Perceptual errors in predicting vehicle approach in typical and atypical populations

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Declaration of Authorship

I Catherine Purcell hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Signed:

Date:

Abstract

As a pedestrian at the roadside, the two most informative cues as to the distance and rate of closure of a vehicle are its optical size and the rate of expansion of the optical image. In addition, the time to arrival of an approaching vehicle can be perceptually estimated by the ratio of these two variables, referred to as tau (Lee, 1976). Sensitivity to optic expansion is critical for collision avoidance and was measured in populations of adults, typically developing children, and in children with Developmental Coordination Disorder (DCD), an idiopathic condition characterised by marked impairments in motor coordination that negatively impact on activities of daily living.

A central tendency was found in adults (*n* = 193) between 18 to 59 years of age to make significant errors in judging the approach rates of two vehicles. Inflated errors were observed in children (*n* = 136) between 6 to 17 years of age, with decreased sensitivity in the youngest age group (6 to 11 years). Furthermore, a significant decrement was found in children (*n* = 9) with DCD between 6 to 11 years of age. Across all groups, a systematic vehicle size bias was found, whereby faster small vehicles were perceived as travelling slower than larger vehicles. This pattern of results suggest that in general, observers are not utilising tau in judgments of relative approach rates for speeds typically encountered at the roadside, but instead rely on optical expansion that does not compensate for image size. Errors due to a reliance on optic size were inflated in children with DCD, potentially placing them at significantly greater risk at the roadside.

To examine the decreased sensitivity observed in DCD, thresholds for detecting visual looming were measured in children (*n* = 11) with DCD between 6 to 11 years of age. A significant deficit was found when vehicles were presented in perifoveal vision,

whereby children with DCD may perceive vehicles that are 5 seconds away as stationary if they are travelling any faster than ~14 mph. This demonstration of a low-level visual processing deficit could suggest an immaturity in the dorsal stream network and explain some of the difficulties that characterise DCD.

Critically, perceptual judgments at the roadside are inextricably linked to the motoric capability of the observer. If a pedestrians crossing time is greater than the time available, collision will occur. Crossing gap thresholds were measured and compared to walking times for a single vehicle approaching at varying speeds. Children (n = 9) with DCD between 6 to 11 years of age left considerably longer temporal crossing gaps than their action capabilities necessitated. However, when children with DCD were presented with multiple vehicles in a virtual reality environment, they accepted crossing gaps at all approach speeds that were shorter than the time it would take them to cross. This suggests that children with DCD may not have the perceptual accuracy to predict their required action gaps in a road crossing situation.

One explanation for these findings could be a difference in DCD in how vision is dynamically allocated to facilitate the preparation of goal-directed actions. Dynamic allocation of visual attention was assessed in a series of experiments that measured eye movement latencies and hand movement accuracy in children (n = 5) with DCD between 6 to 11 years of age. Both measures were found to be comparable in DCD with their typically developing peers regardless of task complexity, indicating that the allocation of visual attention is not deficient in children with DCD.

The prospective control of movement in our everyday lives is critically depended on estimating the immediacy of approaching objects. Combined, these results indicate that children with DCD may be particularly vulnerable at the roadside due to a visual motion processing deficit, consistent with atypical function across broad neural structures such as the dorsal stream.

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Publications

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Chapter 4, Chapter 5, Chapter 6 and Chapter 7 have been presented at refereed conferences with peer-reviewed published abstracts:

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Chapter 1: General Introduction

1.1. Introduction

Development can be considered an adaptive change toward competence and involves the integration of environmental information from multiple sensory modalities that operate in parallel, with the development of one sense intimately linked to the development of another. The ability to perceive the world around us begins its development at birth, but spatially coordinated behaviours, such as reaching, catching a ball or safely executing a road crossing, demand that perceptual information and action are coupled. The function of the visual system is therefore, both to act on the world and represent it.

A critical perceptual-motor skill is the ability to detect and avoid objects on a direct collision course. Failure to select an appropriate response in order to avoid a collision, at the roadside, can have serious consequences. Globally, pedestrian accidents are the third leading cause of death among children between 5 to 9 years of age, with visual limitations in gauging speed and distance cited as a key deficit at the roadside (Toroyan & Peden, 2007). Despite an increasing trend for primary school children to walk to and from school (48%; DfT, 2009) and the alarmingly high proportion of pedestrian accidents involving children, there has been limited research investigating the perceptual accuracy of children for judgments typically made as a pedestrian. Research that has addressed perceptual acuity in pedestrian and driver populations have largely focused on typically developing children and adults, and less so on children demonstrating atypical development, and there has been no systematic examination of the behaviour of children with known motor coordination difficulties at the roadside.

This thesis aims to fill this gap and add to our knowledge of typical and atypical perceptual development in the context of road crossing.

1.2. How do we avoid collisions?

The ecological approach to visual perception (Gibson, 1979) underlined the importance of dynamic visual information for both perception and the online control of movement. As an animal navigates through its environment, flow patterns across the whole retina inform the animal of its heading and rate of motion, whereas the path of a moving object through space can be perceptually discerned by motion of a small part of the retinal image relative to other parts of the image that remain static. The symmetrical expansion of the contour of an object (looming) provides an ecologically valuable signal indicating that an object is on a direct collision course with an animal and informs the immediacy of collision. Collision avoidance is crucial to an animal's survival and despite differences in visual systems almost all animals demonstrate sensitivity to visual looming. For example, Sun and Frost (1998) identified 85 neurons sensitive to visual looming in the dorsal region of the nucleus rotundus (Rt) of pigeons, they classified three classes of neurons, one of which was found to systematically initiate a response at the same time-to-contact[1] (TTC), regardless of the approaching objects size and velocity. In locusts, the Lobular Giant Movement Detector (LGMD) neuron and the Descending Contralateral Movement Dector (DCMD) were found to preferentially respond to looming stimuli on a direct collision course (Peron & Gabbiani, 2009). In addition to avian and insect species, looming sensitive neurons in

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[1] Various terms exist for the description of when an object will reach or pass an observer, these include: time-to-contact; time-to-collision; time-to-passage; time-to-arrival; and time-to-coincidence. As this thesis primarily describes approaching objects that do not pass the observer the term time-to-contact will be used.

many other locomotor animals have been reported, such as in the crab (Oliva & Tomsic, 2007).

Billington, Wilkie, Field and Wann (2011) measured the BOLD responses of ten neurotypical adults to an expanding and contracting 24 cm ball travelling at constant velocity (3.1 m/s). In agreement with regions identified in rapid responses to threatening stimuli in the avian species (e.g. Sun & Frost, 1998), comparative regions in human observers, namely the superior colliculus and pulvinar nucleus of the thalamus were found to respond to looming stimuli, as well as cortical regions associated with motor preparation. These findings reinforce those of Field and Wann (2005) who demonstrated that the neural systems involved in the computational task of extracting TTC from optical expansion information are closely associated with sensorimotor systems involved in preparing a timed motor response, such as collision avoidance or catching a ball. In both studies, looming patterns interpreted as motion in depth toward the observer, which specified an impending collision, activated the dorsal stream network associated with action response preparation.

Throughout the past three decades there has been an appealing account of how humans, and animals, make judgments of impending collision from Lee (1976), who proposed that the retinal expansion of an approaching object is sufficient to prompt an appropriate behavioural response. His work has demonstrated that the TTC of an approaching object, a critical computation for both interceptive actions and collision avoidance, can be determined by the ratio of its distance, $z(t)$, and velocity, $v(t)$, which can be perceptually specified by the ratio of optic size $\theta(t)$ to the rate of looming $\dot{\theta}(t)$:

$$TTC = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} = tau \qquad (1)$$

The theoretical appeal of this ratio, which Lee (1976) termed tau, is that the information necessary for TTC judgments are available without an observer needing to estimate environmental metrics such as distance and velocity, which can be prone to considerable bias as the properties in the scene vary. For example, most distance cues provide an indication of relative distance between objects in a scene, rather than a specification of actual (absolute) distance (see Chapter 5, section 5.1 for example).

According to Lee (1976), as an object approaches an observer, the relative rate of expansion increases and tau decreases, such that at constant approach velocity, the angle $\theta(t)$ subtended by the object on the retina increases exponentially with time and tau specifies TTC between approaching object and observer (see Figure 1.1.).

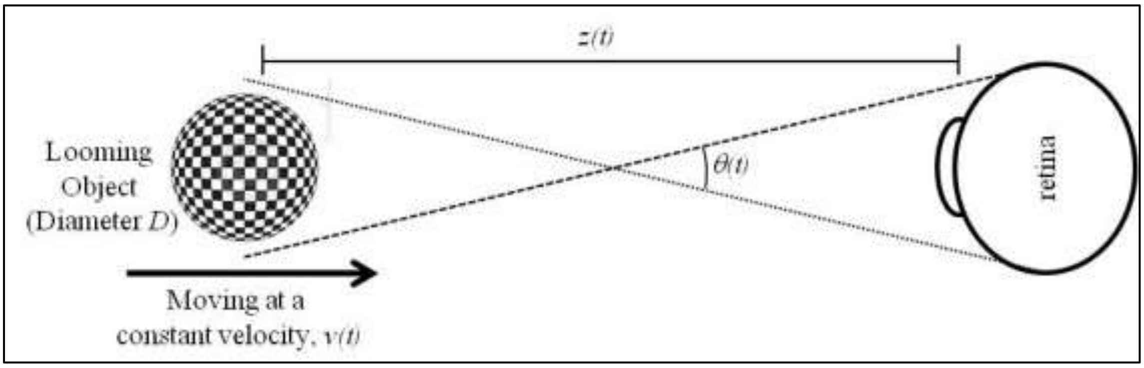

Figure 1.1. A schematic diagram of a looming object of diameter *D* directly approaching the retina at constant velocity *v*, at time *t*, at a distance *z(t)* away, subtends a visual angle of $\theta(t)$.

It follows that the neural circuitry mediating collision avoidance should be preferentially responsive to looming stimuli in order to reliably evoke collision avoidance behaviours. Regan and Beverley (1978) have postulated that the human visual system includes neural networks that selectively process changing size which are organised to be sensitive to expanding and contracting stimuli. Regan and Hamstra (1993) have developed a model for processing changing size and encoding TTC events which incorporates a filter that is activated by isotropic, two-dimensional expansion of a retinal image, which is inversely proportional to the TTC.

1.3. Developing sensitivity to tau

Developmental evidence has found that a transition occurs in infancy such that a reliance on pure optic size at 6 months shifts toward a ratio of optic size to optical expansion (tau) at 12 months (Kayed & Van der Meer, 2009). This transition has been found to coincide with changes in neural activity from 5 to 11 months (van der Weel & van der Meer, 2009). Behaviourally, defensive responses to visual looming have been shown early in development. Ball and Tronick (1971) investigated infant's perceptual sensitivity to symmetrically looming shadows and solid approaching objects. Twenty four infants (eight infants: 2 to 5 weeks of age; eight infants: 5 to 8 weeks of age; and eight infants: 8 to 11 weeks of age) were presented with the percept of a symmetrically looming shadow (collision) and an asymmetrically looming shadow giving the percept of a non-collision object, both approached the infant along a track at 12 cm/sec. They found significant differences between backward avoidance head movements, in the collision compared to the non-collision trials, whilst no differences were found between age groups, suggesting their findings were not a result of learning or exposure. Using a real object (30 cm x 30 cm) seven infants (3 to 6 weeks of age) were exposed to the object approaching on a collision or non-collision path, at an approach rate of 16 cm/sec and the results were similar. They concluded that infants’ as young as 2 weeks of age can distinguish an objects trajectory and relative depth of approach for both solid objects and their optical equivalent.

To examine the strategies used by infants in collision judgments, detailed studies of blink responses to looming virtual stimuli have been conducted. Kayed and van der Meer (2007) demonstrated that infants initially use a strategy based on visual angle (distance) and make a transition to a strategy based on time at around 6 months of age. In their study, a virtual object which initially had a visual angle of 6.18 degrees (diameter 4.32 cm) and expanded to a maximum visual angle of 117 degrees (diameter 130.36 cm), approached on a collision course either at a constant velocity between 1.95 m/s and 5.8 m/s or at constant acceleration between 0.68 m/s^2 and 5.6 m/s^2. Blinking responses were recorded in eleven infants at 22, 26 and 30 weeks of age. They found tuning in perceptual strategy from one based on visual angle (distance) or angular velocity to TTC occurred between 22 and 30 weeks of age. These results suggest that perceptual acuity for defensive responses to an object approaching an infant may be fully developed by 6 months of age. However, a recent study by Wann, Poulter and Purcell (2011) demonstrated that the perceptual system of children between 6 to 11 years of age for detecting looming objects approaching at high velocities is significantly less attuned than adults. The explanation for the difference in findings lies in the nature of the experimental task, but also in the environmental circumstances that the tasks reflect.

In the Kayed and van der Meer (2007) study, the task presented was optically equivalent to a 20 cm ball approaching the infant at between 21 to 64 cm/s. As a result the looming rates $\dot{\theta}(t)$ were equivalent to 18.5 to 55.4 degrees per second and the final TTC that the child would have encountered would have been 0.21 to 0.64 seconds. Wann et al (2011) however, considered the challenge that children face when they start to become independently mobile and are learning to cross the road. In this instance they need to make an action decision (cross or not cross) when an approaching vehicle is approximately 5 seconds away, hence at 20 mph the looming rate is 0.44 degrees per second while at 30 mph it drops to 0.30 degrees per second. The study of Wann et al (2011) suggests that primary school age children may have particular difficulty in perceptual judgments when a vehicle is 5 seconds away once the vehicle approach speeds go above 25 mph. This demonstrates the perceptual acuity needs to be around 100 times greater than has been reported in infancy when children reach an age where they are making judgments of the approach of high speed objects. Importantly, whilst the consequence of a judgment error by an infant would hopefully be minor, an error in judging TTC for a 10 year old child at the roadside could be catastrophic.

1.4. Using tau to differentiate approach rates

Often pedestrians and drivers need to discriminate between vehicles approaching at different rates. If observers are unable to distinguish between the rate of expansion that arises from a vehicle approaching at 40 mph from one at 30 mph, they will fail to notice that the time they have to act will have reduced by 25%. Developmental evidence from preferential looking in infants as young as 20 weeks old has demonstrated that infants are able to discriminate approach speeds between two vertically moving bars at ten paired approach rates, derived from the combination of five possible optical speeds: 2.0, 2.5, 3.3, 5.0 and 10 degrees per second, with a linear relationship showing that speeds between 3.3 and 5.0 degrees per second were distinguishable from 10 degrees per second at this age (Dannemiller & Freedland, 1991). Speed discrimination could be based upon detection of the looming rate, $\dot{\theta}(t)$, or could be based directly upon temporal immediacy (tau). If tau is used in TTC judgments of relative approach rates, then rate of expansion is scaled by optical size and as such vehicle size will not influence TTC judgments. However, if observers rely only on rate of expansion $\dot{\theta}(t)$ in their TTC judgments rather than tau, they may not be able to differentiate between a small vehicle moving quickly and a large vehicle moving slowly. This is because the instantaneous value of $\dot{\theta}(t)$ is determined by the diameter of the object *(D)*, which could be either the width or height of the vehicle, its velocity, *v(t)*, and the square of the absolute distance $z^2(t)$:

$$\dot{\theta}(t) = \frac{Dv(t)}{z^2(t)} \tag{2}$$

Equation 2 demonstrates that there could be a systematic bias whereby smaller vehicles could be perceived as approaching slower than larger vehicles that loom at a greater rate. This size-arrival bias has been demonstrated by for example Caird and Hancock (1994) who found that adult observers underestimated the TTC of full-sized cars and delivery vans (with a large profile) compared to motorcycles and compact cars (with a smaller profile), increasing the risk of collision with smaller vehicles.

According to Lee (1976) if observers are relying on tau to make collision judgments, the size and velocity of moving objects should be irrelevant and a number of studies have provided support for the use of tau in adults' relative approach judgments, using geometric shapes. For example, Todd (1981) presented observers with a simulated display of two gradually approaching squares composed of 24 dots. The squares varied in size (7.6 cm and 38.1 cm) and approach velocities were randomly selected from eight possible values between 6.1 m/s and 27.4 m/s. The initial start distance of the square was varied such that the TTC for one square was fixed at 3 seconds and greater than 4 seconds for the second square. Observers were found to make accurate judgments as to which object would reach the observation point first when the difference in collision times were as small as 0.15 seconds. These findings suggest that participants must have been using tau in their judgments otherwise a size-arrival bias would predict that the larger square would have consistently been judged as reaching the observation point first.

There is also evidence, however, to suggest that judgments could be based on a threshold value for optical expansion, $\dot{\theta}(t)$, rather than tau. For example, Michaels, Zeinstra and Oudejans (2001) found that elbow flexion to punch a falling ball was initiated when $\dot{\theta}(t)$ reached a critical threshold value of between 0.57 and 2.29 degrees per second. Neural evidence, from the locust, supports the notion of behavioural responses being triggered when the rate of optical expansion of an object reaches a critical threshold value (e.g. Fotowat & Gabbiani, 2007).

Alternative explanations for how observers initiate a timed response to approaching objects have led to the suggestion that the visual system can be tuned to various optical variables in TTC judgments, tau is based upon the optical size $\theta(t)$ divided by the rate of expansion $\dot{\theta}(t)$. Alternatively, an optical variable, named eta (η), has been defined as a different combination of θ and $\dot{\theta}$ by López-Moliner and Bonnet (2002), here a constant modulates the magnitude of looming-detector neuron responses, producing a large excitatory response which peaks prior to collision, larger objects reach this peak sooner than smaller objects travelling at the same speed. They used a relative TTC discrimination task to determine which optical variable observers used in the initiation of a manual response. Observers were asked to press one of two buttons to indicate which of two sequentially approaching objects would reach the observation point first. The standard object had a fixed TTC of 1 second and the TTC of the comparison object had six possible values between 0.81 and 1.24 seconds. Nine looming values were selected as a function of ratio size and approach velocity, such that half of the comparison objects had a TTC with a smaller looming rate and half a larger looming rate compared to the standard object. They measured reaction times and accuracy and found that observers initiated a response when the value of η reached a threshold value of 250 milliseconds to 300 milliseconds before contact.

Despite the evidence suggesting that there are alternative optical cues available to observers in TTC judgments, a perceptual myth has developed that skilled human observers can utilise tau to judge TTC with remarkable accuracy, such that positional errors of top sports players are less than 5 cm and temporal errors less than 2 or 3 milliseconds (Regan, 1997). These calculations, however, based on the optimal cricket shot, do not take into account the probability distribution whereby in sport these strokes are often attempted, but seldom achieved, and performance at this level of accuracy is probably two standard deviations above the mean. So what is the mean level of performance for human observers judging objects approaching them? Some studies suggest accuracy in the region of 80 to 100 milliseconds. For example, Gray and Regan

(1998) found that at a viewing distance of 1.6 m, observers were able to make accurate TTC estimates based on the rate of change of binocular disparity, irrespective of the object size (0.7 degrees to 0.03 degrees). Rushton and Wann (1999) also manipulated size and disparity cues in a computer-generated task that involved catching virtual tennis balls. They found that participants' modified their grasp time when rate of expansion specified a TTC that was 100 milliseconds earlier than binocular disparity, whereas disparity was the dominant cue when looming specified a later TTC. From this, the authors proposed a model that is sensitive to both binocular disparity and optical looming, suggesting that the strategy used by an observer is based on whichever optical cue signals the most immediate TTC. This account has ecological appeal due to the survival advantage that it affords.

Only a small percentage of the population participate in sports requiring high precision TTC judgments, whereas most of the population make judgments as to the sufficiency of TTC as a pedestrian or a driver on a daily basis. For example, a pedestrian at the roadside, or a driver waiting to pull out at a junction, attempting to cross two lanes of on-coming traffic, are required to time their action to ensure collision is avoided with both approaching vehicles. One vehicle could be a small motorcycle whilst the other a large bus, therefore the perceptual task is first to notice that the vehicles are approaching, followed by a judgment of how quickly both vehicles are approaching. There is therefore a clear difference between the type of judgments that are made in ball sports and those made for survival at the roadside. In ball sports the principle task is to judge exactly when the ball will arrive (precise TTC) whereas at the roadside, the task is often to judge whether there is sufficient time to execute an action (i.e. TTC > crossing time). Errors in the latter judgment do occur and often result in life threatening consequences. In the UK alone in 2008, a total of 170,591 pedestrians were involved in reported road traffic accidents with adult pedestrians between 16 to 59 years of age accounting for 56% of all pedestrians killed or seriously injured on our roads and children under the age of 15 accounting for 31% (DfT, 2010).

1.5. Selecting suitable crossing gaps

In a road crossing situation, TTC must be judged in order to determine when an approaching vehicle will reach the observer, which informs the time available to cross. A difficulty for young children, in terms of gaining experience at the roadside, is that road crossing usually occurs alongside an adult. Decisions regarding when and where to cross the road are usually made by adults with the children accompanying them (Van der Molen, Van den Herik, & Van der Klaauw, 1983). The risks for children at the roadside have been investigated using various methods. For example te Velde, van der Kamp and Savelsbergh (2008) recruited 5 to 7 year old children (*n* = 20), 10 to 12 year old children (*n* = 14) and adults (*n* = 12) and presented them with a crossing task. The task was to push a doll across a small-scale road between two toy vehicles, which approached one after another. The vehicles approached alternately from the left and right at three constant vehicle speeds (1.1, 1.7 and 2.2 mph) and at three inter vehicle distances (0.15, 0.30 and 0.45 m). They found that 5 to 7 year old children made fewer crossing attempts and collided more frequently (usually with the second vehicle), consistently selecting inter vehicle gaps that were beyond their action capabilities. In addition, the younger children were less able to adjust their own movement speed to the speed of the approaching vehicles and tended to reach the required movement speed late.

Research into the gaps that children accept has also been conducted by Connelly, Conaglen, Parsonson and Isler (1998). Initially they measured walking speeds and found that the youngest children (5 to 6 years of age) had the slowest walking speed over a distance of 4 m (3.16 seconds) with the 8 to 9 year olds faster (2.84 seconds) and the 11 to 12 year olds the fastest (2.77 seconds). The children then made ten gap acceptance judgments for vehicles approaching from the right standing 2 m from the kerbside. Their task was to verbally respond ‘yes’ until the approaching vehicle reached a point at which they would no longer be prepared to cross, at which moment they said ‘no’. A total of 480 vehicles were grouped into five speed categories: 0-31; 32-34; 35-37; 38-40; and over 41 mph. Safe distance indices (m) were calculated by taking the distance gap thresholds obtained from the vehicle speed (m/s) multiplied by the mean crossing times (seconds). They found that the mean safe distance index systematically decreased as vehicle approach speeds increased, reducing from 28.2 m at 0-31 mph to 8.9 m by 41 mph. Safe crossing times also decreased from 2.4 seconds at 0-31 mph to 0.47 seconds at 41 mph. Overall, they found that children below 10 years of age had relatively poor skills at reliably setting safe distance gaps, and therefore consistently failed to make safe crossing decisions, with judgments deteriorating as vehicle approach speeds exceed 34 mph. One criticism of this study could be that it used an unusual measure of road crossing ability. It is unlikely that pedestrians would normally make a judgment of when a gap is no longer large enough, since what is important in completing a safe road crossing is identifying whether a given gap is large enough, not the point at which it stops being large enough.

Using a different approach, Simpson, Johnston and Richardson (2003) designed a virtual environment, consisting of a straight flat 6 m section of road, and investigated the temporal gaps that 5 to 19 year old individuals accepted. Ten vehicles were used in the traffic flow, each had a width of 1.74 m and length of 4.38 m, the first vehicle in each trial passed by the participant within the first 1.5 seconds. This vehicle was included to ensure that participants would collide with it if they crossed immediately after the trial started without looking for traffic. There were two different types of trial: uniform speed, where all vehicles in the traffic flow had the same speed of either: 25, 31 or 37 mph and uniform distance trials where all vehicles were positioned at the same distance of either: 65, 75 or 85 m apart. The time gaps used were either 4, 6, 8 or 10 seconds. They found that the youngest children (5 to 9 years of age) had the highest incidence of collisions and/or tight fits and the oldest participants (>19 years of age) the lowest incidence, as they had predicted. They did not find age differences on any of the timing measures (e.g. crossing time), children as young as 5 years of age behaved in the same way as participants over 19 years of age, even though it would take the 5 year olds longer to cross the road. Participants performed the road crossing task better in the uniform speed trials than the uniform distance trials, suggesting that in general children or adolescents used distance as a guide to safe crossing gaps and did not take speed fully in account, this is consistent with the research by Connelly et al (1998). Interestingly, in the uniform distance trials the more gaps that passed prior to crossing, the shorter the gap actually chosen to cross in. This might suggest that pedestrians would accept smaller gaps if they have to wait to cross. This finding is supported by Hamed (2001) who found that pedestrians who spend more time waiting to cross from the kerb to the centre of the road are likely to have a higher risk of ending their waiting time as they cross from the centre to the far side kerb. However, it should be noted that Connelly et al (1998) did not directly test whether children relied on distance or time information, and that their results could also be explained by a threshold for looming whereby judgments of vehicle approach would be unreliable if the vehicle travelling above the threshold (e.g. 31 mph).

In a separate study using an interactive bicycling simulator in a virtual environment, Plumert, Kearney and Cremer (2007) examined the gaps that children and adults accepted when bicycling across traffic filled intersections. Participants rode a bicycle mounted on a stationary frame positioned in the middle of three 10-foot by 8-foot screens. The task was to cross an intersection without getting 'hit' by approaching traffic from their left-hand side. The traffic travelled at continuous speeds of either 25 or 35 mph, with varying sized gaps between vehicles. They found that relative to adults, children's gap choices were less well attuned to their road crossing behaviour, resulting in children and adults choosing the same size gaps but the children ending up with less time to spare when they cleared the path of the approaching car. This made the margin for error very small, particularly for 10 year old children.

Although the research discussed so far generally shows that young children appear to be worse at making safe road crossing decisions than adults, the visual timing skills required to make safe road crossing decisions have been reported in children as young as 5 years of age. For example Demetre et al (1992) found that children as young as five and six years of age were not markedly different from adults in their ability to make sensible decisions about traffic gaps. Though direct comparisons revealed the children to be generally less skilled than adults as road users, the children were able in some measures to compensate for the deficiencies. In contrast to previous studies, they argue that it would seem highly unlikely that young children's greater vulnerability as pedestrians can be directly attributed to general developmental deficiency in the extraction of temporal information.

A qualitative study by Roberts, Norton, Jackson, Dunn and Hassall (1995) examined 190 cases of child pedestrians aged <15 who were killed or hospitalised after collision with a motor vehicle on a public road during a period of two years and two months. They found that risk was increased at sites with mean speeds over 25 mph as well as associations between risk of pedestrian injury and high traffic volume. The risk of injury for children living in neighbourhoods with the highest traffic volumes was 13 times that of children living in the least busy areas. These results concur with those of Hamed (2001) who found that approaching traffic volume and vehicle speeds were instrumental in determining a pedestrian's waiting time (delay) and the number of crossing attempts. This also agrees with the conclusions of Wann et al (2011) who provided a strong argument for reducing traffic speeds in urban areas as a preventative measure to child pedestrian injuries.

1.6. Immersive virtual reality and crossing gap decisions

Historically, studies considering road crossing behaviour have typically used pretend road paradigms, however, this doesn't necessarily represent a true road crossing environment. An alternative methodology for assessing the crossing gaps that pedestrians accept is the use of immersive virtual environments. Virtual environments have been assessed for training purposes in older pedestrians (also at risk at the roadside) by Dommes, Cavallo, Vienne and Aillerie (2010). In their study 20 participants aged between 65 to 83 years of age completed a training programme comprising two 1.5 hour sessions separated by one week. The training involved a three-screen projection set-up of a simulated road crossing task, where participants were instructed to cross the road between two cars when they thought it was safe to do so. The speeds of the two cars varied between 19 mph to 44 mph and the time gaps between the two cars were 1 to 7 seconds (in 1 second increments). Overall they found that simulator based training produced safer road crossing behaviour in older pedestrians as evidenced by higher safety margins, safer decisions, fewer tight fits, and fewer unsafe decisions at post-test compared to the pre-test, with improvements still visible at a second post-test 6 months after training. In addition, the rehabilitation benefits of virtual environments for safe road crossings have been investigated in right hemisphere stroke (RCVA) patients with unilateral spatial neglect (USN). Katz et al (2005) recruited 11 adults (mean age 62.4 years) to a virtual environment group and 8 adults (mean age 63.3 years) to a control group, all with RCVA and USN. They found that post training, patients who completed the virtual environment training looked left more often in a real road crossing environment compared to the patients who did not receive training. These results indicated that crossing behaviour can change following training, however, if a perceptual deficit exists in terms of judging TTC it is unlikely that training will help.

This transferability from virtual environment to actual road crossing situations has also been reported by Schwebel, Gaines and Severson (2008), who conducted a study to demonstrate the validity of immersive virtual environments as a tool to understand and prevent child pedestrian accidents. They recruited a total of 102 children (twenty-nine 7 year olds, thirty-nine 8 year olds, and thirty-four 9 year olds) and seventy-four adults who completed simulated road crossing tasks, comprising seven road crossings using both ‘shout’ techniques and ‘two-step’ techniques, where participants were tested at a roadside but also with eight road crossings in the virtual environment. Their adult group also completing seven real road crossings. Traffic in their virtual environment was bidirectional and travelled at a constant speed of 30 mph with an average 535 feet between vehicles, which included sedans, SUVs and pick-up trucks. When participants judged it safe to cross the virtual road, they stepped off a pressure plate triggering an avatar to cross the virtual road at a rate matched to the participants' walking speed. Five measures were recorded: average gap size available; average wait time over cars passed; average start delay; errors; and close calls. In the virtual environment, they found that the available gap sizes and close calls between children and adults were not significantly different, but the 7 year old children made significantly more errors than the adults and both the 7 and 9 year old groups waited significantly longer to cross than the adults, with behaviour at roadside comparable to that in the virtual environment. They concluded that the construct validity, internal reliability and face validity support the use of interactive virtual environments as a methodology to train children in pedestrian safety.

As well as investigations of road crossing using virtual environments with typically developing adults and children (e.g. Simpson et al., 2003), the use of virtual environments has been used by Clancy, Rucklidge and Owen (2006) to examine road safety in children with Attention Deficit Hyperactivity Disorder (ADHD). They predicted that participants with ADHD would have lower safety margins than their index group. Participants with ADHD were also expected to demonstrate faster walking speeds owing to their impulsive nature and make significantly more unsafe crossings, due to their inherent problems with attention, impulsivity, and poorer decision making abilities. In line with previous research, it was also expected that crossings would be safer when the distance between vehicles was small, across both groups, due to the observation that distance information is typically used rather than speed by younger pedestrians. A total of twenty-four ADHD children were recruited following screening on a battery of diagnostic assessments, along with twenty-five typically developing children, all children were aged between 13 to 17 years of age. The virtual environment comprised a straight stretch of road, a street light, a tree, sky and roadside grass, in their crossing decisions participants were presented with a line of eleven oncoming vans of alternating colours. Ten crossing gaps of different sizes were presented using three vehicle distances (40, 50 or 60 m) and vehicle velocity was varied to create individual TTC for each participant. Walking speeds were measured before the participants completed 42 experimental trials, during which they were instructed to cross the near-side lane when it appeared safe to do so. Four measures were reported: safety margins; walking speed; unsafe crossings; and percentage gap used. They found significant differences between groups in safety margins with ADHD accepting 2.72 seconds and controls accepting 2.63 seconds. The ADHD group also walked significantly slower (1.73 m/s) compared to the control group (1.93 m/s). The control groups had collisions in 5.7% of trials compared to the ADHD group who collided in 12% of the trials and the ADHD group used 70% of the available gap compared to 75% for the control group. Overall, the results suggest that participants with ADHD have poorer perceptual abilities in judging the TTC of oncoming vehicles, and tended to focus on distance in anticipating the relative arrival times more than their typically developing peers.

1.7. Developmental Coordination Disorder (DCD)

Within the normal population of children, a proportion present with deficits of motor coordination. In the absence of neurological abnormalities, children with pronounced atypical development of motor function are classified as having Developmental

Coordination Disorder (DCD). This condition has been described by the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) as occurring when *“performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured intelligence”.* Problems manifest in difficulties with fine motor tasks, such as handwriting and fastening buttons, and/or gross motor tasks, such as balance and catching a ball (Sugden & Wright, 1998). In the UK, the prevalence of DCD in 7 to 8 year old children was recently found to be around 1.8% (Lingam, Hunt, Golding, Jongmans, & Emod, 2009), and it is generally accepted that children with DCD do not simply ‘grow out of it’, their problems often persist into adolescence and adulthood (Losse et al., 1991).

It is worth highlighting that throughout this thesis DCD is referred to as if it were a heterogeneous disorder, the reality is far more complex than this. There is increasing evidence to suggest that DCD occurs alongside other developmental disorders, for example Reading Disorder (e.g. Kaplan, Wilson, Dewey and Crawford, 1998), behavioural problems and learning difficulties (e.g. Losse et al., 1991). Given this accumulating evidence it has been suggested that further work is needed into the identification of subtypes and the different developmental trajectories of the different subtypes in order to fully understand the aetiology and prognosis of DCD (Visser, 2003).

1.7.1. Perceptual function in DCD

From the discussion so far, the risks for children at the roadside are clear, but they may be greater for children with DCD given the perceptual-motor demands required to achieve a safe road crossing. Whilst no ophthalmic deficits have been reported in DCD

(Mon-Williams, Pascal, & Wann, 1994) there have been suggestions that this group may exhibit visual processing deficits. For example Hulme, Biggerstaff, Moran and McKinlay (1982) asked children classified as 'clumsy[2]' to visually replicate the length of successively presented lines. They found a correlation between motor skill performance and measures of visual ability in assessing line lengths. A follow-up study found that 'clumsy' children were still impaired in perceiving line lengths even when the target line was available for inspection, these findings make deficits in working memory unlikely explanations for the difficulties found in perceiving static line lengths.

More recently, Tsai, Wilson and Wu (2009) investigated non-motor visual perception in a large cohort of 9 to 10 year old children with DCD, using the Test of Visual Perceptual Skills (non-motor) Revised (TVPS-R; Gardner, 1996). Children with DCD obtained significantly lower scores than their typically developing peers on the TVPS-R. From these findings, and many other similar reports, we can infer that children with DCD as a group seem to have specific deficits in visual perception. In addition, a meta-analysis has also suggested that visual-spatial tasks present particular difficulties for children with DCD (Wilson & McKenzie, 1998). Although overall these studies paint a picture of DCD which may include poor visual perception in static tasks that use motionless stimuli and typically require a very simple motor response, if any, the relationship between poor motor ability and poor visual perception is difficult to disentangle. Interestingly, a study by Bonifacci (2004), suggests that level of motor ability, in a typical population, does not predict level of perceptual ability. This finding would suggest that there may be some independence between these skills.

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[2] Twelve children were selected from a physiotherapy treatment group following referral by their schools due to educational difficulties. Children were given a short form of the Wechsler Intelligence Scale for Children (Revised: Wechsler, 1949) and five tests of motor performance developed by Gubbay (1975), and on the basis of this were classified as 'clumsy'.

1.7.2. Motion processing in DCD

It is well established that visual information is processed in parallel by pathways that remain largely separated. The ventral stream transforms visual information into perceptual representations about the surface properties of objects, such as shape and colour. In contrast, the dorsal stream deals with moment to moment information about the relations between objects and about their motion (Milner & Goodale, 1995).

Tests measuring thresholds of global motion coherence (dorsal-stream) and global form (ventral-stream) coherence have been shown to examine distinct functional brain networks (Braddick, O'Brien, Wattam-Bell, Atkinson, & Turner, 2000). A difficulty in processing visual motion could serve to explain a number of the coordination problems exhibited in DCD, but the evidence for distinct deficits in low-level visual processing is unclear. Measures of thresholds for global form (ventral-stream processing) and global motion (dorsal-stream processing; Braddick et al., 2000) have produced mixed results. For example, Sigmundsson, Hansen and Talcott (2003) recruited thirteen school children aged between 10 to 13 years of age with elevated scores on a standard test of motor competence (Movement Assessment Battery for Children, MABC; Henderson & Sugden, 1992). These children were assigned to a 'clumsy' group and thirteen children with the lowest scores on the MABC were assigned to a control group. They tested all children on a series of visual coherence threshold tasks comprising a measure of global motion processing, a measure of static global form processing with a randomised target position and a measure of static global form processing where the target position was fixed. They found that the children with developmental 'clumsiness' were less sensitive (poorer) than the control children on both dorsal and ventral stream function tests. They also reported strong correlations between children's scores on the MABC and sensitivity on all three visual tasks. These results suggest that poor motor skills are associated with reduced visual sensitivity. However, children with ‘dyspraxia’ have been found to have higher thresholds on the (ventral) form task but not the (dorsal) motion (O'Brien, Spencer, Atkinson, Braddick, & Wattam-Bell, 2002). Finally, Wilmut and Wann (2008) found no difference in either global form or motion tasks between a group of individuals with DCD and their typically developing peers, even though deficits in motion processing for action were found in individuals with DCD.

Despite these mixed results in motion detection, as measured by global form and global motion tests, there are findings that suggest that individuals with poor motor skills may also make errors in motion judgments, Pitcairn and Edlmann (2000) found a correlation between poorer performance on a fine motor control task and errors in roadside perceptual judgments, in both typically developing children and adults. Additionally, there is evidence from studies investigating full-term and preterm at-risk infants’ that have shown that preterm infants, later diagnosed with cerebral palsy, fail to shift from a strategy based on distance to one based on time when catching moving objects (e.g. van der Meer, van der Wee, Lee, Laing, & Lin, 1995). Combined these results indicate that the dorsal vs. ventral dichotomy is not a strict one. The evidence discussed does not suggest a clear selective deficit in motion processing for children with DCD, rather it suggests overarching perceptual deficits in both streams that include motion processing deficits.

1.8. Dynamic visual attention

An individual would rarely search for an object in their environment for purely perceptual purposes, nearly always there is an intention to interact with the object being searched for. The motor system does not exist to simply translate thought or sensation into movement as once claimed, but as Rizzolatti and Luppino (2001) have proposed, the motor system is involved in multiple sensory-motor transformations. Arguably, the most complex are those that transform the visual information of an object and its location into appropriate goal-directed actions. Anatomical data suggest there are connectivity differences in the organisation of the posterior and anterior motor areas, such that the parieto-dependent areas receive detailed sensory information originating from the parietal lobe and use it for action. The capacity limitation of conscious visual perception dictates what visual information should be used for action through selection processes. The prefronto-dependent motor areas receive higher order cognitive information, related to long-term motor plans and motivation. The Visual Attention Model (VAM; Schneider, 1995) proposes a functional specialisation such that selection for visual perception is carried out within the ventral pathway whereas selection for spatial motor action is carried out in the dorsal pathway (Schneider & Deubel, 2002). The visual system provides sensory input to perceptual-motor circuits that initiate and guide movement, and according to the premotor theory of attention (Rizzolatti, Riggio, Dascola, & Umilta, 1987), the control of goal-directed movements and the control of attention must be closely linked, with shifts of attention generated whenever shared neural structures are activated during response preparation.

There is evidence that some mechanisms of attention are present from early infancy, for example a review by Colombo (2001) suggests that alertness can be elicited during the first month of life by exogenous simulation and by 10 weeks alertness can be seen more frequently and for longer periods. Whereas, components of the spatial orienting system and object perception are not fully developed until around 6 months of age. Although smooth pursuit is visible in infants less than 4 weeks old, reflex saccades and inhibition of return improve steadily from infancy to 6 months of age and improvements in attentional disengagement are seen from 2 to 4 months of age, along with substantial changes in object attention between 2 months and 6 months of age.

According to Posner and Petersen (1990) attention is best conceptualised by three interrelated neurofunctional networks: the orienting network which mediates visuospatial attention and detects sensory input; the alerting network involved in the maintenance of the alert state; and the executive network responsible for attention shifting, inhibitory control and conflict monitoring. Using this model, Rueda et al (2004) tested twelve children between 6 to 9 years of age on a child version of the Attentional Network Test (Rueda et al., 2004). They hypothesised that the alerting network and executive network develop during childhood but orienting attention remains stable after infancy. As predicted, they found that the orienting network showed no improvements from 6 years of age to adulthood, whereas the alerting network showed a significant improvement between 10 year olds and adults and conflict scores measuring the executive network improved between 6 to 7 years of age.

More often than not, we have to make judgments of a visual scene that is changing moment-to-moment, such as in a road crossing situation. One study has reported that 69% of UK child pedestrian accidents could be attributed to perceptual or cognitive errors on the part of the child (Carsten, Tight, Southwell, & Plows, 1989). Demetre et al (1992) suggest that the differences in the performance of adults and children when making decisions about traffic gaps can be better explained by lapses in attention than by differences in timing ability. Dunbar, Hill and Lewis (2001) suggest that in order to be a skilful pedestrian, it is critical to ignore potentially distracting events outside the current focus of attention and switch attention to a road crossing task. To assess attentional switching, they devised a game whereby a frog appeared on each trial in one of two possible hiding places, either a house or train, the child's task was to press one key if the frog was hiding in the location shown and another if it was not, mapping between targets and responses switched and children had to inhibit a previously correct response. To assess concentration, environmental distractors were used in a task where children had to select one of six images in the lower half of a visual display that matched a target image in the upper half of the display. They found that both switching attention and concentration were related to age, with younger children less effective than older children. They claim that switching attention and concentration appear to be distinct road crossing skills. They also observed road crossing behaviour in their sample. They found similarities in children's ability to switch attention in a computer based task and the likelihood of the child to look at traffic when they were about to cross a road. Also, children who were less able to concentrate when challenged by a distratcting event tended to be more impulsive and cross the road in a less controlled manner.

When considering atypical development, there are clear advantages in having a robust assessment of attentional function for diagnostic purposes. To this end, Kaufmann et al (2009) recruited seventeen children with Attention Deficit Hyperactivity Disorder – Combined Type (ADHD-CT), in an attempt to compare attentional profiles in children with and without ADHD-CT using a commercially available Test of Attentional Performance for Children (KiTAP; Zimmermann & Gondan, 2004). They aimed to assess which attentional components were most descriptive for ADHD-CT and identify the tasks that discriminated between children with and without ADHD-CT. They found that compared with typically developing children, children with ADHD-CT exhibited significantly larger response time variability in a go-nogo task, thought to involve executive attention, and committed significantly more errors than typically developing children in a divided attention task.

It should be noted that the allocation of dynamic visual attention, that requires the visually guided control of goal-directed actions, is quite different from the types of attention measured in formal assessments of attention, such as the Test of Everyday Attention for Children (TEA-Ch; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994). The TEA-Ch is a standardised battery for the assessment of cognitive attention deficits and assesses three aspects of attention: selective attention; sustained attention; and switching attention in line with Posner and Peterson's (1990) proposed separation between selective and sustained attention.

1.8.1. Dynamic visual attention in DCD

DCD is a disorder that is characterised by marked difficulties in performing daily motor activities, but commonly assessed using diagnostic tools that require a well-developed perceptual-motor system. Take for example, the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson, Sugden, & Barnett, 2007), the majority of the tasks administered in all three subsections require the use of visual attention to organise actions. For instance, the ‘posting coins’ task (see Figure 1.2. for example of set-up) requires the child to overtly allocate attention to one coin prior to initiating a reach-to-grasp movement, the child must then rapidly redirect their line of sight to the posting box slot, in order to accurately direct their hand. For a child that falls below expected performance for their chronological age on these types of tasks, their deficit is primarily considered one of motor coordination. However, it is worth considering whether poor performance could, at least in part, be explained as a deficit in the coupling between attention and visual-motor integration.

