movement-specific anxiety, general self-efficacy and / or movement-specific self-efficacy. The order and composition of the three models used were the same as those used in the previous regression analyses performed on the perceptual judgement data, for the same theoretically-driven reasons.

As was the case in the previous study described in Chapter Five, executed action critical ratio (polynomial method) and mean relative safety margin were shown by Pearson analyses to correlate significantly and moderately positively, $r(32) = .46$, $p = .006$. However, as also described previously in chapter five, it was decided that separate regression analyses should be performed with these as distinct dependent variables because they measure distinct aspects of movement and turning behaviour during aperture-crossing.

The first hierarchical multiple regression showed that none of the variables across models one, two, or three significantly explained any of the variance in executed action critical ratio. In terms of results regarding the overall model fit and comparisons between models, in the first model ADC score and movement variability did not significantly explain any variance in executed action critical ratio, $R^2 = .139$, $F(2, 31) = 2.51$, $p = .098$. When added to the second model, general anxiety and movement-specific anxiety jointly did not contribute any significant increment in the percentage of variance explained, $\Delta R^2 = .0184$, $Fchange\ (2, 29) = .317$, $p = .731$. When subsequently added to the third model, general self-efficacy and movement-specific self-efficacy jointly did not contribute any significant increment in the percentage of variance explained (either), $\Delta R^2 = .0794$, $Fchange\ (2, 27) = 1.404$, $p = .263$. The results for each individual predictor within the regression models are shown in Table 6.7. In summary, none of the variables across any of the three models significantly predicted critical ratio in the executed action condition.

Table 6. 7
Hierarchical multiple regression results for the prediction of executed action critical ratio

	β	95% C I for *β*		*B*	*P*
		LL	UL		
Model 1					
ADC score	-.234	-.121	.589	.00137	.189
Movement variability	.230	-.125	.586	.19469	.196
Model 2					
ADC score	-.3274	-.112	.767	.00191	.138
Movement variability	.2311	-.134	.596	.19525	.205
General anxiety	-.1441	-.570	.282	-.00535	.494
Movement-specific anxiety	-.0399	-.437	.357	-3.29e-4	.839
Model 3					
ADC score	.0322	-.535	.600	1.88e-4	.908
Movement variability	.1089	-.282	.500	-.09203	.572
General anxiety	-.2482	-.689	.193	-.00921	.258
Movement-specific anxiety	.0282	-.374	.430	2.33e-4	.887
General self-efficacy	-.0864	-.507	.334	-.01904	.677
Movement-specific self-efficacy	-.4257	-1.046	.195	-.00289	.171

Results from the second hierarchical multiple regression analysis showed, in terms of the overall model fit and comparisons between models, that ADC score and movement variability were found to explain 39% of the variance in relative safety margin, $R^2 = .39$, $F(2, 31) = 9.89$, $p <.001$. When added to the overall model, general anxiety and movement-specific anxiety jointly contributed an increment of 3.38% in the percentage of variance explained, though non-significantly, $\Delta R^2 = .0338$, *Fchange* (2, 29) = .849, $p = .438$. Models one and two together remained significant however, together explaining 42.3% of the variance in relative safety margin, $R^2 = .423$, $F(4, 29) = 5.32$, $p = .002$. When subsequently added to the overall model, general self-efficacy and movement-specific self-efficacy jointly contributed an increment of 5.09% in the percentage of variance explained, though non-significantly, $\Delta R^2 = .0509$, *Fchange* (2, 27) = 1.306, $p = .287$. The three models together therefore remained significant in explaining 47.4% of the variance in relative safety margin, $R^2 = .474$, $F(6, 27) = 4.06$, $p = .005$.

The results for each individual predictor within the regression models are shown in Table 6.8. In summary, higher ADC scores and higher levels of movement variability both significantly predicted bigger relative safety margins. None of the wellbeing variables added subsequently to the regression models were significantly related to relative safety margin.

Table 6. 8
Hierarchical multiple regression results for the prediction of mean relative safety margin

	β	95% C I for *β*		*B*	*P*
		LL	UL		
Model 1					
ADC score	.440	.1403	.739	.00167	.005
Movement variability	.332	.0331	.632	.18295	.031
Model 2					
ADC score	.364	4.61e-4	.728	.00138	.05
Movement variability	.3284	.0267	.630	.18072	.034
General anxiety	.2193	-.1331	.572	.00530	.213
Movement-specific anxiety	-.0953	-.4241	.233	-5.13e-4	.558
Model 3					
ADC score	.1394	-.3318	.611	5.30e-4	.549
Movement variability	.2371	-.0875	.562	.13046	.145
General anxiety	.1390	-.2269	.505	.00336	.442
Movement-specific anxiety	-.0473	-.3809	.286	-2.54e-4	.773
General self-efficacy	.0616	-.2876	.411	.00884	.720
Movement-specific self-efficacy	-.4040	-.9192	.111	-.00179	.119

6.6.3 Critical ratios

In the adults with DCD, there was a strong, positive and significant correlation between the critical ratios in the static and dynamic perceptual judgement conditions, $r(15) = .84$, $p < .001$. There was no significant correlation between the critical ratio in the executed action condition (50% method), and those in either the static or dynamic perceptual judgement conditions.

In the TD adults, there was a strong, positive correlation between the critical ratios in the static and dynamic perceptual judgement conditions, $r(15) = .87$, $p < .001$. There was also a moderate, positive and significant correlation between the critical ratio in the executed action condition (50% method) and the critical ratio in the dynamic perceptual judgement condition, $r(15) = .52$, $p = .032$.

As specified previously, a two-way repeated measures Analysis of Variance (ANOVA) (group x condition) was performed to examine the effect of condition (i.e. static perceptual judgement, dynamic perceptual judgement or executed action) and group (adults with DCD or TD adults) on critical ratios (50% method). Mauchly's test of sphericity showed this assumption to be violated by the data and for this reason the Greenhouse-Geisser correction was used.