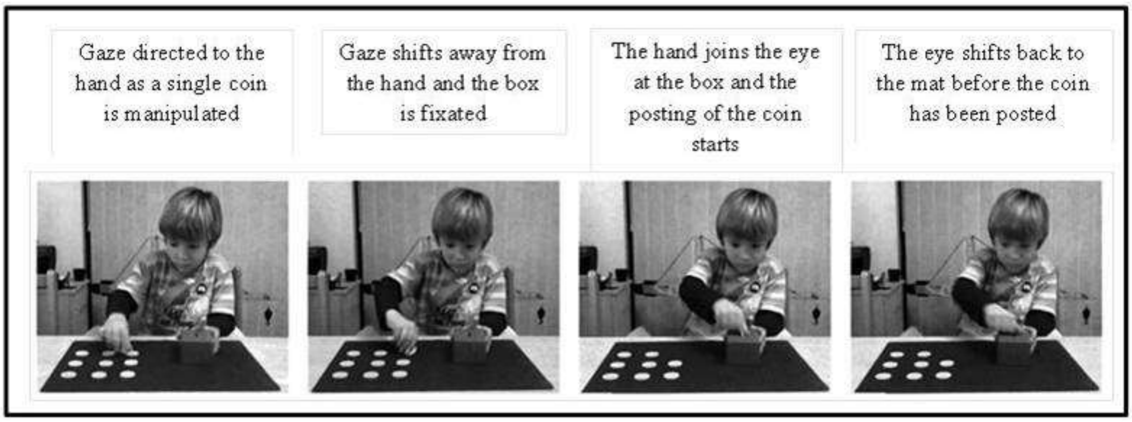

Figure 1.2. Example of a child completing the ‘posting coins’ task, as employed in the MABC-2 with additional annotation as to how attention may be allocated at each stage.

There is also evidence for a deficit in the efficiency of DCD to use advance information. Mon-Williams et al (2005) asked adults, children and children with DCD to complete a series of reach-to-grasp movements in three types of cue conditions with four target locations: full cues where target information was unambiguous and only one target was cued; partial cues where left or right areas were cued, highlighting two possible targets; and null cues where cue information was ambiguous and all targets were cued. They found that children with DCD showed an advantage in the full cue condition, but their movement times in the partial cue condition were similar to the null cue condition. From this they suggest that children with DCD are not using partial or incomplete advance information to plan a response. Furthermore, Wilson, Maruff and McKenzie (1997) found that children with DCD displayed difficulty in using the alerting properties of peripheral spatial cues to prepare a motor response, as seen in their lack of facilitation to a prolonged temporal gap between cue onset and presentation of a target, as well as a disproportionate increase in manual reaction time on invalid cue trials, from this they suggested that children with DCD have a cognitive deficit which impairs their ability to use advance information. Following this, Wilson and Maruff (1999) conducted a spatial pre-cue task to assess whether TD and DCD children differed in their ability to move attention through visual space to a target location. The target appeared peripherally at either the left or right of a central fixation point. Precues lasted either 150 ms or 850 ms before the target and provided information as to the possible location of the target. They used two conditions, one (exogenous) where the cue had greater luminance at one of the two peripheral locations, which should attract attention to that cue and is thought to assess involuntary shifts of attention. In the second (endogenous) the precue (arrow) was used centrally to indicate the location of the target on 83% of the trials, thereby assessing voluntary shifts of attention. They took the reaction time difference between invalid and valid cue as a measure of disengagement efficiency and found that it was significantly larger for their DCD group compared to their typically developing group in the endogenous but not exogenous cue conditions. They concluded that DCD have a selective visuo-spatial deficit but only when attention must be allocated voluntarily.

The results of Wilson and Maruff (1999) suggest that one difference between TD and DCD is in their ability to inhibit response initiation. The first fMRI study to investigate how the attentional brain network is involved during experimental tasks in DCD was conducted by Querne et al (2008). They used a go-nogo task to engage sustained attention and the executive network, the task required participants to rapidly respond on frequent go trials and inhibit their response to rare nogo trials. They found that children with DCD activated the same cerebral regions as typically developing children performing the go-nogo task, but reported differences in connectivity between the DCD and typically developing groups, affecting both direct and indirect pathways between the middle frontal cortex (MFC) and inferior parietal cortex (IPC). They also found that children with DCD showed stronger left hemisphere activation, indicating an abnormal hemispheric lateralisation in DCD. Overall, they concluded that DCD appeared to use the same cerebral regions to typically developing children but in a different way, and although inhibition was good in DCD it was at the cost of more top-down control and executive network, especially the anterior cingulated cortex (ACC) and posterior network than in typically developing children. A study Mandich, Buckolz and Polatajko (2002) aimed to assess whether children with DCD and typically developing children would differ in their ability to inhibit an unwanted initiation of an incorrect manual response. Using the Simon task, stimuli appear at locations either left or right of a central fixation point, the task is to press a key based on the identity of the target whilst ignoring its position. In compatible trials the manual output and target are on the same side and on incompatible trials the key and target cross the midline, typically reaction times are slower for incompatible trials. They tested twenty children with and without DCD aged between 7 to 12 years old and in line with Wilson and Maruff (1999) they found that reaction times and error rates suggest an inhibitory deficit in DCD in manual response inhibition.

Interestingly, Cruddace and Riddell (2006) found that children with movement difficulties, whether alone or in combination with reading difficulties, performed poorly on at least one or more components of the TEA-Ch, compared to children with reading difficulties alone. However, the tasks used in the TEA-Ch do not claim to assess the allocation of dynamic visual attention as occurs in natural movement tasks (~1-2 seconds) and one aim of this thesis was to consider whether children with DCD differ in measures of dynamic allocation of attention and the measures used in the TEA-Ch.

1.9. Aims and hypothesis

As a pedestrian or a driver, when you look down the road you make a decision as to whether you have time to cross or pull-out and, providing the visibility is good, observers tend to be confident in their decisions. However, misjudging vehicle speed is known to be involved in one third of all fatal collisions, furthermore the perceptual limitations in judging speed (rate of expansion) and distance (optic size) of approaching vehicles has been cited as a key contributory factor in children's overrepresentation in pedestrian casualty statistics (Toroyon and Peden, 2007). Using various paradigms, previous research has considered children's use of visual information when gauging object approach in natural and simulated road settings. Some evidence has suggested that children can use rate of expansion (looming) information to a level close to adult performance (e.g. Demetre et al, 1992), but it has also been suggested that children's increased vulnerability at the roadside could be due to decisions being based on optic size information (e.g. Connelly et al, 1998; Simpson et al, 2003). To date, there has been no systematic examination of human observer's threshold to perceptually estimate the ratio of optic size and rate of expansion (looming) for the types of speeds typically encountered at the roadside. The overarching hypothesis of this thesis therefore, is that in a road crossing context, the risk of collision will increase as the perceptual sensitivity of the observer decreases and an over reliance on optic size will exacerbate the risk.

Specifically, the perceptual limitations of primary school age children will be more pronounced than in adults and even less refined in children with reduced motor ability.

In particular, this thesis aims to measure the aptitude of adults and primary school children with and without DCD in five key component skills considered essential at the roadside. First, a pedestrian must decide whether or not a vehicle is approaching, the ability to detect looming vehicles is systematically measured in primary school children with and without DCD in Chapter 5. Second, once an approaching vehicle has been detected, the next essential component is to differentiate between the rate of approach of different vehicles, Chapter 3 measures discrimination thresholds in a large sample of adults and children, while Chapter 4 takes the same methodology to assess this skill in primary school children with and without DCD. Third, pedestrians must decide if gaps in flowing traffic afford the possibility of a safe crossing, Chapter 6 measures gap acceptance thresholds in children with and without DCD when presented with a single vehicle approaching in the near-side lane, and Chapter 7 measures gap acceptance thresholds of children with and without DCD as well as a clinical sample with reported motor difficulties, in a virtual reality environment. Fourth, in a road crossing, the pedestrian needs to complete their walking action within a temporal window. One way of assessing this is to look at the ability of children to get to a particular place in a specific time (interception task), the ability of primary school children with and without DCD to accurately coordinate their movement with a target that moves across their path, with a period of occlusion was measured. Finally, to assess whether children with DCD have poorly developed strategies for the allocation of dynamic visual attention, which might explain some of their coordination difficulties, the final experimental Chapter measures attentional-motor accuracy in dynamic situations.

Overall, this thesis aims to fill the gap in our knowledge of how adults, typically developing and atypically developing children cope with the types of perceptual-motor judgments typically made at the roadside.

Chapter 2: Common Methodology

2.1. Introduction

This Chapter outlines common methodology, it begins by describing the standardised assessment tools used for the identification of motor, cognitive and attentional abilities in children participating in the studies within this thesis. It then moves on to describe how participants were selected and the psychophysical procedures used to obtain threshold values reported within this thesis.

2.2. Developmental Coordination Disorder diagnostic criteria

The term "clumsy child syndrome" was first used in 1975 to describe children who had difficulties in coordination that interfered with academic performance and activities of daily living which could not be explained by low intelligence, or identifiable neurological impairment. Since then, other terms have emerged to describe this disorder, including sensory integrative dysfunction and motor learning difficulty. More recently, the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) refer to such coordination difficulties as Developmental Coordination Disorder (DCD), the diagnostic criteria follow below:

A. Performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured Intelligence. This may be manifested by marked delays in achieving motor milestones (e.g., walking, crawling. sitting), dropping things, “clumsiness,” poor performance in sports, or poor handwriting.

B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living.

C. The disturbance is not due to a general medical condition (e.g., cerebral palsy, hemiplegia. or muscular dystrophy) and does not meet criteria for a Pervasive Developmental Disorder.
D. If mental retardation is present, the motor difficulties are in excess of those usually associated with it.

The diagnostic assessment tools used to fulfil the criteria above are described in the next section.

2.2. Assessment tools

The assessment tools used to assess DSM-IV Criteria A and B were a adapted version of the Movement Assessment Battery for Children Checklist (second edition; MABC-2 checklist; Henderson, Sugden, & & Barnett, 2007) and the Movement Assessment Battery for Children test component (second edition; MABC-2; Henderson et al., 2007). To assess DSM-IV Criteria C and D, a measure cognitive ability was obtained using Raven's Coloured Progressive Matrices (CPM; Raven, 1956). As well as a measure of attention which was obtained using the Test of Everyday Attention for Children (TEA-Ch; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) and teachers' ratings using the Conner's ADHD index (Conners, 1997). These are described below.

2.3. Assessments of motor ability

2.3.1. Movement Assessment Battery for Children Checklist (MABC-2 Checklist)

The Checklist of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007) was developed to screen children for movement difficulties, primarily in the school situation, but can be completed by teachers, parents or professionals as an informal assessment of motor performance and focuses on how a child manages everyday tasks that are encountered at home and at school. It has been designed for children aged between 5 to 12 years of age. It comprises thirty questions divided into three sections. The first two sections refer to motor performance and differentiate between movement situations based on the child and the environment: (a) movement in a static and/or predictable environment; (b) movement in a dynamic and/or unpredictable environment. The third section relates to non-motor factors that might affect movement, e.g. lack of confidence and impulsiveness. In each section, the child is appraised and categorised according to a four point scale (very well, just ok, almost and not close), a high score is taken as an indication of possible motor impairment.

2.3.2. Selection of MABC-2 Checklist items

Due to time limitations of the teachers involved, an adapted version of the Checklist was produced based on a selection of questions from the full Checklist. The adapted Checklist has high face validity, but content validity was not formally assessed. However, in line with the full version, questions were selected to gauge motor performance in different movement situations and included non-motor factors that might affect movement (see Table 2.1. for questions used), yes/no responses were required for each of the ten questions. The intention of the adapted version of the Checklist was to enable teachers to initially identify children with reduced motor ability, these children were then screened on the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007).

Table 2.1. Adapted version of MABC-2 Checklist completed by teachers.

Finds fastening buttons (e.g. on shirt, coat) difficult	YES / NO
Has difficulty with handwriting or drawing	YES / NO
Has a tendency to bump into fixed/stationary objects	YES / NO
Finds throwing (e.g. beanbag, ball) difficult	YES / NO
Finds catching (e.g. a ball) difficult	YES / NO
Can become anxious / timid (fearful of activities, becomes flustered in stressful situations)	YES / NO
Is easily distracted	YES / NO
Tends to be impulsive or overactive (e.g. impatient of details, moves constantly when listening to instructions)	YES / NO
Lacks persistence and gets upset by failure	YES / NO
Overall, do you think this child has movement difficulties If yes, please circle any of the below where it adversely affects the child Classroom learning PE/recreational activities Self esteem Social interaction	YES / NO

2.3.3. Movement Assessment Battery for Children test component (MABC-2)

The test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007) is a recent revision of the well-known Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992), originally named the Test of Motor Impairment (TOMI, Stott et al, 1984). The aim of the MABC-

2 is to identify children with movement difficulties. It is a standardised assessment tool that requires a child to perform a series of motor tasks within certain constraints to objectively measure motor performance in children and adolescents aged between 3 years 0 months to 16 years 11 months. The Performance Test and the Checklist have been standardised using a larger, more representative normative sample than its predecessor and includes four new items, the revision of some items, the creation of a 3- through 6-year and 11- through 16-year age bands, the combination of the 7- through 8- and 9- through 10-year age bands, and a system to assist with score interpretation (see Table 2.2.).

The MABC-2 performance test is divided into three sub-sections: Manual Dexterity, Ball Skills and Static and Dynamic Balance. Together, the three sub-sections contain eight performance tests for each age range from which a total standard score and percentile are obtained, low scores indicate motor difficulties.

Table 2.2. Traffic Light System for Total Test Score, taken from Henderson, Sugden and Barnett in the MABC-2 (2007).

Participant's Score	**Total Test Score**	**Percentile Range**	**Description**
Red Zone	Up to and including 56	At or below the 5th percentile	Denotes a significant movement difficulty
Amber Zone	Between 57 and 67 inclusive	Between the 5th and 15th percentile inclusive	Suggests the child is 'at risk' of having movement difficulty; monitoring is required
Green Zone	Any score above 67	Above the 15th percentile	No movement difficulty detected

There has been much debate as to how to best conceptualise the challenges faced by children who fail to acquire the movement skills required to manage at home and at school. One issue is classification, as demonstrated above, the MABC-2 test authors suggest that total scores falling below the fifth percentile should be considered as indicative of a definite motor problem, while scores between the fifth and fifteenth percentile suggest a degree of difficulty that is borderline, but needs further monitoring. Historically however, within the research community, classification of DCD has varied. Some researchers (e.g. Wilson and Maruff, 2003) have included children within a DCD group that fall below the fifteenth percentile on the MABC (Henderson and Sugden, 1992), whilst others (e.g. Wilmut, Wann and Brown, 2006) have included children falling below the tenth percentile. This inconsistency is unhelpful and this thesis advocates the use of sub-groups by recognising that children falling below the fifth percentile are functionally distinct to those falling below between the fifth and fifteenth percentiles. This provides an interesting comparison in the performance of these sub-groups and is in line with the distinction highlighted by the Leeds Consensus Statement (Sugden, 2006, p.7), that the fifteenth percentile should not be used as a defining percentage for DCD.

2.4. Assessment of cognitive ability

2.4.1. Raven's Coloured Progressive Matrices (CPM)

Raven's Coloured Progressive Matrices (Raven, 1956) is used to measure fluid intelligence i.e. the ability to deal with essentially new problems. It consists of thirty-six items in three sets (A, Ab and B) of twelve items, these are arranged to assess the chief cognitive processes of which children under 11 years of age are usually capable. Each item consists of a pattern drawing with one element missing, on the bottom of the page six elements are printed which might fit into the gap, the child's task is to identify which of these six alternatives best fits the gap (see Figure 2.1. for example item). The items increase in difficulty as do the three sections. On competition, a total score is calculated for each set and combined to produce a total CPM score which is then graded from I to V with high scores taken as an indication of an intellectual impairments.

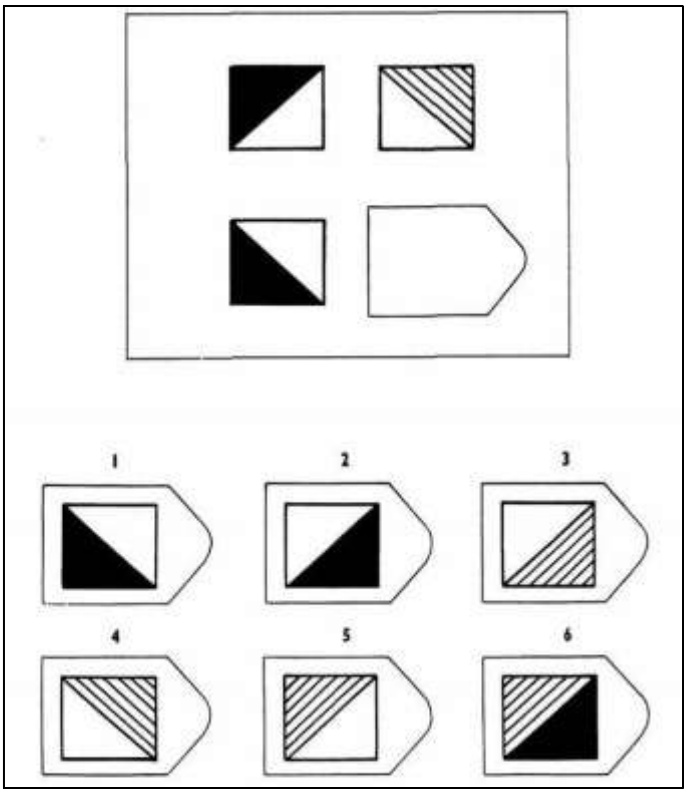

Figure 2.1. Example of an item from set A of Raven's Coloured Progressive Matrices.

When the CPM was developed, five qualitative developments in the order of intellectual capacity were distinguished: Children first distinguish identical figures from different figures, and later similar from dissimilar figures. They are then able to appreciate a figure's orientation with respect to themselves and other objects. They are then able to compare corresponding changes in the characters perceived and adopt this as a logical method of reasoning. Subsequently, they are able to analyse the perceived whole into its constituent parts and distinguish between what is given and what they themselves contribute. Finally, they are able to apprehend two or more discrete figures as forming a whole.

2.5. Assessments of attention

2.5.1. Conners Rating Scales-Revised

The Conners Rating Scales-Revised (Conners, 1997) uses observer ratings to help assess attention deficit/hyperactivity disorder (ADHD) and evaluate problem behaviour in children and adolescents. The short form for teachers, used in this thesis, contains twenty-eight items that provide an assessment of oppositional behaviour, cognitive problems/inattention, hyperactivity and an ADHD index score. Norms are based on a sample of 8000+ children and adolescents, males and females and ages 3 to 17. Standardised data were based on the means and standard deviations for groups of children with ADHD and children without psychological problems and minority group samples were represented.

2.5.2. Test of Everyday Attention for Children (TEA-Ch)

The TEA-Ch (Robertson et al., 1994) is a normed and standardised battery of nine subsets that assesses three types of attention: selective attention; sustained attention; and attentional control/switching in 6 to 16 year olds and includes six separate age bands for males and females. The tasks are designed to minimise the need for other skills such as memory, language and comprehension. The seven sub-sets that were used for assessment purposes in this thesis were as follows:

Selective attention

Sky Search

The child's task is to circle as many paired spaceships as possible on an A3 sheet of paper filled with very similar distractor spaceships. In the second part of the task there are no distractors and the child needs to circle all paired spaceships on the A3 page. For both parts, the time taken is calculated by dividing the time by number of correctly identified targets. Subtracting part two from part one gives a measure of a child's ability to make this selection that is relatively free from the influence of motor slowness and provides a selective attention score.

Sustained attention

Score

For this task the child has to keep count of the number of scoring sounds they hear on a audio recording, the child needs to self-sustain their attention as there are random temporal gaps between sounds. The number of correct counts are taken as a measure of sustained attention.

Score Dual Task

The child's task is to count scoring sounds as above, whilst listening to spoken news reports, during which an animal name is mentioned at some stage during the news clip. The sum of correct animals identified and correct counts are taken as a measure of the child's capacity to sustain attention over time, while they perform two tasks.

Walk-Don't-Walk

The child's task is to take one step along a paper path, using a pen, after each tone they hear on an audio recording. Unpredictably, one tone ends differently from the rest, meaning the next step should not be taken. The total number of correct paths is taken as a measure of sustained attention to action.

Attentional Control/Switching

Creature Counting

Children have to repeatedly switch between two relatively simple activities of counting upwards and counting downwards. They are asked to count creatures in their burrow, with occasional arrows telling them when to change the direction in which they are counting. Time taken and accuracy are scored and a timing score is obtained by dividing the total time for correct items by the total counting direction switches for correct items.

Sky Search Dual Task

Children are asked to combine the Sky Search and Score subsets, finding the paired spaceships and keeping count of scoring sounds. Some children, who may have completed each aspect of the task well, can show a substantial decrement in performance under these dual task conditions.

Opposite Worlds

In the “same” world the child follows a path naming the digits 1 and 2 that are scattered along it. In the “opposite” world the child does the same task except this time they have to say ‘one’ when they see 2 and ‘two’ when they see a 1. The total time for both worlds are taken as a measure of attentional switching.

2.6. Selection of participants used in this thesis

Four distinct populations were used within this thesis: members of the general public; typically developing primary school age children; children with or at risk of DCD; and a clinical sample of children with pronounced motor difficulties. The participants in Chapter 3 of this thesis were members of the general public, recruited as part of the Live Science exhibit housed in the ‘Who am I?’ gallery at the London Science Museum in 2010. The typically developing children and children with or at risk of DCD that participated in Chapters 4 to 9 were recruited from local primary schools in Surrey and Berkshire. The ‘clinical’ cohort in Chapter 7 were recruited from a private occupational therapy (OT) service in North Yorkshire (UK), specialising in children with praxis and developmental and learning difficulties.

The ethics committee of the Department of Psychology, Royal Holloway University of London approved all of the experiments reported in this thesis and opt-in consent was obtained from all adults or parents of participants under the age 16 years old, prior to participation.

2.7. Primary school children

As an initial pre-screening measure, teachers from four primary schools in the Slough and Ascot areas were asked to use the adapted version of the MABC-2 Checklist (see Table 2.1.) to identify children who displayed signs of movement coordination difficulties and those who had apparently typical movement coordination. Once completed, opt-in consent letters were distributed to parents. A total of 101 children whose parents returned consent, were then assessed separately in a meeting room within school on the MABC-2, initial inclusion in the DCD group required a score at or below the 5th percentile on the MABC-2, inclusion in the 'at risk' group required a score at or below the 16th percentile. Out of the 101 children assessed, 13 children (13%) met the criteria for DCD and 13 (13%) met the criteria for being 'at risk' of developing movement difficulties. The remaining 75 children were considered typical in their movement abilities and assigned to a typically developing group, some of these children were later used as age and gender matched controls for children with or at risk of DCD and the clinical cohort. Hence, a proportion of children in all groups were assessed on Raven's CPM. As the tasks used within this thesis were primarily low level perceptual tasks children with low CPM scores were not excluded, but their results were compared for each paradigm and discussed within Chapters.

A proportion of all children also completed the TEA-Ch subsets, and teacher's returned Conners' rating scales for some of the children in the DCD, at risk groups and children in the typically developing group. Some children obtained elevated scores on the Conners' dimensions, however, one conclusion of the Leeds Consensus Statement was that children should not be excluded from a classification of DCD because of other associated problems such as ADHD (Sugden, 1996, pg.6). The issue then is whether any deficit in performance on a specific task is due to the effects of DCD or ADHD, this issue is addressed in the results and discussion sections in each Chapter where applicable.

2.8. Psychophysical procedures: Best Parameter Estimation by Sequential Testing (Best-PEST)

Psychophysics is concerned with measuring the perceptual experience associated with a stimulus. Chapters 3 to 7 of this thesis employ a psychophysical procedure known as

Best-PEST (Lieberman & Pentland, 1982) to obtain threshold values, which are the point of intensity at which the observer can just detect the presence of, or difference in, a stimulus. The method used in this thesis concentrates stimuli around threshold using an adaptive procedure. Using this method, if an observer gives a correct response, the stimulus magnitude is decreased (the task becomes harder); if the observer gives an incorrect response, the stimulus magnitude is increased (the task becomes easier). Each step is based upon an iterative calculation of the probability function surrounding the likely threshold value based on all previous responses. After a criterion number of reversals, the staircase is terminated and a threshold value is estimated, either by taking the average of the last 4 reversals or by taking the maximum likelihood value (see Figure 2.2. for a typical example of Best-PEST adaptive track). Within this thesis the PEST interval value equated to the maximum stimulus level minus the minimum stimulus level divided by 1000 increments, the stimulus range is reported within each Chapter. For example, in Chapter 3, the maximum stimulus value was set at 54 m/s (looming = 1.15 deg/s) and the minimum stimulus value was set at 8.9 m/s (looming = 0.19deg/s), the minimum interval value for each stepwise progression was therefore 0.00096 deg/s . The PEST used for all experiments within this thesis were set up for a two forced-choice response, (e.g. did it get bigger? ‘Yes’ or ‘No’?) which operated to find the threshold at 75% correct.

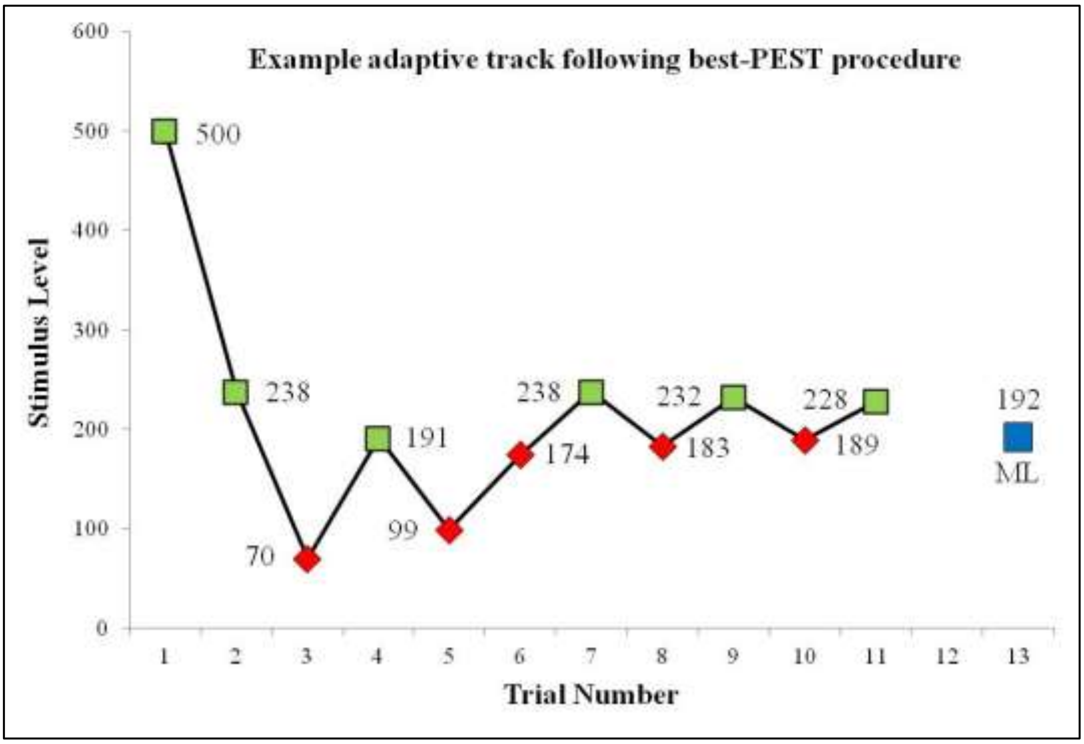

Figure 2.2. Example adaptive track following Best-PEST procedure, with the threshold value in this example taken as the maximum likelihood value (ML). The red diamonds indicate an incorrect / ‘no’ response and the green squares indicate a correct / ‘yes’ response.

Chapter 3: Perceptual Errors in Relative Approach Judgments

"The driver claimed she had looked left, but had simply not seen the motorcyclist, despite the fact that visibility was good and the rider was displaying lights"

(Clarke, Ward, Bartle, & Truman, 2004)

3.1. Introduction

As discussed in the introductory Chapter, one component road side skill is the ability to differentiate the rate of approach between vehicles. If observers are only using rate of expansion $\dot{\theta}(t)$ they may not be able to differentiate between a small vehicle moving quickly and a large vehicle moving slowly because the instantaneous value of $\dot{\theta}(t)$ is determined by the size of the object *(D)*, which could be either the width or height of the vehicle, its velocity, *v(t)*, and the square of the absolute distance, $z^2(t)$:

$$\dot{\theta}(t) = \frac{D\,v(t)}{z^2(t)} \qquad (1)$$

Equation 1 demonstrates that there could be a systematic bias whereby smaller vehicles could be perceived as travelling slower than larger vehicles that loom at a greater rate. According to Lee (1976) if observers are relying on tau to make collision judgments, the size and velocity of moving objects should be irrelevant. However, DeLucia (1991) has shown that pictorial depth information of relative size of approaching objects affect judgments of relative arrival time, suggesting participants were using optic size (θ). In their study, twenty participants viewed a large square and a small square monocularly as they approached the observer at equal velocities whilst suspended above a ground plane. Both objects expanded for 1 second in various slow and fast expansion conditions, manipulated such that the difference in object size in virtual space always projected the smaller object as the smaller image even though it was always closer to the viewpoint. Participants were asked which object would ‘hit’ them first. They found that in the slow expansion scene but not the fast expansion scene, a significant number of observers reported that the large object would hit the viewpoint first. This suggested that observers did not use arrival time information available by optical expansion but instead used pictorial depth information. In a later study, DeLucia and Warren (1994) aimed to determine whether an observer moving at constant velocity toward an object would jump sooner to avoid collision with a large stationary object compared to a smaller object at the same distance and clearance height. Simulations represented self-motion at constant velocity (45.45 m/s) toward a virtual black square of different sizes (4.85 m, 21.82 m or 38.78 m). Participants initiated a jump sooner for larger squares compared to smaller squares approaching from equal distances and velocities, again suggesting that relative size affected arrival time judgments. This size-effect can be readily illustrated by positioning two identically sized objects at different distances within a scene (see Figure 3.1.).

Figure 3.1. Photograph of two cars of identical size against a road scene, by simply positioning the cars at different perceived distances, the nearest car is often misperceived as being smaller.

Further support for the size-effect demonstrated by DeLucia and colleagues comes from Hosking and Crassini (2011) who investigated whether relative TTC judgments are based on a comparison of the instantaneous expansion rates, $\dot{\theta}(t)$, of the two approaching objects, such that the object with the larger rate of expansion will be judged to arrive first. Their displays consisted of two spheres (smaller diameter: 7.0 cm and larger diameter 22.0 cm) approaching the observer 15 cm to the left and right of the centre of the screen for 1 second at constant velocity (1.4 m/s). The TTC of the smaller sphere was systematically varied across six values between 50 and 400 milliseconds, with the larger object positioned further from the viewpoint in order to achieve the same visual angle as the smaller object. They found that the temporal separation that observers needed in order to judge that the two objects would arrive at the same time were consistent with observers basing their judgments on rate of expansion regardless of whether the object was familiar (scaled football and tennis ball) or ambiguous (textured and solid disks). In contrast, Seward, Ashmead and Bodenheimer (2007) used 2 second video animations of a sedan or a semitrailer truck approaching at constant velocity ranging from 10 to 30 mph. They compared adults' TTC judgments for cars and trucks at arrival times of 4, 7 and 10 seconds, they found that TTC thresholds decreased for shorter arrival times for both vehicle types, but the size of the vehicle did not significantly impact upon participants' ability to discriminate TTC at any arrival time. In contrast to studies that have found an effect of vehicle size (e.g. Hosking et al, 2011) these results suggest that for the types of speeds typically encountered at the roadside, a TTC strategy based on tau was being used by observers.

UK accident statistics from 1999 suggest motorcyclists were approximately 28 times more likely to be killed or seriously injured on the roads compared to car drivers. It has been proposed that there is a particular issue surrounding other road users' perception of motorcycles, with other road users appearing to have problems in detecting approaching motorcycles as approaching (Clarke et al., 2004). Mannering and Grodsky (1995) have claimed that car drivers *"tend to be inattentive with regard to motorcyclists and have conditioned themselves to look for other cars as possible collision dangers".* One explanation for the disproportionally high number of road traffic accidents involving motorcyclists compared to cars could be a result of a perceptual error whereby motorcycles (as small vehicles) loom at a lower rate than larger vehicles. In a study by Horswill, Helman, Ardiles and Wann (2005) a series of experiments using a temporal occlusion paradigm aimed to examine why drivers pull out into small temporal gaps in front of motorcycles compared to other cars. They found that regardless of viewing time prior to occlusion (2 seconds and 5 seconds) and for both approach speeds (30 mph and 40 mph) motorcycles were consistently estimated to arrive later than larger cars and vans. This again suggests that observers rely on rate of expansion, which does not scale for optical size, in their decisions.

The experiments described in this Chapter aimed to systematically measure the perceptual thresholds of different populations (adult drivers; children and adult non-drivers) to accurately judge the rate of approach of two vehicles. One vehicle (the reference) approached for one second and disappeared when the TTC was 5 seconds. An identical probe vehicle approached for the same duration, but at a different speed (and therefore starting distance) and disappeared when it was the same optical size (e.g. distance) as the reference vehicle. The probe vehicle therefore presented both a different rate of looming and a different TTC and the task of judging which was approaching faster could be answered either using instantaneous rate of expansion or tau. Size differences were then introduced, using a car and a truck or a car and a motorcycle, varying in speed but again disappearing at the same optical size. If tau is being used then accuracy should be equivalent to that observed for two identically sized vehicles. But if the rate of expansion is not scaled by optical size then a bias would predict that the truck, with a larger profile, will tend to be judged as travelling faster than the smaller car, and the car will tend to be judged as travelling faster than the smaller motorcycle. This size manipulation therefore, provides a direct test of whether observers utilise tau as an estimate of approach velocity or rate of expansion. The consequences of basing judgments on optical expansion can be demonstrated if we consider a reference vehicle approaching at 20 mph at constant velocity at a distance 44m, the TTC equates to 5 seconds. If an observer is unable to discriminate that from a probe vehicle travelling at 40 mph with the same end distance, then they will fail to notice that the TTC of the faster vehicle is 1.64 seconds, reducing the time they have to act by 33%.

One methodological point relevant to both experiments reported in this Chapter and Chapter 4 is that where there is a change in approach speed, with the same stimulus duration, there is always a trade-off between matching either the initial or final optical size of two stimuli. Varying the initial start size, which is only presented for 1 frame (17 ms) and immediately overwritten as the image expands, was preferable to varying the final optical size which would arguably be more obvious to the observer.

Experiment One

3.2. Methods

3.2.1. Participants

As part of the Live Science exhibit housed in the 'Who am I?' gallery at the London Science Museum in 2010 (see Figure 3.2. for a photograph of the experimental space). A total of 193 adult visitors participated in Experiment One. Participants comprised 99 males and 94 females, aged between 18 years to 59 years of age (mean age: 30 years) All participants held a valid driving license and gave written informed consent prior to their participation. At the start of the experiment, following an explanation of what the study involved, participants used a mouse to select their gender, age and to indicate whether they were a driver or non-driver from a series of drop-down menu boxes, before being asked to confirm their consent. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London and complied with health and safety standards outlined by the Science Museum.

Figure 3.2. Photograph showing the experimental space in the 'Who am I?' gallery at the London Science Museum in 2010.

3.2.2. Apparatus

Participants were seated in front of a 30 × 38 cm Dell^{tm} 1905FP TFT display, with a display resolution of 1280 × 1024. The results reported in this experiment were also piloted as part of a larger project within the Wann Lab on a CRT monitor with a small adult group (n = 6) in a repeated measures design and no significant difference was found between the use of a TFT and CRT display for the presentation of the stimuli, $F(1,5) = .9$; $p = .39$. The simulation code used a 60 Hz timer-loop, which ensured that the correct vehicle size and rate of expansion was presented for every frame of each trial. All simulations were scripted in Python and used Vizard 3D simulation tools (Development Edition, WorldViz, Santa Barbara, CA). The Vizard libraries interface with OpenSceneGraph and provide the ability to render highly realistic 3D simulations that are perspective-correct and run at the maximum screen refresh rate. The rendering hardware was an Intel® dual core CPU with an NVidia high performance GPU running under Windows XP.

3.2.3. Stimuli

A tessellated photographic image, where an actual road scene was re-arranged into a 400 tile mosaic, was used for the background. This was used to ensure the background comprised of a similar range of colour and contrast as an actual road scene, but without conflicting relative distance cues behind the vehicles (e.g. negating the cues in Figure 3.1.). The stimuli were viewed bi-ocularly at a distance of approximately 0.5 m. Vehicle combinations were interleaved to present a faster car vs. slower car (both a white Fiat 500), and a faster motorcycle (the probe) vs. slower car (the reference). The image of the motorcycle was scaled to the same height as the car (1.7 m x 1.7 m) with a width of 0.65 m.

A central fixation cross was presented for 1 second, then the observer saw two vehicles presented sequentially with a temporal interval of 100 ms. The vehicles were offset by 1 m (within the 3D scene) to the left or right of the fixation cross and travelled directly towards the observer (isotropic expansion). One vehicle was always travelling at the reference speed and the other at a probe speed which varied. The reference vehicle had a fixed speed of 20 mph (8.9 m/s), and approached for 500 ms from a fixed start distance of 49 m. The reference vehicle had a fixed end distance of 44 m, resulting in a fixed TTC of 5 seconds. This was used because previous research has shown that 5 seconds is the approximate time it would take to cross the width of an average UK urban road safely (5.45 m; Wann, Poulter, & Purcell, 2011). The probe vehicle varied in speed, but was normally faster than the reference. The start distance also varied to allow the same duration of approach (500 ms), but the end distance remained fixed (44 m). Vehicles were presented sequentially rather than simultaneously in order to limit the possibility that participants could pick up initial optical size of the vehicles. Consequently TTC of the probe vehicle varied and was generally less than 5 seconds because of the higher approach speed (see Figure 3.3. for an example of the stimuli).

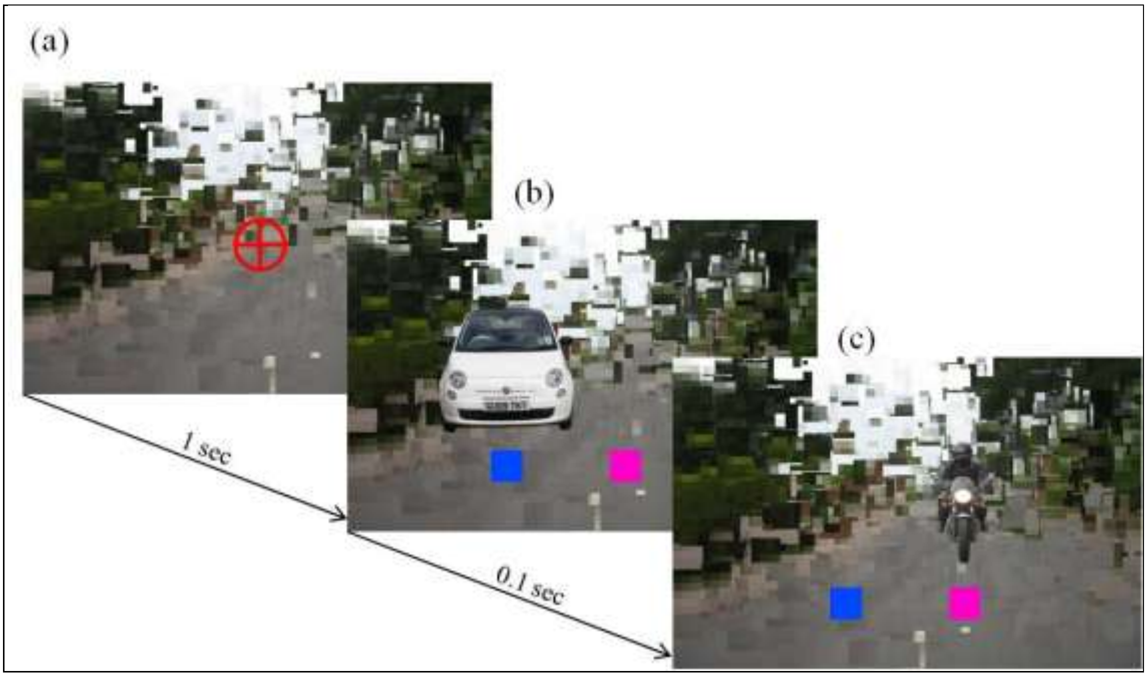

Figure 3.3. Example of stimulus testing speed discrimination thresholds for the slower car (the reference vehicle) and faster motorcycle (the probe vehicle) the sequence shows (a) initial frame showing central fixation cross; (b) end position of car following 500 ms of approach and (c) end position of motorcycle following 500 ms of approach. The blue and pink icons were selected by participants to record their response.

3.2.4. Psychophysical procedure

To converge on each participant’s threshold a Best Parameter Estimation by Sequential Testing (Best-PEST; Lieberman & Pentland, 1982) algorithm was used with a maximum speed for the probe vehicle of 120 mph, split into 1000 steps of 0.1 m/s. The algorithm first presented the participant with a very large speed difference between the reference and probe vehicle, i.e. the reference vehicle approaching at 20 mph and probe vehicle at 120 mph. This first trial should be a simple judgment and provided the answer is correct the algorithm would select the next step size in a downward descent procedure based on probability estimates. On incorrect answers, the algorithm selects an easier stimuli pair for the following trial and records one reversal. Increments of the algorithm were made on vehicle approach speed rather than rate of expansion in order to maintain some ecological validity. The PEST terminated after six reversals and the threshold was obtained for each participant by taking the maximum likelihood value (see Chapter 2, Figure 2.2. for example PEST sequence). The participants' response was forced choice as to which of the two vehicles they judged as approaching faster and they clicked an icon underneath the vehicle in line with the their response, there was no time pressure to respond.

The vehicle combinations were interleaved and the order of the reference and probe was varied, as was the side they were presented on, and observers were not cued to the fact that either vehicle was fixed in speed. In addition to the probe and reference trials, null trials were randomly interleaved showing a faster car vs. slower motorcycle. These were included for methodological reasons to avoid the motorcycle always being the faster vehicle. Any effect of size on perceived approach velocity will mean that participants will almost always select the faster car and as a result will always be correct. A PEST for this combination was not completed as the prediction was that errors in relative approach rate thresholds would be very small (and small TTC differences), but this would be uninformative as it would not provide an indication of perceptual acuity.

3.3. Results

Mean data for both vehicle combinations are presented in Table 3.1. An initial analysis using a one-way ANOVA (gender [Male, Female]) revealed no significant differences of gender on the identically sized vehicle combination ($F(1,192) = .45$, $p = .83$, $\eta^2 = 2.35$) or the different sized vehicle combination ($F(1,192) = .003$, $p = .95$, $\eta^2 = 1.7$), hence subsequent analysis was conducted on all participants regardless of gender. A Paired-Samples t-test was used to compare looming discrimination thresholds for the faster car vs. slower car combination and slower car vs. faster motorcycle combination,. The results showed that participants needed a significantly greater speed difference in the slower car vs. faster motorcycle combination $t(192) = 5.51$, $p < .001$. A one sample t-test was used to compare looming discrimination thresholds to zero for the slower car vs. faster car combination. The results showed that participants needed a significantly greater speed difference in order to judge that the probe car was travelling faster than the reference vehicle $t(192) = 7.80$, $p < .001$. A one sample t-test was also used to compare looming discrimination thresholds for the slower car vs. faster motorcycle combination. The results showed that participants needed a significantly greater speed difference in order to judge that the probe motorcycle was travelling faster than the reference car $t(192) = 11.06$, $p < .001$.

When the TTC of the probe vehicle was calculated using the fixed distance divided by vehicle speed, this revealed that observers could differentiate between a 5 second TTC and a 2.79 second TTC when presented with two cars but this difference widened to just differentiating between a 5 second TTC and 2.25 second TTC for the slower car vs. faster motorcycle vehicle combination.

Table 3.1. Errors in thresholds for looming discrimination (in mph), including standard deviations and 95% confidence intervals (95% CI) for both vehicle combinations. Also included is the mean TTC of the probe vehicle, in seconds, which can be compared to the TTC of the reference vehicle which was always 5 seconds.

	Faster Car vs. Slower Car	Slower Car vs. Faster Motorcycle
N	193	193
Mean threshold difference (mph)	15.34	23.65
Standard deviation	27.34	29.72
95% CI	± 7.76	± 8.44
Mean TTC for probe (s)	2.79	2.25

3.4. Discussion

The findings show that significant perceptual errors can occur in relative speed judgments across a large representative sample of the adult drivers from the general population. In the faster car vs. slower car combination, participants could either compare the rate of expansion of both cars, which would provide a direct indication of relative speed or the TTC of both cars using tau. But even for adults with driving experience, the speed threshold difference was 15 mph, meaning that they can only differentiate between one car travelling at 20 mph and the other at 35 mph, or equivalently between 5 seconds TTC and 2.8 seconds TTC (looming rates 0.45 vs. 0.79 degrees per second). This suggests that unlike in the sporting domain, where it has been proposed that human observers may be able to judge TTC to within a few milliseconds, in many everyday tasks when trying to judge whether there is a suitable time gap these results suggest that in general human observers are not as accurate as has been assumed.

When vehicle size was scaled, the use of tau (Equation 1 in Chapter 1) would predict that optical size (θ) would be compensated for and speed discrimination errors should be equivalent, irrespective of whether observers are presented with a car or motorcycle as the probe. Whereas, the use of rate of expansion ($\dot{\theta}$) without scaling for optical size would predict that the errors for the slower car and faster motorcycle combination would be greater than those observed for the comparison of two cars because the motorcycle was scaled to be the same height as the car but 38% of the width of the car, resulting in the average scaling across both dimensions making the car 144% larger than the motorcycle, which in turn would scale the looming rate by 144% for any given speed (Equation 1). The data in Table 3.1. showing an error 155% greater in the faster motorcycle vs. slower car combination clearly provide some support the latter account.

The conclusion that tau was not being detected could be unfair because participants' were not asked to judge which vehicle presented the shortest TTC. The 'time of arrival' however, is a difficult question to pose to an observer naïve to this type of experimental task. The question asked was "which vehicle is approaching faster", and because both vehicles disappeared at the same final distance, this equates to the same as making a TTC judgment and if tau had been utilised by observers it should have avoided the additional error introduced by vehicle size.

The finding of poor sensitivity to tau has applied relevance. Whether a pedestrian is stood at the side of the road waiting to cross, or a driver is at a junction waiting to pull out in a traffic stream, the perceptual task is equivalent. The observer needs to judge if they have sufficient time to complete their action. These results suggest that those judgments can be quite inaccurate and this may contribute to the accident rates in roadside scenarios. If size does bias judgments of perceived rate of approach, this raises a specific issue with motorcycles, that is further compounded by the observation that 50% of all motorcycles travel faster than the 30 mph speed limit in built-up areas, with 43% exceeding the speed limit by 5 mph or more (DfT, 2010). The basic problem highlighted by this study is that most experienced adults feel that their judgments either at the roadside or behind the wheel of a car are quite reliable and they can accurately judge the speed of an approaching vehicle, or the time available quite precisely. Here the results clearly show that this may not be the case and that errors across a representative sample of adult drivers can be significantly large resulting in an inflation of risk when approaching vehicles are in excess of the anticipated (regulated) speed.

If adults are susceptible to errors in judging the rate of approach between vehicles, then this could be even more problematic for children. As discussed in the introduction, children under the age of 15 are overrepresented in pedestrian road traffic accident statistics. A five year review conducted in the US (Dukehart, Donahue, Deeks, & Prifti, 2007) found that large four-door sedans were involved in more child pedestrian incidents than any other vehicle type (29%), followed by the standard pickup truck (15%). One explanation as to why children may be particularly vulnerable to pedestrian accidents could be due to their exposure to traffic threats that exceed their perceptual ability. If size does bias judgments of perceived approach rates, then children may be particularly susceptible to errors in their judgments of relative approach rates, especially when judgments need to be made between vehicles of different sizes. In the following experiment, children's thresholds in judging relative rate of approach were measured, between vehicles of the same size and when presented with a vehicle scaled to be twice the size of the other.

Experiment Two

3.5. Methods

3.5.1. Participants

Also as part of the Live Science exhibit in the London Science Museum, a total of 168 visitors participated in a second experiment, aimed at probing the size-arrival effect amongst developmental groups. Participants comprised 83 males and 85 females, aged between 6 years to 58 years of age (mean age: 14 years). Unlike in Experiment One, none of the older participants in this experiment held a valid driving license. Written informed consent was obtained for participants over 18 years of age and written parental informed consent was obtained for participants under 18 years of age prior to their participation (See Table 3.2. for a summary of participants). At the start of the experiment, following an explanation of what the study involved, visitors used a mouse to select their gender, age and to indicate whether they were a driver or non-driver from a series of drop-down menu boxes, before being asked to confirm their consent. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London and complied with health and safety standards outlined by the Science Museum.

Table 3.2. Number of participants by developmental group and gender.

Developmental Group	Gender	
	Male	Female
6 to 11 years old	42	36
12 to 17 years old	29	29
18 to 59 years old	12	20
Total	83	85

Groups were defined as children aged between 6 to 11 years old, 12 to 17 years old and 18 to 59 years old in order to provide a comparison between primary school aged children, secondary school aged children and adults. These age groups were selected to represent transitional periods in independence from being accompanied to school during primary school years, to greater independence at secondary school age. Chapter 5 begins to focus on primary school age and explores any differences within this group. To date there has been no psychophysical assessment of the limitations of human observers to detect TTC across the lifespan in the context of road crossing. However, previous research has suggested that by the age of 12 months, children have developed the perceptual acuity necessary to extract TTC from the ratio between optic size and optic expansion (e.g. Kayed & Van der Meer, 2009).

3.5.2. Apparatus

The apparatus used was identical to those outlined in Experiment One (see section 3.2.2).

3.5.3. Stimuli

The stimuli used were identical to those outlined in Experiment One (see section 3.2.3), except the interleaved vehicle combinations presented in this experiment comprised a faster car vs. slower car (both a white Fiat 500) and a faster car (the reference) vs. slower truck (the probe). As discussed in the introduction there seems to be a particular issue with drivers misperceiving the approach speeds of motorcyclists, although the issues are the same, as the participants in this experiment were all non-drivers, and the majority were children, it was considered more meaningful to use a truck instead a motorcycle as children in particular are likely to have less experience of motorcyclists on a daily basis. The image of the truck was a white HGV scaled to be exactly twice the size of the car (3.4 m x 3.4 m). See Figure 3.4. for an example of the stimuli.

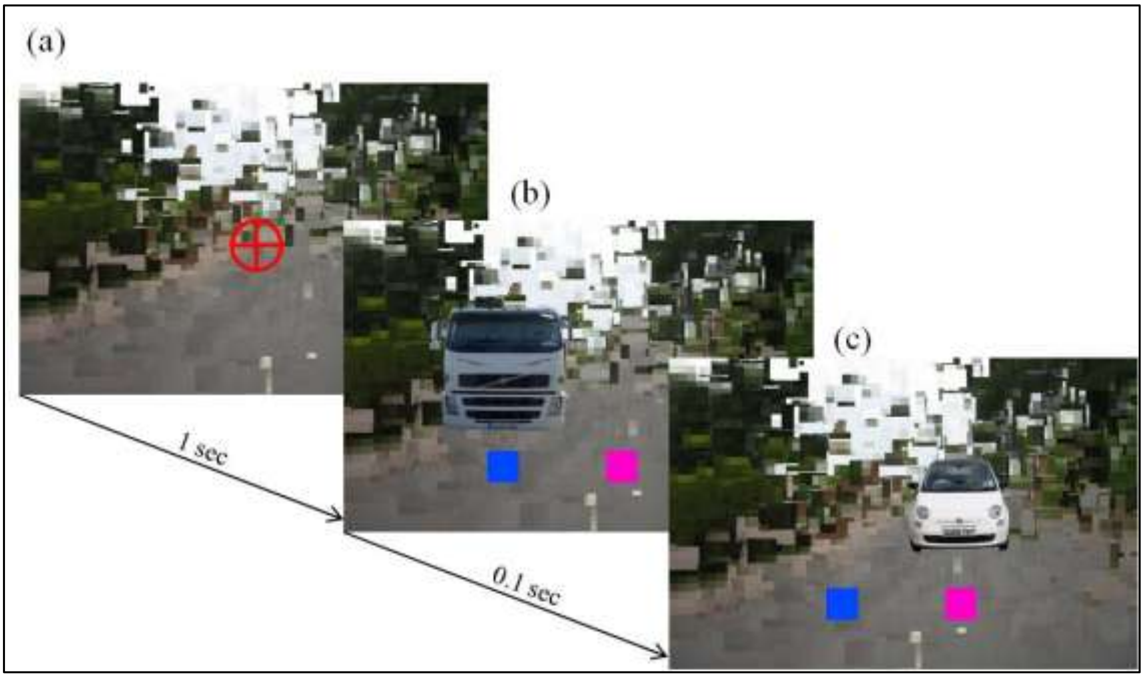

Figure 3.4. Example of stimulus testing speed discrimination thresholds for the slower truck (the probe vehicle) and faster car (the reference vehicle) the sequence shows (a) initial frame showing central fixation cross; (b) end position of the truck following 500ms of approach and (c) end position of car following 500ms of approach. The blue and pink icons were selected by participants to record their response.

3.5.4. Psychophysical Procedure

The psychophysical procedure was identical to that used in the previous experiment (see section 3.2.4), except that in this experiment the two interleaved staircases were a faster car vs. slower car and faster car vs. slower truck. A third interleaved combination presented a faster truck vs. slower car. These were included for methodological reasons to avoid the car always being the faster vehicle. But in the faster truck condition, any effect of size on perceived approach velocity will mean that participants will almost always select the faster truck and as a result will always be correct. Therefore, the PEST for this combination was not completed but these trials were included as foils.

3.6. Results

An initial analysis using a 3 x 2 ANOVA (age [6 to 11 years, 12 to 17 years, 18 to 59 years], gender [Male, Female]) revealed a non-significant effect of gender on the identically sized vehicle combination, $F(1,162) = 1.64$, $p = .20$, $\eta_p^2 = .01$, or the different sized vehicle combination $F(1,162) = .17$, $p = .68$, $\eta_p^2 = .001$, hence subsequent analysis was conducted on all participants ignoring gender. A two-way mixed ANOVA (age [6 to 11 years, 12 to 17 years, 18 to 59 years], vehicle combinations [faster car vs. slower car, faster car vs. slower truck) revealed a significant main effect of vehicle combination $F(1,165) = 67.12$, $p < .001$, $\eta_p^2 = .29$ and a significant main effect of age $F(2,165) = 3.03$, $p = .05$, $\eta_p^2 = .04$. A non-significant interaction was found for vehicle combination and age $F(2,165) = .90$, $p = .41$, $\eta_p^2 = .01$, post hoc Tukey HSD analysis revealed that the discrimination thresholds for the youngest children aged 6 to 11 years were significantly higher (worse) than adults aged between 18 to 59 years ($p = .04$). The TTC for the probe vehicle was calculated for each age group and these are reported along with the mean thresholds for each age group and vehicle combination in Table 3.3. (mph) and are illustrated in Figure 3.5. (deg/sec).

Table 3.3. Errors in thresholds for looming discrimination (in mph), including standard deviations and 95% confidence intervals (95% CI) for both vehicle combinations. Also included is the mean TTC of the probe vehicle, in seconds, which can be compared to the TTC of the reference vehicle which was always 5 seconds.

	6 to 11 year olds	12 to 17 year olds	18 to 59 year olds
Faster Car vs. Slower Car			
N	78	58	32
Mean threshold difference (mph)	16.51	10.77	8.77
Standard deviation	17.97	8.63	5.17
95% CI	± 6.02	± 6.98	± 9.40
Mean TTC for probe (s)	2.70	3.20	3.42
Faster Car vs. Slower Truck			
N	78	58	32
Mean threshold difference (mph)	32.74	33.22	25.93
Standard deviation	25.33	24.91	21.08
95% CI	± 10.93	± 12.67	± 17.06
Mean TTC for probe (s)	1.87	1.85	2.14

It is worth noting that there are comparable reductions in TTC for the probe vehicle in the faster car vs. slower truck combination (57%: 2.14 seconds) presented in this experiment for participants aged 18 to 59 and the 55% reduction in TTC for the probe vehicle in the slower car vs. faster motorcycle combination (2.25 seconds) reported in Experiment One.

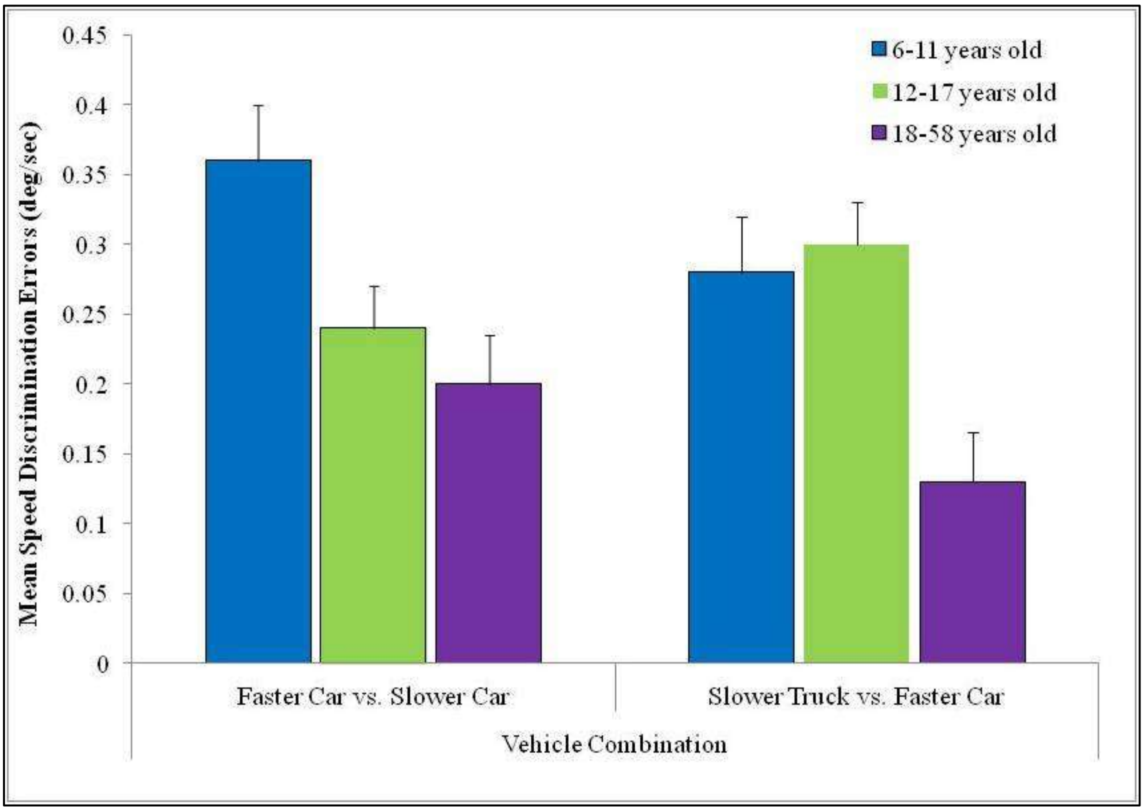

Figure 3.5. Mean threshold speed discrimination errors (deg/sec) for each age group when differentiating between identically sized objects (faster car vs. slower car) and differently sized objects (slower truck vs. faster car).

3.7. Discussion

It has been suggested that gauging the approach speed of oncoming vehicles is one of the leading factors contributing to the over representation of children's involvement in pedestrian motor vehicle accidents (Toroyan & Peden, 2007). This raises the question of whether children are equivalently able to utilise optical information in order to make appropriate roadside decisions. This experiment aimed to systematically examine whether children were more likely to misperceive vehicle approach speed compared to adults which could, in part, serve to explain the alarmingly high number of children killed and seriously injured on our roads each year.

These results demonstrate a clear developmental trend for speed discrimination thresholds between two identically sized cars, with the discrimination threshold for youngest children (6 to 11 years of age) nearly twice as poor as for adults. The observed thresholds equate to the youngest age group being unable to differentiate the speed difference between one car travelling at 20 mph and one travelling at 37 mph. Whilst the 12 to 17 year olds performed statistically equivalently to the adult group, they would still be unable to reliably detect the difference between one car approaching at 20 mph and another at 31 mph. It is interesting to note that the adult group in this experiment who were all non-drivers performed significantly ($p < .001$) better than in Experiment One where the adults were all drivers, in the faster car vs. slower car combination. This difference could be due to the smaller sample size in the current experiment or it could suggest some complacency amongst more experienced road users compared to non-drivers whose experience is limited as a pedestrian.

When examining the magnitude of the effect of vehicle size on speed judgments, it can be seen from Figure 3.5. that all groups displayed similar thresholds in deg/sec when comparing trucks to cars but because a difference in size scales to looming rate (Equation 1), the same difference in rate of expansion ($\dot{\theta}$) will only arise with bigger speed differences. For participants aged 6 to 17 years of age the smaller car could be travelling up to 33 mph faster than the larger truck and still be perceived as travelling at the same speed. Even adults would be unable to reliably discriminate between a large truck travelling at 20 mph and a smaller car travelling at 46 mph, reducing their crossing time by ~43%. In real world terms, this means that all participants, but particularly children, are more susceptible to the misperception that a smaller vehicle is travelling slower due to its smaller optical size and rate of expansion. As rate of expansion is a component part of TTC estimation, these results suggest that observers are likely to perceive the TTC of a smaller vehicle to be longer than it really is (e.g. 5 seconds compared to 1.87 seconds for 6 to 11 year olds).

3.8. General discussion

The findings from Experiment One suggest that adult drivers may misperceive the rate of approach between two vehicles, whereby one car travelling at 20 mph may be perceived as travelling at the same speed a car travelling at ~35 mph. These errors are inflated when adult drivers are presented with a faster vehicle with a smaller profile, such that a motorcycle would need to be travelling at 44 mph and a car at 20 mph for the speed difference to be discernable. This suggests that participants were basing their judgments on rate of expansion ($\dot{\theta}$) without scaling for optical size, and may account, at least in part, for the disproportionate number collisions involving motorcycles. These findings provide an explanation for those of Horswill et al., (2005) who found participants consistently judged motorcycles as arriving later than cars, they also concur with previous research (e.g. Hosking and Crassini, 2011) that has found that objects with a larger rate of expansion will be judged to arrive first.

Experiment Two suggest that children may be even more susceptible to this systematic bias, whereby smaller vehicles could be perceived as approaching slower than larger vehicles that loom at a greater rate. In this instance children under the age of 12 years old needed a 33 mph difference in order to tell that the car was travelling faster than the truck. This perceptual decrement reduced their crossing time from 5 seconds to 1.85 seconds and may explain the overrepresentation of children involved in pedestrian accidents. These findings suggest that children were less able to compensate for relative size and may be more predisposed towards just relying upon rate of expansion. Overall, the results suggest that the development of a neural mechanism sensitive to tau occurs gradually during childhood.

The next Chapter presents the same paradigm utilised in Experiment Two to children with DCD, who have been found to have deficits in motion processing (e.g. Wilmut & Wann, 2008). One might predict a deficit in the perceptual thresholds of primary school children with DCD to accurately judge the rate of approach between two vehicles, which would potentially make this population more vulnerable at the roadside. If a perceptual decrement is found in this population, then this could be problematic given that in 2010 in Great Britain, 47% of primary school children walked to school (DfT, 2011), a deficit in TTC judgments would have implications for children with DCD to become independent road-users.

Chapter 4: Perceptual errors in relative approach judgments in Developmental Coordination Disorder

"I have noticed even people who claim everything is predestined, and that we can do nothing to change it, look before they cross the road"

(Stephen Hawking)

4.1. Introduction

In the previous Chapter, two studies were presented which measured the perceptual thresholds of a large sample of adult drivers, children and adult non-drivers to accurately judge the rate of approach of two vehicles. The current Chapter presents the same paradigm to children with DCD. A fundamental feature of accurate and efficient motor coordination involves the assimilation of visual information from the environment. It was first suggested in the 1980s that 'clumsiness' in children could be explained as a general deficit in processing visual information. This proposition has been supported by evidence from functional tasks such as handwriting (Wann, 1986) and more recently by Tsai, Wilson and Wu (2009) who investigated non-motor visual perception in a large cohort of 9 to 10 year old children with DCD. They used the Test of Visual Perceptual Skills (non-motor) Revised (Gardner, 1996) and found that children with DCD had significantly lower scores than their typically developing peers on the TVPS-R. These deficits cannot be accounted for by ophthalmic deficits (Mon-Williams, Pascal, & Wann, 1994). In addition, a large meta-analysis has been conducted by Wilson and McKenzie (1998) to examine which information processing measures are important in distinguishing between children with DCD and control children. They found the main deficits associated with DCD were visual-spatial processing, kinaesthetic perception and cross-modal integration, and concluded that perceptual problems, patricianly in the visual modality, are associated with deficits in motor coordination.

In a road crossing situation, pedestrians have to make judgments of a visual scene that is changing moment-to-moment: this is a very specific visuo-perceptual task which involves the perception of motion. In a study that considered the use of moving cues to prompt movement direction in individuals with DCD, Wilmut and Wann (2008) manipulated the length of the dynamic cues available, including short (2 moving dots indicated target location), medium (4 moving dots indicated target location) and long (6 dots indicated target location). Typically developing individuals showed a reduction in movement latency for all lengths of dynamic cue as compared to when no cue was available. In contrast individuals with DCD only showed a reduction in movement latency for the longest dynamic cue length, suggesting that individuals with DCD were not using the visual information to forward plan or anticipate a movement in the same way as controls.

Although the findings of Wilmut and Wann (2008) suggest a general motion deficit in individuals with DCD, which could serve to explain a number of difficulties observed in DCD, as discussed in Chapter 1, tests measuring thresholds of global motion coherence (dorsal-stream) and global form (ventral-stream) coherence have produced mixed results and until now, there has been no examination of motion processing in DCD for the types of perceptual-motor tasks that are typically required at the roadside. Using the same paradigm as Experiment Two in the previous Chapter, the current study aimed to systematically measure the perceptual thresholds of primary school children with DCD to accurately judge the rate of approach of two vehicles.

4.2. Methods

4.2.1. Participants

A total of thirty participants took part in this study: fifteen typically developing (TD) children aged between 6 to 11 years old; nine children with DCD aged between 6 to 11 years old; and six children at risk of developing DCD aged between 7 to 11 years old (see Table 4.1. for group information). Children were recruited from a local primary school, and screened in accordance with DSM-IV guidelines. To assess DSM-IV Criteria A and B, teachers were given an adapted version of the MABC-2 checklist (MABC-2; Henderson et al., 2007) and asked to identify children with coordination difficulties that they deemed significantly interfered with their academic achievement, and children without coordination difficulties. Teachers returned checklists for seven children that were subsequently identified as DCD, for five (71%) of these children, teachers responded yes to *"Overall do you think this child has movement difficulties"*. All children were then assessed on the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007). Children in the age and gender matched TD group scored $\geq$ 25th percentile, indicating typical motor development, children identified as DCD scored $\leq$ 5th percentile, denoting significant movement difficulties. Children who scored > 5th but $\leq$ 16th percentile are in a borderline category and for brevity within the text will be referred to as being "at risk" of having movement difficulties. This separation of children failing below the 16th percentile is in line with the Leeds Consensus Statement on assessment and classification (Sugden, 2006).

To assess DSM-IV Criteria C and D, all children were assessed on the Coloured Progressive Matrices (CPM; Raven, 1956). Twenty-six children (87%) fell at or above intellectually average for their chronological age (between 25th - 100th percentile), and one TD child and three children with DCD (13%) fell below intellectual capacity for their age (between 10th - 25th percentile). The data for these four children for all tasks were looked at individually and were not found to be significantly different from the group mean and so were included in the final sample. Given reported comorbidity rates between DCD and ADHD, teachers also completed Conners' Teacher Rating Scale – Revised (Conners, 1997) for their children. A number of the control and DCD children had elevated scores on the Conners' dimensions[3]. It is likely that the inflated scores reflect changes in the classroom environment in the last decade. In terms of screening, there were no marked differences between the control group and index groups on the Conners' teacher ratings. It should be noted however, that one conclusion of the Leeds Consensus Statement is that children should not be excluded from a classification of DCD because of other associated problems such as ADHD (Sugden, 1996, pg.6). The issue then is whether any deficit in performance on a specific task is due to the effects of DCD or ADHD, this issue is addressed in the results and discussion sections.

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[3] One TD child scored > 75 % on the oppositional dimension, suggesting this child is likely to break rules and have problems with authority; two TD children and four children with DCD scored > 75 % on the cognitive / inattention dimension, suggesting these children may have more academic difficulties compared to their peers, and have problems organising their work or concentrating on tasks that require sustained mental effort; one child with DCD scored > 75 % on the hyperactivity dimension, suggesting this child may have difficulty sitting still.

Table 4.1. Participant information for each group, information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 range and mean MABC-2 total test score, number of children with Ravens scores ≥ grade IV, Conners' ADHD index number of children with scores between > 75% and < 86%, and gender ratio (female to male).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	15	6	9
Mean decimal age	9.1	9.0	9.1
Age range	6.4 - 11.4	7.1 – 11.0	6.7 – 11.7
Mean MABC-2 centile	47	13	3
MABC-2 range	25 – 91	9 – 16	1 – 5
Mean MABC-2 total test score	78	62	48
Ravens (N ≥ grade IV)	1	0	3
Conners' ADHD index (N > 75% and < 86%)	1	0	2
Gender ratio (f:m)	5:12	1:5	4:7

Parental informed consent was obtained for all children in advance of the study, and each child provided verbal assent immediately prior to the start of the experiment. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London.

4.2.2. Apparatus

The apparatus was identical to those outlined in Experiment One in Chapter 3 (see section 3.2.2).

4.2.3. Stimuli

The stimuli was identical to those outlined in Experiment Two in Chapter 3 (see section 3.2.3).

4.2.4. Psychophysical Procedure

To converge on each child's threshold a Best Parameter Estimation by Sequential Testing (Best-PEST; Lieberman & Pentland, 1982) algorithm using a maximum speed for the probe vehicle of 230 mph, split into 1000 steps of 0.1 m/s, was used. This algorithm first presented the child with a very large speed difference between the reference and probe vehicle, i.e. the reference vehicle approaching at 20 mph and probe vehicle at 230 mph. This first trial should be a simple judgment and provided they answer correctly the algorithm selects the next step size in a downward descent procedure based on probability estimates. On incorrect answers, the algorithm selects an easier stimuli pair for the following trial and records one reversal. The PEST terminated after six reversals and the threshold value was obtained for each participant by taking the average of the last four reversals in the PEST series, unless there were a series of ten or more correct responses between reversals 3 and 6, in which case the child's lowest correct response was taken as a more accurate measure of performance. Each child's response was verbal and there was no time pressure to make a response, although most children responded within 2 to 3 seconds. If a child failed to notice the stimuli at all (e.g. due to momentary distraction) they were aware that they could request a re-run of the stimuli for that trial, although the number of times this was required was extremely infrequent.

It is important to note that a PEST was completed for the faster truck and slower car combination, but no marked differences were expected between groups for the combination. These trials were included for methodological reasons to avoid the truck always being the slower vehicle. Any effect of size will mean that children (and adults) will almost always select the faster truck and as a result will always be correct. Therefore, the prediction for the PEST was that thresholds for this combination would converge towards small errors in relative approach rate thresholds (and small TTC differences). This is not an indication of perceptual acuity, simply that the size bias lends to a response in the correct direction, creating an illusion of precision. For this reason the results of this set of trials are not included in the group analysis. One useful indication from these trials is that if a child was not attending and responding randomly then the function would not converge towards small errors in relative approach rate thresholds, but would plateau somewhere between stimulus points 500 and 1000 (speed difference errors of over 110 mph).

4.2.5. Data Analysis

Levene’s test confirmed that parametric assumptions were not met for the faster car vs. slower truck combination. This might be expected with a downward descent towards zero-errors in speed difference, which will tend to skew the distributions differentially if groups vary in their perceptual acuity. Therefore, inter-group differences were considered using Kruskal-Wallis and paired Mann-Whitney *U* post hoc comparisons. An additional non-parametric Spearman’s rho correlation analysis was conducted on the threshold errors in relative approach rate judgments for the car vs. car combination and the MABC-2 sub-sections, to determine whether any sub-sections of the MABC-2 were related to poor performance. Individual data are presented in Figures 4.1. and 4.2. in the Results section.

4.3. Results

Data for all three vehicle combinations are presented in Table 4.2. Initial analysis was conducted between a combined at risk and DCD group and the TD group, Kruskal-Wallis yielded a non-significant group effect for vehicle combinations car vs. car: $\chi^2 = 5.26$, $p = .07$ and slower car vs. faster truck: $\chi^2 = 1.02$, $p = .60$. A significant group effect was found for faster car vs. slower truck: $\chi^2 = 6.84$, $p = .03$).

Following this outcome, analyses were conducted separating the DCD and the at risk groups. When presented with two identical cars and asked to judge which was approaching faster, there was a significant group effect between TD children and children with DCD in the threshold errors in judging relative approach rates. TD children converged to a speed difference of 33 mph and equivalently children in the at risk group 29 mph. In contrast, children with DCD needed a mean speed difference of 82 mph in order to judge that one car was travelling faster than another. Kruskal-Wallis yielded a non-significant overall group effect ($\chi^2 = 5.26$, $p = .07$), due to the equivalence of the at risk and TD group. However, a pairwise comparison between TD children and children with DCD was significant, $U = 33$, $z = 2.1$, $p = .04$, $r = .4$.

When presented with a faster car alongside a slower truck that was twice the image size, all children showed a size-effect. Compared to the car vs. car condition, this inflated the threshold errors in judging relative approach rates for the TD children to 60 mph (155%), whereas the threshold for the at risk group rose to 36 mph (123%), and for the DCD group it rose to 98 mph (119%). Kruskal-Wallis yielded a significant group effect, $\chi^2 = 6.84$, $p = .03$, and a pairwise comparison between TD children and children with DCD was also significant, $U = 29$, z = 2.3, $p = .02$, $r = .5$. There were no significant differences for either condition between TD children and those in the at risk group.

The results for trials with a faster truck vs. slower car are shown in Table 4.2., but as discussed in the methods these are not informative regarding perceptual acuity. They do converge towards small threshold errors in judging relative approach rates as predicted, due to the size-effects, and this confirms that the children were attending to all trials (as vehicle combinations were interleaved). The minor difference in the final level between the DCD group and other groups is not significant nor is it significantly different from zero. This confirms that the children with DCD were attending to the task. For the two children in the DCD group with higher scores on Conners', one child's threshold was in-line with the size-effect predictions, the other child's threshold however did not show the predicted size-effect for this combination, one possible explanation for this is 'inattention' but for this child alone. Individual data for the two tasks are illustrated in Figures 4.1 and 4.2.

Table 4.2. Errors in thresholds for looming discrimination (in mph), including standard deviations and 95% confidence intervals (95% CI) for car vs. car, faster car vs. slower truck and slower car vs. faster truck combinations across groups. Also included is the mean TTC of the probe vehicle, in seconds, which can be compared to the TTC of the reference vehicle which was always 5 seconds.

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
	faster car vs. slower car		
N	15	6	9
Mean threshold difference (mph)	33.21	29.25	82.22
Mean threshold difference (deg/sec)	0.74	0.65	1.33
Standard Deviation	25.32	28.84	61.95
95% CI	± 28.04	± 60.53	± 95.24
Mean TTC for probe (s)	1.86	2.00	0.97
	faster car vs. slower truck		
N	15	6	9
Mean threshold difference (mph)	50.67	36.11	97.48
Mean threshold difference (deg/sec)	0.69	0.80	2.19
Standard Deviation	46.66	23.75	57.34
95% CI	± 51.68	± 49.84	± 88.18
Mean TTC for probe (s)	1.39	1.76	0.83
	slower car vs. faster truck		
N	15	6	9
Mean threshold difference (mph)	1.48	-4.78	18.51
Mean threshold difference (deg/sec)	N/A	N/A	N/A
Standard Deviation	9.46	3.72	16.50
95% CI	± 10.48	± 19.12	± 76.08
Mean TTC for probe (s)	4.63	6.55	2.48

A strong significant negative correlation was found between children's MABC-2 percentile obtained for the aiming and catching sub-section and threshold errors in judging relative approach rates for the car vs. car combination, r_s = -.46 p = .01. Furthermore, taking the MABC-2 raw score for the age relevant catching task only, also yielded a strong significant negative correlation, r_s = -.50, p = .005.

Individual threshold data (in mph) for the faster car vs. slower car combination are presented in Figure 4.1. When vehicle size remained constant, errors in judging relative approach rates ranged between 4 to 81 mph for TD children and children at risk, compared to 67% of children with DCD whose errors fell above the 95% confidence interval (95% CI) of the TD mean and ranged from 3 to 167 mph.

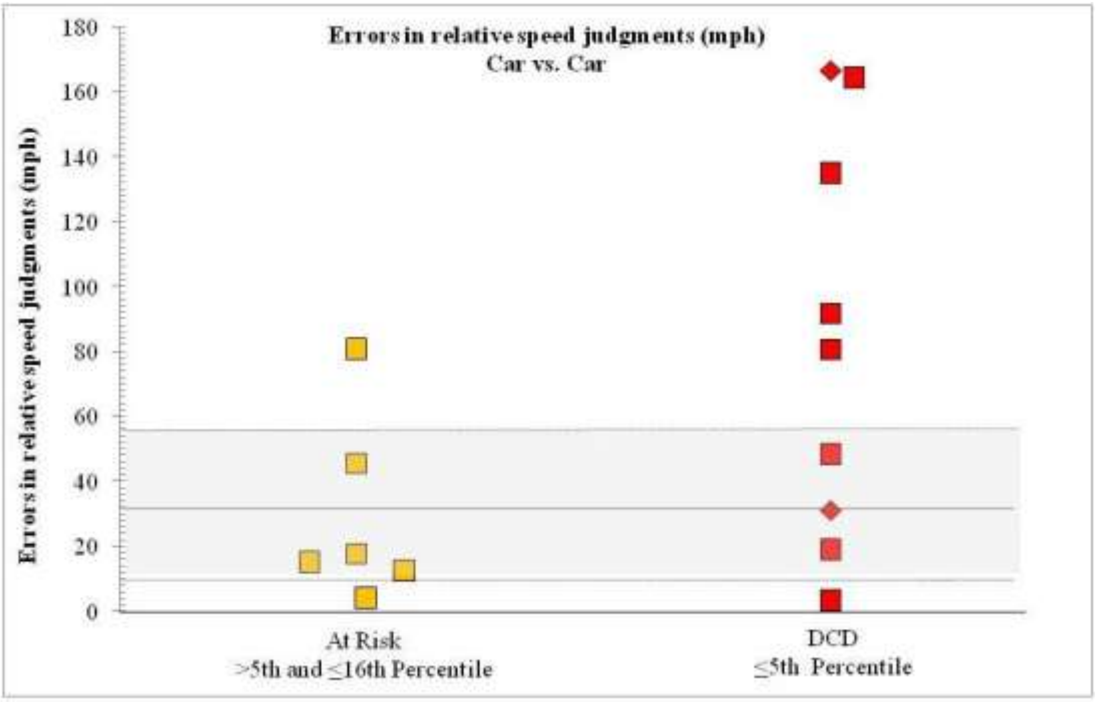

Figure 4.1. Individual threshold errors in relative approach rate judgments (in mph) for the car vs. car combination for children at risk and DCD children. The mean threshold error for TD children (n = 15) is shown by the solid line, with the 95% CI of the TD mean and upper and lower bounds represented by the shaded area and dotted lines. The two children in the DCD group that obtained ADHD index scores >75% are shown as diamonds.

Individual threshold data (mph) for the faster car vs. slower truck combination are shown in Figure 4.2. When presented with a faster car alongside a slower truck, that was twice the image size, errors for all children in relative speed judgments increased as predicted by a size-arrival bias. Errors ranged between 9 to 193 mph for TD children and children at risk, compared to 67% of children with DCD whose errors fell above the 95% confidence interval (95% CI) of the TD mean and ranged from 20 to 193 mph.

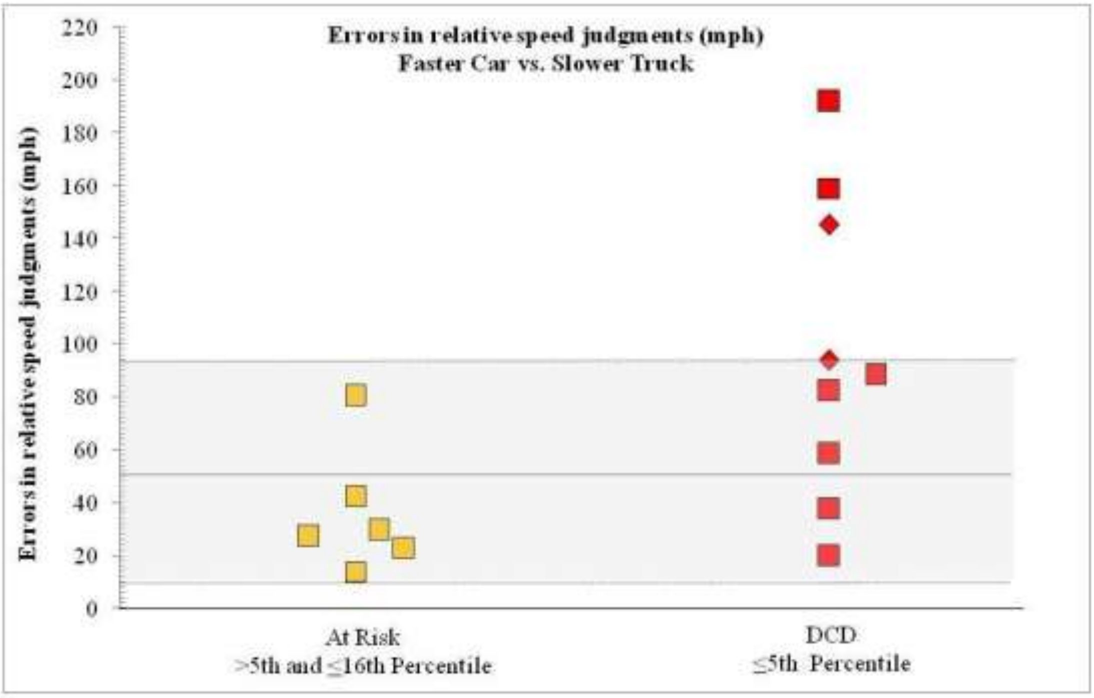

Figure 4.2. Individual threshold errors in relative approach rate judgments (in mph) for the faster car vs. slower truck combination for children at risk and DCD children. The mean threshold error for TD children (*n* = 15) is shown by the solid line, with the 95% CI of the TD mean and upper and lower bounds represented by the shaded area and dotted lines. The two children in the DCD group that obtained ADHD index scores >75% are shown as diamonds.

4.4. Discussion

This is the first study to assess the specific issue of sensitivity to TTC in a DCD population and relate it to judging vehicle approach. The results confirmed that children with DCD showed a marked deficit in making relative approach rate judgments based on TTC. When presented with two cars this meant they were only able to reliably discriminate between the speed of two vehicles when one was travelling at 20 mph and the other is over 100 mph, whereas in the typically developing sample the threshold was reached at 20 mph vs. 53 mph. The potential impact of this is clear. At the termination of each trial, both vehicles were the same optic size (e.g., distance) and the slower (reference) vehicle had presented a final TTC of 5 seconds. For a vehicle travelling at say 81 mph the TTC would have dropped to approximately 1.0 second, but children with DCD did not reliably notice this speed difference. This is not an issue of general attention, as trials in other combinations, such as faster truck vs. slower car where the looming differences are more salient, show that the children with DCD can follow a downward descent (Best-PEST) procedure to converge towards ideal performance.

The issue of what information is being detected is an intriguing one. Presumably, it is simple rate of expansion (looming) without scaling for optical size, but it could equally be a comparison of start and end size of each vehicle, although this is just a very crude index of average looming rate, based on memory (because the stimuli were sequential) and is a rather unlikely candidate when real-time looming is presented. It is well known that neurons in motion sensitive visual areas respond to expansion (Field, & Wann, 2005), but to accurately judge TTC children should use the instantaneous ratio of optic size to optic expansion, which is robust against size changes (Lee, 1976). This was tested by introducing a size manipulation with a faster car compared to a slower truck (twice the optical size). This raised the threshold speed by 55% and 23% in the TD and at risk group, respectively, and 19% in the children with DCD. As with both experiments reported in the previous Chapter, this demonstrated a clear size-effect, which was significantly greater for children with DCD, which suggests that if they are sensitive to tau, they are only using it to a limited extent, or that any tau-based judgments are skewed by the final end-size. It is also of note however that the size manipulation did not double the speed error in the TD group unlike in the larger developmental study reported in Chapter 3, where thresholds were twice as large for 6 to 11 year olds (n = 78). This suggests that the generally inflated TD thresholds in this study could be due to the smaller sample size. There was still a difference between the TD and DCD groups in the car vs. truck task, but the size-bias in the children with DCD was not as large as you might have expected. The most likely explanation for this is a simple ceiling effect. The speed difference they converged upon (98 mph) is 42% of the maximum speed difference that was possible with the experimental set-up. At 98 mph the car starts at only 1.23 deg of visual angle and initially looms at 0.72 deg/s; at 200 mph it starts at 0.88 deg of visual angle and initially looms at 0.70 deg/s. So there is a zone in the upper end of the series presented where speeds of 100 mph, 150 mph and 200 mph start to look equivalent to a human observer.

One interesting observation is that the children between the 5th and 16th percentiles that were judged to be at risk of DCD, were performing equivalently, and in some cases marginally better than the TD group. This suggests that any impairment of motion processing does seem to be specific to children with more pronounced movement control problems and further emphasises the importance of treating these groups separately within the research community. Finally there was quite a strong correlation between some sub-components of the MABC-2 and the errors in speed discrimination. It would be premature at this stage, to elaborate as to why sub-components of the

MABC-2 are correlated with errors in speed discrimination. The observation simply suggests that children who perform poorly on some sections of the MABC-2 are most at risk in making relative approach speed judgments. Any underlying causal influences would require a more detailed investigation.

The evidence for motion processing deficits in DCD is mixed (e.g. Sigmundsson, Hansen, & Talcott, 2003; Wilmut & Wann, 2008). But this is the first study to systematically examine the perceptual abilities of DCD to cope with the types of speeds typically encountered at the roadside. Overall, the findings from this study highlight low-level perceptual deficits in motion processing that may give rise to potential errors in the road crossing behaviour of children with DCD and demonstrates errors in judgments of TTC that could lead to serious mis-estimation of vehicle approach speeds. This also demonstrates that they are still a long way from the optimal sensitivity for TTC judgments that are required to be skilled and competent at crossing judgments and this has implications for their ability to become an independent road-user.

In this paradigm, children were required to judge which out of two sequentially approaching vehicles was travelling faster. An interesting question that arises from the findings is whether children with DCD exhibit deficits in TTC judgments as a result of an over reliance on optic size (e.g. start and end size of each vehicle), whereby they simply select the larger vehicle if they are unsure, or at a motion processing level (i.e. rate of expansion). The next Chapter addresses this question, by presenting primary school aged children with and without DCD with a simple low level looming detection task.

Chapter 5: Establishing Thresholds for Looming Detection

> ***... She could not cross the street because of her inability to judge the speed of a car, but she could identify the car itself without difficulty. "When I'm looking at the car first, it seems far away, suddenly the car is very near."***
>
> (Zihl, von Cramon, & Mai, 1983)

5.1. Introduction

As discussed in the introductory Chapter, Lee (1976) has demonstrated that the TTC of an approaching object can be determined by the ratio of its distance, $z(t)$, and velocity, $v(t)$, which can be perceptually specified by the ratio of optic size $\theta(t)$ to the rate of looming $\dot{\theta}(t)$:

$$\text{TTC} = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} = tau \qquad (1)$$

For a pedestrian standing at the kerb, there is a limited amount of information available about the TTC of an approaching vehicle. For example to estimate TTC from Equation 1 an observer could judge distance, $z(t)$, and estimate velocity, $v(t)$ from this. However, most cues to distance only provide relative estimates which can be prone to considerable bias with changes in road topography. For example, for a vehicle at 55 m (e.g. 5 seconds TTC travelling at 25 mph), a 1 degree increase or decrease in the slope of the road can make the height of a vehicle in the scene equivalent to a vehicle that was four times the distance (~200 m), or half the distance (~28 m). It is feasible that binocular cues could be used to judge the absolute distance of a vehicle approaching a pedestrian, however, the utility of binocular information becomes negligible beyond distances of 10 m (Tresilian, Mon-Williams, & Kelly, 1999) and most approaching vehicles are beyond 50 m at the point at which road crossing decisions are made. Alternatively, pedestrians could use prior knowledge of the absolute dimensions of vehicles to estimate the absolute distance of a vehicle based on its optical size, but this does not yield a direct estimate of the other critical variable which is approach speed. Given the unpredictability of road layouts, one of the few reliable indications of vehicle distance is the ratio of the optical size to its rate of expansion (tau), which can provide the basis for judgments of TTC.