The results revealed that there was not a statistically significant interaction between the effects of condition and group, $F(1.27) = 1.39$, $p = .254$. Furthermore, there was no significant effect of condition ($p = .062$), nor group, ($p = .643$).

However, it is pertinent to note that an independent samples t-test did show group membership to have a significant effect on executed action critical ratio (polynomial curve method), $t(32) = 2.94$, $p = .006$ as described at the beginning of section 6.6.2 with the values shown in Table 6.5. These showed the DCD group to have significantly higher executed action critical ratios (polynomial method) than the TD group. The implications of this difference in result regarding the critical ratios calculated with different methods will be discussed subsequently.

6.7 Discussion

Considering first the results relating to perceptual judgements, correlational evidence tentatively suggests that in TD adults lower general self-efficacy may relate to higher critical ratios, which could be interpreted as more cautious judgements about the point at which they would need to turn, when making judgements about walking through apertures from a position of standing still. It is notable that this relationship is also significantly reflected within the third regression model from the perceptual judgement data in the static condition (see table 6.3), but only on the level of general self-efficacy as an individual predictor variable. The fact that this is not reflected at a statistically significant level within the overall model fit however does not allow any conclusions to be drawn from this. It also does not provide any insight into the potential effect of general self-efficacy across the spectrum of ADC scores (used as a proxy for group as described previously, and offering a nuanced measure of movement ability and skill level across both groups). This would be an interesting aspect for future research to explore.

It is interesting however to see the hint of a possible relationship between general self-efficacy and perceptual judgements in the TD adults but not the adults with DCD. If this relationship were to truly exist in adults with typical motor skills but not those with DCD, it may suggest that where TD adults take into account how well they think they can execute appropriate movement behaviour when making prospective affordance judgements while standing still, adults with DCD may not do so. This may suggest that in adults with DCD different factors are involved in this process of judging affordances in the surrounding environments while standing still than in TD adults.

Otherwise, the lack of significance across the regression models pertaining to both static and dynamic critical ratios is once again striking. In particular, the fact that neither ADC score nor level of movement variability were significant predictors of static or dynamic perceptual judgement critical ratio, either individually or in combination, did not align with what was hypothesised nor with previous findings in TD children and children with DCD (Chen et al., 2014; Wilmut et al., 2016). However, linking back to the previous paragraph's point, this is perhaps an interesting finding in itself as regards those with high ADC scores, i.e., the adults with DCD. Indeed, it could be another indication that adults with DCD may not take into account the nature or level of their own motor control and consistency when making prospective perceptual judgements about affordances, either from standing still or during the approach phase of a potential movement behaviour.

Moreover, the lack of any further significant relationship detected between the wellbeing variables (general anxiety, movement-specific anxiety, general self-efficacy and movement-specific self-efficacy) and perceptual judgement critical ratios in the static and dynamic conditions did not align either with what was hypothesised and, in particular regarding anxiety, do not support previous findings among TD adults (e.g., Graydon et al., 2012; Hackney et al., 2015; Harris & Wilmut, 2020). As such, and for similar potential reasons as those discussed in Chapter Five with regards to the similar findings in study two's sample of TD adults, in the current study the results from both the perceptual judgement tasks indicate that higher anxiety and lower self-efficacy - general and movement-specific - do not lead to more cautious perceptual judgements of the 'passability' of apertures in either a static or a dynamic context among either TD adults or adults with DCD.

Moving on to consider the results relating to executed actions, these first of all suggest that adults with DCD demonstrate different turning behaviour to TD adults in terms of critical ratio (polynomial method) and relative safety margin, supporting findings from previous research (Wilmut et al., 2015). In other words, a significant difference in both critical ratio and relative safety margin was shown between the groups. That is, the adults with DCD started to turn at different shoulder-width-to-aperture ratios than the TD adults. So, the mean critical ratio for the DCD group was 1.54 suggesting that when walking through an aperture size that was proportionally 1.54 the width of their own shoulders or smaller they turned, while for the TD group the mean critical ratio was significantly smaller at 1.38. Additionally, the adults with DCD left a significantly bigger safety margin for themselves relative to their own shoulder width by turning to a greater degree to get through the gaps between the doors without bumping into the sides, compared to the TD adults (see table 6.6 for details).

In terms of relationships between the movement and wellbeing variables, at a whole group level the Pearson correlation analyses suggested some interesting relationships. Lower movement-specific self-efficacy related to higher relative safety margins, higher critical ratios and increased movement variability. General self-efficacy was also shown to relate to higher relative safety margin. Interestingly, movement-specific anxiety did not significantly relate to any of the movement variables, but general anxiety related to higher relative safety margin. However, when correlation analyses were performed on the data from each group separately, the only relationship that remained significant was between movement-specific self-efficacy and relative safety margin in the DCD group. So, those adults with DCD who had lower movement-specific self-efficacy left themselves more space to successfully pass through the gaps. This relationship was not shown in the TD adults.

As regards the results from the regression analyses, the lack of significance in the first regression relating to executed action critical ratio (polynomial method) did not align with what was hypothesised. This may be to do with measurement choice given that there are various ways of calculating critical ratios for movement behaviour; another method may have offered different insights and this methodological limitation will be discussed further as part of the general discussion in chapter seven. However, the second regression analysis offered certain significant insights into the effect of the movement variables on relative safety margin, i.e. how much space beyond their own body width individuals with and without DCD leave themselves to pass through different sized apertures without bumping into the sides. Indeed, these results indicated that level of movement ability and movement consistency related significantly to relative safety margin. In other words, where movement ability and consistency were lower (i.e. those with high ADC scores and high levels of movement variability as measured by lateral trunk movement: the adults with DCD), relative safety margin was significantly bigger.