For an observer to make an accurate TTC judgment based on a tau ratio, the rate of expansion $\dot{\theta}(t)$ in Equation 1 needs to be above the perceptual threshold of the observer. If a pedestrian at the roadside is unable to detect the expansion of the vehicle image then TTC goes to infinity (Equation 1) and the vehicle may look small and stationary in the scene. The rate of optical looming during a period of approach (t) is a function of the object size (D) which could be its height or width, approach velocity (v) and the square of the absolute distance (z):

$$\dot{\theta}(t) = \frac{D v(t)}{z^2(t)} \tag{2}$$

Where the perceptual threshold for looming $(\dot{\theta}_{th})$ is known for an individual, Equation 2 can be reversed to work out the maximum speed of approach that allows the observer to make a reliable decision given the time they require (t_c) to complete the road crossing action (Wann et al., 2011):

$$v_{\max} = \frac{D}{t_c^2\, \dot{\theta}_{th}} \tag{3}$$

There are two important features illustrated by Equation 3: First, if the level at which looming can be reliably detected is elevated (poorer acuity), then the speed at which vehicle approach can be reliably detected is reduced if t_c is fixed. Second, if t_c increases, then again the speed at which vehicle approach can be detected is reduced. To illustrate this, consider an observer with a fixed (t_c), from the simple fact that time-to-arrival=distance/velocity, then a car travelling twice as fast must also be twice as far away if the observer is to cross in that fixed time. Considering Equation 2, although this doubles the velocity term because of the z^2 divisor in Equation 2, the doubling of distance will actually result in a net reduction in the looming rate by 50%. So contrary to what might be assumed, for a pedestrian seeking to select a specific time-gap in which to cross the road, faster vehicles will loom at a lower rate than slower vehicles at the time at which the crossing decision needs to be made. This general reduction in looming for faster vehicles then means that for an individual with a specific acuity $(\dot{\theta}_{th})$ and crossing time (t_c), there will be cars that are approaching too quickly (v_{max}) for them to be able to make a reliable judgment.

Hoffmann (1994) found a developmental effect where estimated thresholds for children aged 5 to 8 years of age were twenty times higher (poorer) than those for adults (0.04 rad/s vs. 0.002 rad/s). In addition, Wann et al (2011) directly measured visual looming detection thresholds and found a protracted time course for development, with thresholds for the detection of isotropic looming in foveal vision 2.5 times higher for 6 to 7 years olds compared to adults and 1.6 times as large for children aged between 10 to 11 years compared to adults.

The first experiment presented in this Chapter, systematically measured a sample of typically developing primary school aged children’s thresholds for the detection of looming at rates equivalent to those that may be encountered at the roadside using the psychophysical methods employed by Wann et al (2011) but with three specific modifications: (1) to minimise the time taken to complete each trial, the number of reversals were reduced from ten to six; (2) to eliminate any potential static scene cues to relative distance in the backdrop, a mosaic background of a road scene was used instead of an actual road scene and; (3) due to the reduction in the total number of reversals, the maximum likelihood value was taken as the threshold value rather than a mean of the last five reversals. This amended methodology was used with thirty typically developing children to ensure the results were consistent with the findings reported by Wann et al., (2011). The second experiment presented in this Chapter, uses this amended methodology with children with DCD to establish whether this population have the equivalent ability to their typically developing peers to detect looming under various viewing conditions.

Experiment One

5.2. Methods

5.2.1. Participants

A total of thirty children aged between 6 years and 4 months to 11 years and 5 months participated in this study (see Table 5.1. for participant information). Children who had high false-positive rates were excluded (see the psychophysical procedure section), so the number of children in some conditions was less than the original sample size. None of the children had any reported history of behavioural or neurological problems that would qualify as exclusion criteria for this study and all children had normal or corrected-to-normal vision. As these children are later used as a control group to compare with children with DCD, all children were assessed for motor coordination using the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007) All children scored ≥25th percentile indicating typical motor development. Twenty-two children were also assessed on the Coloured Progressive Matrices (CPM; Raven, 1956). Twenty-one children (95%) fell at or above intellectually average for their chronological age (between 25th-100th percentile), and one child (aged 8 to 9 years age) fell below intellectual capacity for their age (between 10th-25th percentile). A recent systematic review reported the prevalence rates of ADHD to be between 2-18% (Rowland, Lesesne, & Abramowitz, 2002), so teachers were also asked to complete Conners' Teacher Rating Scale – Revised (Conners, 1997). Completed teacher ratings were returned for thirteen children, of these one child (aged 8 to 9 years of age) scored 86% on the ADHD index (dimension scores: 73% oppositional; 80% cognitive/inattention; 67% hyperactivity). In addition, a subset of the Test of Everyday Attention for Children (TEA-Ch; Robertson et al., 1994) was administered to fifteen children, who were later used as matched controls for a DCD group, to assess three specific types of attention: focused attention; sustained attention; and attentional control. Two children in the group aged 8 to 9 years of age and one child in the oldest age group (10 to 11 years old) obtained an overall age scaled score below their chronological age. The issue of whether a child is on task is discussed in the psychophysical procedure section.

Table 5.1. Participant information for the three developmental groups. Information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 range and mean MABC-2 total test score, Ravens Progressive Matrices index: number of children with scores ≥ grade IV, Conners' ADHD index: number of children with scores >75 % and <86%, mean TEA-Ch age scaled score and gender ratio (female to male).

	6 to 7 year olds	8 to 9 year olds	10 to 11 year olds
N	7	17	6
Mean decimal age	7.44	9.10	11.03
Age range	6.4 – 7.8	8.0 – 9.9	10.9 – 11.5
Mean MABC-2 centile	54	52	50
MABC-2 range	25 – 91	50 – 95	37 – 75
Mean MABC-2 total test score	81	79	79
Ravens (N ≥ grade IV)	0 (*n* = 5)	1 (*n* = 14)	0 (*n* = 3)
Conners' ADHD index (N > 75% and <86%)	0 (*n* = 6)	1 (*n* = 5)	0 (*n* = 2)
Mean TEA-Ch age scaled score	10.39 (n=6)	7.93 (*n* = 7)	9.08 (*n* = 2)
Gender ratio (f:m)	3:4	1:16	1:2

Parental informed consent was obtained for all children in advance of the study, and each child provided verbal assent immediately prior to the start of the experiment. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London.

5.2.2. Apparatus

Participants were seated and stimuli displayed on a Dell flat LCD monitor (34 x 27 cm) with an aspect ratio of 5:4 and display resolution of 1280 × 1024 sufficient for all presentations. The rendering hardware was an Intel® dual core CPU and NVidia high performance graphics processing unit running under Windows XP. All simulations were scripted in Python employing Vizard 3D simulation tools (Development Edition; WorldViz, Santa Barbara, USA). The Vizard libraries interface with OpenSceneGraph enabling highly realistic 3D simulations at the maximum screen refresh rate (60 Hz). To avoid the potential confound of bi-ocular cues, participants viewed the stimuli monocularly, using their preferred eye at a distance of 2 m.

5.2.3. Stimuli

In all conditions, a photographic image of a car was presented on a background photographic image of a road scene. The road scene image used as the backdrop was re-arranged into a 400 tile mosaic, ensuring the same scene statistics and relative contrast as a real road scene, but eliminating any static object in the scene being used as a cue to relative distance in the scene. The size of the car image (1.725 m) was taken as the mean of the car width (1.80 m) and height (1.65 m) and these metrics were then used in generating a perspective correct 3D scene. Walking speeds were measured and it was found that children would need 5 seconds to cross an average UK road (5.45 m wide) safely, TTC was therefore fixed at 5 seconds at stimulus onset, but in order to maintain a constant rate of change of the visual angle the TTC was slightly more than 5 seconds (~5.4 seconds) at the end of the PEST staircase. In all conditions the car was presented for 200 ms at an image size simulating different virtual distances and a rate of expansion equivalent to different speeds of approach (see Figure 5.1. for a sample of the stimuli). A total of four conditions were randomly presented: (a) foveal isotropic expansion; (b) foveal isotropic expansion with simulated viewpoint motion; (c) perifoveal isotropic expansion; (d) perifoveal isotropic expansion with simulated viewpoint motion. Isotropic stimuli expanded uniformly in all orientations, in the foveal conditions car images were presented at central fixation. In the perifoveal conditions, the car images were presented 4.25 deg from central fixation (3 deg in the vertical and horizontal planes), in one of four randomly selected quadrants. This might occur in natural scenes if pedestrians did not fixate directly on a vehicle when visually scanning a cluttered road scene. Detection of isotropic expansion in a static scene simulates the direct approach of a vehicle, but does not necessarily test sensitivity to looming, as the judgment could equally be made by detecting the movement of any edge or discreet feature. Hence, simulated viewpoint motion was included in both foveal and perifoveal conditions. In these conditions the child was required to extract looming (isotropic expansion) from lateral edge motion, as might be experienced as a result of the child moving their head whilst scanning the road scene. The amount of image motion was scaled to the virtual distance of the car and was equivalent to the observer moving forwards by 55 cm. This resulted in 0.7 degree of displacement for a vehicle 44 m away (e.g. 20 mph and TTC = 5 seconds), but 0.35 degree for a vehicle 88m away. This scaling was not only viewpoint correct but retained the 1/3 ratio of lateral displacement to image size. The direction of displacement was randomly oriented to one of the four screen quadrants. Each condition incorporated randomly interleaved stationary cars that did not simulate forward motion (50% of trials). Each child’s response was verbal forced-choice and there was no time pressure to make a response, although most children responded with 2 to 3 seconds.

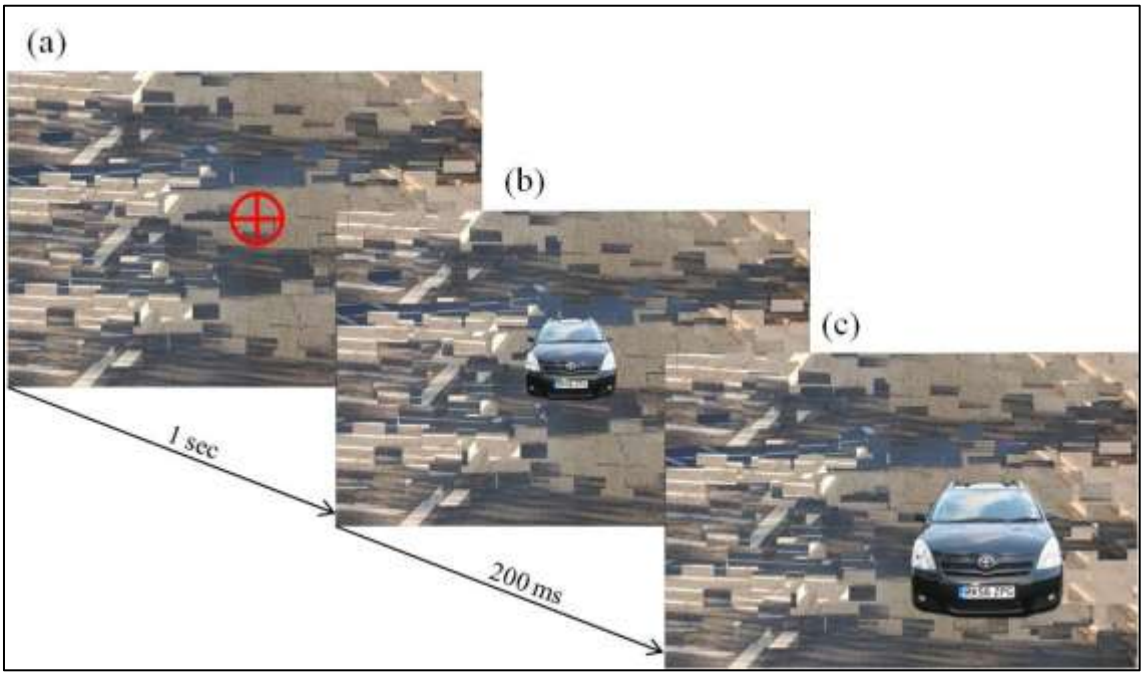

Figure 5.1. Example of stimulus testing detection thresholds for looming in foveal vision with 1 degree of lateral motion against a mosaic road scene background (a) initial frame showing central fixation cross; (b) starting position of car (c) end position of car following 200ms of looming and 1 degree of lateral motion.

5.2.4. Psychophysical Procedure

The child's task was to verbally indicate whether the car got bigger or stayed the same size. To converge on each child's looming detection threshold a Best Parameter Estimation by Sequential Testing (Best-PEST: Lieberman & Pentland, 1982) staircase procedure was used which progressed in a downward descent sequence using 1000 intervals based on probability estimates. To ensure the first stimuli presented could be easily perceived by each child the first presentation equated to setting a low speed (high rate of expansion) for the highest interval value (999) and following a correct decision was made the procedure would then progress by presenting a lower rate of expansion (higher speed). The initial speed was entered manually for each child and typically for foveal expansion the highest interval value was presented at 15 mph and for perifoveal expansion at 25 mph. When image expansion was not detected, the algorithm selected an easier stimulus level, and recorded a reversal. Stationary car images were set to the virtual distance of the previously presented moving car. The algorithm terminated after six reversals and the maximum likelihood threshold value was obtained for each participant. To determine the reliability of participants' responses false positive rates were recorded. High false positive rates might suggest that the child was guessing, perhaps due to inattention or task complexity. Data was excluded where false positive rates exceeded 33%, this resulted in data from three children being excluded from the foveal isotropic expansion condition and four children in the foveal isotropic expansion with lateral motion condition.

5.3. Results

5.3.1. Detection of foveal isotropic expansion

Table 5.2. shows the mean looming detection thresholds for each age group. A one-way ANOVA (age [6 to 7 years, 8 to 9 years, 10 to 11 years]) revealed a non-significant effect of age group on detection of looming thresholds in foveal vision, $F(2, 26) = .14$, $p = .87$. One sample t-tests were used to compare thresholds obtained for this sample and the equivalent condition reported by Wann et al (2011) and were found not to be significantly different for all age groups: 6 to 7 year olds, $t(6) = 1.32$, $p = .24$; 8 to 9 year olds, $t(14) = 1.41$, $p = .18$; 10 to 11 year olds, $t(4) = 1.84$, $p = .14$.

5.3.2. Detection of foveal expansion with additional lateral motion

When the looming vehicle was laterally displaced, there was a significant effect of age group on detection thresholds for looming in foveal vision, $F(2, 25) = 4.10$, $p = .03$. Post hoc Tukey HSD analysis revealed that there were no significant difference for detection thresholds between 8 to 9 year olds and 10 to 11 year olds ($p = .74$) but children aged 10 to 11 years had a significantly lower (better) thresholds than those aged 6 to 7 years (*p* =.04) and children aged 8 to 9 years had a significantly lower thresholds than those aged 6 to 7 years (*p* = .05). Again, one sample t-tests compared the thresholds obtained for this sample and those reported in the comparable condition by Wann et al (2011) and they were found not to be significantly different for all age groups: 6 to 7 year olds, *t*(4) = 1.48, *p* = .21; 8 to 9 year olds, *t*(15) = .72, *p* = .48; 10 to 11 year olds, *t*(4) = 1.48, *p* = .21.

5.3.3. Detection of perifoveal isotropic expansion

For isotropic expansion in perifoveal vision, a non-significant effect of age group on detection of looming thresholds was found, *F*(2, 27) = 2.67, *p* = .09. One sample t-found the comparable condition in the Wann et al (2011) was not significantly different for all age groups: 6 to 7 year olds, *t*(6) = 1.66, *p* = .15; 8 to 9 year olds, *t*(15) = 1.15, *p* = .27; 10 to 11 year olds, *t*(4) = 0.43, *p* = .69.

5.3.4. Detection of perifoveal expansion with additional lateral motion

When the looming vehicle was also laterally displaced, there was no significant effect of age group on detection threshold for looming in perifoveal vision, *F*(2, 29) = .06, *p* = .94. One sample t-tests comparing thresholds obtained for this sample and those reported in the comparable condition in Wann et al (2011) was found not significantly different for all age groups: 6 to 7 year olds, *t*(6) = .22, *p* = .84; 8 to 9 year olds, *t*(16) = .04, *p* = .97; 10 to 11 year olds, *t*(5) = 1.12, *p* =.31. Overall, these findings are in line with the findings reported by Wann et al (2011), who found a significant difference between adults and developmental groups on detection thresholds for looming in foveal vision with additional lateral motion, but not in perifoveal vision.

Table 5.2. Foveal and perifoveal mean looming detection thresholds (in deg / sec and mph), standard deviations and 95% Confidence Intervals (95% CI) for each condition and age group.

	6 to 7 years old	8 to 9 years old	10 to 11 years old
	foveal isotropic expansion		
N	7	15	5
Thresholds (in deg / sec)	0.25	0.22	0.20
Standard deviation	0.16	0.16	0.11
95% CI	± 0.30	± 0.18	± 0.29
Thresholds (in mph)	35	40	44
	foveal isotropic expansion with additional lateral displacement		
N	5	16	5
Thresholds (in deg / sec)	0.60	0.36	0.29
Standard deviation	0.36	0.12	0.11
95% CI	± 0.90	± 0.13	± 0.27
Thresholds (in mph)	15	25	30
	perifoveal isotropic expansion		
N	7	16	5
Thresholds (in deg / sec)	0.42	0.30	0.27
Standard deviation	0.14	0.11	0.17
95% CI	± 0.26	± 0.11	± 0.42
Thresholds (mph)	21	29	33
	perifoveal isotropic expansion with additional lateral displacement		
N	7	17	6
Thresholds (in deg / sec)	0.40	0.37	0.38
Standard deviation	0.17	0.22	0.20
95% CI	± 0.31	± 0.23	± 0.42
Thresholds (mph)	22	24	23

5.3.5. Vehicle speed thresholds

Using Equation 3, the observed thresholds were converted into equivalent vehicle speeds for a vehicle width of 1.725 m at a TTC of 5 seconds.

Detection thresholds for all age groups in the condition in which children could respond to any discrete edge motion (i.e. foveal trials with isotropic expansion) equated to an ability to detect vehicle approach for speeds in excess of the existing UK urban speed limit (30 mph; see Figures 5.2.a and 5.2.b). When edge motion was controlled for (i.e. foveal trials with expansion and additional lateral motion), children across all age groups were only able to detect that a car was travelling toward them at speeds less than 30 mph and the youngest children (6 to 7 year olds) were unable to reliably detect a car approaching 5 seconds away if it was travelling faster than 15 mph. Children’s perceptual limitations were also evident in their detection thresholds for approaching cars in perifoveal vision, where only the oldest age group (10 to 11 year olds) could reliably detect approaching cars approaching at speeds over 30 mph for isotropic expansion, but even they may fail to detect cars travelling faster than the typical UK urban speed limit (30 mph) in perifoveal vision when edge motion is controlled for. These values are comparable to those of Wann et al (2011) who found that for all age groups, when participants could respond to any discrete edge motion (isotropic expansion), thresholds were above those of existing urban speed limits (30 mph to 40 mph), but when edge motion was controlled for, children were unable to detect vehicles travelling at speeds greater than 25 mph and in both preifoveal conditions, 6 to 9 year olds were only able to detect vehicles travelling at speeds below 30 mph.

The threshold speeds recorded for all viewing conditions, except simple foveal isotropic expansion are lower than the actual vehicle speeds that were monitored outside the children's school: the time taken for randomly free-flowing vehicles to cover a set distance outside their school (*n* = 118) was recorded and the average speed of 34 mph was found.

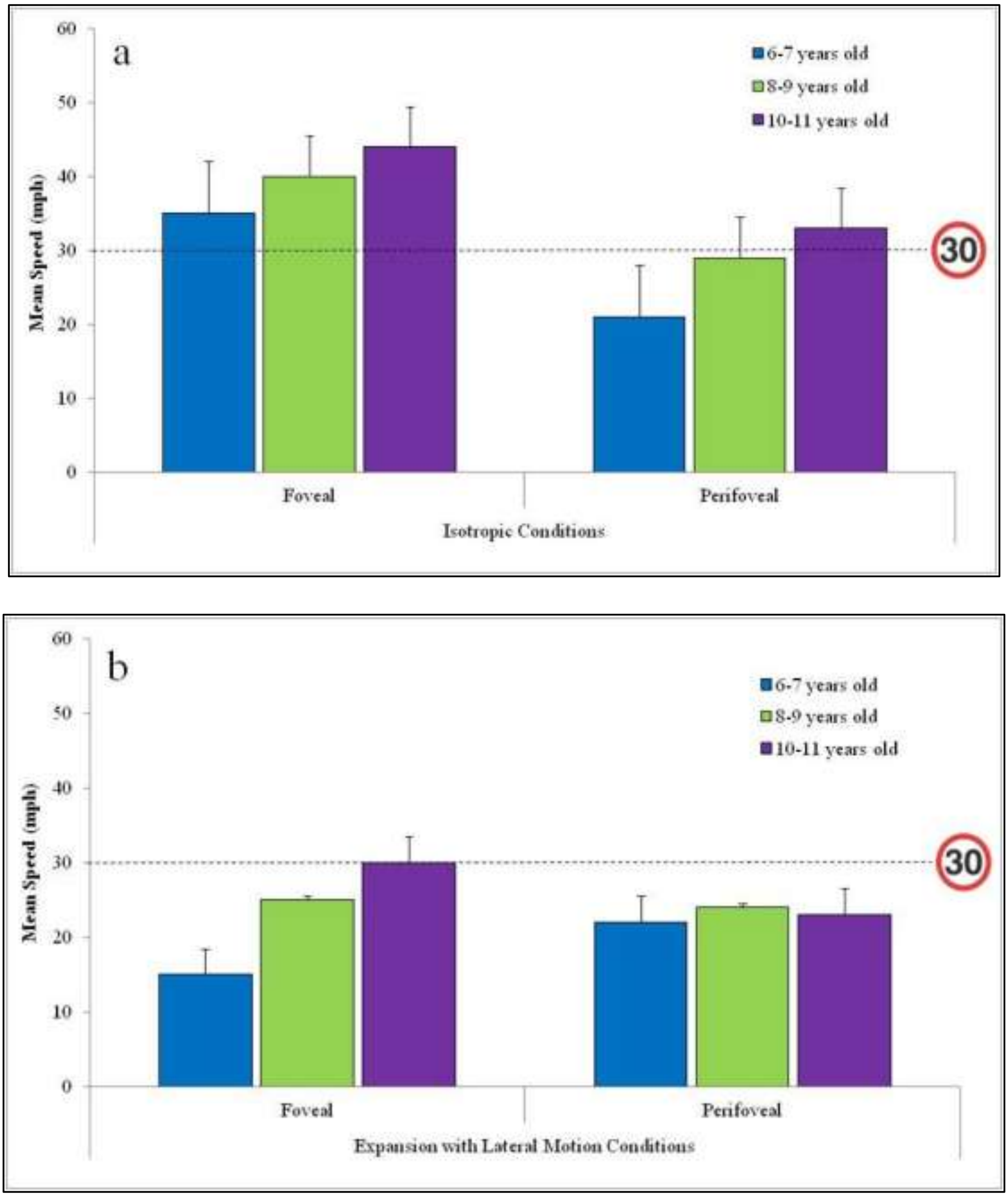

Figure 5.2. Mean speed threshold up to which each age group could reliably detect expansion when the car (a) expanded isotropically or (b) expanded isotropically with additional lateral motion. Results are presented separately for cars in foveal and perifoveal vision. The dotted line represents the typical urban speed limit of 30 mph.

5.4. Discussion

These results concur with those of Wann et al (2011) in that children cannot reliably detect approaching vehicles that are 5 seconds away travelling at speeds greater than the typical urban speed limit (30 mph) if the vehicle is even slightly outside central vision, or if optical expansion occurs in the presence of other scene motion. Unlike in the Wann et al (2011) study, significant age differences were found between 6 to 7 year olds and 8 to 11 year olds in the foveal expansion condition with additional lateral motion, although the thresholds obtained for this sample and those reported in the comparable condition by Wann et al (2011) were not significantly different. The non-significant differences between these results and those reported in the Wann et al (2011) study suggest that the methodological differences between the two studies produced equivalent results. Therefore, this methodology was extended to children with DCD to establish whether this population have developed the ability to detect looming under various viewing conditions equivalently to their typically developing peers.

Experiment Two

5.5. Methods

5.5.1. Participants

A total of twenty-two participants, between 6 to 11 years of age, were recruited from a local primary school. None of the children had any reported history of behavioural or neurological problems that would qualify as exclusion criteria for this study. Inclusion criteria for Developmental Coordination Disorder were evaluated in line with the DSM-IV). To assess Criterion A and B, which states that deficits in motor coordination should substantially interfere with activities of daily living, teachers were asked to identify children with coordination difficulties that they deemed significantly interfered with their academic achievement, and children without coordination difficulties, using an adapted version of MABC-2 checklist (MABC-2; Henderson et al., 2007). All children were then assessed on the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007). Children in the age and gender matched typically developing (TD) group all scored ≥37th percentile (n = 11), indicating typical motor development, children identified as DCD all scored ≤5th percentile, denoting significant movement difficulties (n = 11).

To assess DSM-IV Criterion C and D, which states that deficits in motor coordination should not be attributable to a pervasive developmental disorder or mental retardation, all children were assessed on the Coloured Progressive Matrices (CPM; Raven, 1956). Seventeen children (74%) fell at or above intellectually average for their chronological age (between 25th-100th percentile), and one TD child (5%) and four children with DCD (18%) fell below intellectual capacity for their age (between 10th-25th percentile). Given reported comorbidity rates between DCD and ADHD, teachers also completed Conners'

Teacher Rating Scale – Revised (Conners, 1997). Two children with DCD had elevated ADHD index scores[4] (see Table 5.3. for group information). It should be noted that one conclusion of the Leeds Consensus Statement is that children should not be excluded from a classification of DCD because of other associated problems such as ADHD (Sugden, 2006, pg.6). The issue then is whether any deficit in performance on a specific task is due to the effects of DCD, attention or task complexity. This is addressed in the results section.

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[4] Four DCD children scored > 75 % on the cognitive / inattention dimension, suggesting these children may have more academic difficulties compared to their peers, and have problems organising their work or concentrating on tasks that require sustained mental effort; one child with DCD scored > 75 % on the hyperactivity dimension, suggesting this child may have difficulty sitting still.

Table 5.3. Participant information for each group. Information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 range and mean MABC-2 total test score, Ravens Progressive Matrices index: number of children with scores ≥ grade IV, Conners' ADHD index: number of children with scores between > 75 % and < 86 %, gender ratio (female to male).

	TD	DCD
	Typically Developing	≤ 5th Percentile
N	11	11
Mean decimal age	8.9	9.1
Age range	6.4 - 11.2	6.7 - 11.7
Mean MABC-2 centile	54.8	3.2
MABC-2 range	37 - 91	1 - 5
Mean MABC-2 total test score	80.6	48.1
Ravens (No. ≥ grade IV)	1	4
Conners' ADHD index (No. > 75 % and < 86 %)	0	2
Gender ratio (f:m)	4:7	4:7

Parental informed consent was obtained for all children in advance of the study, and each child provided verbal assent immediately prior to the start of the experiment. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London.

5.6. Results

Data was excluded where false positive rates exceeded 33%, this resulted in data from two children (two children with DCD and their age matched TD children) being excluded from the foveal isotropic expansion with lateral motion condition. A one-way ANOVA (group [TD, DCD]) for each condition revealed a non-significant group effect for foveal looming detection thresholds, ($F(1, 20) = 2.03$, $p =.17$, $\eta_p^2 = .09$, $r = .27$), and foveal looming detection with simulated viewpoint motion ($F(1, 16) = 1.29$, $p = .272$ $\eta_p^2 = .075$, $r = .27$), although DCD group thresholds were considerably poorer (higher) in both conditions than their typically developing peers (see Table 5.4.). In contrast, a one-way ANOVA (group [TD, DCD]) revealed a significant between group effect for perifoveal looming detection thresholds, ($F(1, 20) = 5.13$, $p = .04$, $\eta_p^2 = .20$, $r = .42$), and perifoveal looming detection thresholds with simulated viewpoint motion ($F(1, 20) = 8.84$, $p = .008$, $\eta_p^2 = .31$, $r = .53$), see Table 5.4. This suggests that a failure to directly fixate on an approaching vehicle could lead to substantial deterioration in the ability to detect looming when just outside the fovea.

Table 5.4. Mean looming detection thresholds (in deg / sec), standard deviations and 95% Confidence Interval (95% CI) for each condition and each group.

	TD Typically Developing	DCD ≤5th Percentile
Foveal isotropic expansion thresholds (in deg / sec)		
N	11	11
Thresholds (in deg / sec)	0.25	0.36
Standard deviation	0.14	0.24
95% CI	± 0.18	± 0.33
Foveal isotropic expansion with simulated viewpoint motion thresholds (in deg / sec)		
N	9	9
Thresholds (in deg / sec)	0.45	0.61
Standard deviation	0.23	0.33
95% CI	± 0.36	± 0.51
Perifoveal isotropic expansion thresholds (in deg / sec)		
N	11	11
Thresholds (in deg / sec)	0.35	0.52
Standard deviation	0.15	0.21
95% CI	± 0.20	± 0.28
Perifoveal isotropic expansion with simulated viewpoint motion thresholds (in deg / sec)		
N	11	11
Thresholds (in deg / sec)	0.36	0.64
Standard deviation	0.22	0.23
95% CI	± 0.29	± 0.30

Using Equation 3 observed thresholds were converted into equivalent vehicle speeds for a vehicle size of 1.725m and a TTC of 5 seconds. These values are illustrated for the four conditions in Figures 5.3.a and 5.3.b. These figures illustrate that the children with

DCD obtained consistently lower speed thresholds compared to typically developing controls. The results for children with DCD suggest that in all viewing conditions their perceptual acuity is below what is required to cope with the standard urban speed limit in the UK (30 mph).

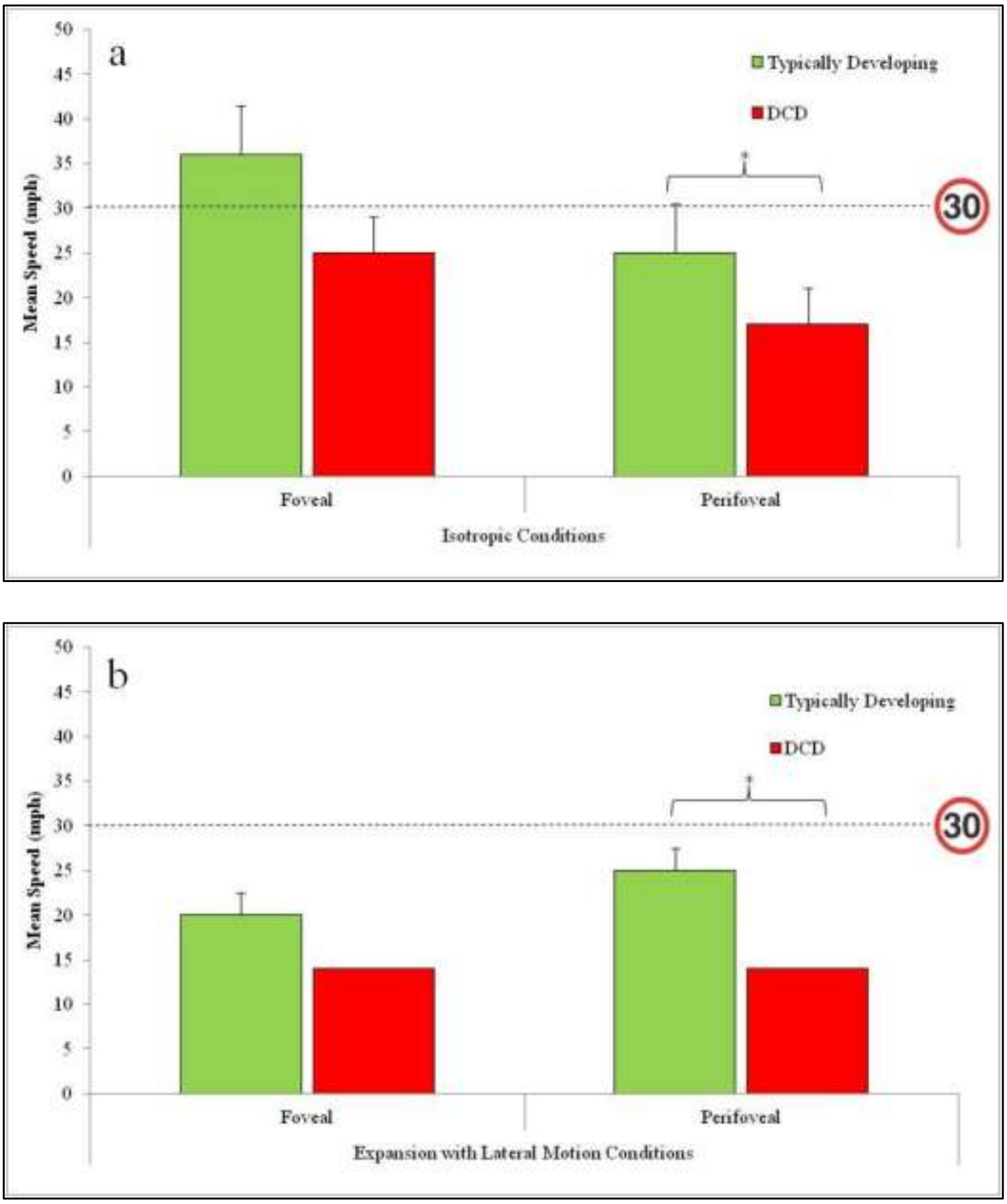


Figure 5.3. Mean speed threshold up to which group could reliably detect expansion when the car (a) expanded isotropically or (b) expanded isotropically with additional lateral motion. Results are presented separately for cars in foveal and perifoveal vision. The dotted line indicates the typical urban speed limit of 30 mph.

If sensitivity to optical expansion is reduced in children with DCD, one might expect that percentile scores obtained on the MABC-2, which require skilled perceptual-motor integration, might negatively correlate with looming detection acuity such that a lower percentile score obtained on the MABC-2 might negatively correlate with higher looming detection thresholds. Pearson's analysis on this cohort revealed non-significant negative correlations between foveal isotropic expansion and overall MABC-2 percentiles ($r_p = -.30$, $p = .09$, one-tailed) as well as between foveal isotropic expansion with simulated viewpoint motion ($r_p = -.33$, $p = .09$, one-tailed). However significant negative correlations were found between looming detection thresholds for perifoveal isotropic expansion ($r_p = -.36$, $p = .05$, one-tailed) and perifoveal isotropic expansion with simulated viewpoint motion ($r_p = -.48$, $p = .01$, one-tailed) and overall MABC-2 percentiles. In addition, significant negative correlations were found between the three MABC-2 test sub-sections and perifoveal isotropic expansion with simulated viewpoint motion: manual dexterity $r_p = -.37$, $p = .04$, one-tailed; static and dynamic balance $r_p = -.41$, $p = .03$, one-tailed; and aiming and catching $r_p = -.54$, $p = .005$, one-tailed and between the static and dynamic balance MABC-2 subsection and perifoveal isotropic expansion $r_p = -.32$, $p = .03$ (one-tailed).

5.7. Discussion

The prospective control of movement in our everyday lives critically depends on estimating the trajectory and immediacy of approaching objects. Sensitivity to looming has been shown to develop during the first year of life, but as outlined in the introductory chapter, the level of sensitivity that is required to make safe judgments at the roadside may need to be 50 to 100 times greater than what has been demonstrated in infancy. The diagnostic measures used to identify children with DCD include anticipatory tasks such as ball catching so this may be a group where the risk of misjudgement at the roadside is significantly higher. This study is the first to demonstrate that mechanisms for the detection of looming are not as well developed in primary school children with DCD as in their typically developing peers. This observation of a specific visual processing deficit is consistent with what has been proposed regarding the potential neural basis of DCD. It has been suggested that the pattern of deficits seen in DCD are consistent with atypical function across broad neural structures such as the dorsal stream and cerebellum (Wilson, 2005; Hyde & Wilson, 2011). Neural imagining with typically developing adults has demonstrated that looming detection is processed through sub-cortical structures that then project up to the dorsal-stream network (Billington, Wilkie, Field, & Wann, 2011) and that judgments of TTC activate the superior-parietal cortex and motor cortex, areas which are necessary for preparing an action response (Field & Wann, 2005). The decrement seen in the processing of looming in DCD could suggest an immature dorsal-stream network. Comparing the findings from this study with those from a large sample (*n* range = 64 to 103) of typically developing children using the same paradigm (Wann et al., 2011), the thresholds for looming detection in children with DCD for the simplest detection condition (foveal isotropic expansion), were double those reported for both the equivalent age group and the younger group in that earlier study and, as in this study, are equivalent to the thresholds obtained if the stimuli are presented outside of the fovea for typically developing children. So this does suggest a general immaturity in processing for these stimuli. It should be noted that the thresholds obtained for the foveal conditions amongst typically developing children in the current study are higher than those reported for the equivalent age group in the larger developmental study, although this difference is not significant. The thresholds for typically developing children for perifoveal conditions across the two studies are almost identical and there are significant differences in the ability of children with DCD to detect approaching stimuli which are outside of the fovea (only 4.25 deg outside of central fixation). The correlations between visual processing of approaching vehicles and performance of the ball-catching task in the MABC-2 is interesting and could suggest that children who perform poorly on some sections of the MABC-2 have poorer acuity at judging rate of expansion. But there is a difference between the type of judgment that is made at the roadside (TTC > crossing time), and the judgment when catching a ball (precise TTC, which also then requires a precise grasping action) so speculation as to why sub-components of the MABC-2 are correlated with looming detection thresholds, is probably unwarranted at this stage.

Considering the findings in terms of road safety, the ability to detect isotropic expansion in central vision was not significantly different for children with DCD and their typically developing peers and equate to an ability to detect vehicle approach speeds in excess of existing lower urban speed limits (20 mph). But in this condition decisions could be based on detecting any edge motion, which is a strategy that does not transfer to natural road scenes where a number of features may be in motion. What this condition does confirm is the ability of all children to accurately complete the basic detection task. When edge motion detection is controlled for, by adding lateral motion, equivalent to viewpoint motion, the threshold speeds that typically developing children could reliably detect dropped to 20 mph, and those for children with DCD to 14 mph. The intra-group variability undermined a statistical difference being demonstrated but in applied terms both these thresholds are below the most common urban speed limit of 30 mph, and the result for the DCD group is below the lowest urban limit of 20mph. As a pedestrian, scanning a cluttered road scene, initial detection of an approaching vehicle should ideally occur without the requirement to directly fixate on a vehicle, and this initial detection or “pop-out” will then capture and direct attention. The perceptual limitation~~s~~ for looming detection in perifoveal vision amongst children with DCD suggest this may lead to failures in detecting approaching fast moving vehicles. Although it is feasible, that if children with DCD scan the road scene carefully, putting each nearby vehicle into foveal vision (for at least 200 ms), they may be able to judge whether a car is approaching as well as their typically developing peers. However, for simple isotropic expansion, just outside the fovea, the errors displayed by children with DCD suggest they may fail to detect cars that are 5 seconds away travelling at speeds greater than 17 mph, and when edge motion is controlled for the results suggest that errors may occur when approach speed is above 14 mph. These estimates can be compared to the average vehicle speeds that were noted outside participating schools. As previously discussed, the time taken for randomly selected free-flowing vehicles to cover a set distance outside the school were monitored (*n* = 118) and an average vehicle speed of 34 mph (range: 21 to 51 mph) was found. This should also be considered in the light of data showing that that reducing speeds by 9 mph results in a 64% annual reduction in child road traffic accidents (DfT, 1999).

These findings illustrate that there are clear deficits in the motion processing ability of children with DCD and this does support previous suggestions regarding potential immaturity in the development of dorsal stream function. These findings also highlight that a deficit in motion processing of this type can have serious and applied impact. What these results show is that a decrement in looming detection amongst primary school children with DCD can place them at considerably greater risk at the roadside in certain situations. These data suggest that it may be feasible to moderate that risk through children being tutored in the use of careful scanning and fixation of all vehicles visible within a road scene, but as levels of distraction and social interaction increase, the incidence of errors classified as “looked but failed to see” (DfT, 2010) may also increase in this group of children.

5.8. General Discussion

The rate of expansion (looming) of an object provides an invaluable signal that informs us of the immediacy of a collision. The detection of looming is an essential component in TTC judgments and is critical for everyday skills such as catching and road crossing. The first experiment reported in this Chapter suggests that children develop sensitivity to looming during childhood. Younger children (6 to 7 year olds) obtained higher (poorer) looming detection thresholds in all conditions, such that even if a vehicle is approaching in foveal vision, where any edge motion would indicate the vehicle was approaching, they may perceive it as stationary if it is travelling faster than 35 mph, compared to 10 to 11 year olds, who could detect vehicles travelling at 44 mph under the same viewing conditions. For the younger children looming detection thresholds drop to 15 mph when edge motion is controlled for compared to 30 mph for older children. This developmental reduction in looming detection acuity for younger children suggest that they may be more at risk of stepping in front of vehicles that are travelling at higher speeds.

The second experiment demonstrates that there are situations in which children with DCD may fail to detect vehicles approaching at speeds in excess of 14 mph, suggesting a developmental immaturity in looming sensitivity. This provides the first clear demonstration of low-level motion processing deficits in children with DCD. The decrement observed may give rise to potential errors in the road crossing behaviour of these children, whereby vehicles approaching within urban speed limits could still be perceived as stationary. Even when a vehicle is foveated and there is no other motion in the scene, children with DCD are more likely to step out in front of vehicles travelling at speeds greater than 25 mph. The impact of this is alarming, especially considering that pedestrians only have a 50% chance of surviving an impact with a car travelling at speeds in excess of 28 mph (Toroyan & Peden, 2007).

Given the perceptual deficits found in children with DCD for the types of speeds typically encountered at the roadside, the question that arises from this Chapter is whether children with DCD are more cautious in their road crossing behaviour as a means of compensating for their perceptual limitations. To address this, the next Chapter considers the skill of road crossing from a perceptual-motor perspective by measuring the gap acceptance thresholds children, with and without DCD, typically leave for vehicles approaching at different speeds.

Chapter 6: Selecting Suitable Crossing Gaps

“The perceptual information guiding movement must extrapolate the movement into the future and must be readily available.”

(Lee, 2011)

6.1. Introduction

The previous Chapters have considered the perceptual sensitivity of distinct populations to detect simple looming ($\dot{\theta}$) and discriminate between relative rates of expansion, with and without size manipulations, in a road crossing context. The next two Chapters, will focus on the task of road crossing from a more ecological perspective. The ability to safely cross a road is a perceptual-motor skill that involves coordination between a pedestrian’s perception of the approaching vehicle and their locomotive capability to execute the road crossing action. The road crossing task is not therefore one of perceiving the absolute size of a traffic gap but one of ensuring that the size of the gap is related to the time needed to cross safely. If a pedestrian overestimates the gap size or underestimates their crossing time, an error will occur in their judgment as to whether the gap is large enough to afford them a safe road crossing.

Previous research has shown that adults are able to judge the TTC of an object, travelling at constant velocity, based on a ratio of the speed *(v)* and distance *(z)* of the approaching vehicle, which can be perceptually specified as the relative rate of dilation of the retinal image (tau: Lee, 1976), defined as:

$$\text{TTC} = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} = tau \qquad (1)$$

Where $\theta(t)$ is the instantaneous angular subtense of the approaching vehicle and $\dot{\theta}(t)$ is the rate of change of its angular subtense.

Most studies indicate that children's TTC judgments rely heavily on a distance factor (Connelly, Conaglen, Parsonson, & Isler, 1998). Proponents of this position generally attribute this deficiency to inferior physical and motor abilities. Pitcairn and Edlmann (2000) considered this, they recruited twenty-seven children, aged between 6 years 8 months to 7 years 10 months, and thirty-six adults, aged between 18 years 1 month to 26 years 5 months. They recorded a video film of traffic on a two-lane urban road, where the speed limit was 30 mph and contained a number of traffic gaps which were either safe or unsafe for crossing ($\leq$ 5.5 seconds). Participants viewed two monitors positioned to their left and right, their task was to press the pause button at the point at which they decided it was safe to cross the road. In addition an age appropriate bead threading task was completed by all participants. They found that although the relation amongst variables was similar between adults and children, adults crossed more frequently, delayed less, accepted smaller gaps and crossed more safely. Factor analysis also found that the bead threading task was related to the safety factor for children and unawareness factor for adults, meaning that children with good fine motor ability are more likely to be safe and adults with poor motor ability to be more unaware.

One study has been conducted by te Velde, Savelsbergh, Barela and van der Kamp (2003) on road crossing with children with cerebral palsy (CP), characterised as a heterogeneous group displaying motor and postural dysfunction. They aimed to investigate whether children with CP have the capacity to perceive safe crossing gaps relative to their constrained walking times. They used a simulated road on which one slowly moving bicycle approached at different speeds, and children were required to judge whether or not to cross the road while standing still and while walking on the kerbside. Twenty children were included in their study, ten children with CP (2 girls and 8 boys) and ten non-handicapped children (4 girls and 6 boys) who served as the control group. It is worth noting that the age range for the CP participants (4 to 14 years of age) contained younger and older children than for the control group (6 to 12 years of age), which may have influenced the results. The functional inclusion criterion was the ability to walk independently. All participants with CP were diagnosed with spastic hemiplegia or diplegia of mild to moderate severity. The experimental vehicle was a bicycle that approached in the far lane from the right side as seen from the child's perspective. The bicycle travelled at a constant velocity up to a maximum of 4 mph. Manipulations to the bicycle were made by changing the starting distance (2.3, 4.3, 6.3 and 8.3 m) and changing the velocity (2 and 3 mph), resulting in eight different bicycle approaching times. Children performed two conditions, deciding whether or not to cross in front of the bicycle whilst stationary on the kerbside and deciding whether or not to cross in front of the bicycle while locomoting on the kerbside. They found that children with right hemisphere lesions had difficulties in safely crossing the road, these children made more unsafe decisions than children with left hemisphere lesions and their non-handicapped peers. Unlike the children with left hemisphere damage, the children with right hemisphere lesions sometimes crossed the road when there was not sufficient time to do so and also remain on the kerbside when they could have crossed safely. This suggests that these children were not compensating for risky or unsafe decisions by walking faster, and this could be because they were unable to perceive the TTC of the bicycle accurately and did not adjust their crossing time. If the information on which judgments are based is mainly processed through the right hemisphere, this might explain the poor performance of children with right hemisphere lesions. They found no differences in the time gaps that children accepted between the locomoting condition compared to the standing condition.

In the two experiments described in this Chapter, children were presented with a computer generated realistic simulation of a road crossing scene, with a single vehicle approaching in the near-side lane and investigated differences in gap thresholds that children accept. Vehicle speeds were varied between 20, 30, 40 and 50 mph. Previous research has suggested that children rely on relative distance estimates to judge safe crossing gaps, rather than a combination of approach speed and absolute distance. Experiment One aimed to assess this and predicted that all children would leave shorter temporal gaps as approach speeds increased. Temporally acceptable crossing gaps need to be considered in relation to motoric capabilities, therefore, to aid the interpretation of the results each child’s walking speed was measured over a 5.45 m distance (selected on the basis of typical UK urban roads), in order to estimate the time needed to complete a road crossing and thus predict the margins for error that children might leave at the roadside. Given that abnormalities in motor control are often related to perceptual deficits that may complicate the perception of temporal and spatial properties of the environment, Experiment Two aimed to ask the question as to whether the temporal gaps selected by children with DCD would be more pronounced when compared to their typically developing peers.

Experiment One

6.2. Methods

6.2.1. Participants

A total of fifty-seven children aged between 6 years and 1 month to 11 years and 2 months participated in this study (see Table 6.1. for participant information). None of the children had any reported history of behavioural or neurological problems that would qualify as exclusion criteria for this study and all children had normal or corrected-to-normal vision. As these children are later used as a control group to compare with children with DCD, all children were assessed for motor coordination using the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007). All children scored ≥25th percentile indicating typical motor development. Fourteen children were also assessed on the Coloured Progressive Matrices (CPM; Raven, 1956). Thirteen children (93%) fell at or above intellectually average for their chronological age (between 25th-100th percentile), and one child (aged 8 to 9 years of age) fell below intellectual capacity for their age (between 10th-25th percentile). Following a recent systematic review reporting the prevalence rates of ADHD to be between 2-18% (Rowland et al., 2002), teachers were also asked to complete Conners' Teacher Rating Scale – Revised (Conners, 1997). Completed teacher ratings were returned for twelve children, one child (aged 8 to 9 years of age) scored 86% on the ADHD index (dimension scores: 73% oppositional; 80% cognitive/inattention; 67% hyperactivity). In addition, a subset of the Test of Everyday Attention for Children (TEA-Ch; Robertson et al., 1994) was administered to fourteen children, to assess three specific types of attention: focused attention; sustained attention; and attentional control. Three children in the group aged 8 to 9 years of age and two children in the oldest age group (10 to 11 years old) obtained an overall age scaled score below their chronological age.

Table 6.1. Participant information both age groups. Information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 range and mean MABC-2 total test score, Ravens Progressive Matrices index: number of children with scores ≥ grade IV, Conners' ADHD index: number of children with scores >75% and <86%, mean TEA-Ch age scaled score and gender ratio (female to male).

	6 to 7 year olds	8 to 9 year olds	10 to 11 year olds
N	12	30	15
Mean decimal age	7.06	9.20	10.55
Age range	6.17 - 7.74	8.06 – 9.99	10.02 – 11.19
Mean MABC-2 centile	48	54	43
MABC-2 range	25 – 91	37 – 95	25 - 75
Mean MABC-2 total test score	79	81	77
Ravens (N ≥ grade IV)	0 *(n = 5)*	1 *(n = 7)*	0 *(n = 2)*
Conners' ADHD index (N > 75% and <86%)	0 *(n = 6)*	1 *(n = 4)*	0 *(n = 2)*
Mean TEA-Ch age scaled score	0 *(n = 6)*	3 *(n = 6)*	2 *(n = 2)*
Gender ratio (f:m)	7:5	2:3	2:3

Parental informed consent was obtained for all children in advance of the study, and each child provided verbal assent immediately prior to the start of the experiment. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London.

6.2.2. Apparatus

Participants were seated in front of a 34 × 27 cm flat monitor display, with an aspect ratio of 1.26 and resolution of 1280 × 1024. The simulation code used a 60 Hz timer-loop, which ensured that the correct vehicle size and rate of expansion was presented for every frame of each trial. All simulations were scripted in Python and used Vizard 3D simulation tools (WorldViz, USA). The Vizard libraries interface with OpenSceneGraph and provide the ability to render highly realistic 3D simulations that are perspective-correct and run at the maximum screen refresh rate. The rendering hardware was an Intel® dual core CPU with an NVidia high performance GPU running under Windows XP.

6.2.3. Stimuli

Two photo-realistic road environments (see Figure 6.1. for an example stimulus sequence) were randomly interchanged to avoid the use of constant distance cues in the scene. Both backgrounds showed a straight stretch of road from the perspective of a pedestrian waiting at the kerb. Approaching cars in the near-side lane travelled from the right-hand side (as in the UK), there were no cars approaching from the left-hand side. Four levels of vehicle approach speed were used, interleaved in two randomised runs (cars travelling at 20 mph and 40 mph and cars travelling at 30 mph and 50 mph). A central fixation cross was presented for 1 second followed by a car which underwent forward motion for 1 second before disappearing. The child was asked if they would ‘go’ or ‘stop’ (see Figure 6.1.) and the experimenter clicked the appropriate icon. In addition, each child walked over a distance equivalent to the width of an average single lane (~ 2.7 m) at two walking paces (preferred pace and as fast as possible) to measure their walking time, this was doubled to obtain a walking time for a typical UK urban road (5.45 m). They completed three trials for each walking pace from which their average ‘crossing’ time was obtained.

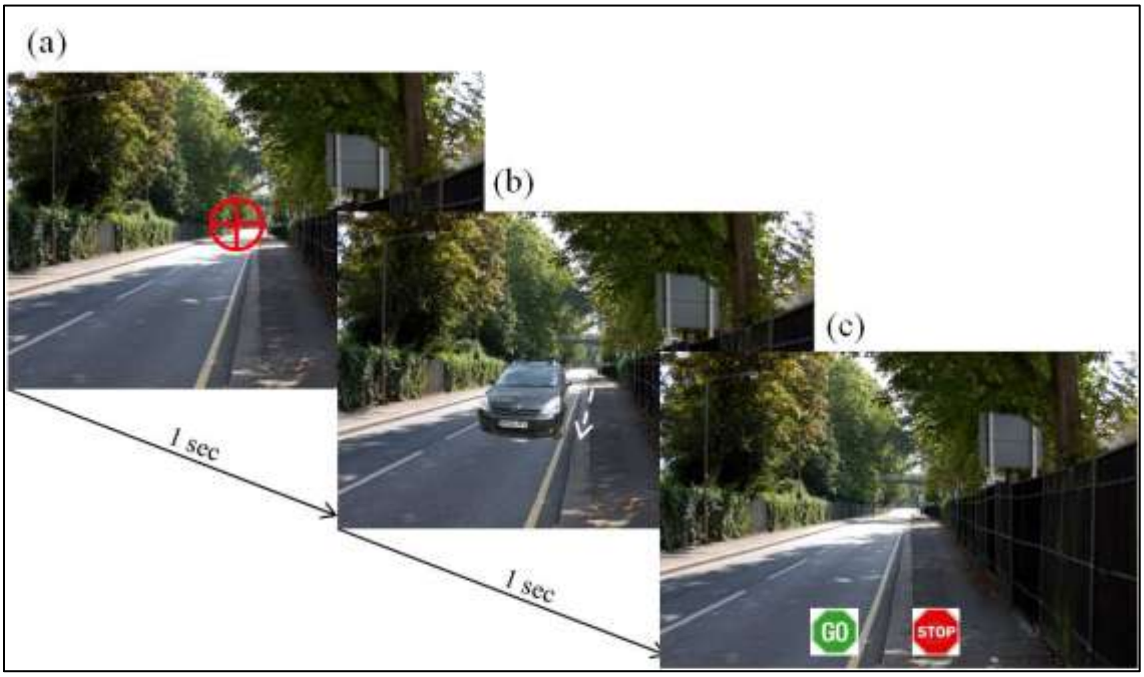


Figure 6.1. Example of stimulus testing gap acceptance thresholds for an approaching car (a) initial frame showing central fixation cross; (b) end position of car following 1 second of approach at constant velocity (c) action icons which prompted participants to verbally indicate whether they would ‘go’ or ‘stop’.

6.2.4. Psychophysical Procedure

The child’s task was to verbally indicate whether they would ‘go’ or ‘stop’. To converge on each child’s gap acceptance threshold a Best Parameter Estimation by Sequential Testing (Best-PEST: Lieberman & Pentland, 1982) staircase procedure was used which progressed in a downward descent sequence using 1000 intervals based on probability estimates. The maximum TTC was set at 30 seconds, for all approach speeds the first presentation was set half way down the procedure equating to a TTC of 15 seconds. This resulted in different starting distances for each approach speed such that the 20 mph vehicles started at a distance of 142 m, 30 mph at 213 m, 40 mph at 284 m and 50 mph at 355 m. The algorithm terminated after six reversals and the mean of the last 4 reversals was taken as each participant's gap acceptance threshold.

6.3. Results

6.3.1. Temporal Gap Acceptance Thresholds

Mean temporal data for all approach speeds and developmental groups are presented in Table 6.2. and Figure 6.2. An initial analysis using a one-way ANOVA (gender [Male, Female]) revealed no significant gender differences for any of the approach speeds (20 mph: $F(1,56) = .55$, $p = .46$; 30 mph: $F(1,56) = .26$, $p = .61$; 40 mph: $F(1,56) = .12$, $p = .73$; 50 mph: $F(1,56) = 2.46$, $p = .12$), hence subsequent analysis was conducted on all participants regardless of gender. A two-way mixed ANOVA (age [6 to 7 years; 8 to 9 years; 10 to 11 years], vehicle approach speed [20, 30, 40 and 50 mph]) was used to compare gap acceptance thresholds for each approach speed between developmental groups. The results show a significant main effect for vehicle approach speed on the temporal gaps that children accepted ($F(2.04,110.16) = 104.62$, $p < .001$, $\eta_p^2 = .66$. Greenhouse-Giesser reported due to violation of sphericity), but a non-significant main effect was found between developmental groups ($F(2,54) = .10$, $p = .91$, $\eta_p^2 = .004$). A non-significant interaction was also found for vehicle approach speed and developmental group on the temporal gaps that children accepted ($F(4.8,110.16) = .39$, $p = .82$, $\eta_p^2 = .01$. Greenhouse-Giesser reported due to violation of sphericity) was found.

In line with previous research, the temporal gaps accepted within each age group decreases as approach speed increases. This suggests that within age groups children were basing their judgments on something other than TTC (e.g. optic size), otherwise the temporal gaps accepted would be equivalent across approach speeds. This is supported by a significant linear trend for speed of approach $F(1,54) = 157.88$, $p < .001$. To assess whether the time gaps selected were constant across 20 mph – 50 mph, the slope for each developmental group was tested against zero using one-sample t-tests. A significant difference from zero was found for 6 to 7 year old children, mean slope = 6.41, $t(11) = 4.4$, $p = .001$, 8 to 9 year old children, mean slope = 6.70, $t(29) = 9.4$, $p < .001$, and 10 to 11 year old children, mean slope = 6.98, $t(14) = 8.0$, $p < .001$.

Table 6.2. Descriptive statistics for temporal gap acceptance thresholds (in seconds), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30, 40 and 50 mph.

	6 to 7 year olds	8 to 9 year olds	10 to 11 year olds
	20 mph		
N	12	30	15
Mean Threshold (s)	14.02	13.67	13.76
Standard Deviation	7.62	6.49	6.30
95% CI	± 7.74	± 4.90	± 6.93
	30 mph		
N	12	30	15
Mean Threshold (s)	12.00	10.71	10.75
Standard Deviation	6.07	5.18	5.91
95% CI	± 6.44	± 4.07	± 5.76
	40 mph		
N	12	30	15
Mean Threshold (s)	8.13	8.07	7.30
Standard Deviation	4.41	3.81	3.44
95% CI	± 4.45	± 2.82	± 3.98
	50 mph		
N	12	30	15
Mean Threshold (s)	7.62	6.98	6.78
Standard Deviation	4.38	3.48	3.46
95% CI	± 4.26	± 2.69	± 3.81

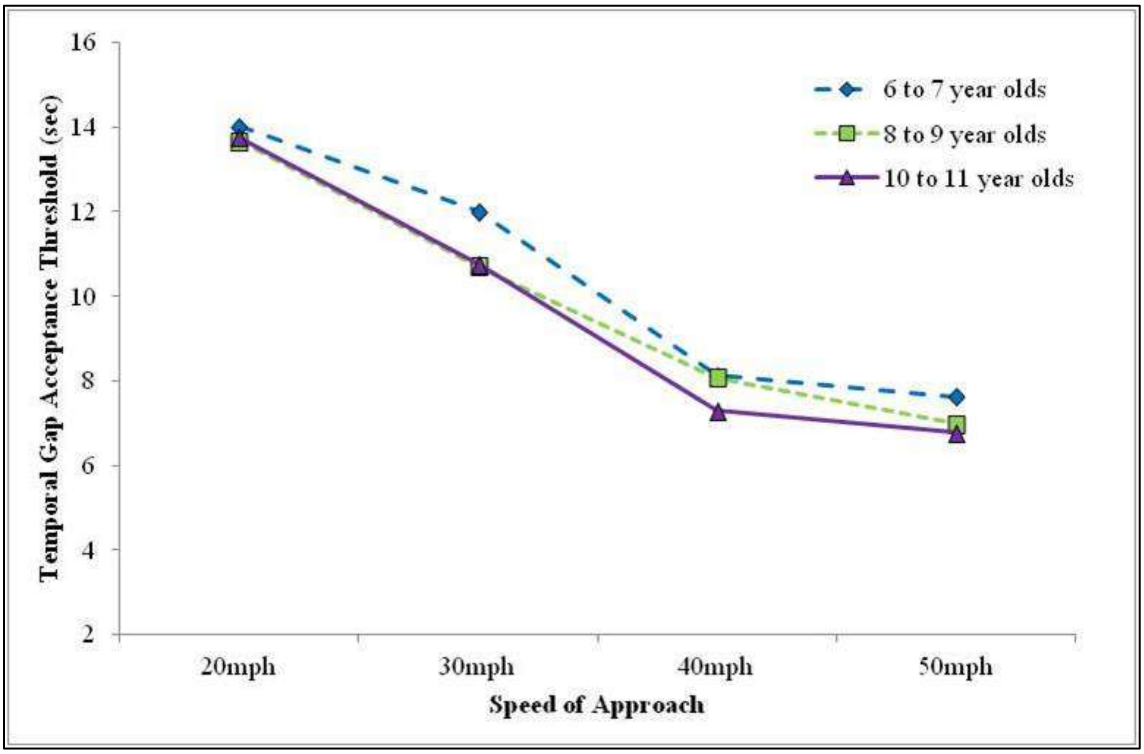


Figure 6.2. Mean temporal gap acceptance thresholds (in seconds), for cars approaching at 20, 30, 40 and 50 mph, for each age group.

6.3.2. Distance Gap Acceptance Thresholds

In this paradigm, speed of approach was set at one of four levels (20, 30, 40 and 50 mph) and at the end of the PEST sequence the child's decision will have settled towards a specific temporal gap for each speed, which has been analysed in the section above. Because distance = speed*time, this also means they have settled towards a specific vehicle distance for each speed of approach. If children are basing their judgments on optic size in addition to rate of looming (tau), then the temporal gaps accepted would not vary with approach speed. If children however, are basing their judgments on just optic size (distance), the temporal gaps accepted would be an inverse function of approach speed and the distance gap thresholds would be constant across speeds. The findings discussed in previous Chapters have demonstrated that the ability to discriminate looming rate is constrained and this will result in errors in using tau, but the extent of these errors may vary across the four approach speeds and will certainly vary across children. The temporal gap thresholds significantly vary across approach speeds, but analysing whether vehicle distance thresholds vary across approach speeds then informs the discussion as to whether any of the groups are using pure optic size (distance) or a mixed model which compensates for vehicle approach speed.

Mean distance data for all approach speeds and developmental groups are presented in Table 6.3. and Figure 6.3. A two-way mixed ANOVA (age [6 to 7 years; 8 to 9 years; 10 to 11 years], vehicle approach speed [20, 30, 40 and 50 mph]) was used to compare distance gap thresholds for each approach speed between developmental groups. A significant main effect was found for vehicle approach speed on the distance gaps that children accepted ($F(1.96,105.57) = 17.45$, $p < .001$, $\eta_p^2 = .24$. Greenhouse-Giesser reported due to violation of sphericity). The results however, show a non-significant main effect between developmental groups ($F(2,54) = .13$, $p = .88$, $\eta_p^2 = .005$, a non-significant interaction was also found for vehicle approach speed and developmental group on the distance gaps that children accepted ($F(5.84,103.21) = .618$, $p = .71$, $\eta_p^2 = .034$. Greenhouse-Giesser reported due to violation of sphericity).

The significantly shorter temporal gap thresholds that children within each developmental group left suggest that they may have been basing their judgments on optic size (distance). If this were the case then the distance gap thresholds should be equivalent across approach speeds within each group, this is supported by a significant linear trend for approach speed $F(1,54) = 32.96$, $p < .001$ on the distance gap thresholds, therefore, to assess whether the distance gaps selected were constant across 20 mph – 50 mph, the slope for each developmental group was tested against zero using one-sample t-tests. A significant difference from zero was found for 6 to 7 year old children, mean slope = 44.7, *t*(11) = 2.1, *p* = .03, 8 to 9 year old children, mean slope = 33.48, *t*(29) = 4.6, *p* < .001, and 10 to 11 year old children, mean slope = 28.34, *t*(14) = 3.3, *p* = .005. These results suggest that children were not relying on optic size (distance) but were using a mixed model of optical size (distance) with some compensation for rate of expansion (tau ≈ time).

Table 6.3. Descriptive statistics for distance gap acceptance thresholds (in meters), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30, 40 and 50 mph across age groups.

	6 to 7 year olds	8 to 9 year olds	10 to 11 year olds
	20 mph		
N	12	30	15
Mean Threshold (m)	124.63	121.53	122.33
Standard Deviation	67.76	57.68	56.01
95% CI	± 68.83	± 43.53	± 61.56
	30 mph		
N	12	30	15
Mean Threshold (m)	160.03	142.73	143.28
Standard Deviation	80.92	69.08	78.80
95% CI	± 85.89	± 54.32	± 76.83
	40 mph		
N	12	30	15
Mean Threshold (m)	144.58	143.53	129.69
Standard Deviation	78.34	67.66	61.14
95% CI	± 79.17	± 50.07	± 70.81
	50 mph		
N	12	30	15
Mean Threshold (m)	169.35	155.01	150.66
Standard Deviation	97.24	77.44	76.86
95% CI	± 94.59	± 59.83	± 84.61

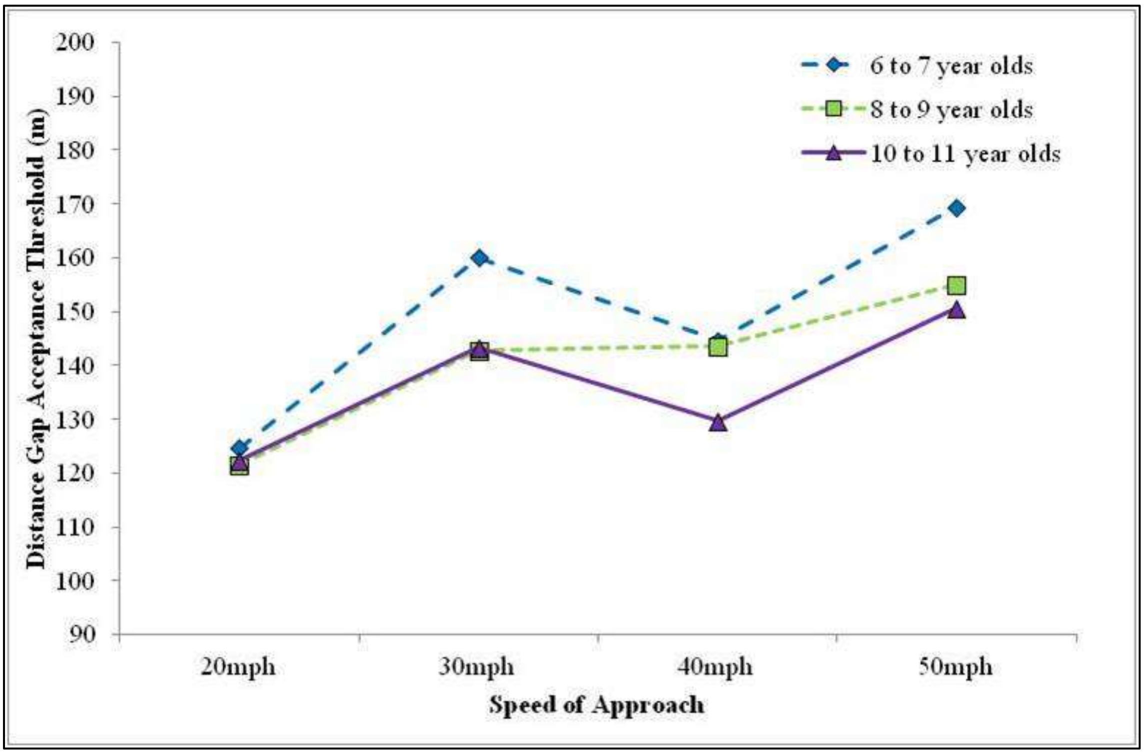


Figure 6.3. Mean distance gap acceptance thresholds (in meters), for cars approaching at 20, 30, 40 and 50 mph, for each age group.

6.3.3. Walking Times

Walking times over a distance equivalent to the width of an average two lane road at two walking paces (preferred pace and as fast as possible) are shown in Table 6.4. with the ratio of temporal gap chosen from Table 6.2. to preferred walking pace calculated as an estimate of the margins for error children might leave at the roadside. Two one-way ANOVAs (age [6 to 7 years; 8 to 9 years; 10 to 11 years]) for the preferred and fast walking pace with Tukey HSD post hoc comparisons were conducted to assess developmental differences in walking speeds.

Overall, walking times at the preferred pace were slower for children aged between 8 to 9 years of age. There was a main effect of age $F(2, 46) = 3.6$, $p = 0.04$. Post hoc tests confirmed that the differences between children aged 6 to 7 years of age and 8 to 9 years of age were significant (*p* = 0.05). There was a non-significant main effect of age *F*(2, 46) = 2.2, *p* = 0.13 for the fast walking pace.

Table 6.4. Mean and SD crossing times (in seconds) for the average width of a UK road and estimated margins for error for each approach speed, based on the ratio of gap acceptance thresholds to preferred pace walking times across the average width of a road. Margins should be greater than 1.5 seconds to ensure safety.

	6 to 7 year olds	8 to 9 year olds	10 to 11 year olds
	crossing time (in seconds)		
At preferred pace	4.35 (0.72)	5.16 (0.91)	4.67 (0.66)
As fast as possible	3.10 (0.28)	3.40 (0.46)	3.24 (0.26)
	margins for error		
20 mph	3.22	2.65	2.95
30 mph	2.76	2.08	2.30
40 mph	1.87	1.56	1.56
50 mph	1.75	1.35	1.45

Margins for error were compared between developmental groups using a one-way ANOVA (age [6 to 7 years; 8 to 9 years; 10 to 11 years]) and were found to be non-significant for all approach speeds: 20 mph - *F*(2, 46) = .31, *p* = .74; 30 mph - *F*(2, 46) = .86, *p* = .43; 40 mph - *F*(2, 46) = .16, *p* = .86; 50 mph - *F*(2, 46) = 1.20 *p* = .31. Tukey HSD post hoc comparisons also confirmed that there were no significant differences between the development groups for any of the approach speeds.

6.3.4. Road crossing questionnaire

A total of 352 primary school children were asked to complete a questionnaire which aimed to assess their confidence and appreciation of the dangers associated with the task of road crossing. The purpose of this questionnaire was to gain a measure of the frequency that primary school age children make road crossing judgments and the confidence that they have in their judgments. The face validity of the questionnaire was high and the content validity was assessed post-hoc using principal component analysis described below. Mean ratings for all questionnaire items, presented in order, are shown in Tables 6.5. and 6.6.

Table 6.5. Mean frequency of children's reported road crossings.

	6 to 7 year olds	8 to 9 year olds	10 to 11 year olds
Q1. How Often do you cross the road to get to school and home again? *1=never; 2=rarely; 3=sometimes; 4=often; 5=very often*			
Male	4.3	3.5	3.9
Female	3.5	3.2	3.9
Q2. How often do you cross the road with a parent/adult to get to school and home again?			
Male	3.9	3.5	3.0
Female	3.8	3.9	3.0
Q3. How often have you walked across the road but then had to start running because a car was travelling faster than you realised?			
Male	2.3	2.2	2.3
Female	1.8	2.0	2.0
Q4. How often do you wait for a car to pass but then realise you would have had time to cross?			
Male	2.2	2.9	2.9
Female	2.4	2.7	2.9

A principal component analysis (PCA) was conducted on the frequency questions (Table 6.5.) with orthogonal rotation (varimax). The Kaiser-Meyer-Olkin (KMO) measure verified sampling adequacy for the analysis was .50 and all KMO values for individual items were > .90, which is well above the acceptable limit of .50 (Field, 2009). Bartlett's test of sphericity χ^2 (6) = 48.45, *p* < .001, indicated that correlations between items were sufficiently large for PCA. An initial analysis identified two components with eigenvalues over Kaiser's criterion of 1 and in combination explained 63% of the variance. Table 6.6. shows the factor loadings after rotation.

Table 6.6. Summary of exploratory factor analysis results for road crossing questionnaire

Item	Rotated Factor Loadings	
	Road crossing frequency	Road crossing behaviour
How Often do you cross the road to get to school and home again?	.81	.15
How often do you cross the road with a parent/adult to get to school and home again?	.78	-.20
How often have you walked across the road but then had to start running because a car was travelling?	-.03	.77
How often do you wait for a car to pass but then realise you would have had time to cross?	-.009	.76

The questions that cluster under component 1 represent the frequency of road crossing. A positive factor score would indicate that a child crossed the road more often than the mean. Component 2 represents road crossing behaviour, a positive factor score here would indicate a child was less proficient in crossing behaviour than the mean. A one-way ANOVA (age [6 to 7 years; 8 to 9 years; 10 to 11 years]) was conducted on the factor scores between developmental groups for the two components. A significant main effect was found for the road crossing behaviour component $F(2, 337) = 3.30$ $p = .04$, with Tukey HSD post hoc analysis revealing a significant difference between 6 to 7 year olds and 10 to 11 year olds ($p = .03$), but not between other developmental groups. Indicating that the oldest children made less proficient road crossing decisions compared to the younger children.

Table 6.7. Children’s mean perceived road crossing ability.

Q5. How good are you at judging when it is safe to cross? *1=very poor; 2=poor; 3=average; 4=good; 5=very good*			
Male	4.2	4.2	4.1
Female	4.1	3.7	4.1
Q6. How good do you think you are judging how far away a car is?			
Male	3.8	3.9	3.6
Female	3.7	3.3	3.7
Q7. How good do you think you are at cross road safely?			
Male	4.1	4.2	4.3
Female	4.1	3.9	4.2
Q8. How good do you think you are at judging how fast cars are travelling towards you?			
Male	3.2	3.9	3.5
Female	3.4	3.1	3.8

A PCA was conducted on the 4 judgment questions shown in Table 6.7. with orthogonal rotation (varimax). The KMO measure verified sampling adequacy for the analysis (.70), and all KMO values for individual items were > .70, which is well above the acceptable limit of .5 (Field, 2009). Bartlett's test of sphericity χ^2 (6) = 219, $p < .001$, indicated that correlations between items were sufficiently large for PCA. An initial analysis identified one component with an eigenvalue over Kaiser's criterion of 1 and explained 52% of the variance. Table 6.8. shows the factor loadings without rotation as only one component was extracted.

Table 6.8. Summary of exploratory factor analysis results for road crossing questionnaire

	Factor Loadings
Item	Perceived road crossing ability
How good are you at judging when it is safe to cross?	.75
How good do you think you are judging how far away a car is?	.76
How good do you think you are at cross road safely?	.69
How good do you think you are at judging how fast cars are travelling towards you?	.69

The items that cluster under component 1 represent perceived road crossing ability with a positive factor score indicating a child with a higher perceived ability than the mean. A one-way ANOVA (age [6 to 7 years; 8 to 9 years; 10 to 11 years]) was conducted on the factor scores between developmental groups and the perceived ability component. A non-significant main effect was found $F(2, 325) = .65$, $p = .52$.

One might predict that as perceived danger in road crossing increases, confidence in road crossing decreases, the final two questions (see Table 6.9.) considered the relationship between these two variables using a Pearson’s correlation. A significant medium positive correlation was found between children’s ratings on their confidence in crossing a road safely by themselves and danger perceived in crossing roads, $r_p = .29$ $p < .001$. In addition, significant positive correlations were found for each developmental group (6 to 7 years, $r = .30$, $p = .009$; 8 to 9 years, $r_p = .19$, $p = .016$; 10 to 11 years, $r_p = .24$, $p = .012$)

Table 6.9. Children’s mean confidence and perceived danger in road crossing.

	6 to 7 year olds	8 to 9 year olds	10 to 11 year olds
Q9. How confident are you that you can cross the road safely by yourself? 1=totally unconfident; 2=fairly unconfident; 3=neither confident or unconfident; 4=fairly confident; 5=totally confident			
Male	3.6	4.4	4.4
Female	3.1	3.7	4.3
Q10. How dangerous do you think it is to cross the road? 1=very dangerous; 2=dangerous; 3=neither safe or dangerous; 4=safe; 5=very safe			
Male	2.1	2.5	3.1
Female	1.7	2.4	2.8

6.4. Discussion

In this experiment children observed cars approaching at 20, 30, 40 and 50 mph, and were asked to judge if it would be safe to cross. In order to execute a safe road crossing, the TTC of an approaching vehicle must be greater than the time required to cross, otherwise collision will occur. If children utilise tau in their judgments of TTC then the temporal gaps accepted would be equivalent across approach speeds, for example if crossing time plus some margin for error time equals 6.5 seconds, children would leave 6.5 second time gaps, regardless of approach speed, causing the distance gap thresholds to increase as speed of approach increases. If children on the other hand are only utilising optic size (distance) in their judgments, they would accept distance gaps that would be equivalent across approach speeds, for example accepting a distance gap of ~58 m (based on a 6.5 second crossing time), regardless of approach speed, causing TTC to decrease as approach speed increased.

The general finding across all children was that they allowed significantly shorter temporal crossing gaps as vehicle approach speed increased, which is in line with previous research (e.g. Connelly et al., 1998). This decrease suggests that children rely to some degree upon optical size of the vehicle (distance) in making judgments of safe crossing gaps, regardless of the speed of the approaching vehicle. However, the significant differences in the distance gap thresholds suggest that all children were using a mixed model of optical size (distance) with some compensation for rate of expansion (tau ≈ time). This suggests that children were not taking speed of approach fully into account. One consequence of this strategy is that as speed increases the TTC children leave decreases as do the margins for error that children leave themselves.

The lack of significant developmental effects between groups is interesting, in applied terms the temporal and distance gap acceptance thresholds accepted by the youngest age group (6 to 7 year olds) were larger for all approach speeds compared to the other two developmental groups, whereas the 8 to 9 year olds and 10 to 11 year olds accepted comparable temporal and distance gaps. This suggests a more cautious strategy in the youngest age group. The margins for error support this, with all developmental groups leaving greater than the recommended 1.5 seconds for all approach speeds, except for vehicles approaching at 50 mph, which children are less likely to have been exposed to as pedestrians. The youngest age group left larger margins for error for all approach speeds compared to the other developmental groups. Comparing the temporal gap acceptance thresholds across all approach speeds to preferred walking speeds for each developmental group suggests that children of all ages were leaving sufficient temporal gaps to cross the width of the road scene used in this experiment.

One consequence of leaving large temporal gaps for example cars approaching at 20 mph and 30 mph (speeds most typically encountered as pedestrians) is that they may miss opportunities to cross. Previous research by Simpson et al (2003) suggests that pedestrians might accept smaller crossing gaps if waiting time increases. One explanation for these findings could be young children’s lack of experience at crossing roads independently, as road crossing decisions are often made by or in the presence of an adult. As a consequence, children may not appreciate the dangers associated with the task of road crossing. Routledge, Repetto-Wright and Howarth (1974) describe a survey of children’s exposure to road crossings. Interviews were conducted with a representative sample of school children about their journeys in the previous 24 hours and the number of roads crossed and the traffic densities of these roads were recorded. They found little evidence of a difference in the exposure of boys and girls, but a pronounced and statistically significant increase in exposure with age for both sexes. They concluded that the reasons for differences in accident rates, are not due to children's exposure to traffic, but in their behaviour when crossing roads.

As part of this experiment, a questionnaire was completed by a total of 352 primary school aged children (75 children aged 6 to 7 years; 163 children aged 8 to 9 years; and 114 children aged 10 to 11 years). In response to the question *How confident are you that you can cross the road safely by yourself?* 42% responded that they were totally confident. Only 28% of children aged 6 to 7 years of age responded that they were totally unconfident compared to the 10 to 11 year old children where 55% were totally confident and only 2% indicated that they would be totally unconfident. The children also answered the question *How dangerous do you think it is to cross the road?* To this question, 43% indicated that it was totally safe. 28% of children aged 6 to 7 years of age responded that it was dangerous compared to 55% who thought it was totally safe and 2% of children aged 10 to 11 year old children who indicated that they thought it was safe. In general females tended to be less confident and appreciated the dangers associated with road crossing more than males. Correlations between these two questions suggest that, as would be predicted, as perceived danger in road crossing increases, confidence in road crossing decreases. However, no differences in developmental group were seen across factor scores for either crossing frequency or perceived crossing ability.

The findings reported in Chapters 4 and 5, suggest that children with known movement difficulties may have a general deficit in visual motion processing. Given the perceptual-motor demands in executing a road crossing, one might predict that a motion processing deficit combined with potentially slower walking times, may place this population at significantly more risk in the context of road crossing. The following experiment employs the same paradigm as Experiment One and aims to systematically measure whether children with DCD are cautious in their road crossing behaviour as a means of compensating for their perceptual motor limitations.

Experiment Two

6.5. Methods

6.5.1. Participants

The participants that completed this experiment were the same as those described in Chapter 4 (section 4.2.1). Table 6.10. provides a summary of participant information.

Table 6.10. Participant information for each group, information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 range and mean MABC-2 total test score, Ravens number of children with scores ≥ grade IV, Conners' ADHD index number of children with scores between >75% and <86%, and gender ratio (female to male).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	15	6	9
Mean decimal age	9.1	9.0	9.1
Age range	6.4 – 11.4	7.1 – 11.0	6.7 – 11.7
Mean MABC-2 centile	47	13	3
MABC-2 range	25 – 91	9 – 16	1 – 5
Mean MABC-2 total test score	78	62	48
Ravens (N ≥ grade IV)	1	0	3
Conners' ADHD index (N > 75 % and < 86 %)	1	0	2
Gender ratio (f:m)	5:12	1:5	4:7

Parental informed consent was obtained for all children in advance of the study, and each child provided verbal assent immediately prior to the start of the experiment. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London.

6.5.2. Apparatus

The apparatus used were identical to those outlined in Experiment One (see section 6.2.2.).

6.5.3. Stimuli

The stimuli used was identical to those outlined in Experiment One (see section 6.2.3.).

6.5.4. Psychophysical Procedure

The psychophysical procedure used was identical to those outlined in Experiment One (see section 6.2.4.).

6.6. Results

Levens statistic revealed that homogeneity of variance was violated for the temporal gap acceptance thresholds and distance gap acceptance thresholds for vehicles approaching at 50 mph. Therefore results were compared between groups using the more conservative non-parametric Kruskal-Wallis one-way analysis of variance, with Mann-Whitney *U* post hoc comparisons.

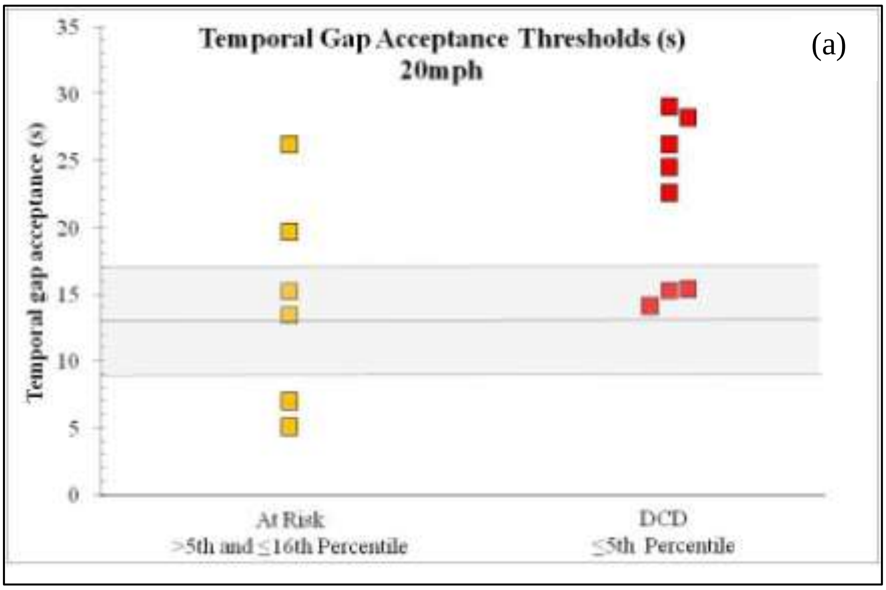
6.6.1. Temporal Gap Acceptance Thresholds

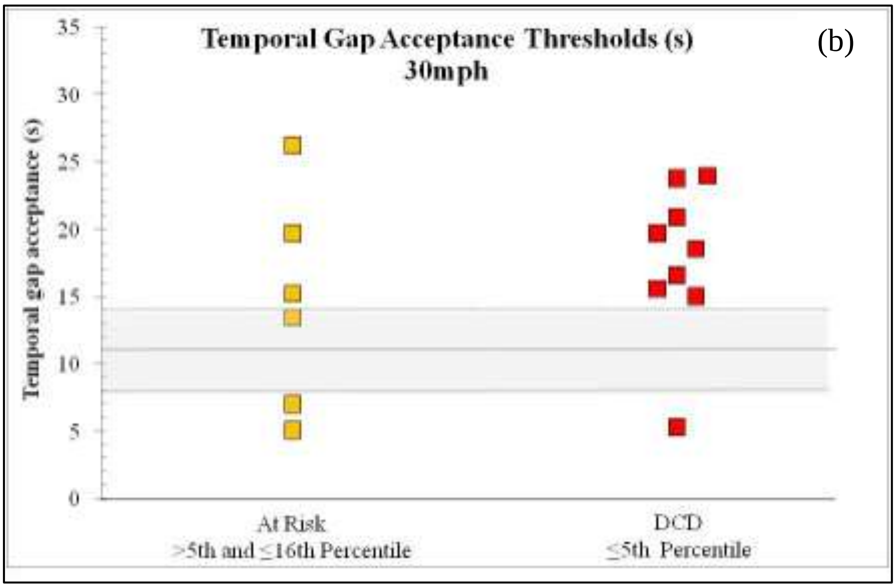
Across all vehicle approach speeds, the temporal gaps chosen were longest for the children with DCD, with children in the at risk group leaving similar temporal gaps to TD children (see Table 6.11. and Figure 6.4.). An initial analysis was conducted between a combined at risk and DCD group and TD children. Kruskal-Wallis yielded a non-significant group effect for vehicle approach speeds of: 40 mph (χ^2 = 3.5, *p* = .06); 50 mph (χ^2 = 3.5, *p* = .06), there was a significant group effect for the vehicle approaching at 20 mph (χ^2 = 6.3, *p* = .04) and 30 mph (χ^2 = 4.6, p = .03). Mann-Whitney *U* tests (alpha of $p<.017$ used due to elevation of Type I error) were used to explore the group effects, for both speeds a significant difference was seen between TD children and children with DCD (20 mph: *p* = .013; 30 mph: *p* = .008), no differences were seen between other comparable groups.

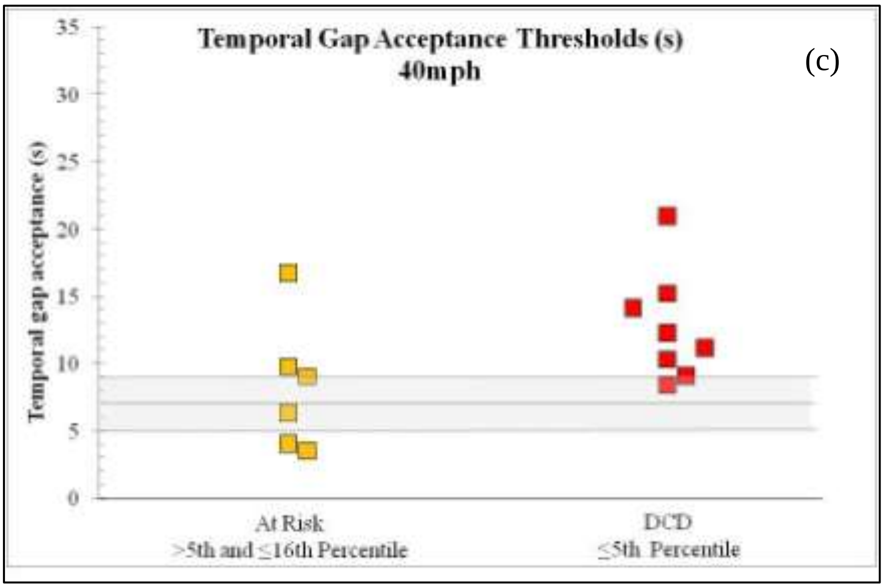
Table 6.11. Descriptive statistics for temporal gap acceptance thresholds (in seconds), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30, 40 and 50 mph across groups.