Although to a certain extent this can be seen to align with what was hypothesised in relation to the movement variables, it offers limited supports to findings from previous research since these showed critical ratio to be the predictive factor rather than relative safety margin (see e.g., Wilmut et al., 2015; 2016). However, this finding does echo the broader suggestion from previous studies that level of movement variability does affect movement behaviour in populations with less consistent movement due to atypical motor skills (e.g., as in DCD) or possible age-related changes such as the higher movement variability shown by older adults in Hackney and Cinelli's previous research (2011; 2013). Once again, taking a broader perspective this links to the notion of a perception-action loop within the wider conceptual framework of the ecological approach whereby awareness of higher movement variability (or in other words less consistent movement) could be interpreted through this lens as leading to more cautious movement behaviour.

Yet, the fact that none of the wellbeing variables were shown to significantly relate to relative safety margin was surprising, particularly considering the finding from the previous study among TD adults only of a relationship between higher movement-specific anxiety and bigger relative safety margin. Potential reasons for and limitations relating to this will be further discussed as part of the general discussion (Chapter Seven). However, considering this finding in the context of the limited previous research so far into anxiety's influence on movement behaviour in individuals with DCD, as explored in Chapter One, it is notable that Parr et al. (2020) detected a relationship between task-specific anxiety and more variable movement and gaze behaviours in children with DCD during a stair negotiation task, whereas no relationship between anxiety and movement behaviour was found in the current study among adults with DCD.

However, notably this was a follow up study which explicitly aimed to use an ecologically valid task where a natural risk of falling was involved, for which anxiety levels may therefore be naturally heightened. Parr et al.'s (2020) initial study had failed to detect the same relationship in the context of a stepping task involving obstacle avoidance, where – similarly to the aperture navigation task in the current study – there is a very low risk of any injury occurring. This once again speaks to the idea mentioned previously that the relationships between anxiety, perception and movement behaviour are highly nuanced. As such the type of anxiety under study and the choice of measurement tools, as well as task and environmental considerations are all important factors to consider which may impact on how and the extent to which any underlying relationships are indeed detected or detectable.

The difference in findings between the two regression analyses in the current study adds support to the point made in Chapter Five that, despite being related, what can be detected through the lenses of critical ratio and relative safety margin differ, sometimes significantly. This supports the idea that future research may benefit from measuring movement behaviour from the perspective of several facets that offer further nuance, and not just critical ratio, particularly when examining potential relationships between emotional and physical factors. It suggests more broadly that the presence or absence of a specific behaviour, like turning – as measured by critical ratio – may not show the whole picture and that measures of the exact nature of the movement under study are necessary to gain a fuller insight into both the behaviour itself and possible constraining factors, linking back to the constraints-based approach (Newell, 1986), as will be discussed further in the general discussion (Chapter Seven).

Finally, turning to examine the results relating to the comparison of critical ratios across task conditions and between groups (TD adults and adults with DCD), the correlational evidence suggests the presence of a more smoothly linked perception-action cycle in the TD adults than the adults with DCD. This is indicated by the fact that in the TD adults, critical ratio in the executed action condition correlated positively and significantly with critical ratio in the dynamic perceptual judgement condition, whereas these did not correlate significantly in the adults with DCD. It may be expected that a typically functional adult perception-action cycle would see a link between perceptual judgement during the approach to a subsequently executed movement behaviour. The presence of DCD may therefore be expected to affect, and even lead to a lessening or absence of such a link. This offers support for Wade and Kazeck's (2018) theory that DCD is caused by a deficit in perception-action coupling which in typically developing individuals is a relationship leading to stable coordination. Looking at this through a constraints-based lens, DCD could even be considered as an individual-based constraint affecting this element of the perception-action cycle in those individuals with the condition.

6.7.1 Limitations

It must be noted that this correlational evidence is limited, and it is telling that the two-way repeated measures ANOVA showed no significant effect of task condition (static perceptual judgement, dynamic perceptual judgement or executed action) or group on critical ratios, or indeed any interaction between the effects of the two (task condition and group membership). In relation specifically to the TD adult group, this stands in contrast to the previous study's findings as described in Chapter Five where critical ratios in the executed action condition were shown to be significantly higher than those in the static perceptual judgement condition. As previously noted in the results section however, the '50%'method used to calculate the critical ratio in the executed action condition for the purposes of comparing critical ratios across the three task conditions may not allow for the most accurate value. The fact that an alternative calculation of executed action critical ratio using the third order polynomial curve method showed adults with DCD to have significantly higher critical ratios than TD adults (see table 6.5, and t-test results: $t(32) = 2.94$, $p = .006$) suggests that due to these methodological limitations, the two-way repeated measures ANOVA undertaken here to compare critical ratios across conditions and between groups may in fact be unable to detect any underlying significant differences that could potentially exist. This highlights once again an important aspect of the challenges inherent in attempting to measure elements of perception and especially perception as it relates to action via both verbal report and physiological measures, as will be considered further in the general discussion (Chapter Seven).

As has already been alluded to and as was the case in the previous study described in chapter five, in the current study a principal limitation was the tension between attempting to capture the most accurate value for executed action critical ratio on the one hand, and being able to compare these values across task conditions using a consistent method on the other. Both this and the other limitations discussed in the closing paragraphs of chapter five are equally applicable to the current study. Where appropriate these will be examined in further depth as part of the general discussion in chapter seven.

6.8 Conclusion

In conclusion, the results of the current study suggest that despite the hint of a possible relationship between general self-efficacy and perceptual judgements in TD adults, anxiety and self-efficacy, both general and movement-specific, do not significantly influence perceptual judgements of either TD adults or adults with DCD in relation to the 'passability' of apertures either from standing still or during an approach phase. However, in relation to the execution of this movement behaviour, i.e. walking through the apertures, the findings suggest that adults with DCD show different turning behaviours to TD adults. Specifically, the adults with DCD showed higher critical ratios (i.e., start turning for bigger apertures) and bigger relative safety margins (i.e., leave more space beyond their own body width to safely pass through) than the TD adults. This supports findings from previous research.