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
		20 mph	
N	15	6	8
Mean Threshold (s)	13.27	14.33	21.88
Standard Deviation	7.46	7.89	6.24
95% CI	± 7.69	± 7.06	± 4.76
		30 mph	
N	15	6	9
Mean Threshold (s)	10.67	13.83	17.75
Standard Deviation	6.07	8.59	6.18
95% CI	± 6.48	± 12.15	± 11.17
		40 mph	
N	15	6	8
Mean Threshold (s)	7.27	8.17	12.50
Standard Deviation	4.38	5.12	4.17
95% CI	± 7.52	± 10.24	± 10.52
		50 mph	
N	15	6	9
Mean Threshold (s)	7.07	9.00	14.25
Standard Deviation	3.81	5.76	9.25
95% CI	± 9.67	± 6.51	± 8.87

Following this outcome analyses were re-run for the DCD and at risk groups separately. Results showed that there was a significant group effect for three of the approach speeds: 20 mph ($\chi^2 = 6.3$, $p = .04$); 30 mph ($\chi^2 = 6.2$, $p = .05$); and 40 mph ($\chi^2 = 6.4$, $p = .04$). Pairwise comparisons between TD children and children with DCD revealed that children with DCD left significantly longer temporal gaps than the TD children for all approach speeds: 20 mph ($U = 23$, $z = 2.4$, $p = .01$, $r = .5$); 30 mph ($U = 25$, $z = 2.6$, $p = .008$, $r = .5$); 40 mph ($U = 22$, $z = 2.5$, $p = .01$, $r = .5$); and 50 mph ($U = 30$, $z = 2.3$, $p = .02$, $r = .5$). Individual temporal gap threshold data for all approach speeds are presented in Figures 6.4. a to d.







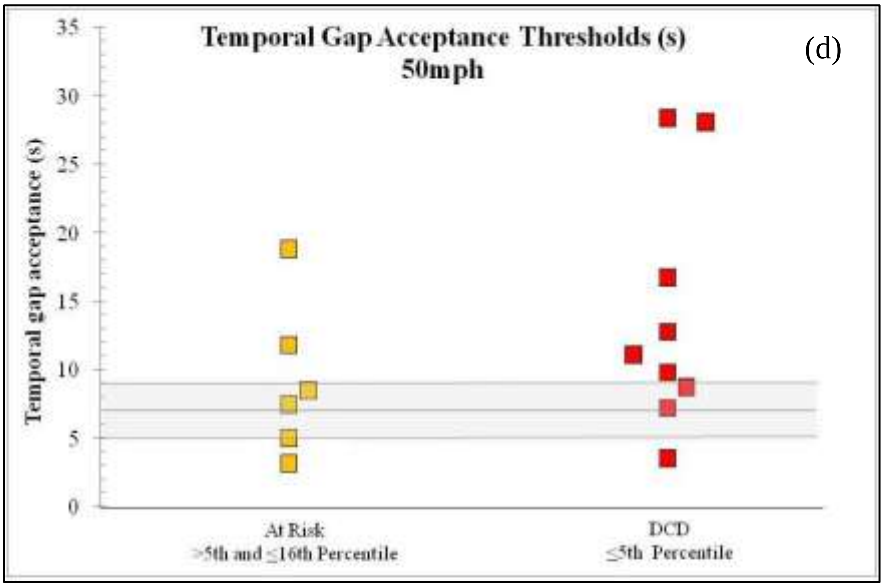


Figure 6.4. Individual temporal gap acceptance threshold data (in seconds) for: (a) 20 mph; (b) 30 mph; (c) 40 mph; and (d) 50 mph children at risk and DCD children. The mean temporal gap acceptance threshold for TD children (*n* = 15) is shown by the solid line, with the 95% CI of the TD mean and upper and lower bounds represented by the shaded area and dotted lines.

If children were utilising tau in their decisions, then the temporal gap thresholds regardless of vehicle speed should be equivalent (see Figure 6.5.). A significant linear trend was found for approach speed $F(1,26) = 31.28$, $p < .001$ therefore, to assess whether the temporal gaps selected was constant across 20 mph – 50 mph the slope was tested for each group against zero using one-sample t-tests. For typically developing children this revealed a significant difference, mean slope = 6.15, *t*(14) = 5.37, *p* = < .001. The difference was not significantly different from zero, however, for at risk children, mean slope = 5.32, *t*(5) = 1.96, *p* = .11, or for children with DCD, mean slope = 7.74, *t*(8) = 1.90, *p* = .10. Although non-significant, the slope against zero for children with DCD was -2 seconds steeper than for typically developing children, suggesting that they are not compensating for speed as well as the TD children and that the lack of a significant difference is due to intra-group variability and a Type II error. The slope against zero for the at risk children and TD children were equivalent. The overall reduction in the temporal gaps accepted as vehicle speed increased (see Table 6.11.) is in line with previous suggestions that children rely to some degree upon optic size (distance cues), so the distance thresholds that children accepted are explored in the following section.

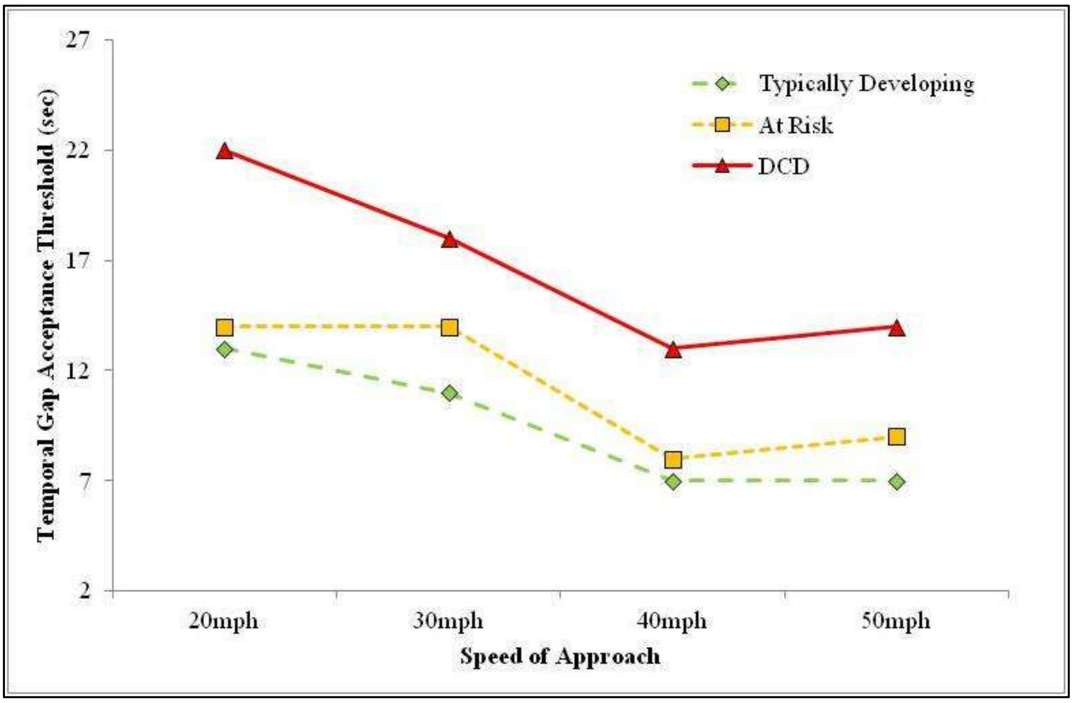


Figure 6.5. Mean temporal gap acceptance thresholds (in seconds), for cars approaching at 20, 30, 40 and 50 mph, for each group.

6.6.2. Distance Gap Acceptance Thresholds

The equivalence of the temporal gaps accepted across approach speeds for children with DCD and children at risk of DCD suggest they could be utilising optic size in addition to rate of expansion (tau) in their crossing judgments, if this is the case then their distance gap thresholds should increase as approach speed increases (see Table 6.12.). A significant linear trend was found for distance $F(1,26) = 9.30$, p = .005 therefore, to assess whether the distance gap thresholds were constant or increased across 20 mph – 50 mph the slope against zero was tested for each group using one-sample t-tests. For typically developing children this revealed a significant difference, mean slope = 6.15, $t(14) = 5.37$, $p = .001$, however a non-significant difference from zero was found for at risk children, mean slope = 5.32, $t(5) = 1.96$, $p = .11$, and for children with DCD, mean slope = 5.46, $t(8) = 1.29$, $p = .23$. This strongly supports the argument that the TD group were able to compensate to some degree for speed of approach (but not fully, see Table 6.12.). It also suggests that children with DCD and children at risk of DCD did not compensate for speed and relied upon optic size (distance), although it should be noted that the weaker trend in the DCD and the at risk group could be due to intra-group variability, so this could be a Type II error.

Table 6.12. Descriptive statistics for distance gap acceptance thresholds (in meters), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30, 40 and 50 mph across groups.

	TD	At Risk	DCD
	Typically Developing	> 5th but ≤ 16th Percentile	≤ 5th Percentile
		20 mph	
N	15	6	8
Mean Threshold (m)	117.33	127.83	192.00
Standard Deviation	67.05	70.54	54.82
95% CI	± 74.26	± 148.05	± 91.67
		30 mph	
N	15	6	9
Mean Threshold (m)	142.67	183.83	235.78
Standard Deviation	83.08	114.40	75.75
95% CI	± 92.01	± 240.11	± 116.45
		40 mph	
N	15	6	8
Mean Threshold (m)	129.67	146.00	225.38
Standard Deviation	75.82	86.74	72.72
95% CI	± 83.97	± 182.05	± 121.59
		50 mph	
N	15	6	9
Mean Threshold (m)	156.80	201.67	310.11
Standard Deviation	84.47	125.25	197.67
95% CI	± 93.55	± 262.88	± 303.89

6.6.3. Walking Speeds

Walking times over a distance equivalent to the width of an average two lane road at two walking paces (preferred pace and as fast as possible) is shown in Table 6.13. with the ratio of temporal gap chosen from Table 6.11. to preferred walking pace calculated as an estimate of the margins for error children might leave at the roadside. Data were homogenous for both datasets (Levene's) and two one-way ANOVAs (group [TD, at risk, DCD]) for preferred and fast walking pace with Tukey HSD post hoc comparisons were conducted.

Walking times at the preferred pace were slower for children with DCD. There was a main group effect $F(2, 115) = 14.26$, $p < .001$. Post hoc tests confirmed that the differences between children with DCD and the TD group were significant ($p < .001$) as were the differences between children with DCD and the at risk group ($p = .001$). There was also a main group effect $F(2, 115) = 25.21$, $p < .001$ for the fast walking pace. Post hoc tests again confirmed that the differences between children with DCD and the TD group were significant ($p < .001$) as were the differences between children with DCD and the at risk group ($p < .001$). There were no significant differences between children at risk of DCD and the TD group for either normal or fast walking conditions.

Table 6.13. Mean and SD crossing times (in seconds) for the average width of a UK road and estimated margins for error for each approach speed, based on the ratio of gap acceptance thresholds to preferred pace walking times across the average width of a road. Margins should be greater than 1.5 seconds to ensure safety.

	TD	At Risk	DCD
	Typically Developing	> 5th but ≤ 16th Percentile	≤ 5th Percentile
crossing time (in seconds)			
At preferred pace	4.47 (1.12)	4.74 (1.12)	5.68 (1.00)
As fast as possible	2.96 (0.52)	3.23 (0.72)	3.77 (0.93)
margins for error			
20 mph	2.96	3.02	3.85
30 mph	2.39	2.92	3.13
40 mph	1.63	1.72	2.20
50 mph	1.58	1.90	2.51

Margins for error were compared between groups using one-way ANOVA's (group [TD, DCD]) for each approach speed and were found to be non-significant for all approach speeds: 20 mph - $F(2, 29) = .46$, $p = .64$; 30 mph - $F(2, 29) = 1.34$, $p = .28$; 40 mph - $F(2, 29) = .74$, $p = .49$; 50 mph - $F(2, 29) = 1.97$ $p = .16$. Tukey HSD post hoc comparisons also confirmed no significant differences in the margins for error between groups for any of the approach speeds.

6.6.4. Road crossing questionnaire

A total of 21 out of 30 children completed a questionnaire (12 typically developing children and 8 children with DCD) which aimed to assess their confidence and appreciation of the dangers associated with the task of road crossing. The results are shown in Tables 6.14., 6.15. and 6.16. In Experiment One factor analysis demonstrated that these questions load onto three factors (crossing frequency, crossing behaviour and perceived crossing ability). Data from the children with DCD and their matched controls were grouped in the same way and Cronbach's alpha used to check for internal reliability for these participants. Crossing frequency and crossing behaviour demonstrated very low internal consistency (< .10), however, perceived crossing ability demonstrated high internal consistency (.77). Data for perceived crossing ability was reduced by taking the mean score across these four questions. A one-way ANOVA (group [DCD; TD]) found no difference in perceived crossing ability scores *F*(1,15) = .05, *p* = .82).

Table 6.14. Mean frequency of children's reported road crossings for the TD and DCD groups.

1=never; 2=rarely; 3=sometimes; 4=often; 5=very often	TD Typically Developing	DCD ≤ 5th Percentile
Q1. How often do you cross the road to get to school and home again?	3.3	2.8
Q2. How often do you cross the road with a parent/adult to get to school and home again?	3.6	3.4
Q3. How often have you walked across the road but then had to start running because a car was travelling faster than you realised?	2.3	1.8
Q4. How often do you wait for a car to pass but then realise you would have had time to cross?	2.8	2.9

Table 6.15. Children's mean perceived ability in road crossing judgments for the TD and DCD groups.

1=very poor; 2=poor; 3=average; 4=good; 5=very good	TD Typically Developing	DCD ≤ 5th Percentile
Q5. How good are you at judging when it is safe to cross?	4.3	4.0
Q6. How good do you think you are judging how far away a car is?	3.8	3.5
Q7. How good do you think you are at crossing a road safely?	3.9	3.5
Q8. How good do you think you are at judging how fast cars are travelling towards you?	3.4	3.1

In general, one might predict that as perceived danger in road crossing increases, confidence in road crossing decreases, the final two questions (Table 6.16.) considered the relationship between these two variables and were analysed using a Pearson's correlation. A weak positive correlation was found between children's ratings on their confidence in crossing a road safely by themselves and danger perceived in crossing roads, $r_p = .13$, $p = .59$. However, a one-way ANOVA (group [TD, DCD]) found that children with DCD were equally confident in their ability to execute a safe road crossing by themselves as their typically developing peers (*F*(1,19 = 2.44, *p* = .14) but perceived the task as significantly more dangerous (*F*(1,19 = 13.33, *p* = .007)

Table 6.16. Children's mean confidence and perceived danger in road crossing judgments for the TD and DCD groups.

	TD Typically Developing	DCD ≤ 5th Percentile
1=totally unconfident; 2=fairly unconfident; 3=neither confident or unconfident; 4=fairly confident; 5=totally confident		
Q9. How confident are you that you can cross the road safely by yourself?	4.0	2.9
1=very dangerous; 2=dangerous; 3=neither safe or dangerous; 4=safe; 5=very safe		
Q10. How dangerous do you think it is to cross the road?	3.4	1.8

6.7. Discussion

From the results reported in previous Chapters one might predict that children with DCD may misjudge the speed of the faster vehicles and leave much shorter temporal gaps than for slower vehicles. In line with this, the results for the DCD and at risk groups reported in this experiment suggest that they do not compensate well for vehicle approach speed and as a result their perceptual estimates are based on optic size (distance) and they do not compensate well for vehicle approach speed. But, a notable between-group effect was that DCD children adopted a cautious strategy, selecting much larger time and distance gaps compared to TD children or children at risk of DCD. Given that they had significantly slower walking speeds and the margins for error they adopted were higher than those of the other two groups, this would enable them to compensate for their longer crossing times. Although these results go against the initial hypothesis, it is comforting that children are not making rash crossing judgments in a roadside scenario. One interpretation of the excessively large temporal and distance gaps left by children with DCD is that they lack experience and confidence in such scenarios and are prone to err towards caution. The questionnaire data suggest that children with DCD perceive the task of road crossing as significantly more dangerous than their typically developing peers, which could account for their cautious approach to this task. This may be only in a formal testing scenario, but at this stage it could be assumed that this would also be the case at the roadside as well. There are consequences, however, of leaving such large margins for error. Measurements were taken on the roads surrounding the schools where this study was conducted; the majority of these were not regulated to 20 mph. The typical temporal gaps between cars on these roads that children might cross on their way to school at school travel times, were around 8 seconds. A cautious road-crossing strategy will have even more impact as the children progress onto independence in secondary education. If there is no pelican crossing available and a child only feels safe to cross if there is a temporal gap of 14–22 seconds then they will either be waiting at the roadside for a very long time or be forced to make a decision to cross even if they are unsure if it is safe or not.

6.8. General Discussion

The results from Experiment One suggest that typically developing children accept sufficient temporal gaps which decrease as vehicle approach speed increases. To this end, younger children (6 to 7 year olds) behaved in a similar way to older children (9 to 10 year olds). A finding consistent with previous research which has demonstrated that children as young as five years of age were not markedly different from adults in their ability to make sensible decisions about traffic gaps (e.g. Demetre et al., 1992). Younger children generally adopted a more cautious strategy which is supported by the questionnaire data that suggest that younger children perceived the road crossing task as more dangerous and were less confident than older children. In general research in this area has suggested that children rely on distance as a guide to safe crossing gaps and do not take speed fully in account (e.g. Simpson, et al., 2003) however, the findings from Experiment One suggest that children are using a mixed model based upon optical size of the vehicle (distance), with some compensation based on rate of expansion (time ≈ tau).

The results from Experiment Two suggest that children with DCD may rely more heavily on optic size (distance) and compensate less well for vehicle approach speed compared to typically developing children. In applied terms, children with DCD, like their typically developing peers left shorter temporal crossing gaps as speed increased but generally adopted a much more cautious strategy, selecting much larger temporal and distance gaps compared to TD children or children at risk of DCD for all approach speeds. One consequence of a cautious strategy is that children with DCD may be forced to make a road crossing decision when they are unsure as to whether it is safe or not. One explanation for these findings could be due to an increased perception of danger associated with road crossing and reduced confidence. An alternative explanation could be that, in an experimental setting, children with DCD were more prone to rejecting suitable gaps if they perceived the car as approaching from any distance.

The following Chapter addresses this by systematically measuring gap acceptance thresholds in a road crossing simulation using a virtual environment, where multiple vehicles approached from only the near-side lane or bi-directionally from both near and far-side lanes.

Chapter 7: Selecting Suitable Crossing Gaps in a Virtual Environment

"Vision without action is a daydream. Action without vision is a nightmare"

(Japanese proverb)

7.1. Introduction

The ability to safely cross the road can be considered a perceptual-motor skill, involving coordination between perception of the TTC of approaching vehicles and the individual's own locomotive speed. In the previous Chapter, typically developing children, children at risk of DCD and children with DCD were presented with a perspective correct road scene image, with a single car approaching in the near-side lane. It was found that children with DCD selected significantly larger temporal and distance gaps compared to typically developing children or children at risk of DCD. Furthermore, taking into account locomotive speed and a safety margin of 1.5 seconds (criterion set on the basis of Simpson, Johnston, & Richardson, 2003), 89% of children with DCD missed suitable crossing opportunities for cars approaching at 30 mph, compared to only 60% for their typically developing peers. One explanation for these findings could be that children with DCD were overly cautious in their road crossing decisions, often rejecting suitable gaps if they perceived the car as approaching from any distance. An alternative methodology for assessing acceptable crossing gaps is the use of immersive virtual environments. Seward et al., (2007) have demonstrated the comparability of judgments made in a desktop environment versus a virtual environment using a head-mounted display. Furthermore, the benefits of virtual environments have been reported for training and skill enhancement of children and arguably, the use of virtual environments as a tool has the potential for improving the lives of children with disabilities (Strickland, Marcus, Mesibov, & Hogan, 1996).

As previously discussed, the ability to safely cross a road is a perceptual-motor skill that involves coordination between perception of the oncoming vehicles and the action of walking across the road. Judgments as to whether a gap in the traffic is sufficient to safely cross requires the determination of the TTC with the planned crossing trajectory and assessment of whether this TTC exceeds the time required to cross the road, taking into account one's own locomotive speed. This Chapter systematically measured gap acceptance thresholds in a road crossing simulation using a virtual environment, where multiple vehicles, in three speed conditions, approach from only the near-side lane (one-lane condition) or both near and far-side lanes (two-lane conditions). Gap acceptance thresholds and safety margins are compared for typically developing children, children with DCD and a clinical sample with reported motor difficulties, as well as more general developmental delays.

7.2. Methods

7.2.1. Participants

A total of twenty-five children aged between 6 years and 0 months and 11 years and 8 months participated in this study, see Table 7.1. Fifteen children were recruited from a local primary school and comprised a sub-group of the children that completed Experiment Two in Chapter 6 during a separate testing session. None of the children had any reported neurological problems that would qualify as exclusion criteria for this study. In accordance DSM-IV all children in the DCD and typically developing groups were assessed on the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007). All of the children in the typically developing (TD) group scored $\geq$25th percentile on the MABC-2 indicating typical motor development. All children in the DCD group all scored <5th percentile denoting significant movement difficulties.

The remaining ten children were recruited from a private occupational therapy (OT) service in North Yorkshire (UK), specialising in children with developmental and learning difficulties. These children all received a thorough assessment by an OT, seven children received a primary diagnosis of sensory processing, one child had a primary diagnosis of asperger syndrome, one child a primary diagnosis of praxis and one child a primary diagnosis of congenital hypotonia and they were assigned to a ‘clinical’ group for the purposes of this study. OTs reported that all of these children had some level of motor impairment.

Table 7.1. Participant information for each group. Information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 percentile range, mean MABC-2 total test score, MABC-2 total test score range, and gender ratio (female to male).

	TD Typically Developing	DCD ≤ 5th Percentile	Clinical
N	10	5	10
Mean decimal age	9.70	8.70	8.84
Age range	7.71 – 11.25	6.04 – 10.35	6.03 – 11.72
Mean MABC-2 centile	57	1	-
Mean MABC-2 Total Test Score	82	38	-
MABC-2 range	69 – 98	45 – 49	-
Gender ratio (f:m)	1:3	2:3	1:1

Parental informed consent was obtained for all children in advance of the study, and each child provided verbal assent immediately prior to the start of the experiment. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London.

7.2.2. Apparatus

Participants were seated and stimuli displayed on three Dell flat LCD monitors (38 × 30 cm), with an aspect ratio of 1.26 and resolution of 1280 × 1024 sufficient for all presentations. The simulation code used a 60 Hz timer-loop and all simulations were scripted in Python and used Vizard 3D simulation tools (Development Edition; WorldViz, Santa Barbara, USA). The Vizard libraries interface with OpenSceneGraph and provide the ability to render highly realistic 3D simulations and run at the maximum screen refresh rate. The rendering hardware was an Intel® dual core CPU with an NVidia high performance GPU running under Windows 7.

7.2.3. Stimuli

In all conditions, the virtual road consisted of a straight flat section of road within a virtual city. The road was marked with a continuous white line nearest the viewpoint and a pavement was visible furthest from the viewpoint. There were dashed white centre lines that divided the road into two 3.1m wide lanes. The three screens provided a heading viewpoint, a left viewpoint and a right viewpoint by angling the left and right screens (yaw = 113°) to give the 3D impression of looking right and left down the virtual road scene. At the start of each trial, the heading viewpoint simulated a road crossing at 1.05 m/s to demonstrate the approximate time that it would take the child to execute a road crossing at a normal walking pace (6.5 seconds). Vehicles were represented as blocks, sized to be equivalent to a typical UK car (Renault Logan -

length: 4.25 m, width: 1.74 m; height: 1.53 m) and the blocks alternated in colour between red and blue to ensure each approaching vehicle was easily distinguishable from the previous one. Children completed a total of eight road crossing conditions in the virtual environment. In four conditions they encountered six oncoming vehicles approaching in the near-side lane (single-lane condition) at either 20 mph, 30 mph or 40 mph and in the other four conditions vehicles approached bi-directionally at either 20 mph, 30 mph or 40 mph from both the near-side and far-side lanes (two-lane condition). In the two-lane condition, the vehicles in the far-side lane were a mirror-image of those approaching in the near-side lane. The trials were presented in blocks (one-lane conditions and two-lane conditions) and the speed of vehicle approach within each block were randomly presented, the fourth trial in each block was a repetition of the first approach speed, presented to minimise any order effects (see Figure 7.1. for example of experimental set up). At the end of the experimental session, walking times over a distance equivalent to the width of an average two lane road at two walking paces (preferred pace and as fast as possible) were measured.

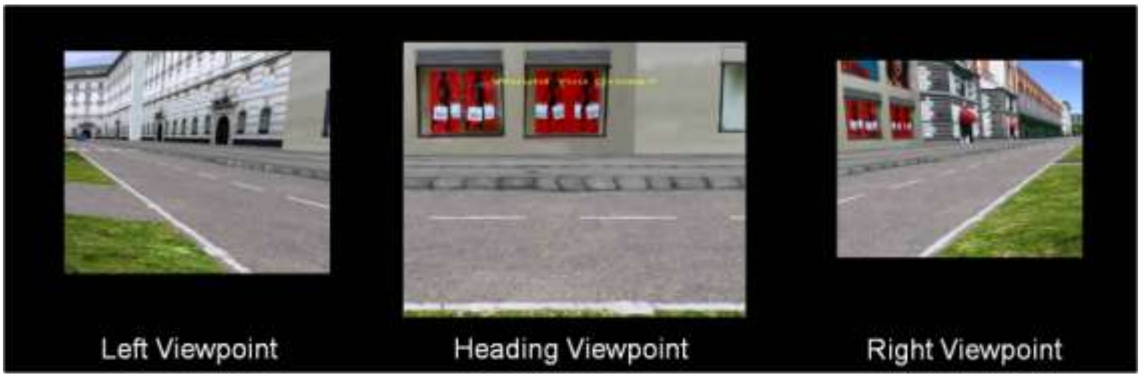


Figure 7.1. Example of experimental set-up testing gap acceptance thresholds in a virtual environment. Six vehicles either approached from the right (one-lane conditions) or from the right and left (two-lane conditions) at 20, 30 and 40 mph.

7.2.4. Psychophysical Procedure

The child's task was to verbally indicate whether they would 'cross' or 'not cross' between the approaching vehicles. To converge on each child's gap acceptance threshold a Best Parameter Estimation by Sequential Testing (Best-PEST: Lieberman & Pentland, 1982) staircase procedure was used which progressed in a downward descent sequence using 1000 intervals based on probability estimates. The maximum TTC was set at 20 seconds and the minimum at 2 seconds. This resulted in different distances between approaching vehicles for each approach speed such that the vehicles at 20 mph had an inter-vehicle distance of 142 m, 30 mph resulted in 213 m and 40 mph resulted in 284 m. For all conditions the first presentation had a fixed TTC of 2 seconds between vehicles to discourage participants from immediately accepting an unsafe crossing gap without looking for traffic. The algorithm terminated after nine reversals and the maximum likelihood value was taken as each participant's gap acceptance threshold.

7.3. Results

7.3.1. Temporal Gap Acceptance Thresholds

Mean temporal data for all approach speeds and both groups are presented in Table 7.2. for the one-lane condition and Table 7.3. for the two-lane condition. A two-way mixed ANOVA (group [TD, DCD, Clinical], vehicle approach speed [20, 30 and 40 mph]) was used to compare gap acceptance thresholds for each of the approach speeds between groups. The results for the one-lane condition show a significant main effect of vehicle approach speed on the temporal gaps that children accepted ($F(1.42,31.27) = 9.70$, $p = .002$, $\eta_p^2 = .31$ Greenhouse-Giesser reported due to violation of sphericity). A non-significant main effect was found between groups ($F(2,22) = .40$, $p = .68$, $\eta_p^2 = .04$ and a non-significant interaction was also found between vehicle approach speed and group on the temporal gaps that children accepted ($F(4,44) = 2.45$, $p = .06$, $\eta_p^2 = .18$).

For the one-lane condition, generally the temporal gaps accepted within each group decreased as approach speed increased. As discussed in the previous Chapter (see Discussion section 6.4.) this suggests that within groups children were utilising something other than tau (e.g. optic size), otherwise the temporal gaps accepted would be equivalent across approach speeds. This was supported by a significant linear trend for approach speed $F(1,22) = 15.60$, $p = .001$. To assess whether the temporal gaps selected were constant across 20 mph – 40 mph, the slope was tested against zero for both groups using one-sample t-tests. A significant difference from zero was found for the index group, mean slope = 1.69, $t(9) = 2.71$, $p = .024$ and clinical group, mean slope = 1.18, $t(9) = 2.71$, $p = .024$, but not for children with DCD, mean slope = 1.26, $t(4) = 2.02$, $p = .11$.

Table 7.2. Descriptive statistics for one-lane temporal gap acceptance thresholds (in seconds), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30, and 40 mph across groups.

	TD Typically Developing	DCD ≤ 5^{th} Percentile	Clinical
one-lane vehicles approaching at 20mph			
N	10	5	10
Mean Threshold (s)	5.28	4.25	4.25
Standard Deviation	4.08	1.61	2.14
95% CI	± 5.83	± 4.00	± 3.06
one-lane vehicles approaching at 30mph			
N	10	5	10
Mean Threshold (s)	4.10	5.21	3.22
Standard Deviation	2.32	2.28	1.21
95% CI	± 3.32	± 5.67	± 1.74
one-lane vehicles approaching at 40mph			
N	10	5	10
Mean Threshold (s)	3.59	2.99	3.08
Standard Deviation	2.17	0.85	1.22
95% CI	± 3.10	± 2.11	± 1.74

The results for the two-lane conditions also revealed a significant main effect of vehicle approach speed on the temporal gaps that children accepted ($F(1.49,31.28) = 4.8$, $p = .023$, $\eta_p^2 = .19$ Greenhouse-Giesser reported due to violation of sphericity), but a non-significant main effect of group ($F(2,21) = .86$, $p = .44$, $\eta_p^2 = .08$ was found and a non-significant interaction for vehicle approach speed and group on the temporal gaps that children accepted ($F(2,42) = .47$, $p = .76$, $\eta_p^2 = .04$). A significant linear trend was found for approach speed *F*(1,21) = 6.97, *p* = .016 therefore, to assess whether the temporal gaps selected in the two-lane condition were constant across 20 mph – 40 mph, the slope was tested against zero for all groups using one-sample t-tests. A significant difference from zero was found for the index group, mean slope = 2.03, *t*(9) = 3.30, *p* = .011 but not for children with DCD, mean slope = 1.43, *t*(3) = 1.62, *p* = .21 or clinical group, mean slope = .81, *t*(9) = .87, *p* = .41. Mean group data for both one-lane and two-lane conditions is shown in Figure 7.2.

Table 7.3. Descriptive statistics for two-lane temporal gap acceptance thresholds (in seconds), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30, and 40 mph across groups.

	TD Typically Developing	DCD ≤ 5th Percentile	Clinical
two-lane vehicles approaching at 20mph			
N	10	4	10
Mean Threshold (s)	6.60	5.39	4.40
Standard Deviation	4.42	2.27	3.55
95% CI	± 6.32	± 7.22	± 5.08
two-lane vehicles approaching at 30mph			
N	10	4	10
Mean Threshold (s)	4.90	4.62	3.44
Standard Deviation	2.92	1.59	1.31
95% CI	± 4.04	± 5.06	± 1.87
two-lane vehicles approaching at 40mph			
N	10	4	10
Mean Threshold (s)	4.57	3.95	3.59
Standard Deviation	3.39	2.78	1.20
95% CI	± 4.86	± 8.86	± 1.72

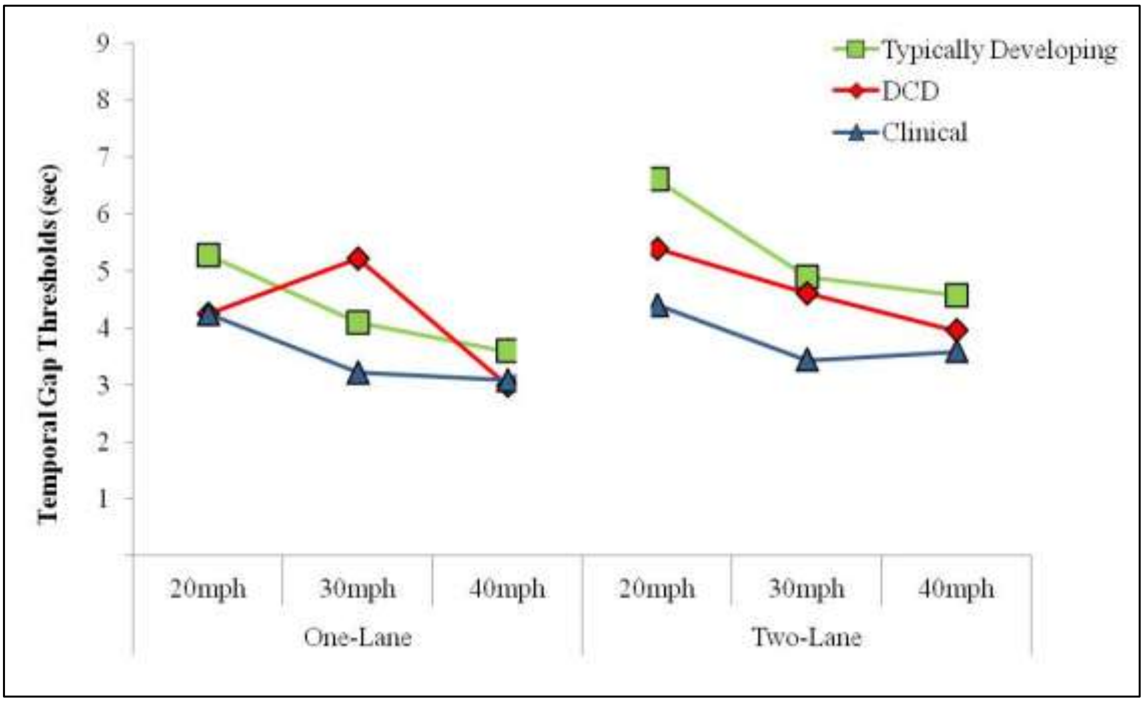


Figure 7.2. Mean temporal gap acceptance thresholds (in seconds), for cars in the one-lane and two-lane conditions, approaching at 20, 30 and 40 mph, for all groups.

Given the small sample size of the DCD group, individual data for the one-lane conditions are shown in Figures 7.3. a to c and the two-lane conditions 7.4. a to c, the shaded areas for each group represent time gaps that would be insufficient to achieve a safe road crossing in the virtual environment (6.2 m).

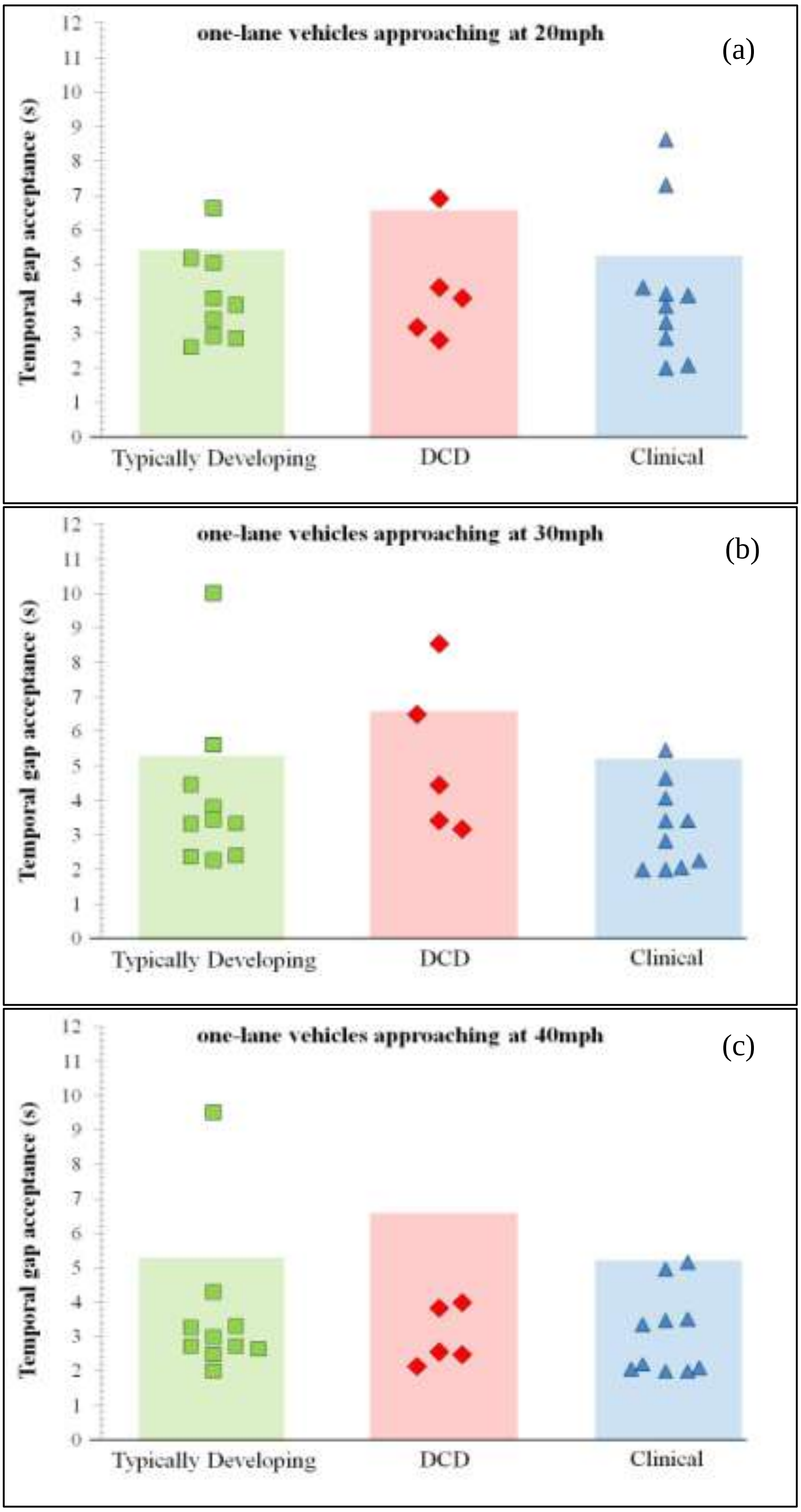


Figure 7.3. Individual data for typically developing children (green), children with DCD (red) and children in the clinical group (blue) for vehicles approaching in the following conditions: (a) one-lane 20 mph; (b) one-lane 30 mph; (c) one-lane 40 mph, shaded areas for each group represent time gaps that would be insufficient to cross.

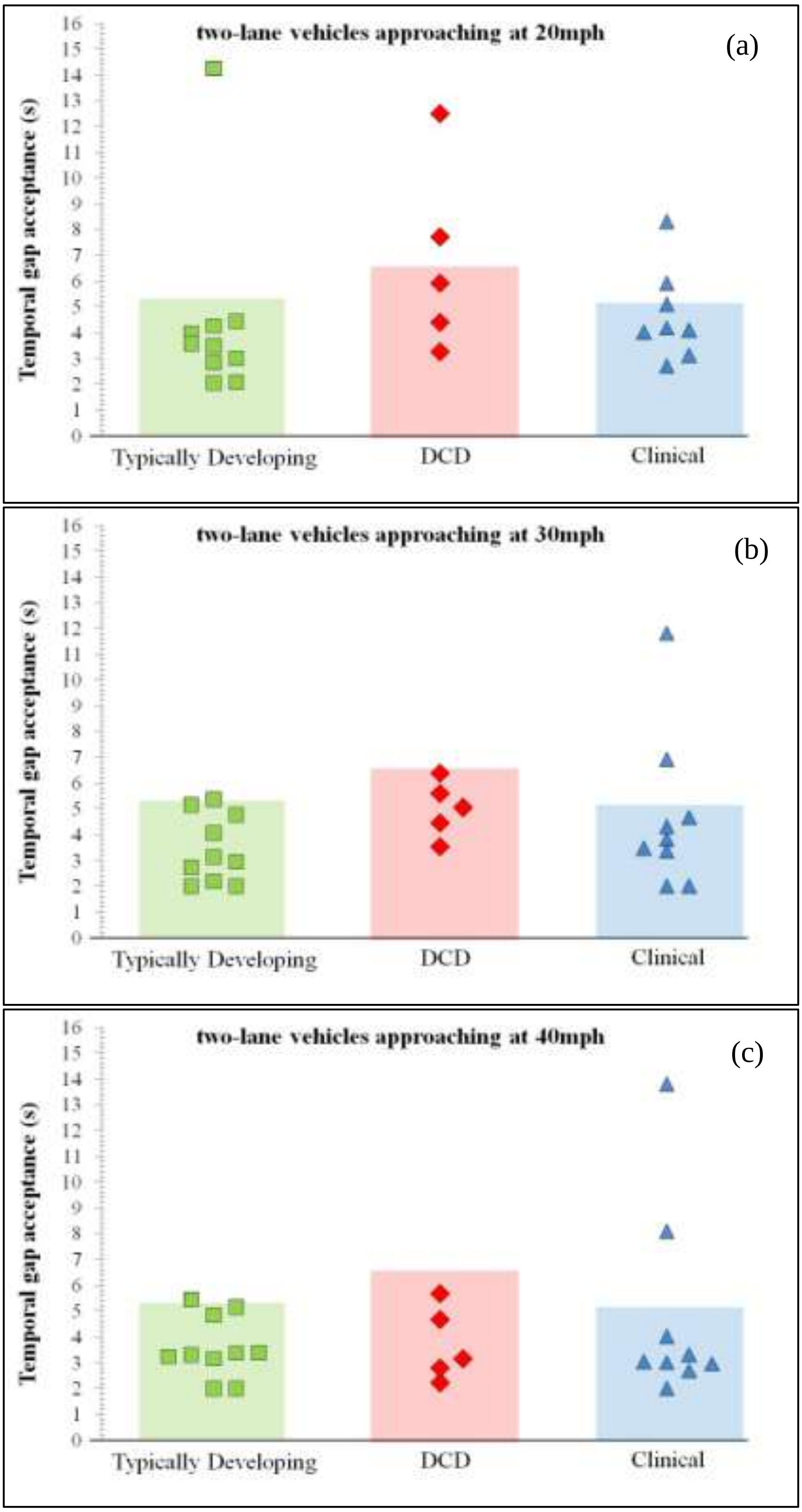


Figure 7.4. Individual data for typically developing children (green), children with DCD (red) and children in the clinical group (blue) for vehicles approaching in the following conditions: (a) two-lane 20 mph; (b) two-lane 30 mph; (c) two-lane 40 mph, shaded areas for each group represent time gaps that would be insufficient to cross.

7.3.2. Distance Gap Acceptance Thresholds

In addition to temporal gap acceptance thresholds children will have also settled towards a specific inter-vehicle distance for each speed of approach. Mean distance gap thresholds for all approach speeds and both groups are presented in Table 7.4. (one-lane) and Table 7.5. (two-lane). A two-way mixed ANOVA (group [TD, DCD, Clinical], vehicle approach speed [20, 30 and 40 mph]) was used to compare distance gaps for each of the approach speeds between groups. The results for the one-lane condition show a significant main effect of vehicle approach speed on the distance gaps that children accepted ($F(2,44) = 19.2$, $p < .001$, $\eta_p^2 = .47$), but a non-significant main effect between groups ($F(2,22) = .40$, $p = .67$, $\eta_p^2 = .04$). A significant interaction was found for vehicle approach speed and group on the distance gaps that children accepted ($F(4,44) = 4.8$, $p = .003$, $\eta_p^2 = .30$).

Table 7.4. Descriptive statistics for one-lane distance gap acceptance thresholds (in meters), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30 and 40 mph across groups.

	TD Typically Developing	DCD ≤ 5th Percentile	Clinical
one-lane vehicles approaching at 20mph			
N	10	5	10
Mean Threshold (m)	47.17	37.97	38.02
Standard Deviation	36.44	14.42	19.14
95% CI	± 52.13	± 35.80	± 27.38
one-lane vehicles approaching at 30mph			
N	10	5	10
Mean Threshold (m)	55.02	69.93	43.11
Standard Deviation	31.07	30.61	16.26
95% CI	± 44.45	± 76.01	± 23.26
one-lane vehicles approaching at 40mph			
N	10	5	10
Mean Threshold (m)	64.15	53.40	54.99
Standard Deviation	38.74	15.19	21.75
95% CI	± 55.43	± 37.72	± 31.12

The significantly shorter temporal gap thresholds that TD children left across approach speeds suggest that they may have been relying predominately on optic size (distance), if this were the case one would expect the time gaps accepted to be constant across speeds. The non-significant temporal gap thresholds that DCD children left across approach speeds is perhaps a consequence of variability within this group, if they were however, utilising tau in their decisions, then the distance gap thresholds should increase as approach speed increases. A significant linear trend was found for approach speed, *F*(1,22) = 47.2, $p < .001$, therefore, to assess whether the distance gaps selected were constant across 20 mph – 40 mph in the one-lane condition, the slope was tested against zero for both groups using one-sample t-tests. A significant difference from zero was found for the index group, mean slope = -16.98, *t*(9) = 8.06, $p < .001$ and the clinical group mean slope = -16.98, *t*(9) = 4.1, *p* = .003, but not for the DCD group, mean slope = -15.44, *t*(4) = 2.30, *p* = .08.