Although in the adults with DCD lower movement-specific self-efficacy correlated with bigger relative safety margins where it did not in the TD adults, none of the wellbeing variables included in the regression analyses predicted either critical ratio or relative safety margin while walking through the apertures. In this regard, the only significant predictors of relative safety margin were movement ability - whether participants had typical motor skills or motor skills consistent with DCD, as measured by their ADC scores - and the consistency of their movement (i.e. movement variability), as measured by how much they moved side to side during the movement task.

Finally, neither task condition (static perceptual judgement, dynamic perceptual judgement or executed action) nor group (TD adults or adults with DCD) had a significant effect on the aperture size at which behaviour changed from walking straight ahead to turning shoulders to go through. Despite this finding, correlational evidence did suggest a more firmly linked perception-action cycle in the TD adults as compared to the adults with DCD.

Together, and along with the findings from the previous study, these findings further support studying perception and action in tandem to elicit the differing constraints that may influence the processes involved in both and among different populations. Considering the findings from the current, preceding and first questionnaire study (see Chapter Three) through a comparative lens, the differences between these, along with the possible reasons for and implications of this will be discussed in the following chapter.

Chapter Seven: General Discussion and Conclusions

7.1 Summary

To orientate the ensuing general discussion, the key components and findings of the three studies comprising this thesis will first be summarised to offer a clear overview.

The first study (see Chapter Three) examined the relationships between general and movement-specific anxiety, self-efficacy, general resilience and self-concept in adults with DCD and TD adults aged 18 to 60 years. Seventy-four adults with diagnosed DCD, 26 adults with suspected DCD and 79 TD adults completed an online questionnaire composed of a mixture of existent psychometric measures and novel scales. The results indicated that general and movement-specific anxiety, self-efficacy and general resilience were all poorer in adults with diagnosed and suspected DCD compared to TD adults. Higher resilience was related to higher self-efficacy and lower anxiety in adults with DCD. Individuals with suspected DCD for whom motor skills difficulties were an important aspect of their self-concept had lower movement-specific self-efficacy. The principal conclusion of this first study was that interventions to improve the psychosocial wellbeing of adults with DCD should include a focus on lowering anxiety and building self-efficacy and resilience, with particular attention to movement-related domains. Its implications will be discussed together with those of the subsequent two studies at a later point.

The second study (see Chapter Five) investigated the roles of anxiety, self-efficacy, resilience, and motor control (one's ability to move consistently) in how TD adults think they will behave (their perceptual judgement) and how they actually behave (their executed action). Forty-one adults with typically developing motor skills (33 female: 8 male) aged 18-55 years completed a questionnaire composed of the Adult DCD/ Dyspraxia checklist, several standardised scales and two movement-specific scales which together aimed to measure different aspects of anxiety and self-efficacy. Following this they completed a perceptual judgement task and an executed action task. In the perceptual judgement task participants judged whether they would need to turn their shoulders or not to walk through different sized apertures between 0.9 and 1.9 their shoulder width-to-aperture ratio. This involved a static condition (judging from standing still 6.5m away) and a dynamic condition (judging after walking forwards to 4.5m away from the aperture). The executed action task involved actually walking through different sized gaps between the doors. Statistical analyses were undertaken using questionnaire and motion capture data.

The results indicated that higher movement-specific anxiety leads to TD adults leaving bigger safety margins when walking through apertures. This ‘cautiousness’ was not however reflected in their perceptual judgements. The results furthermore indicated that the point of behaviour change - the critical ratio - differed significantly between static perceptual judgement (what participants said they would do while standing still) and executed action (the actual movement behaviour). Together these findings further highlight the importance of studying perception and action in tandem, given that they can be subject to different constraints, while also highlighting how important the specificity of measures is in being able to detect nuanced relationships between wellbeing factors and the perception-action cycle. This study aimed moreover to act as a springboard for exploring these same relationships in adults with DCD as compared to TD adults.

In light of this, the third and final study (see Chapter Six) investigated the roles of anxiety, self-efficacy, resilience, and movement variability in the perceptual judgements and executed actions of adults with DCD as compared to TD adults. There were 34 participants in total: 17 adults with DCD and 17 TD adults aged 18 to 60, matched as closely as possible by sex and age. Participants followed the same procedure as described in the above summary of the second study, apart from the addition of the MABC-2 completed on arrival before any of the tasks began by participants in the adults with DCD group.

The results from this study did not echo those of the previous study in relation to TD adults, and they suggested that movement-specific as well as general anxiety and self-efficacy do not significantly influence the static or dynamic perceptual judgements of the ‘passability’ of apertures in adults with DCD or TD adults. What’s more, neither anxiety nor self-efficacy were shown to significantly influence turning behaviour (critical ratio and relative safety margin) in the executed action task. However, the results did suggest that adults with DCD show different turning behaviour to TD adults in terms of both higher critical ratios and bigger relative safety margins, which supports findings from previous research. Moreover, movement ability and level of movement variability - or how consistently participants moved - significantly predicted relative safety margin. Finally, although task condition and group were not found to significantly affect turning behaviour, correlational evidence pointed towards a stronger link between perception and action in the TD adults than in the adults with DCD. Together with the findings from the second study, these results once again illustrate how important it is to study perception and action together, especially when comparing different populations, to gain insight into how these may be constrained differently by individual-, task- and environmental-based constraints.

The findings of these three studies will now be examined through a comparative lens, considering potential wider explanations and implications, as well as the limitations involved and the potential effects of these.

7.2 Wider explanations

In assessing the findings of the three studies together, there are two overarching aspects to be addressed. The first of these centres on the clear differences in anxiety and self-efficacy levels between adults with and without DCD found in the first study, and the unexpected finding that these did not significantly affect perceptual judgements or executed actions in the third study. The second of these relates to the set of surprising disparities between the findings in study two of TD adults only and the findings in study three comparing TD adults with age- and sex-matched adults with DCD.

As regards the first point, it was identified that levels of anxiety and self-efficacy, both general and movement-specific, were not as significantly different across groups (i.e., between adults with DCD and TD adults) in the sample who participated in study three as compared to the sample who participated in study one (see section 3.5.1 and Table 6.2). It is notable that the sample sizes differed greatly between these studies, although the age range and mean age of participants across both samples are similar. As such, study three may not have benefitted from the statistical power offered by a much bigger sample in terms of being able to detect any underlying differences between adults with and without DCD.

Another consideration is the methodological difference between the studies, and the potential influence of this on participant recruitment. That is to say, choosing to take part in a 15-minute online questionnaire and choosing to take part in a lab-based movement study are very different experiences as a research participant. Perhaps those adults with DCD who volunteered to come into a lab to take part in a study assessing their perceptual judgements and their movement may be among those in the population who actually have higher self-efficacy and lower anxiety than other adults with DCD to whom choosing that kind of experience may not appeal. If this were the case, it may have acted as a potential mitigating factor against being able to detect any underlying effect of high anxiety or low self-efficacy on perceptual judgements and / or executed actions across the groups. Indeed, the 'self-selection' of those individuals with DCD who choose to participate in research may even have implications for the broader understanding of the condition particularly in terms of its psychosocial impacts. For example, if there is a greater tendency for those with lower anxiety and higher confidence to take part in research on DCD then it challenges the possibility for such research to gain a genuine insight into the whole picture, particularly in terms of understanding the interactions between motor difficulties and secondary impacts of the condition.

As regards the surprising disparities in findings between studies two and three, there are several aspects to consider. The first is the striking difference in findings regarding the effect of movement-specific anxiety on relative safety margin. As noted in the previous chapter, it was surprising that higher movement-specific anxiety led to bigger relative safety margins in the sample of TD adults in study two, while this was not found in either the TD adults or the adults with DCD in study three. However, this may have been affected by the sample size differences between the two studies and the associated difference in statistical power between the two. As mentioned in relation to the previous point, the comparatively lower statistical power of the samples of TD adults (N=17) and adults with DCD (N=17) in study three as compared to the sample of TD adults in study two (N=41) may have mitigated against the possibility of detecting any underlying effects in both groups or indeed any differences in effect or effect strength between the two groups.

Another element at play could also have been the demographic differences between the samples in each study. In terms of these, although the age ranges were very similar across the samples in both studies, the mean age in study two was lower than that of both groups in study three. A more striking difference however is the percentage of female and male participants across the studies. In study two 80.49% of participants were female, whereas in both group samples in study three only 58.82% were female. It is possible that sex differences could have a role in the relationship between movement-specific anxiety and turning behaviour (i.e. the size of relative safety margin) in light of previous research suggesting that anxiety can manifest differently in males and females (see e.g., Armstrong & Khawaja, 2002; Christiansen, 2015). Although it is beyond the scope of this thesis to address this further, the potential impact of sex could be a useful factor to consider in future studies considering these relationships or even an interesting future research focus in both individuals with typical and atypical motor development.

In light of previous research into anxiety specifically, as has been noted it was especially surprising to see no effect of anxiety - generalised or movement-specific - on perceptual judgements about prospective movements or on movement behaviour itself in either group, but particularly in the DCD group where this effect was most expected. However, in light of the finding that ADC score - used as a proxy for group based on movement ability - was a significant predictor of relative safety margin, it is possible that the movement difficulties experienced by those in the DCD group may in fact have accounted for any underlying effect of anxiety. This turns the discussion once again towards the question of measurement tools. It is possible that the anxiety measures used in studies two and three were not sensitive enough to tease out the potentially underlying effect of anxiety from the effect of movement impairment on movement behaviour - and perhaps even on perceptual judgement of movement behaviour - in the adults with DCD. This limitation and its implications for both this body of research and future studies in this area will be discussed further in the following section.

Returning to a final point of comparison between the findings of study two and study three, arguably dynamic perceptual judgement and executed action were shown to be more closely linked in the sample of TD adults (N=41) from study two and in the sample of TD adults (N=17) from study three, than in the sample of adults with DCD (N=17) from study three. These findings could signal that certain stages involved in the perception-action cycle may be more firmly linked in TD adults than in adults with DCD. This offers support for aspects of the wider theoretical frameworks explored in Chapter One, and in particular within the ecological approach for Wade & Kazeck's (2018) concept of DCD resulting from a deficit in the perception-action loop. The data resulting from the current studies can therefore be seen to fit within the wider theoretical landscape.

7.3 Limitations

There are a range of limitations to the research undertaken to comprise this thesis and with various implications. Some of these have been touched on already and pertain specifically to only one or two of the individual studies, while some are related to the body of research as a whole and to the wider field of research into perception and action in individuals with typical and atypical motor skill development.

One consideration to be borne in mind when interpreting the results across the three studies was the focus on gross body movements and mobility on foot in the movement-specific anxiety and self-efficacy scales. Mobility on foot is only one sub-category of motor skills and the motor effects of DCD relate to all categories of motor skills which extend further than navigating the everyday environment on foot. Therefore, findings related to movement-specific anxiety and movement-specific self-efficacy across the studies may be limited to these domains of movement.

Turning to now discuss a principal limitation related to measurement in studies two and three only, as has been described and referred to in Chapters Four, Five and Six, critical ratio was measured in two different ways. The details of each method, the reasons for choosing them and the advantages they facilitated in allowing comparative analyses across task conditions alongside more nuanced insight into movement behaviour have already been discussed. Consideration will be given here to the impact on the studies comprising this thesis of broader issues and limitations faced by research in the field of perception and action in terms of measuring critical ratios - the point at which one behaviour switches to another behaviour - across the processes of perceiving affordances and executing movement behaviours.