The results for the two-lane condition show a significant main effect of vehicle approach speed on the distance gaps that children accepted (*F*(2,42) = 7.4, *p* = .002, η_p^2 = .26) but a non-significant main effect of group (*F*(2,21) = .69, *p* = .51, η_p^2 = .06). A significant interaction was found for vehicle approach speed and group on the distance gaps that children accepted (*F*(2,42) = 7.4, *p* = .002, η_p^2 = .26). A significant linear trend was found for approach speed *F*(1,21) = 11.5, *p* = .003, however, to assess whether the distance gaps selected were constant across 20 mph – 40 mph in the two-lane condition, the slope for both groups was tested against zero using one-sample t-tests. A significant difference from zero was found for the index group, mean slope = -22.73, *t*(9) = 8.06, $p < .001$ and the clinical group mean slope = -21.04, *t*(9) = 4.10, *p* = .003, but not for the DCD group, mean slope = -22.51, *t*(3) = 1.23, *p* = .31. Mean group data for both one-lane and two-lane conditions is shown in Figure 7.5.

Table 7.5. Descriptive statistics for two-lane distance gap acceptance thresholds (in meters), including standard deviations and 95% confidence intervals (95% CI) for cars approaching at 20, 30 and 40 mph across groups.

	TD Typically Developing	DCD ≤ 5th Percentile	Clinical
two-lane vehicles approaching at 20mph			
N	10	4	10
Mean Threshold (m)	58.97	48.18	43.14
Standard Deviation	39.49	20.29	30.10
95% CI	± 56.49	± 35.39	± 43.06
two-lane vehicles approaching at 30mph			
N	10	4	10
Mean Threshold (m)	65.69	61.89	46.08
Standard Deviation	37.84	21.37	17.52
95% CI	± 54.14	± 39.27	± 25.07
two-lane vehicles approaching at 40mph			
N	10	4	10
Mean Threshold (m)	81.69	70.69	64.17
Standard Deviation	60.70	49.84	21.52
95% CI	± 86.84	± 79.90	± 30.79

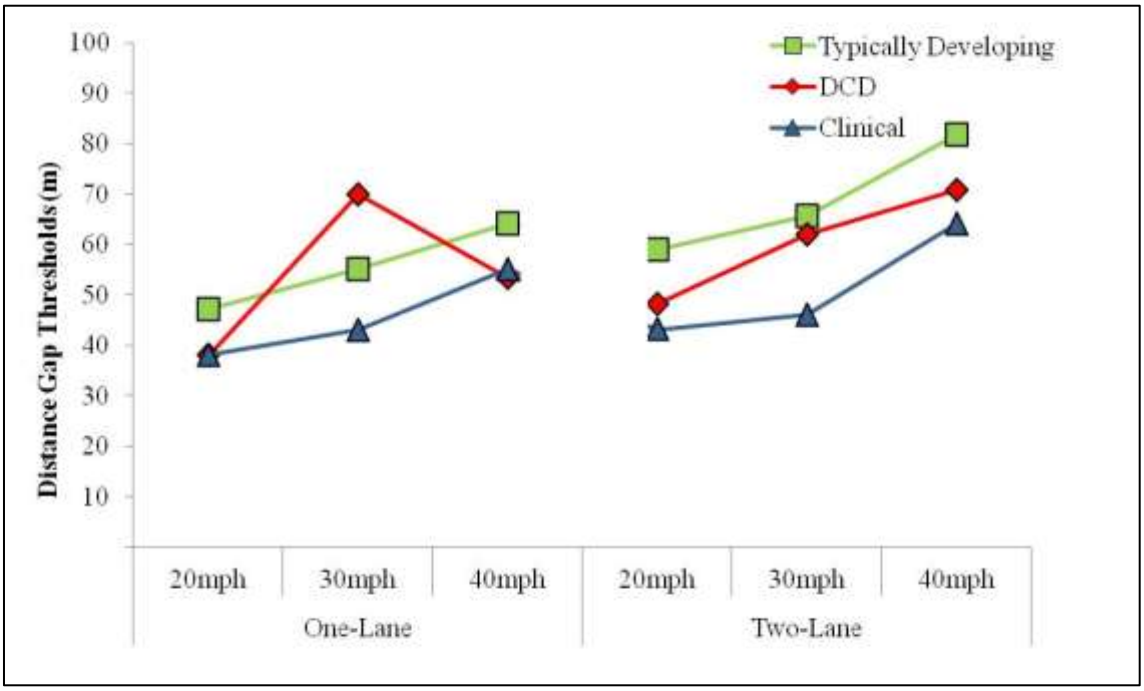


Figure 7.5. Mean distance gap acceptance thresholds (in meters), for cars in the one-lane and two-lane conditions, approaching at 20, 30 and 40 mph, for all groups.

7.3.3. Margins for error

The measured walking times over a distance equivalent to the width of an average two lane road at two walking paces (preferred pace and as fast as possible) are shown in Table 7.6. with the ratio of temporal gap chosen from Table 7.2. (one-lane condition) and Table 7.3. (two-lane condition) to preferred walking pace calculated as an estimate of the margins for error children might leave at the roadside.

Walking times at the preferred pace were slower for children with DCD. A one-way ANOVA (group [TD, DCD, Clinical]) was conducted and there were no significant differences between groups *F*(2,16) = 3.45, *p* = .06 at the preferred walking pace, or at the fast walking pace *F*(2,15) = 2.67, *p* = .12.

Table 7.6. Mean and SD crossing times (in seconds) for the width of the virtual road (6.2m) and estimated margins for error for each approach speed, based on the ratio of gap acceptance thresholds for the one-lane condition to preferred pace walking times across the road. Margins should be greater than 1.5 seconds to ensure safety.

	TD Typically Developing	DCD ≤ 5th Percentile	Clinical
	crossing time (in seconds)		
At preferred pace	5.35 (0.81)	6.55 (0.63)	5.21 (0.69)
As fast as possible	3.45 (0.57)	4.36 (0.04)	3.47 (0.45)
	margins for error one-lane conditions		
20 mph	0.98	0.64	0.82
30 mph	0.76	0.79	0.62
40 mph	0.66	0.45	0.59
	margins for error two-lane conditions		
20 mph	0.81	0.82	0.84
30 mph	0.91	0.70	0.66
40 mph	0.85	0.60	0.69

Margins for error for the one-lane condition were compared between groups using a one-way ANOVA (group [TD, DCD, Clinical]) and were found to be non-significant for all approach speeds: 20 mph - *F*(2,24) = .66, *p* = .53; 30 mph - *F*(2,24) = .66, *p* = .53; 40 mph - *F*(2,24) = .80, *p* = .46. Margins for error for the two-lane condition were also compared between groups using a one-way ANOVA (group [TD, DCD, Clinical]) and were found to be non-significant for all approach speeds: 20 mph - *F*(2,23) = .90, *p* = .42; 30 mph - *F*(2,23) = 1.09, *p* = .36; 40 mph - *F*(2,23) = .54, *p* = .59.

7.4. Discussion

The results from Experiment Two in the previous Chapter, suggest that children with DCD might leave longer inter-vehicle temporal gaps than their TD peers, due to an over-reliance on optic size (distance) in their crossing judgments. In this experiment, the task had an equivalent response (i.e. *'would you cross?'*), but unlike the previous Chapter, which presented children with a single car approaching in the near-side lane, the paradigm used in this Chapter presented children with a stream of vehicles in a virtual environment. This difference meant that in the previous chapter, the task was to decide whether there was sufficient time perceptually to cross before the car arrived at the crossing point, compared to the current paradigm in which the child needed to decide whether there was sufficient time to cross in between a stream of vehicles. These vehicles approached in either the near-side lane or bi-directional traffic approaching from the near-side and far-side lanes. Another notable difference between the current paradigm and that used in the previous Chapter was the set-up. In the previous Chapter a single car approached on two randomly presented road scenes, the current paradigm used a more ecologically valid and immersive road crossing simulation. The results in this Chapter are starkly different from those in the previous Chapter. In contrast to the excessively large temporal gaps adopted by children with DCD in the previous Chapter, in this experiment DCD children converged upon temporal gaps that would result in collision if translated to the roadside.

If the child uses rate of looming in addition to optic size, this gives them access to an estimate of TTC, in which case the temporal gaps accepted would not vary with approach speed, and as a consequence vehicle distance would increase. If they rely predominantly on just optic size, the time gaps accepted would be an inverse function of approach speed and the distance gaps (optic size) would be constant across speeds.

When vehicles approached in the near-side lane, all children generally left shorter temporal gaps as speed of approach increased. This suggests that children’s perceptual estimates may rely more heavily on optic size (distance). This is illustrated by the comparison of the change in the temporal gaps accepted by TD children and children in the clinical group at 40 mph vs. 20 mph, where the slope was significantly greater than zero. This was not confirmed statistically in the DCD group, but due to the small sample size, there is an issue of variability within this group. It is of note, however, that the slope for the distance gaps (Figure 7.5.) was also significantly greater than zero for the TD children and children in the clinical group, which argues for a mixed model based on optic size with some compensation for speed, through the use of optic expansion.

In applied terms, the strategy used by both TD children, children with DCD and children in the clinical group would result in collision, with the temporal gaps accepted by all groups less than the time it would take them to execute a safe road crossing for all approach speeds. The very small margins for error provide further support this and may be more problematic for children with DCD and children in the clinical group who could be slower to adjust to a fast walking pace once their walking movement to cross the road has been initiated.

There was a general trend for all groups, whereby the temporal gaps that children accepted decreased as speed increased. The results from the one-lane condition suggest that the clinical group and typically developing children were again basing their judgments on a mixed model based on optic size with some speed compensation in their crossing decisions. The clinical group however, did not show a significant trend in the temporal gaps they accepted as speed increased. The temporal gaps decreased by 0.8 seconds (13%), but this was statistically equivalent across approach speeds. In applied terms, the temporal gaps all children were accepting, however, were already well under the time they required to cross and would result in collision, this is clear when considering the margins for error that children left which were all substantially below the recommended 1.5 seconds.

As discussed in the introduction, in order to avoid collision the TTC needs to be greater than the time it takes to cross, overall, the experiments reported in this Chapter suggest that children below the age 11 are relatively poor at reliably setting safe TTC gaps when presented with multiple vehicles approaching bidirectionally as typically encountered at the roadside, and therefore, consistently fail to make safe crossing decisions, with judgments generally deteriorating as vehicle approach speeds increase. This general finding is consistent with those of Connelly et al (1998). Although all groups left similar temporal gaps across approach speeds, the differences in walking speeds result in smaller margins for error in the DCD group and children in the clinical group.

Overall, the results suggest that primary school age children left temporal gaps that if translated to the roadside would result in collision. There is some evidence that all groups can make some compensation for vehicle approach speed, but in general there is an over-reliance upon optic size (distance) as compared to skilled adult performance. The next Chapter explores the ability of children with and without DCD, to select the initiation of an action (to cross or not to cross) on the basis of perceptual information using an interception task.

Chapter 8: Intercepting Moving Targets

“We must perceive in order to move, but we must also move in order to perceive”

(Gibson 1979, p. 223)

8.1. Introduction

In the previous Chapters it has been discussed that younger children make significantly more road crossing errors as evident from road accident statistics; however the findings from Chapter 6 suggest that younger children and children with DCD leave large temporal crossing gaps, although the data from Chapter 7 suggest in a more immersive environment all children leave gaps that are too short. In a recent study by te Velde, van der Kamp, Barela and Savelsbergh (2005) they compared verbal judgments and actual walking across a simulated road, they found that verbal judgments did not represent actual crossing behaviour. The approaching bicycle that they used as a vehicle in their study had very low velocities (2-3 mph), but nevertheless, it does suggest that research should also consider the completion of the action component as well as perceptual acuity.

In crossing a road, a child needs to complete their action (walking) within a temporal window. Unless you make that window smaller and smaller (cars closer and closer) it is difficult to assess the errors that occur in the completion of the action, one way of assessing this is to look at the ability of children to get to a particular place in a specific time. So rather than being an avoidance task, this becomes an interception task and then the challenge is to be able to separate the perceptual and action components of interception. The constant bearing angle (CBA) model proposed by Fajen and Warren (2004) suggests that interception is achieved by maintaining a constant direction of the target relative to a fixed exocentric reference direction. The model describes an invariant relationship between the direction of change (positive or negative) in bearing angle and the sufficiency of the observer's current walking velocity to achieve an interception. Assuming the observer is on a straight interception path, if the bearing angle decreases the observer would need to accelerate to avoid the target passing in front of them, equally if the bearing angle increases, the observer would need to decelerate to avoid the target passing behind them (see Figure 8.1.). A series of studies by Fajen and Warren (2004) explored the visual information used in walking to a moving target (0.6 m/s), they found that participants (n = 8), did not use a strategy based on a target bearing angle of zero ($\beta = 0$), but instead used an interception strategy whereby target bearing angle was greater than zero ($\beta > 0$) and guided by the egocentric direction of the target.

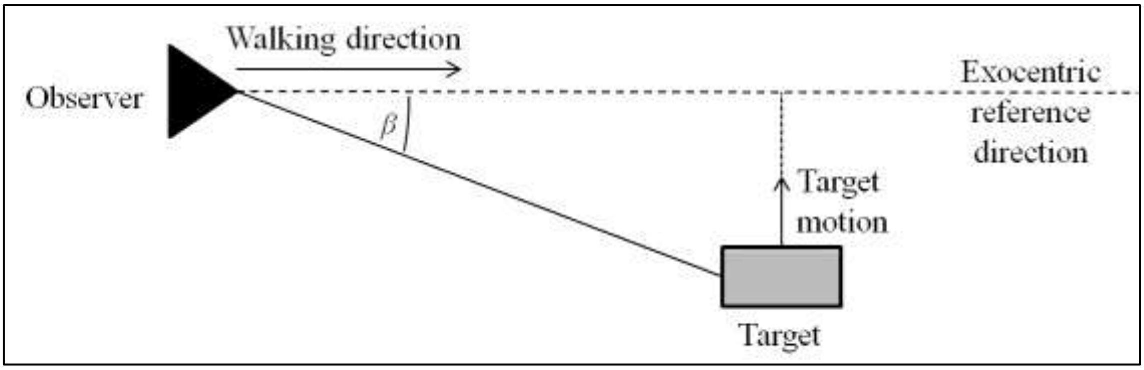


Figure 8.1. Schematic representation of an interception task, showing the bearing angle (β) of the target with respect to an exocentric reference direction.

One insufficiency with the CBA model is that it is hard to fully explain interceptions that involve targets that vary in speed. A study Diaz, Phillips and Fajen (2008) examined participants' (twelve undergraduates) ability to anticipate changes in target speed. They used visual displays of a spherical target (radius 0.35 m) that approached an interception point from one of three angles with one of three initial starting speeds (between 2.5 and 3.25 seconds), they randomly changed the final target speed and participants had to use a foot pedal to control their simulated speed to reach the target interception point (between 25 and 30 m) along a fixed path. They found that participants were able to anticipate the likely increase in target speed and did not attempt to maintain a CBA, instead participants tended to base their judgments on the targets mean actual TTC. The TTC is the amount of time before the target crosses the interception point and according to Bootsma and Oudejans (1993) can be optically specified by:

$$TTC \approx \frac{\theta(t)}{\dot{\theta}(t)} \approx \frac{\beta(t)}{\dot{\beta}(t)} \qquad (1)$$

Where the ratio of bearing angle $\beta(t)$ to the change in bearing angles $\dot{\beta}(t)$ equivalent to the ratio of optic size $\theta(t)$ to rate of expansion $\dot{\theta}(t)$ (tau; Lee, 1976).

One paradigm used for measuring the coordination of movement with the motion of an object are prediction motion (PM) tasks, where a moving object is occluded prior to reaching a specified position and the observer is required to temporally coincide their response with the objects arrival at that specified position. In a study by Benguigui, Broderick, Baurès and Amorim (2008) forty-eight children between 6 to 11 years of age and a group of 12 adults were recruited and tested on a PM task. Apparent motion was simulated using a 4 m length of 200 red LEDs that sequentially switched moving left to right, positioned at 2 cm intervals. After a series of training trials, 25 occlusion conditions were used with durations of 0 to 1.32 seconds with steps of 20 milliseconds between 0 and 200 milliseconds and with steps of 80 milliseconds between 200 and 1.32 seconds. They found that errors increased with occlusion time (>200 milliseconds) and improved with age, with younger children (6, 7.5 and 9 year olds) tending to use distance rather than time information in their TTC judgments.

When intercepting a moving target, if an observer's speed is less than required the target will pass in front of them, unless they accelerate to intercept the target. If the observer waits too long, however, the amount of acceleration needed will exceed the maximum speed that the observer is able to achieve and this holds equally true for the setting where the pedestrian is hoping to avoid collision. At the roadside, the critical skill is therefore, the ability to predict the future state of a movement. Forward internal models use an efference copy to predict the future state of a movement and provide stability to the motor system by predicting the outcome of movements before sensorimotor feedback becomes available (Wolpert, 1997). The predictive model is then compared with the desired state to generate online error correction signals that are transmitted to the motor-planning system allowing subtle and rapid adjustments to the timing of a movement. The ability to predict the location of an object and intercept it has been demonstrated early in development by von Hofsten and Lindhagen (1979), who found that babies at 4 months can track moving objects and can move an arm ahead of the target pathway to intercept the object, that is they can anticipate the future location of a moving object and can lead the object to make an interception.

It has been suggested that children with DCD have an underlying deficit in generating and/or monitoring internal models of action (e.g. Wilson et al, 2004), visual perceptual deficits will hinder the perception of the location of an object which will in turn have consequences for planning a goal-directed movement. When crossing busy roads, it is critical that motor coordination is closely synchronised with perceptual information that specifies the potential for colliding with oncoming vehicles. This experiment uses a predictive motion task to explore whether children with DCD are able to accurately coordinate their movement with a target that moves across their path, with a period of occlusion that will enable assessment of both the perceptual judgment and the interceptive action (walking).

8.2. Methods

8.2.1. Participants

A total of thirty participants took part in this experiment: fifteen typically developing (TD) children aged between 6 to 11 years old; eight children with DCD aged between 6 to 11 years old; and seven children at risk of developing DCD aged between 7 to 11 years old (see Table 8.1. for group information). Children were recruited from a local primary school, and screened in accordance with DSM-IV guidelines. To assess DSM-IV Criteria A and B, teachers were given an adapted version of the MABC-2 checklist (MABC-2; Henderson et al., 2007) and asked to identify children with coordination difficulties that they deemed significantly interfered with their academic achievement, and children without coordination difficulties. Teachers returned checklists for six children that were subsequently identified as DCD, for five (83%) of these children, teachers responded *'yes'* to *'Overall do you think this child has movement difficulties'*. Checklists were also returned for five children that were subsequently identified as at risk of movement difficulties, teachers responded *'yes'* to the same question for two (40%) of these children. All children were then assessed on the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007). Children in the age-matched TD group scored ≥ 25th percentile, indicating typical motor development, children identified as DCD scored ≤ 5th percentile, denoting significant movement difficulties. Children who scored > 5th but ≤ 16th percentile are in a borderline category and for brevity within the text will be referred to as being "at risk" of having movement difficulties. This separation of children failing below the 15th percentile is in line with the Leeds Consensus Statement on assessment and classification (Sugden, 2006).

Table 8.1. Participant information for each group, information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 range and mean MABC-2 total test score, Ravens number of children with scores ≥ grade IV, Conners' ADHD index number of children with scores between > 75% and < 86%, and gender ratio (female to male).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	15	7	8
Mean decimal age	8.83	9.06	8.41
Age range	6.35 – 11.19	9.05 – 11.03	6.68 – 11.01
Mean MABC-2 % tile	49	13	3
MABC-2 range	25 – 91	9 - 16	1 - 5
Mean MABC-2 total test score	79	59	47
Ravens (N ≥ grade IV)	1	0	3
Conners' ADHD index (N > 75 % and < 86 %)	1	0	2
Gender ratio (f:m)	1:4	1:6	1:3

To assess DSM-IV Criteria C and D, twenty-seven children were assessed on the Coloured Progressive Matrices (CPM; Raven, 1956). Twenty-four children (89 %) fell at or above intellectually average for their chronological age (between 25th-100th percentile), and one TD child and three children with DCD fell below intellectual capacity for their age (between 10th-25th percentile). These four children's data for all tasks were looked at individually and were not found to be significantly different from the group mean and so were included in the final sample. Given reported comorbidity rates between DCD and ADHD, teachers also completed Conners' Teacher Rating Scale – Revised (Conners, 1997) for twenty-five children. One TD child and two DCD children had elevated scores on the Conners' dimensions[5]. It is likely that the inflated scores reflect changes in the classroom environment in the last decade. In terms of screening, there were no marked differences between the control group and index groups on the Conners' teacher ratings.

8.2.2. Apparatus

See Figure 8.2. for schematic of experimental set-up. A two meter length of model train track was used. A model train was positioned at the end of the track on the right hand side. A one meter tunnel was positioned 50 cm from the starting position of a model train and occluded the train track at that point. The interception point was half way along the tunnel and was clearly marked on the outside of the tunnel. The train travelled at two speeds: 1.6 m/s and 3.1 m/s along the track.

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[5] One TD child and two children with DCD scored > 75 % on the cognitive / inattention dimension, suggesting these children may have more academic difficulties compared to their peers, and have problems organising their work or concentrating on tasks that require sustained mental effort; one child with DCD scored > 75 % on the hyperactivity dimension, suggesting this child may have difficulty sitting still.

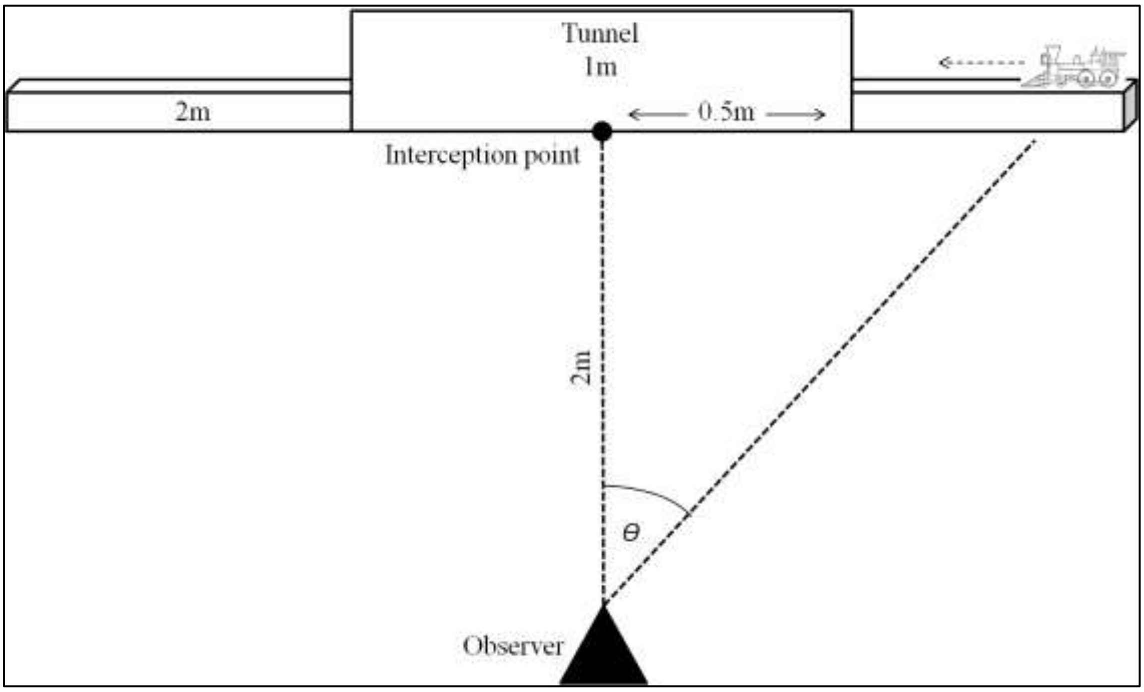

Figure 8.2. Schematic of train interception task, in the dynamic conditions intercepting the moving train will be successful if the observer matches the speed of the train

8.2.3. Procedure

Four conditions were included: (a) child stood stationary and the train travelled at 1.6 m/s (static and slow); (b) child stood stationary and the train travelled at 3.1 m/s (static and fast); (c) the child timed their walking to intercept the train whilst it travelled at 1.6 m/s (dynamic and slow); and the child timed their walking to intercept the train whilst it travelled at 3.1 m/s (dynamic and fast). In all conditions, the child was positioned 2 meters away from the track and in the static conditions, stood on a pressure mat positioned directly in front of the child to stop the train when they judged that it had reached the occluded interception point. In the dynamic conditions, children timed their walking speed to intercept the train by standing on the pressure mat positioned directly in front of the interception point. Children completed five trials in each condition that were randomly presented.

8.3. Results

See Table 8.2. for summary of results. The signed error for each trial was calculated by taking the difference between actual value and true value ($A_e = A_v - T_v$), which measures deviation from the interception point and enables examination as to whether children were intercepting too early or too late, a positive value indicates a response after the train has passed the interception point. To obtain the mean square error for each condition, the absolute error (A_e) values were squared and the mean square error calculated ($MSE = mean(A_e^2)$). The root mean square error is simply the square root of the MSE. A one-way ANOVA (group [TD, at risk, DCD]) for each condition was conducted on the RMSE.

Table 8.2 Descriptive statistics for Signed Error (cm) and Standard Deviation (SD) and Root Mean Squared Error (cm) and Standard Deviation (SD) for (a) static slow condition, (b) static fast condition, (c) dynamic slow condition, and (d) dynamic fast condition for each group. A negative number indicates a response before the actual arrival time of the train at the interception point.

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
	Static and Slow Condition		
N	15	7	8
Signed Error	-2.8 (5.5)	-3.3 (4.0)	5.0 (10.4)
Root Mean Squared Error	9.7 (7.1)	8.4 (2.4)	15.7 (12.1)
	Static and Fast Condition		
N	14	7	8
Signed Error	4.3 (5.9)	3.4 (6.6)	5.2 (6.8)
Root Mean Squared Error	11.7 (5.8)	12.7 (6.7)	16.4 (9.2)
	Dynamic and Slow Condition		
N	14	7	7
Signed Error	-5.0 (4.5)	-4.8 (6.3)	-6.1 (8.6)
Root Mean Squared Error	9.0 (3.2)	9.1 (3.5)	15.3 (6.3)
	Dynamic and Fast Condition		
N	15	7	8
Signed Error	4.3 (4.9)	1.5 (3.8)	8.9 (11.0)
Root Mean Squared Error	9.9 (3.6)	10.7 (4.5)	16.9 (10.3)

8.3.1. Static and Slow Condition

In this condition, children stood 2 meters from the train track whilst the train travelled at 1.6 m/s, the task was to stand on the pressure mat, positioned directly in front of the child) when the train was judged to have reached the occluded interception point. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for root mean squared error, (*F*(2, 29) = 1.95, *p* =.162). Post hoc Tukey HSD analysis confirmed that there were no significant differences between TD children and children at risk (*p* = .93) or between TD children and children with DCD (*p* = .22), or between children at risk and children with DCD (*p* = .20).

8.3.2. Static and Fast Condition

In this condition, children stood 2 meters from the train track whilst the train travelled at 3.1 m/s, the task was identical to the static slow condition. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for root mean squared error, (*F*(2, 28) = 1.17, *p* =.326). Post hoc Tukey HSD analysis confirmed that there were no significant differences between TD children and children at risk (*p* = .95) or between TD children and children with DCD (*p* = .30), or between children at risk and children with DCD (*p* = .57).

8.3.3. Dynamic and Slow Condition

In this condition, children started 2 meters from the train track whilst the train travelled at 1.6 m/s, the task was to synchronise their walking speed to reach the pressure mat, positioned directly in front of the interception point, when the train was judged to have reached the occluded interception point. A one-way ANOVA (group [TD, at risk, DCD]) revealed a significant group effect for root mean squared error, (*F*(2, 27) = 5.78, *p* =.009). Post hoc Tukey HSD analysis found that there were no significant differences between TD children and children at risk (*p* = .99) however children with DCD had significantly higher RMSE compared to TD children (*p* = .01) as did children with DCD and children at risk of DCD (*p* = .03).

8.3.4. Dynamic and Fast Condition

In this condition, children started 2 meters from the train track whilst the train travelled at 3.1 m/s, the task was identical to the dynamic slow condition. A one-way ANOVA (group [TD, at risk, DCD]) revealed a significant group effect for root mean squared error, (*F*(2, 29) = 3.518, *p* =.04). Post hoc Tukey HSD analysis found that there were no significant differences between TD children and children at risk (*p* = .96), nor between children with DCD and children at risk of DCD (*p* = .15), however children with DCD had significantly higher (poorer) RMSE compared to TD children (*p* = .04).

8.4. Discussion

Previous research suggests that observers base their interceptive judgments on TTC (e.g. Diaz et al, 2008). Findings from previous Chapters reported in this thesis suggest that primary school children with DCD may have a deficit in utilising the optical variables in TTC judgments. This experiment is the first to attempt to disentangle the perception and action components in an interception task in DCD to examine whether children with DCD are able to accurately coordinate their movement with a target that moves across their path, with a period of occlusion. The results from the static conditions, which assessed perceptual judgments, found children with DCD performed as well as their typically developing peers, but when the task required them to coordinate their movement to intercept the train during self-motion, they performed significantly poorer than TD children. The signed errors for the static conditions suggest that when the train was travelling at the slower speed, both TD children and children at risk of DCD judged that the train would have arrived at the interception point earlier than it did. Whereas, children with DCD judged the train to have a delayed arrival time. In the static condition where the train was travelling at a fast speed, all children misjudged the train's arrival time at the interception point to be later than it was (i.e. once it had already passed the interception point).

In the dynamic conditions, which assessed the coordination of self-motion with object-motion, when the train was travelling at 3.1 m/s children with DCD intercepted the train when it had travelled 8.9 cm past the interception point, compared to 4.3 cm for TD children and 1.5 cm for children at risk of DCD. This suggests that when children with DCD were required to coordinate their self-motion with object-motion, they walked significantly too slowly to accurately intercept an occluded moving target on foot, but when static performed equivalently to their TD peers. It's interesting to note, that the children at risk of DCD performed equivalently to their TD peers and in some cases marginally better, suggesting that level of motor impairment is an important factor in coordinating self-motion with object-motion.

In the current experiment, rather than presenting children with an avoidance task that required them to accept or reject a temporal crossing window, children were presented with an interception task that aimed to assess the perceptual component of interception (static conditions) and perceptual-action component of interception (dynamic conditions). The results from the perceptual component suggest that children with DCD were equally able to perceptually intercept a target moving across their path during a period of occlusion as their typically developing peers. Whereas, when an action component was included and children were required to coordinate self-motion with object-motion, to intercept a target that moved across their path with a period of occlusion, children with DCD were significantly poorer than their typically developing peers in judging the available temporal window. When the train was travelling slowly, they arrived at the interception point too soon (around 6 cm before the train had arrived), compared to when the train was travelling more quickly and they arrived too late (around 9 cm after the train had arrived).

At the roadside, the critical skill is to predict the future state of a movement. Although the speeds of approach in the current experiment were significantly slower than those used in the avoidance task in Chapter 6, where children were required to judge whether they would cross or not cross when presented with a vehicle approaching in the near-side lane at varying approach speeds (20 mph to 50 mph) the perceptual judgment is similar. If an observer (walking at constant velocity) underestimates the TTC of an approaching vehicle, it will have passed in front of the observer by the time they arrive. If the intention is cross before the vehicle, the observer should adopt a strategy that would overestimate the TTC, to allow some margin for error. In the experiment reported in Chapter 6 children with DCD consistently overestimated the TTC of the vehicle regardless of the approach speed, whereas in current experiment when the train approached at 7 mph and children with DCD were required to coordinate self-motion with object-motion in order to achieve an interception, they underestimated its TTC by 9 cm. Overall, these results suggest that at low approach speeds children with DCD are perceptually equivalent to their typically developing peers in judging the TTC of an approaching object during a period of occlusion, but are generally less able than their typically developing peers to coordinate self-motion with object motion.

The premotor theory of attention proposed by Rizzolatti et al (e.g. Sheliga, Craighero, Riggio & Rizzolatti, 1997) suggests that the control of goal directed movements and the control of attention are closely linked, to the extent that a direction of attention utilises the same neural networks that are used for motor responses. As such, ocular motor programming is at the basis of spatial attention (Sheliga et al., 1997). All of the experiments reported thus far in this thesis, have assessed the perceptual abilities of different populations in the types of judgments that are typically encountered at the roadside. The final experimental Chapter considers whether the deficits could be explained, particularly in children with DCD, by poorly developed strategies for the allocation of dynamic visual attention and whether this could serve as one explanation for their poorer performance in the tasks presented thus far.

Chapter 9: Dynamic Allocation of Attention in children with Developmental Coordination Disorder

"No one knows what attention is... there may not even be an 'it' to be known about (although of course there might be)"

(Pashler, 1998)

9.1. Introduction

As discussed in the introductory Chapter, traditionally it was believed that the attentional system was modular and specific brain regions were dedicated to attentional control, performing operations independently of other systems (Posner & Petersen, 1990). This would suggest that the perceptual-motor system would not be involved in a task that requires only the shifting of covert attention. However, the premotor theory of attention (Rizzolatti, Riggio, Dascola, & Umilta, 1987) suggests a different model of attentional allocation. According to this theory, shifts of attention are affected through the preparation of an eye movement to a particular location in space. The preparation of a saccade produces a processing advantage for stimuli at the location toward which the motor program is prepared. Covert allocation of attention is the result of an eye movement that is prepared but never executed. Therefore, according to this theory the central arrow in endogenous cueing tasks (Posner & Petersen, 1990) that instructs participants to direct attention to a particular location, is effective because it prompts the preparation of an eye movement even though that movement is never executed.

Wilmut and Wann (2008) aimed to extend research on static cues used by Mon-Williams et al., (2005) to include directional dynamic cues. They recruited participants with DCD aged between 6 to 23 years old and in addition to static cues presented peripherally around the targets and static cues presented centrally indicating peripheral targets, they used predictive motion cues with four possible target locations and predictive motion cues with twelve possible target locations. They found that although individuals with DCD show an atypical hand movement response to partial cues (no facilitatory effect is seen, in line with the findings of Mon-Williams et al, 2005). they show typical eye movement latency in the partial cue condition. If the lack of utilisation of cue information in the partial condition was due to a deficit in the allocation of covert attention then a slowness in both the eye and hand latency would have been seen. It seems that the allocation of covert attention is typical in DCD and it is realisation of an action which is deficient in this population (as demonstrated in Chapter 8). In addition, Estil, Ingvaldsen and Whiting (2002) have shown that children with motor coordination problems show larger temporal and spatial errors when predicting the final location of a moving ball, they suggest that this was due to a visual-spatial anticipation problem whereby more time was needed to appreciate the direction of the ball.

The series of experiments reported in this Chapter aimed to assess whether children with DCD, in simple movement tasks, have poorly developed strategies for the allocation of dynamic visual attention, and whether this could explain some of the perceptual-motor difficulties that characterise DCD.

9.2. Methods

9.2.1. Participants

A total of thirty-one children aged between 6 years and 4 months to 11 years and 7 months participated in this study (see Table 9.1. for participant information). None of the children had any reported history of behavioural or neurological problems that would qualify as exclusion criteria for this study and all children had normal or corrected-to-normal vision. Inclusion criteria for Developmental Coordination Disorder were evaluated in line with DSM-IV. To assess Criterion A and B, which states that deficits in motor coordination should substantially interfere with activities of daily living, teachers were asked to identify children with coordination difficulties that they deemed significantly interfered with their academic achievement, and children without coordination difficulties, using an adapted version of MABC-2 checklist (MABC-2; Henderson et al., 2007). All children were then assessed for motor coordination using the test component of the Movement Assessment Battery for Children (second edition, MABC-2; Henderson et al., 2007). All children in the typically developing (TD) group scored ≥25th percentile indicating typical motor development, children identified as DCD scored ≤ 5th percentile, denoting significant movement difficulties. Children who scored > 5th but ≤ 16th percentile are in a borderline category and for brevity within the text will be referred to as being “at risk” of having movement difficulties. To assess DSM-IV Criteria C and D, thirty children were assessed on the Coloured Progressive Matrices (CPM; Raven, 1956). Twenty-five children (83%) fell at or above intellectually average for their chronological age (between 25th-100th percentile), and five children, one in the TD group and four in the DCD group, all aged 9 to 11 years of age, fell below intellectual capacity for their age (between 5th - 25th percentile). Following a recent systematic review reporting the prevalence rates of ADHD to be between 2-18% (Rowland et al., 2002), teachers were also asked to complete Conners’ Teacher Rating Scale – Revised (Conners, 1997). Completed teacher ratings were returned for twenty-three children, of these three children (one in the TD group and two in the DCD group, all aged 7 to 9 years of age) scored >75% on the ADHD index (mean dimension scores: 47% oppositional; 82% cognitive/inattention; 73% hyperactivity).

In addition, a subset of the Test of Everyday Attention for Children (TEA-Ch; Robertson et al., 1994) was administered to thirty children, to assess three specific types of attention: focused attention; sustained attention; and attentional control. Nine children in the TD group, four children in the at risk group and seven children in the DCD group obtained an overall age scaled score below their chronological age. Correlational analysis between diagnostic measures are discussed in the results section.

Table 9.1. Participant information for each group, information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 percentile range and MABC-2 total test score, Ravens number of children with scores ≥ grade IV, Conners' ADHD index number of children with scores between >75% and <86%, Test of Everyday Attention for Children mean age difference scores (age scaled scores – chronological age), and gender ratio (female to male).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	15	6	10
Mean decimal age	9.01	9.04	9.06
Age range	6.35 – 11.19	7.05 – 11.03	6.68 – 11.67
Mean MABC-2 centile	49	13	3
MABC-2 range	25 – 91	9 – 16	1 - 5
Mean MABC-2 total test score	78	62	48
Ravens (N ≥ grade IV)	1	0	4
Conners' ADHD index (N > 75 % and < 86 %)	1	0	2
Test of Everyday Attention (TEA-Ch) age difference	0.13	-0.54	-2.37
Gender ratio (f:m)	1:4	1:5	2:3

Parental informed consent was obtained for all children in advance of the study, and each child provided verbal assent immediately prior to the start of the experiment. The study was approved by the ethics committee of the Department of Psychology, Royal Holloway, University of London.

9.2.2. Apparatus

Participants were seated in front of a 34 × 27 cm flat monitor display, with an aspect ratio of 1.26 and resolution of 1280 × 1024. All simulations were scripted in Python and used Vizard 3D simulation tools (WorldViz, USA). The Vizard libraries interface with OpenSceneGraph and provide the ability to render highly realistic 3D simulations that are perspective-correct and run at the maximum screen refresh rate (60Hz). The rendering hardware was an Intel® dual core CPU with an NVidia high performance GPU running under Windows XP. An Arrington Research ViewPoint Eye Tracking® system was used to record gaze behaviour and children used a Logitech Force 3D Pro joystick to navigate in all conditions.

9.2.3. Stimuli

All stimuli were viewed binocularly at a distance of 0.5 m. A total of eight conditions were completed, in each condition prior to each trial, a short calibration sequence was completed to ensure the eye tracker was aligned as accurately as possible. This comprised of the child using a joystick to navigate a ball from its start position to collide with a duck positioned to the left of the screen followed by a duck positioned at the centre of the screen and finally a duck positioned to the right of the screen. Unless otherwise specified participants completed 6 trials for each condition. The maximum joystick velocity in both x and y directions was fixed at 1.5m/s and at the end of the calibration sequence the next experimental trial was presented.

9.2.3.1. Condition one: joystick familiarisation

The aim of the first condition was to familiarise all children with the joystick by requiring the child to synchronise their movement with a static visible shape displayed on a screen. The child’s task was to navigate their white ball around a visible green square. The square had a clearly defined end point (yellow cube) and corners (red squares). The child's task was to keep to the green line as closely as possible, colliding with small red squares in each corner, which changed colour on collision and a large yellow target cube, positioned in the furthest corner. At the start of each trial an arrow indicated the direction that the child should navigate their ball around the square. If the arrow indicated that the child should navigate in a clockwise direction, the target cube was always positioned in the top right hand corner of the square, if the arrow indicated that the child should navigate in an anti-clockwise direction, the target cube was always positioned in the bottom right hand corner of the square. At the end of each trial a large green ball was presented in the centre of the screen indicating to the child that trial was complete.

9.2.3.2. Condition two: selective attention without ambiguity

The aim of this condition was to explore the ability of children with DCD to orient attention by assessing their ability to organise their movement when there is no ambiguity in the spatial location of the target. The child's 'ball' started in a fixed initial location on the right hand side of the screen with a yellow rotating cube (the target) positioned in a fixed location on the left hand side of the screen. The child's task was to navigate their ball in the straightest possible line from their initial position to collide with the target cube. At the end of each trial a gender matched avatar appeared clapping, indicating to the child the end of that trial.

9.2.3.3. Condition three: selective attention with ambiguity

The aim of this condition was to assess the ability of children with DCD to organise their movement when some ambiguity in their spatial location and target spatial location was introduced. The basic display set-up was the same as was used in condition two above. The child’s ‘ball’ was randomly positioned in one of four possible initial locations on the right hand side of the screen. In each trial and a yellow rotating cube (the target) was randomly presented in one of six possible locations on the left hand side of the screen. The child’s task was to navigate their ball in the straightest possible line from their initial position to collide with the target cube. At the end of each trial a gender matched avatar appeared clapping, indicating to the child the end of that trial.

9.2.3.4. Condition four: selective attention with distraction

The aim of this condition was to assess the ability of children with DCD to organise their movement to select a target in the presence of non-targets. As in condition 3, the child’s ‘ball’ was randomly positioned in one of four possible initial locations on the right hand side of the screen. Three yellow rotating cubes (possible targets) were positioned on the left hand side of the screen, the distractor cubes rotated in a clockwise direction and the target cube rotated in an anti-clockwise direction. The target cube position was randomly varied. The child’s task was to identify the target cube from non-target cubes and navigate their ball in the straightest possible line from their initial position to the target cube. At the end of each trial a gender matched avatar appeared clapping to indicate the end of that trial.

9.2.3.5. Condition five: executive control modifying an executed movement

The aim of this condition was to assess the ability of children with DCD to modify an executed movement. Children were presented with twelve trials, in each their ball was randomly positioned in one of four possible locations on the right hand side of the screen. Three rotating cubes were positioned on the left hand side of the screen, the distractor cubes were gray in colour and the target cube yellow in colour. The target cube position was randomly varied between the three possible locations. On 50% of the trials, the target cube switched places with one of the distractor cubes when the ball crossed the midpoint of the screen (perturbation trials). The child's task was to navigate to the target cube, changing direction as quickly as possible in the perturbation trials. At the end of each trial a gender matched avatar appeared clapping indicating to the child the end of that trial.

9.2.3.6. Condition six: executive control inhibition of movement

The aim of this condition was to assess the speed at which children with DCD were able to inhibit an already initiated movement. Children were presented with twelve trials which were identical to condition three. On 50% of the trials a 'stop' sign appeared to the right of the yellow target cube and the child had to use the joystick to stop their movement towards the target cube when the ball crossed an invisible trigger point (inhibition trials). Once the x joystick velocity reached near zero a 'go' sign appeared to the left of the target cube and the child continued their path to the target cube. At the end of each trial a gender matched avatar appeared clapping indicating to the child the end of the trial.