The approaches taken in studies two and three were chosen for clear reasons. To re-summarise, the 50% method allowed comparison of critical ratios across the three task conditions: static perceptual judgement, dynamic perceptual judgement and executed action (Warren, 1984; Harris & Wilmut, 2020). A drawback to this was an inevitable loss of nuance in capturing the executed action critical ratio which may have led to it being higher or lower than values seen in previous related research which used different methods applied to richer movement data. To mitigate against such a loss of nuance and potential accuracy in capturing critical ratio in the executed action data, as described previously another method taken by certain other previous studies of movement through apertures was also used (Warren & Whang, 1987; Wilmut & Barnett, 2011; Wilmut et al., 2015; 2017).

Although the use of parallel methods described above facilitates useful comparisons of the results of the current research with the previous studies referenced here, it does point towards the unavoidable question of what constitutes the capturing of a 'true' value for critical ratio in terms of both perceptual and movement behaviour. This question is amplified by the fact that several other previous studies of affordances and perceptual and movement behaviour change using the aperture-task paradigm have actually used different methods still for calculating critical ratios (see for example, Hackney & Cinelli, 2011; 2013; Hackney et al., 2015). This illustrates an ongoing methodological inconsistency in certain areas of perception-action research that may limit the extent to which findings across studies may be usefully compared. However, it also serves to further highlight the reasons for which the methods employed in the current studies were chosen, so that the critical ratios *could* be usefully compared to those that had been calculated in previous studies of individuals with DCD.

Another limitation in terms of measurement was the use of anxiety tools that had a limited scope given their nature as questionnaires based on self-report and which only focused on certain types of anxiety. Linking back to the points made in Chapter Six (section 6.7) regarding Parr et al.'s (2020) detection of a relationship between task-specific anxiety and movement behaviour in children with DCD, the scales used in the current studies only considered general and movement-specific anxiety and did not ask about anxiety directly in relation to the task. Although it was beyond the scope of the research undertaken in this thesis, the use of more nuanced and sensitive tools may have offered more insight into any underlying relationships between anxiety, perception and action.

Indeed, one or several physiological measures of anxiety may have been the most effective tools, given the nature of movement and motion capture research. This would facilitate the comparison of one behavioural-physiological factor (i.e. movement) and another (i.e. physiological measure of stress at the point of perceptually judging or executing the movement behaviour). Physiological measures of anxiety that have been used in previous psychological research include, for example, heart rate, electromyography which measures electrical activity during musical response, eye movements, pupillometry which measures pupil reactivity and size, electrodermal activity (EDA) which measures the state of sweat glands based in the skin (Kantor, Endler, Heslegrave & Kocovski, 2001; Meer, Breznitz & Katzir, 2016; Tichon, Wallis, Riek & Mavin, 2013; Roos et al., 2022). Some previous research into both clinical and non-clinical anxiety has benefited from using self-reported and physiological measures in tandem to gain insights both into the relationships between these and to explore which of the various components of anxiety - including for example affective, cognitive, motivational and physiological aspects - mediate the performance of different kinds of activities including academic presentations and reading (e.g., Kantor et al., 2001; McLeod, Hoehn-Saric & Stefan, 1986; Meer et al., 2016; Roos et al., 2022).

In relation to movement research specifically, this combination of self-report and physiological measures has previously been used by Pijpers, Oudejans, Holsheimer & Bakker (2003) to study and compare the subjective, physiological and behavioural manifestations of anxiety during a climbing activity which had induced low- and high-anxiety conditions. The results suggested that anxiety manifested on all three levels to a greater extent during the high-anxiety climbing condition: participants self-reported higher state anxiety, had significantly higher heart rates, showed more muscle fatigue and greater blood lactate concentrations, and interestingly also exhibited different movement behaviour demonstrated by longer climbing times and increased geometric index of entropy (which can be defined as the movement of the centre of mass from an 'ideal' trajectory line; lower geometric entropy is associated with lower energy expenditure and more economical movement during climbing (Watts, España-Romero, Ostrowski & Jensen, 2019). It would therefore be interesting to build on the research undertaken to comprise this thesis by incorporating physiological as well as with self-report tools to measure the different facets of anxiety and to gain further insight into how these may relate to one another and to perceptual judgements of affordances along with the associated execution of movement behaviour.

7.4 Implications

Each of the three studies described and discussed in this chapter has standalone implications, while there are also implications regarding the body of research taken together and from each study in relation to one another. Each of these elements will be addressed in this section.
The findings from study one (see Harris, Wilmut & Rathbone, 2021) build on research into the ongoing secondary impacts of DCD beyond childhood and adolescence in terms of factors affecting mental wellbeing including anxiety, self-efficacy, resilience, and self-concept. These offer novel insights into the impacts of these under and unexplored factors on

general and movement-specific domains in adulthood for individuals with both diagnosed and suspected DCD. These findings highlight the important role of resilience as a protective factor to be harnessed in the development and use of strategies to effectively manage the secondary impacts of DCD. The relationships between the factors explored in study one – general and movement-specific – illustrate the importance of addressing all the aspects of an individual's perception and experience, and especially of considering how they are linked together and can potentially therefore affect one another. Finally, the findings from study one open a new conversation about self-concept and DCD in adulthood, suggesting further pathways for research to explore which will be discussed further in the following section.

Although in standalone terms the findings from study two only offer insights relevant to adults with typically developing motor skills, in this regard they are nonetheless valuable in that they add to the evidence base for the existence of a perception-action cycle in which perceptual judgements and executed actions are subject to differing constraints. This further reinforces the argument within the broader research area for studying perceptual judgements and their related movement behaviours together without assuming that one may be taken as a proxy for the other (Newell, 1986; Richardson et al., 2008; Warren & Whang, 1987; Wilmut & Barnett, 2010; 2011). What's more, study two's findings offer some initial and novel insight into the existence of a relationship between emotion and action: in this case between anxiety about movement on foot around everyday environments and the movement behaviour involved in walking through apertures of different sizes relative to one's own body width. This aspect of study two's findings also has wider implications for methodological choices in future work that could build on this research in terms of measure type and specificity when trying to detect potentially highly nuanced links between how individuals *feel* and how they *act*.

Thirdly, the findings from study three considered from a standalone perspective offer different implications than when they are considered in relation to the findings of studies one and two. When considered alone, they are unable to offer insight into the existence or nature of any relationship between the emotional factors examined (anxiety and self-efficacy) and either perceptual judgements or executed actions. In standalone terms, the results of this third study principally support findings from previous research in illustrating the differences in perception during movement behaviour - or action perception - between adults with DCD and adults with typically developing motor skills. Although this is a somewhat limited implication, in light of how limited the research into the relationship between perception and action in adults with DCD still currently is, it is still a valuable contribution to this foundational evidence base in this particular population (see e.g., Wilmut et al., 2015).

Moreover, study three's findings do also point tentatively towards the perception-action link operating differently in adults with DCD compared with their typically developing peers. This in itself implies some tentative support of initial evidence of deficits in visual-motor mapping and cognitive-motor integration, and feeds into the theoretical notion of a 'disrupted' - or in more ecological terms a 'differently constrained' perception-action cycle or loop in individuals with DCD than in typically developing individuals (see e.g., Blank et al., 2019; Subara-Zukic et al., 2022; Wilson et al., 2018). This implication is bolstered further when study three and study two's findings are considered in relation to one another.

Indeed, when the findings of all three studies are considered in relation to one another, the implications shift and broaden somewhat. Linking back to a point raised previously, the differences in findings between the studies lead to a further questioning of whether anxiety plays a role in movement behaviour in individuals with DCD. If it does, there remains the question of the extent to which this may be masked by the motor impairment itself and also whether *level* of motor impairment may have a role in this regard. Indeed, the differences in findings in the context of the differing sample sizes and demographics implies that some interesting underlying relationships may exist between emotional factors, perceptual and movement behaviour in adults with typical and atypical development; yet more research would need to be undertaken, with larger sample sizes across both populations to increase statistical power as much as possible and with more sensitive and varied emotion-related measures to further detect and gain insight into their nature and strength.

It is noteworthy that one of the principal findings in study one related to resilience: higher resilience was shown to significantly relate to higher self-efficacy and lower anxiety in adults with DCD. However, for statistical reasons regarding the multicollinearity shown in the data from studies two and three between resilience and the other wellbeing factors (general and movement-specific anxiety and self-efficacy), it was not possible to further examine the role of resilience as a distinct affective construct in relation to perceptual and movement behaviour. This could be a useful and interesting focus for future research, as will be discussed further in the following section.

As a final point regarding measurement in this section, the debate surrounding methods for calculating critical ratio also highlights the comparative clarity afforded by the measurement of relative safety margin as a complementary or alternative measure of movement behaviour within the context of this task paradigm.

7.5 Future Directions

The research undertaken in this thesis points towards several possible paths that future work could build on.

One aspect relates to the measures of movement-specific anxiety and self-efficacy. Future research building on the initial development by the current studies of emotion-related movement-specific scales could develop these beyond the limited domain of mobility on foot. These could be expanded to address all of the key elements of fine and gross motor skills covered, for example, by the MABC-2. By doing so, findings regarding movement-specific emotion in relation to perceptual judgements and/or executed actions could be extended and interpreted more broadly.

As alluded to in the previous section, and linking to the points made regarding both the sensitivity and specificity of measurement tools used in the current research, future work building on this could refine the choice of measurement as regards resilience. Both an interesting and useful avenue to explore would be the design and development of a tool focused specifically on resilience in the domains of movement and motor skills specifically. This could potentially open a door to further insight into resilience as a protective factor not only in psychosocial terms, but perhaps even with regard to confidently and effectively perceiving and navigating the daily environment for adults with DCD.

Another aspect that future research could address is the further study of self-concept among adults with DCD and without DCD, and especially their self-concept with regard to movement domains. Future work could develop and/or use tools that aim to measure the emotional valence of responses. This could cultivate the nascent conversation about self-concept and movement in adults - and especially among adults with DCD - begun by Study One, so that useful and insightful comparisons may be made with the other research to date that has examined self-concept among children with DCD.

Indeed, future work building on the methodological choices and subsequent findings of the current studies could benefit from taking a different approach to the measurement of emotional factors, perceptual and movement behaviour for the reasons discussed in the previous sections of this chapter. It could do so by using a wider range of measurement tools designed with both specificity and diversity in mind with the aim of capturing as broad yet as nuanced a picture as possible of the web of potential relationships between these elements. These could include both questionnaire-based and physiological measures where possible and appropriate, for example to measure physiological manifestations of anxiety.

As regards the challenges inherent in attempting to measure perception or perceptual judgement, future work using the aperture-crossing paradigm could take a different approach in an effort to capture more nuanced data by asking participants to stand in the exact position at which they *think* they *would* pass through the doors, rather than relying on the more subjective and binary nature of answering the question of 'turn or no turn?'. A complementary piece of this puzzle, also building on findings from the current studies, would be further developing and cultivating the use of alternative or complementary measures of movement behaviour change, such as relative safety margin in the case of the aperture-crossing paradigm. This could help mitigate the debate surrounding the different methods for measuring and calculating critical ratios discussed earlier in this chapter.

Finally, it would be beneficial to test whether the findings of the current studies would replicate, were they to be undertaken with bigger sample sizes from the same populations. This would facilitate gaining insight into the role of statistical power and whether this may be a key element in detecting any underlying relationships that may exist between anxiety, self-efficacy, perceptual judgement and executed action.

7.6 Conclusions

Drawing together the findings from and reflections on the three studies comprising this thesis, several conclusions emerge. The first is that interventions to improve the psychosocial wellbeing of adults with DCD should include a focus on lowering anxiety and building self-efficacy as well as resilience, with particular attention to movement-related domains. This would offer a potentially valuable contribution toward the effective development of strategies to manage motor skills difficulties and their impact on everyday life for adults with DCD.

Another conclusion to emerge is that although the findings were limited in the current research, they do offer initial evidence of relationships between some of the wellbeing factors examined - namely movement-specific anxiety - and movement behaviour in adults with typically developing motor skills. For the varied reasons discussed throughout this chapter, future research using bigger samples for more statistical power and with a range of more sensitive measurement tools would be needed to examine whether and to what extent this and other relationships between anxiety, self-efficacy and even resilience may actually exist in both typically developing adults and adults with DCD, the latter being a population in which it may be particularly challenging to tease apart the effects of anxiety and other affective elements from the effects of the motor difficulties themselves.

What's more, the findings offer valuable further evidence that perceptual judgement and executed action are constrained differently and by different factors in adults with and without DCD. This further supports the notion that it is crucial to study perception and action together and that conclusions about one may not be applicable to the other. The support and additional nuance offered by the current findings to build on previous research into the wellbeing, perceptions, and actions of adults with DCD are valuable contributions to a research area that remains relatively limited, yet of a widely acknowledged importance. Beyond their specific relevance to adults with DCD, the findings from the studies comprising this thesis also offer some initial novel insights into the possible roles of emotion and wellbeing in the relationships between perception and action in typically and atypically developing adults.

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Appendix 1

Movement-Specific Self-Efficacy and Anxiety Scales

Please rate **your ability** to carry out these actions in a **quiet environment** (for example, on a path with no other or very few other people around) by recording a number from 0 - 100 using the scale below.

If you wish to answer with '0', please click on the grey vertical line until it turns blue and slide it back to '0'. Otherwise, move it to any number between 1 and 100 that you wish to.

	Cannot do at all / Can do fairly well / Can do very well 0 10 20 30 40 50 60 70 80 90 100
Moving past objects without bumping into them (for example, past displays in shops) ()	
Estimating the space I need when walking between two objects (for example, between tables in a restaurant or two parked cars) ()	
Being able to move from A to B without tripping / falling / bumping into things along the way (for example, from the entrance in a café to the table you wish to sit at) ()	
Walking on an uneven surface without tripping (for example, a rocky path or a broken pavement) ()	
Avoiding an obstacle that appears in your path (for example, a dog running out in front of you) ()	

Please rate the **degree of anxiety** you generally feel regarding your ability to carry out these actions in a **quiet environment** (for example, on a path with no other or very few other people around) by recording a number from 0 - 100 using the scale below.

If you wish to answer with '0', please click on the grey vertical line until it turns blue and slide it back to '0'. Otherwise, move it to any number between 1 and 100 that you wish to.

	Not at all anxious / Fairly anxious / Highly anxious 0 10 20 30 40 50 60 70 80 90 100
Moving past objects without bumping into them (for example, past displays in shops) ()	
Estimating the space I need when walking between two objects (for example, between tables in a restaurant or two parked cars) ()	
Being able to move from A to B without tripping / falling / bumping into things along the way (for example, from the entrance in a café to the table you wish to sit at) ()	
Walking on an uneven surface without tripping (for example, a rocky path or a broken pavement) ()	
Avoiding an obstacle that appears in your path (for example, a dog running out in front of you) ()	

Please rate **your ability** to carry out these actions in a **busy environment** (for example, on a path crowded with people, bicycles and / or dogs being walked) by recording a number from 0 - 100 using the scale below.

If you wish to answer with '0', please click on the grey vertical line until it turns blue and slide it back to '0'. Otherwise, move it to any number between 1 and 100 that you wish to.

	Cannot do at all / Can do fairly well / Can do very well 0 10 20 30 40 50 60 70 80 90 100
Moving past objects without bumping into them (for example, past displays in shops) ()	
Estimating the space I need when walking between two objects (for example, between tables in a restaurant or two parked cars) ()	
Being able to move from A to B without tripping / falling / bumping into things along the way (for example, from the entrance in a café to the table you wish to sit at) ()	
Walking on an uneven surface without tripping (for example, a rocky path or a broken pavement) ()	
Avoiding an obstacle that appears in your path (for example, a dog running out in front of you) ()	

Please rate the **degree of anxiety** you generally feel regarding your ability to carry out these actions in a **busy environment** (for example, on a path crowded with people, bicycles and / or dogs being walked) by recording a number from 0 - 100 using the scale below.

If you wish to answer with '0', please click on the grey vertical line until it turns blue and slide it back to '0'. Otherwise, move it to any number between 1 and 100 that you wish to.

Please try to disregard the current COVID-19 situation when thinking about how anxious you would usually feel in a busy environment like this.

	Not at all anxious / Fairly anxious / Highly anxious 0 10 20 30 40 50 60 70 80 90 100
Moving past objects without bumping into them (for example, past displays in shops) ()	
Estimating the space I need when walking between two objects (for example, between tables in a restaurant or two parked cars) ()	
Being able to move from A to B without tripping / falling / bumping into things along the way (for example, from the entrance in a café to the table you wish to sit at) ()	
Walking on an uneven surface without tripping (for example, a rocky path or a broken pavement) ()	
Avoiding an obstacle that appears in your path (for example, a dog running out in front of you) ()	

Appendix 2

The contents of a published article have been removed from this version of the thesis due to copyright restrictions.
Harris S, Wilmut K and Rathbone C, Anxiety, confidence and self-concept in adults with and without developmental coordination disorder, *Research in Developmental Disabilities* 119
https://doi.org/10.1016/j.ridd.2021.104119