9.2.3.7. Condition seven: executive control dual task

The aim of this condition was to assess the ability of children with DCD to select a target cube in the presence of distracter cubes, whilst completing a dual counting task. Children were presented with twelve trials, which were identical to the fourth condition. In this condition however, the child's task was not only to collide with the target cube and avoid non-target cubes, but also count 'boings' which were presented randomly through speakers and interleaved with a continuous stream of audible 'beeps'. There were a minimum of zero and maximum of four boings in any one trial. At the end of each trial a gender matched avatar appeared clapping indicating to the child the end of the trial.

9.2.3.8. Condition eight: executive control inhibition of an executed movement

This condition, similar to condition six aimed to assess the speed at which children with DCD are able to inhibit an already initiated movement in a more naturalistic road crossing scenario. Children were presented with twelve trials using a naturalistic road scene background. A gender matched avatar was positioned on the right kerbside and a non-gender matched avatar positioned on the left kerbside, between them was a two lane road. The child's task was to navigate their gender matched avatar across the road to join the non-gender matched avatar. There were three possible randomly presented trial types: no vehicles present; near-side lane vehicle present; and far-side lane vehicle present. In near-side vehicle trials, the vehicle appeared when the gender matched avatar stepped off the kerbside and the child's task was to stop a quickly as possible and return to the near-side kerb where the non-gender matched avatar was now positioned. In far-side vehicle trials, the vehicle appeared when the gender matched avatar reached the mid-point of the road ($x = 0.5$) and the child's task was to stop a quickly as possible and return to the near side kerb where the non-gender matched avatar was now positioned. At the end of each trial the two avatars appeared clapping indicating to the child the end of that trial. In the no vehicle trials, the children crossed from near-side kerb to far-side kerb without any vehicles approaching to reach the non-gender matched avatar on the far-side kerb, these were included to avoid a vehicle appearing in every trial.

9.2.4. Procedure

The primary measures recorded for conditions were: (1) mean time to target – mean time taken from the start of the trial to reach the target; (2) root mean square error (RMSE) – mean deviation from the actual path taken to the perfect path; (3) heading error – the deviation from the perfect path during initial movement; (4) peak velocity (PV) – the maximum joystick velocity achieved; (5) acceleration time – the time taken to reach PV; (6) time spent looking left - the time spent looking to the left of the centre of the screen; (7) time spent looking right – the time spent looking to the right of the centre of the screen. Reaction time was also measured in conditions six and eight and counting accuracy in condition seven. The RMSE was calculated as the difference between the perfect trajectory from initial start position to target position and the actual trajectory achieved by each child. The heading error was calculated as the difference between the perfect heading trajectory from 0.30 seconds post trial onset to target position and the actual heading trajectory achieved by each child. The first set of analysis looked at relationships between diagnostic measures across the three groups. Due to variability within groups and often equivalent performance of children at risk of DCD, initial analysis for each condition was conducted for each condition between all three groups, followed by an additional analysis between TD children and children with DCD.

9.3. Results

As this chapter is concerned with attention it seems sensible to first consider the relationships between motor skill and attentional diagnostic measures.

9.3.1. Test of Everyday Attention for Children (TEA-CH) overall profile

A one-way ANOVA (group [TD, at risk, DCD]) on TEA-Ch age difference scores revealed a non-significant between group difference (*F*(2,29) = 2.78, *p* = .08). However, an independent samples t-test comparing TEA-Ch age difference scores between TD children and children with DCD revealed a significant difference (*t*(22) = 2.39, *p* = .03) between these groups (see Figure 9.1. for mean TEA-Ch score across groups).

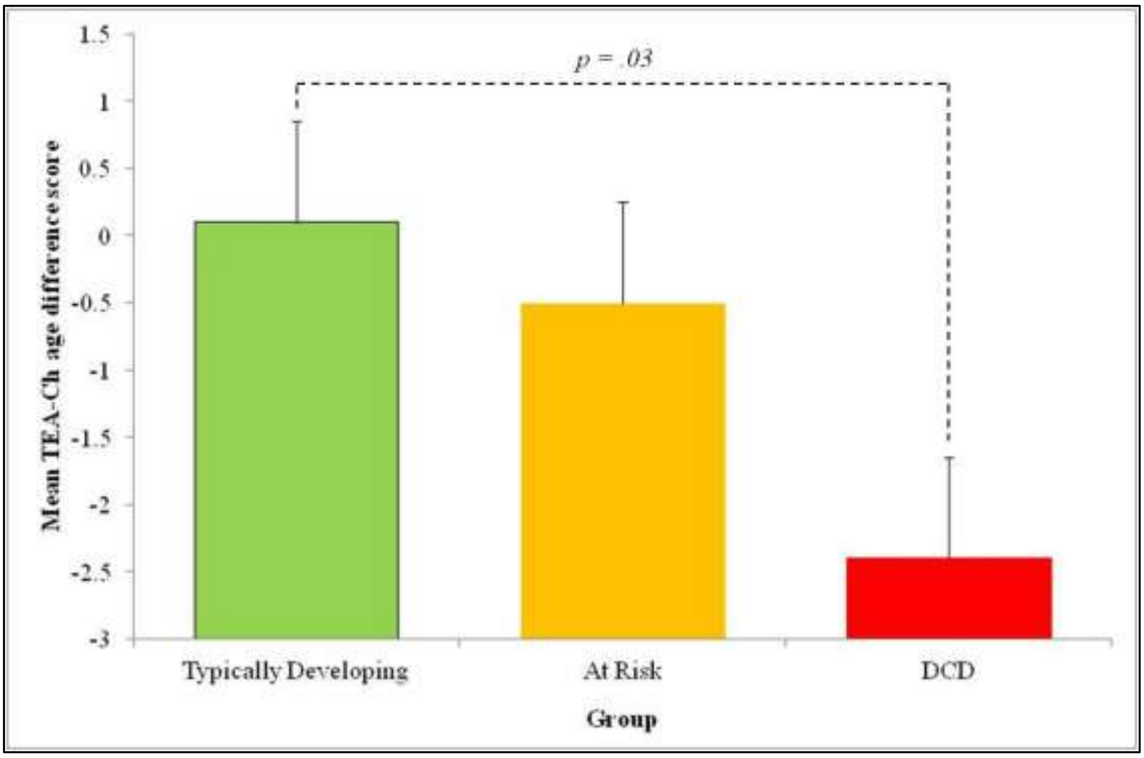

Figure 9.1. Mean TEA-Ch age difference scores for each group, showing a significant difference between TD children and children with DCD.

Using a one-way ANOVA (group [TD, at risk, DCD]) the age difference scores across each of the three TEA-Ch dimensions were compared between groups, no significant between group differences were found, due to the equivalence of the at risk group (Selective attention: *F*(2,30) = .25, *p* = .78; Attentional control/switching: *F*(2,30) = 1.32, *p* = .28; Sustained attention: *F*(2,30) = 2.95, *p* = .07). However, an independent sample t-test comparing age difference scores for each TEA-Ch dimension between TD children and children with DCD revealed a significant difference for the Sustained Attention dimension (*t*(23) = 2.22, *p* = .04), but not for the Selective attention (*t*(23) = .57, *p* = .57) or Attentional Control / Switching (*t*(23) = 1.45, *p* = .16) dimensions (see Figure 9.2. for mean TEA-Ch dimension scores across groups).

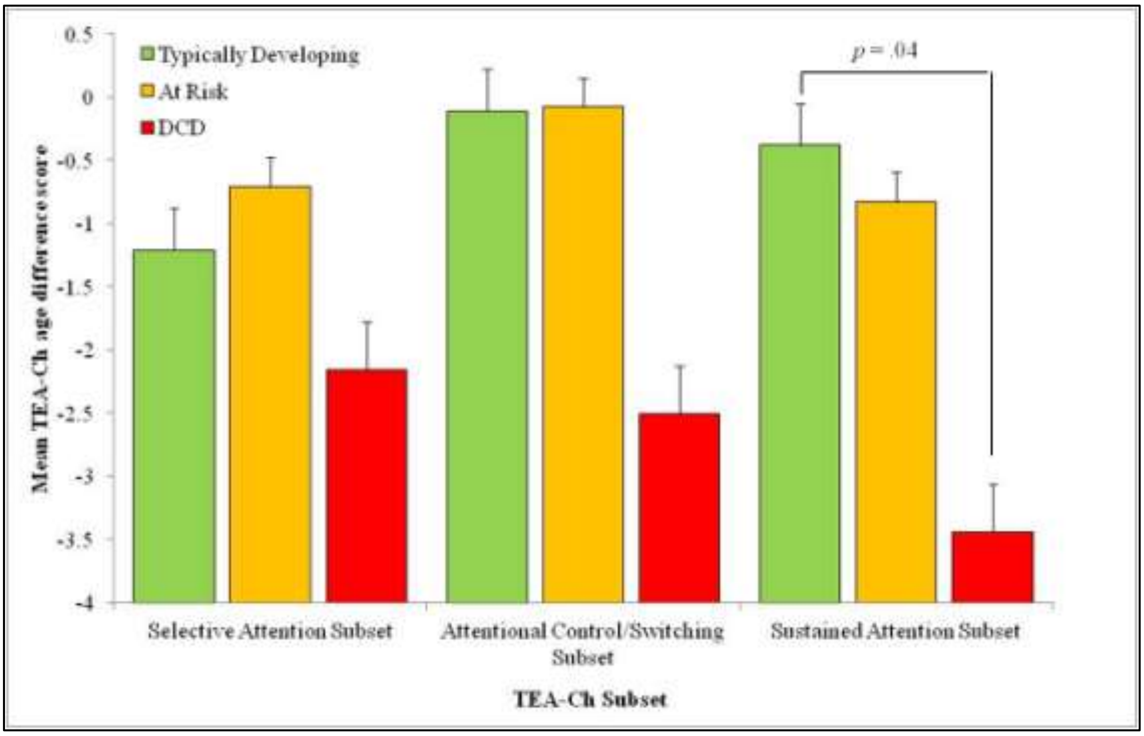

Figure 9.2. Mean TEA-Ch dimension age difference scores for each group, showing a significant difference between TD children and children with DCD in the sustained attention dimension.

9.3.2. Correlation between age difference scores on the Test of Everyday Attention for Children (TEA-Ch) and total test scores on the Movement Assessment Battery for Children (MABC-2)

A Pearson product-moment correlation coefficient was computed to assess the relationship between the TEA-Ch age difference scores and MABC-2 total test scores. There was a significant positive moderate correlation between these two variables, r_p = 0.41, *p* = .03.

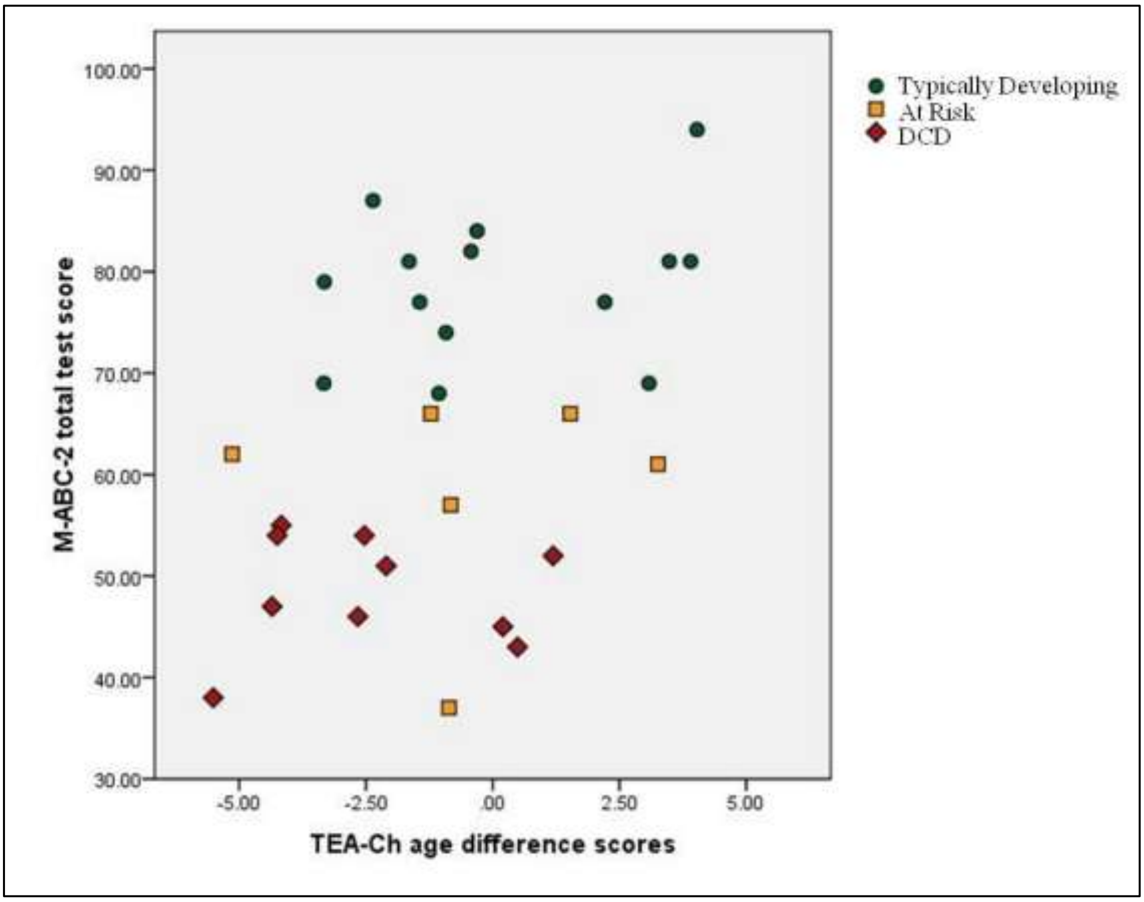

Figure 9.3. Scatter plot showing relationship between TEA-Ch age difference scores and MABC-2 total test scores for each group.

9.3.3. Correlation between age difference scores on the Test of Everyday Attention for Children (TEA-Ch) and total test scores on the Conners' ADHD Index

A Pearson product-moment correlation coefficient was computed to assess the relationship between the TEA-Ch age difference scores and Conners' ADHD index scores. A non-significant weak negative correlation between these two variables was found, $r_p = -.39$, $p = .07$.

9.3.4. Correlation between age difference scores on the Test of Everyday Attention for Children (TEA-Ch) and total test scores on the Raven's CPM

A Pearson product-moment correlation coefficient was computed to assess the relationship between the TEA-Ch age difference scores and Conners' ADHD index scores. A non-significant weak negative correlation between the two variables was found, $r_p = -.13$, $p = .52$. A scatter plot summarizes the results (Figure 9.11.).

9.3.5. Condition One: joystick familiarisation

The aim of the first condition was to familiarise all children with the joystick by presenting a minimum of six trials that required the child to synchronise their movement with a static visible shape displayed on a screen. Mean data for all groups are presented in Table 9.2. A one-way ANOVA, (group [TD, at risk, DCD]) revealed a non-significant main group effect for RMSE ($F(2,30) = 1.14$, $p = .33$); peak velocity ($F(2,30) = 1.41$, $p = .26$); time to target ($F(2,30) = .20$, $p = .82$); the number of times children collided with the edge of the screen ($F(2,30) = 1.19$, $p = .32$); and initial direction error ($F(2,30) = .25$, $p = .78$). Tukey HSD post hoc comparisons confirmed that the differences between TD children, at risk children and children with DCD were non-significant.

Table 9.2. Mean and Standard Deviation (SD) for Condition One for Root Mean Square Error (RMSE; in cm), Peak Velocity (in m/s), Total Time to Target (in sec), Number of Times Edge of Screen was Hit and Initial Direction Error for each group.

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	15	6	10
RMSE (cm)	1.20 (0.28)	1.06 (0.36)	1.30 (0.32)
Peak Velocity (m/s)	1.09 (0.34)	0.87 (0.20)	1.15 (0.36)
Time to Target (sec)	14.03 (4.64)	14.81 (2.53)	13.44 (4.34)
Number Times Hit Edge of Screen	4.00 (2.95)	2.17 (1.94)	4.20 (2.78)
Initial Direction Error	0.40 (0.51)	0.50 (0.55)	0.60 (0.97)

9.3.6. Condition two: selective attention without ambiguity

The aim of this condition was to explore the ability of children with DCD to orient attention by assessing their ability to organise their movement when there is no ambiguity in spatial location. Mean data for all groups are presented in Table 9.3. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant main group effect for RMSE ($F(2,31) = 1.03$, $p = .37$); heading error ($F(2,31) = 1.10$, $p = .35$); peak velocity ($F(2,31) = 2.27$, $p = .12$); and time to target ($F(2,31) = 1.04$, $p = .37$). Eye data for this conditioned revealed that the time spent looking left ($F(2,31) = .15$, $p = .86$), and time spent looking right ($F(2,31) = 1.73$, $p = .20$) were equivalent between groups. Tukey HSD post hoc comparisons confirmed that the differences between TD children, at risk children and children with DCD were non-significant.

Table 9.3. Mean and Standard Deviation (SD) for Condition Two for Root Mean Square Error (RMSE; in cm), Heading Error (in cm), Peak Velocity (in m/s), Total Time to Target (in sec), Time Spent Looking Left (sec) and Time Spent Looking Right (sec).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	16	6	10
RMSE (cm)	11.77 (6.91)	8.32 (3.19)	12.42 (4.79)
Heading Error (cm)	14.08 (11.79)	9.16 (7.95)	19.43 (18.44)
Peak Velocity (m/s)	0.96 (0.22)	0.74 (0.12)	0.91 (0.26)
Time to Target (sec)	2.64 (0.72)	3.13 (1.08)	3.13 (1.23)
Time Spent Looking Left	1.96 (0.72)	1.94 (0.97)	2.19 (1.63)
Time Spent Looking Right	1.34 (0.65)	1.80 (0.62)	1.80 (0.81)

9.3.7. Condition three: selective attention with ambiguity

The aim of this condition was to assess the ability of children with DCD to organise their movement when some ambiguity in their spatial location and target spatial location was introduced. Mean data for all groups are presented in Table 9.4. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for RMSE ($F(2,31) = 1.03$, $p = .37$); heading error ($F(2,31) = 1.10$, $p = .35$); peak velocity ($F(2,31) = 2.27$, $p = .12$); and time to target ($F(2,31) = 1.04$, $p = .37$). Eye data recorded for this condition revealed that the time spent looking left ($F(2,30) = .23$, $p = .80$), and time spent looking right ($F(2,30) = .55$, $p = .58$) were equivalent between groups. Tukey post hoc comparisons confirmed that the differences between TD children, at risk children and children with DCD were non-significant.

Table 9.4. Mean and Standard Deviation (SD) for Condition Three for Root Mean Square Error (RMSE; in cm), Heading Error (in cm), Peak Velocity (in m/s), Total Time to Target (in sec), Time Spent Looking Left (sec) and Time Spent Looking Right (sec).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	16	6	10
RMSE (cm)	13.86 (8.32)	14.27 (4.69)	20.70 (20.84)
Heading Error (cm)	16.94 (14.40)	14.76 (10.96)	18.35 (13.87)
Peak Velocity (m/s)	0.99 (0.24)	1.01 (0.22)	1.08 (0.27)
Time to Target (sec)	2.88 (1.16)	2.71 (1.34)	3.14 (1.54)
Time Spent Looking Left	1.55 (0.74)	1.77 (1.04)	1.73 (0.75)
Time Spent Looking Right	1.72 (0.80)	1.35 (0.82)	1.81 (1.01)

9.3.8. Condition four: selective attention with distraction

The aim of this condition was to assess the ability of children with DCD to organise their movement to select a target in the presence of non-targets. Mean data for all groups are presented in Table 9.5. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for RMSE (*F*(2,31) = 1.99, *p* = .15); heading error (*F*(2,31) = .08, *p* = .92); peak velocity (*F*(2,31) = .40, *p* = .67); number of non-targets collided with (*F*(2,31) = .44, *p* = .65); and time to target (*F*(2,31) = .74, *p* = .49). Eye data recorded for this condition revealed that the time spent looking left (*F*(2,31) = 1.79, *p* = .19), and time spent looking right (*F*(2,31) = .91, *p* = .41) was equivalent across groups. Tukey post hoc comparisons confirmed that the differences between TD children, at risk children and children with DCD were non-significant.

Table 9.5. Mean and Standard Deviation (SD) for Condition Four for Root Mean Square Error (RMSE; in cm), Heading Error (in cm), Peak Velocity (in m/s), Total Time to Target (in sec), Number of Non-targets Collided with, Time Spent Looking Left (sec) and Time Spent Looking Right (sec).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	16	6	10
RMSE (cm)	20.64 (9.09)	22.30 (10.88)	29.59 (14.38)
Heading Error (cm)	24.29 (16.52)	27.16 (16.13)	24.87 (11.14)
Peak Velocity (m/s)	1.05 (0.15)	1.06 (0.18)	1.12 (0.26)
Time to Target (sec)	3.52 (1.35)	4.22 (1.98)	4.01 (0.86)
Number of Non-Targets Collided with	0.69 (0.70)	0.67 (0.82)	1.00 (1.15)
Time Spent Looking Left	1.57 (0.88)	2.74 (2.51)	1.77 (0.80)
Time Spent Looking Right	2.48 (1.55)	3.54 (2.65)	2.86 (0.92)

9.3.9. Condition five: executive control modifying a movement

The aim of this condition was to assess the ability of children to modify an executed movement. Mean data for all groups are presented in Table 9.6. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for peak velocity ($F(2,29) = .60$, $p = .56$); time to target ($F(2,29) = .26$, $p = .77$); number of non-targets collided with ($F(2,29) = 2.37$, $p = .11$); time to adjust movement in the perturbation trials ($F(2,29) = .72$, $p = .50$). Eye data was recorded for this condition and revealed that the time spent looking left ($F(2,29) = .001$, $p = .99$), and time spent looking right ($F(2,29) = .18$, $p = .83$) was equivalent across groups. Tukey HSD post hoc comparisons confirmed that the differences between TD children, at risk children and children with DCD were non-significant.

Table 9.6. Mean and Standard Deviation (SD) for Condition Five for Peak Velocity (m/s), Time to Target (sec), Number of Non-targets Collided with, Time to Adjust Movement after Jump, Time Spent Looking Left (sec) and Time Spent Looking Right (sec).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	15	5	10
Peak Velocity (m/s)	1.19 (0.17)	1.06 (0.25)	1.17 (0.28)
Time to Target (sec)	2.82 (0.66)	2.66 (0.23)	2.93 (0.82)
Number of Non-targets Collided with	1.00 (0.93)	1.60 (1.52)	0.50 (0.53)
Time to Adjust Movement	2.19 (0.46)	1.94 (0.26)	2.13 (0.32)
Time Spent Looking Left	1.42 (0.75)	1.41 (0.79)	1.45 (0.59)
Time Spent Looking Right	1.80 (0.66)	1.67 (0.51)	1.67 (0.53)

9.3.10. Condition six: executive control inhibition of movement

The aim of this condition was to assess the speed at which children with DCD were able to inhibit an already initiated movement. Mean data for all groups are presented in Table 9.7. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for RMSE ($F(2,31) = 1.09$, $p = .35$); heading error ($F(2,31) = .19$, $p = .83$); time to target ($F(2,31) = .11$, $p = .89$); reaction time ($F(2,31) = 2.26$, $p = .12$); time spent looking left ($F(2,30) = .17$, $p = .84$), and time spent looking right ($F(2,30) = .80$, p =

.46). A significant difference was found between groups in peak velocity (*F*(2,31) = 5.34, *p* = .01) with TD children significantly slower than children at risk of DCD. Otherwise, post Tukey post hoc comparisons confirmed that the differences between TD children, at risk children and children with DCD were non-significant. Eye data was recorded for this condition and revealed that the time spent looking left (*F*(2,31) = .09, *p* = .92) and time spent looking right (*F*(2,31) = 2.78, *p* = .08) was equivalent between groups.

Table 9.7. Mean and Standard Deviation (SD) for Condition Six for Root Mean Square Error (RMSE; in cm), Heading Error (in cm), Peak Velocity (in m/s), Total Time to Target (in sec), Reaction Time (sec), Time Spent Looking Left (sec) and Time Spent Looking Right (sec).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	16	6	10
RMSE (cm)	15.44 (5.92)	16.63 (7.69)	20.33 (11.37)
Heading Error (cm)	20.03 (12.45)	18.91 (10.79)	22.86 (16.97)
Peak Velocity (m/s)	0.96 (0.26)	1.34 (0.19)	1.17 (0.28)
Time to Target (sec)	4.02 (1.13)	3.95 (1.21)	3.81 (1.06)
Reaction Time (sec)	0.79 (0.26)	0.73 (0.11)	0.96 (0.28)
Time Spent Looking Left	2.26 (1.01)	2.05 (0.89)	2.35 (0.82)
Time Spent Looking Right	2.34 (0.93)	2.40 (0.66)	1.93 (0.95)

9.3.11. Condition seven executive control dual task

The aim of this condition was to assess the ability of children with DCD to select a target cube in the presence of non-target cubes, whilst completing a dual counting task. Mean data for all groups are presented in Table 9.8. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for RMSE ($F(2,28) = 2.46$, $p = .11$); heading error ($F(2,28) = 1.20$, $p = .32$); peak velocity ($F(2,28) = .86$, $p = .43$); number of non-targets collided with ($F(2,28) = 2.00$, $p = .16$); boing count error ($F(2,28) = 2.16$, $p = .14$); and time to target ($F(2,28) = 2.00$, $p = .16$). Eye data was recorded for this condition and revealed that the time spent looking left ($F(2,28) = 1.28$, $p = .30$), and time spent looking right ($F(2,28) = .32$, $p = .73$) was equivalent between groups. Tukey HSD post hoc comparisons confirmed that the differences between TD children, at risk children and children with DCD were non-significant.

Table 9.8. Mean and Standard Deviation (SD) for Condition Seven for Root Mean Square Error (RMSE; in cm), Heading Error (in cm), Peak Velocity (in m/s), Total Time to Target (in sec), Number of non-targets Collided with, Boing Count Error, Time Spent Looking Left (sec) and Time Spent Looking Right (sec).

	TD Typically Developing	At Risk $> 5^{th}$ but $\leq 16^{th}$ Percentile	DCD $\leq 5^{th}$ Percentile
N	16	4	9
RMSE (cm)	22.40 (9.30)	23.79 (12.75)	33.03 (14.85)
Heading Error (cm)	27.82 (11.92)	37.83 (18.75)	30.15 (6.01)
Peak Velocity (m/s)	1.01 (0.21)	1.05 (0.23)	1.13 (0.24)
Time to Target (sec)	3.74 (0.97)	4.31 (2.35)	5.74 (3.87)
Number of Non-targets Collided with	1.75 (2.29)	1.25 (1.26)	3.56 (2.92)
Boing Count Error	3.25 (6.93)	0.00 (0.82)	14.89 (25.33)
Time Spent Looking Left	2.69 (0.72)	3.16 (1.51)	3.28 (0.98)
Time Spent Looking Right	3.10 (0.68)	3.48 (1.17)	3.15 (1.02)

9.3.12. Condition eight executive control inhibition of a movement

The aim of this condition was to assess the speed at which children with DCD are able to inhibit an already initiated movement using a naturalistic road scene backdrop, that presented looming vehicle stimuli. Mean data for all groups are presented in Table 9.9. A one-way ANOVA (group [TD, at risk, DCD]) revealed a non-significant group effect for peak velocity ($F(2,29) = .53$, $p = .59$); reaction time ($F(2,29) = 2.06$, $p = .15$). Eye data was recorded for this condition and revealed that the time spent looking left ($F(2,29) = 1.68$, $p = .21$); and time spent looking right ($F(2,29) = 1.71$, $p = .20$) was equivalent between groups. Tukey HSD post hoc comparisons confirmed that the differences between TD children, children at risk and children with DCD were non-significant.

Table 9.9. Mean and Standard Deviation (SD) for Condition Eight for Peak Velocity (in m/s), Reaction Time (sec), Time Spent Looking Left (sec) and Time Spent Looking Right (sec).

	TD Typically Developing	At Risk > 5th but ≤ 16th Percentile	DCD ≤ 5th Percentile
N	15	5	10
Peak Velocity (m/s)	1.35 (0.12)	1.26 (0.14)	1.33 (0.22)
Reaction Time (sec)	0.61 (0.16)	0.69 (0.25)	0.75 (0.14)
Time Spent Looking Left	1.97 (0.59)	1.81 (0.67)	2.44 (0.92)
Time Spent Looking Right	1.58 (0.69)	2.23 (0.46)	1.56 (0.69)

9.3.13. Comparison between conditions three and four

Condition three aimed to assess the ability of children with DCD to organise their movement when there was some ambiguity in the spatial location of both the child’s initial starting position and target position, condition four included the same ambiguity but with the additional task complexity of selecting the target in the presence of non-targets, the comparison of the two conditions provides a measure of selective attention. Using independent samples t-tests, comparison between performance measures in condition three and condition four were made for TD children and children with DCD. This revealed that TD children had a significantly greater RMSE in condition four compared to condition three ($t(9) = 2.53$, $p = .03$) whereas children with DCD did not

($t(9) = 1.76$, $p = .11$). However, children with DCD had a significantly greater heading error in condition four than condition three ($t(9) = 3.27$, $p = .01$), whereas TD children did not ($t(9) = 1.80$, $p = .11$). Peak velocity was comparable for both groups between conditions, but children with DCD took significantly longer ($t(9) = 4.80$, $p < .001$) than TD children ($t(9) = 2.10$, $p = .07$) to complete the trial in condition 4, whereas TD children did not.

9.3.14. Comparison between conditions

9.3.14.1. Conditions four and five

Condition four aimed to assess the ability of children with DCD to organise their movement in the presence of non-targets, the fifth condition used a similar display with additional task complexity that involved children modifying an executed movement, thereby providing a controlled estimate of the ability to modify the direction of an ongoing response. Statistically no main effects or interactions involving group were significant.

9.3.14.2. Conditions four and seven

Condition four aimed to assess the ability of children with DCD to organise their movement in the presence of non-targets, condition seven used the same display but with an additional dual task that involved counting random auditory ‘boing’ sounds whilst completing their movement. Statistically no main effects or interactions involving group were significant.

9.3.14.3. Conditions six and eight

Condition six aimed to assess the speed at which children with DCD were able to inhibit an already initiated movement, the aim of condition eight was the same, except in this condition a naturalistic road scene background was used and children inhibited their movement to approaching vehicles instead of a static stop sign. Statistically no main effects or interactions involving group were significant.

9.4. Discussion

From the studies described in the introductory chapter, it would seem that children with DCD have difficulty in responding to cued information and seem to be unwilling to plan movements on early visual information if that information is ambiguous or if it is likely to change. For example, the findings from the Wilmut and Wann (2008) study suggest that individuals with DCD are allocating visual attention in the same way as TD children, but are not using the visual information to forward plan or anticipate a movement. The series of conditions reported in this Chapter aimed to assess whether children with DCD have poorly developed strategies for allocating dynamic visual attention and whether any deficit found could account for some of the perceptual-motor difficulties that characterise DCD.

Exploratory analysis was conducted on diagnostic measures, children with DCD obtained significantly lower age difference scores on the Test of Everyday Attention for Children (TEA-Ch) performing approximately 2.5 years below would be expected for their mean chronological age, compared to their typically developing peers who on average performed as expected for their mean chronological age. When age difference scores were analysed across the three dimensions, it was the sustained attention dimension of the TEA-Ch where children with DCD performed significantly poorer, the tasks in this dimension included ‘Score’; ‘Score Dual Task’ and ‘Walk Don’t Walk’. Given the poorer performance on the ‘Score Dual Task’ TEA-Ch subset it might be expected that children with DCD would vary in their movement kinematics in condition seven where the aim was to assess the ability of children with DCD to select a target cube in the presence of non-target cubes whilst completing a counting task, but in this task they performed equivalently to their TD peers. Arguably, the ‘Walk Don’t Walk’ subset in the TEA-Ch measures inhibition and is in principle comparable to the inhibition trials in condition six, which aimed to measure the speed at which children with DCD are able to inhibit an already executed movement, again there were no kinematic differences in this task. It is interesting that a significant correlation was found between TEA-Ch age difference scores and MABC-2 total test scores, such that lower MABC-2 total test scores were associated with poorer performance on the TEA-Ch, why this might be the case, however, would need further investigation.

The results for condition one, where children were being familiarised with the joystick suggest that children with DCD tended to move faster and were generally less accurate, the statistical comparisons however, suggest that all children were equally able to use the joystick to navigate their ball around the screen. Condition two presented children with a very simple task that required them to navigate the ball from a known starting location to a known target location, the eye data suggest that children with DCD tended to look more at the target (left hand side of the screen) than the other two groups and the kinematic data suggest that children with DCD were generally less accurate, they were statistically equivalent to their TD peers and children at risk of DCD, who performed slightly better on some measures that TD children. Condition three included some ambiguity in the starting location of the child’s ball and the target location, again although statistically equivalent, children with DCD had a noticeably larger RMSE and heading error, reached a faster peak velocity but took longer to reach the target, suggesting they took a more indirect route to the target than the other groups. When presented with a task that required children to locate a target amongst non-targets (condition four), a condition essentially the same as the no cue condition in the Wilmut and Wann (2008) study, children with DCD performed statistically equivalently to the other two groups, but the mean data for RMSE suggest that they were less sure as to where the target was located when they began their movement.

Condition five used a perturbation protocol where children were asked to steer a ball to one of three possible target locations using a joystick. In all cases, target location was indicated at the start of the trial. In the perturbation trials the target jumped to one of two other locations after the child had begun their movement (this only happened on 50% of trials). One might expect that the children with DCD might find the ambiguity of target location more difficult and that this may be reflected in a larger detriment in hand movement kinematics, but this was not the case. The results of Wilson and Maruff (1999) suggest that one difference between TD and DCD is in their ability to inhibit response initiation, condition six, where children were required to inhibit an already initiated movement aimed to assess this. Although children with DCD were 17 ms slower in reacting they were not significantly slower than their TD peers. Condition eight also aimed to assess inhibition but using a naturalistic back drop of a road scene, once again although DCD were 14 ms slower to react to vehicles approaching along the road, they performed statistically equivalently to their TD peers.

The lack of significant differences for these conditions on all measures suggest that children with DCD are equally able to allocate dynamic visual attention in these simple tasks. The equivalence between groups could also be due to the small sample sizes or the small number of trials presented to children (for practical reasons) in some conditions. Additional analysis between the performance of DCD and TD children between conditions aimed to assess whether children with DCD were adopting a different movement kinematic strategy between similar conditions with increased task complexity. Comparisons between condition three that included ambiguity in the initial starting location and target location and condition four which including the same ambiguity and required children to select the target in the presence of non-targets found that when non-targets were present, children with DCD had a significantly larger heading error, suggesting that they were starting their movement without being sure where the target was located, this is supported by their significantly greater trial time in condition four compared to condition three.

Overall, the lack of an atypical response is in itself interesting, although it could be explained by the relatively easy motor task given to these children, but it still does not suggest any deficits in the allocation of attention for action in children with DCD. At this stage, therefore, it could not be suggested that children with DCD have a problem with allocation of attention at the roadside. The previous Chapters, however, have shown perceptual deficits in children with DCD.

Chapter 10: General Discussion and Final Thoughts

The aim of this thesis was to examine the perceptual proficiency of different populations in component roadside skills, in order to assess whether the risk of collision increases as the perceptual sensitivity of the observer decreases. Due to the over representation of younger children in pedestrian road traffic accidents, the focus was mainly on primary school children, but with a particular focus on children with DCD, whose deficits have been attributed to perceptual-motor deficiencies, potentially placing this population at significantly greater risk in the context of executing a road crossing.

This thesis examined five component road crossing skills: the ability to accurately judge the relative approach rates of vehicles, with and without size manipulations; the ability to detect looming vehicles under various viewing conditions; the ability to select appropriate crossing gaps, for both a single vehicle and when presented with a stream of vehicles; the ability to accurately coordinate self-motion with a target that moves across a path with a period of occlusion; and the ability to allocate visual attention in dynamic environments. In general, this thesis has demonstrated that all human observer's have a threshold in their ability to utilise the visual information used to estimate the TTC of approaching objects, for the types of speeds typically encountered at the roadside. Furthermore, this thesis has shown that as the perceptual sensitivity of different populations decrease, the risk of collision increases. There is no evidence that the perceptual sensitivity of human observer's, in this context, can be improved. Therefore, the responsibility lies firmly with drivers to regulate their speed. The overall results of each of these component skills will be considered below.

10.1. Perceptual Errors in Relative Approach Judgments

As a pedestrian or a driver, the ability to differentiate between different rates of approach is critical in determining which vehicle will arrive first and therefore whether there is time to act. Previous evidence has suggested that infants by the age of 20 weeks are able to make accurate judgments as to the arrival times of two approaching objects (e.g. Dannemiller & Freedland, 1991). However, the speeds typically encountered at or on roads are significantly faster than those encountered by infants and the consequences of a mis-judgment significantly more dangerous. According to Lee (1976) the ability to differentiate rate of approach could be based upon detection of the looming rate, or it could be based upon temporal immediacy (tau). If tau is used then rate of expansion is scaled by optical size and therefore, vehicle size should not influence judgments. If, however, observers rely on rate of expansion then a size-bias would be predicted whereby, smaller vehicles with a lower rate of looming could be misperceived as approaching slower than larger vehicles with a greater looming. Using geometric shapes, a number of studies have found that observers utilise tau in relative approach judgments (e.g. Todd, 1981), however, there is also evidence that pictorial depth information of the relative size of approaching objects affect judgments of relative arrival time (e.g. DeLucia, 1991). For the types of speeds typically encountered at the roadside, there is evidence using video animations for the use of tau in judgments of TTC (Seward et al, 2007). There is also evidence, however, that motorcyclists are more at risk on our roads due to their smaller profile, suggesting that observers rely on looming rate that does not scale for optical size (Horswill et al, 2005). Chapters 3 and 4 of this thesis aimed to systematically measure the perceptual thresholds of different populations (adult drivers; children and adult non-drivers; primary school children with DCD) to accurately differentiate the rate of approach of two vehicles, with and without vehicle size manipulations.

A large sample of adult drivers (*n* = 193) from the general population participated in the first experiment. Observers were required to indicate which of two sequentially approaching vehicles (faster car vs. slower car and slower car vs. faster motorcycle) was travelling faster. If performance was perfect then observers would need near to zero speed difference between vehicles in order to accurately judge which was travelling faster. When presented with two vehicles of identical size (faster car vs. slower car) observers needed a 15 mph speed difference between vehicles before they were able to differentiate the rate of approach (one car travelling at 20 mph and the other at 35 mph). This equated to observers differentiating between a 5 second TTC and a 2.79 second TTC. When size manipulations were introduced (slower car vs. faster motorcycle), observers needed a 24 mph speed difference between vehicles before they were able to differentiate the rate of approach (car travelling at 20 mph and the other at 44 mph), equating to a 5 second TTC and 2.25 second TTC. Despite the generally held view, that observers are able to base TTC judgments on tau with great accuracy, these findings suggest that tau was not being used in relative approach rate judgments in this task and that significant perceptual errors occur across a large sample of adult drivers from the general population. This is in agreement with previous research by Hosking and Crassini (2011) who found that looming rate was used to judge the arrival time of familiar and ambiguous spherical objects.

In the second experiment, a large sample (*n* = 168) of non-drivers aged between 6 years to 58 years of age participated in the same experiment, but in this version observers were required to indicate which of the two sequentially approaching vehicles (faster car vs. slower car and faster car vs. slower truck) was travelling faster. Gauging the speed of approaching vehicles has been cited a leading contributing factor to the over-representation of children in pedestrian accidents (Toroyan & Peden, 2007) and this experiment aimed to systematically measure the perceptual acuity of developmental groups in order to assess whether children are equivalently able to utilise optical information in order to make safe road crossing judgments. The results show a clear developmental trend. Children aged 6 to 11 years old were significantly poorer at differentiating the approach speed of two identically sized cars, whereby they were only able to tell that one car was travelling faster than the other when one was travelling at 20 mph and the other at 37 mph, this was twice the speed difference needed by the adult group. When size manipulations were introduced (faster car vs. slower truck), the decrement in the younger age groups equated to 37% reduction in their crossing time, the difference between a 5 second TTC and 1.87 second TTC. These results suggest an over-reliance in children (6 to 17 year olds) on looming rate, which does not scale for optical size. In real world terms this infers that children are more likely to misperceive smaller vehicles as travelling slower, due to their smaller optical size and looming rate.

It has been suggested that children with DCD may have a deficit in motion processing (e.g. Wilmut & Wann, 2008), so one might predict that these children may be more prone to errors in gauging the approach speed of vehicles. Using the same paradigm, the aim was to systematically measure the perceptual thresholds, of primary school aged children with DCD and children at risk of DCD, to differentiate the speed of approach of two vehicles (faster car vs. slower car and faster car vs. slower truck). A significant perceptual deficit was found in children with DCD for both the same size vehicles and when size manipulations were included. When presented with two cars, children with DCD were only able to reliably differentiate between the speed of approach when one was travelling at 20 mph and the other at over 100 mph. Interestingly children at risk of DCD performed equivalently to the typically developing group, suggesting that motion processing impairments are more likely in children with more pronounced motor difficulties.

Overall, the results from this series of experiments suggest that adult drivers make significant errors in judging the approach speed of two vehicles, although if asked they report an optimistic confidence in judging the speed of approaching vehicles. Significantly inflated errors were found in younger age groups and a significant decrement was found in children with DCD. The question that then arises is whether children with DCD, in particular, have reduced sensitivity to looming, a critical skill when estimating the immediacy of approaching vehicles at the roadside. The following section explored this by presenting children with and without DCD with a low level looming detection task.

10.2. Establishing Thresholds for Looming Detection

Lee (1976) has proposed that the retinal expansion of an approaching object (looming) is sufficient to prompt an appropriate behaviour response, without the need to estimate environmental metrics such as distance and velocity. Sensitivity to visual looming stimuli has been documented in infants as young as 22 weeks old (e.g. Kayed et al, 2007), however, the perceptual acuity needs to be around 100 times greater than has been reported in fancy when children reach an age where they are making judgments of high speed objects (Wann et al, 2011). Neural networks specialised for detecting visual looming have been documented in pigeons (Sun & Frost, 1998), locusts (Peron & Gabbiani, 2009) and humans (Billington et al, 2011). For a pedestrian to accurately judge the TTC of an approaching vehicle, the rate of looming needs to above the perceptual threshold of the observer. If the rate of expansion is below the observer’s perceptual threshold, then the vehicle will appear small and stationary in the scene. If the time it takes a pedestrian to cross the width of a road is fixed, then poor acuity (high thresholds) will result in a reduction in the speed at which vehicle approach can be detected. Furthermore, with a fixed crossing time, faster vehicles will loom less as their approach distance increases. Wann et al (2011) measured visual looming in a large sample of children and found a protracted time course for development, whereby younger children cannot reliably detect approaching vehicles that are 5 seconds away if they are travelling at speeds in excess of 30 mph. This suggests that the neural mechanisms that are sensitive to visual looming may not be fully developed during primary school years.

Using the paradigm employed in the Wann et al (2011) study, the first experiment in this section aimed revisit the findings from the larger study, with a group that could be used as a control group for the DCD index group. The results suggest that despite the small methodological differences between the two studies, both produced equivalent results. The ability to detect looming is an essential component in TTC judgments at the roadside, children aged between 6 to 7 years old obtained poorer looming detection thresholds for all conditions compared to the other developmental groups. In foveal vision younger children may misperceive a vehicle as being stationary if it is travelling any faster than 35 mph, if they are not directly fixating on an approaching vehicle the decrement in acuity results in a speed reduction of 14 mph, whereby they may misperceive a vehicle as being stationary if it is travelling any faster than 15 mph. This compares to 44 mph and 30 mph respectively for children aged between 10 to 11 years old.

This methodology was then extended to primary school aged children with DCD (*n* = 11) and a significant deficit was found when vehicles were presented in perifoveal vision. This finding provides the first clear demonstration of low-level motion processing deficits in children with DCD and supports previous suggestions regarding the neural basis of DCD which have included atypical function of the dorsal stream and cerebellum (e.g. Hyde & Wilson, 2011). In applied terms, these results show that even if a vehicle is foveated and the scene is static, children with DCD are more likely to step out in front of a vehicle travelling at speeds greater than 25 mph. This decrement in looming sensitivity seen in children with DCD may suggest an immature dorsal-stream network, an area found to be involved in the processing of looming detection (Billington et al, 2011).

The deficit found in children with DCD to visual looming has serious and applied impact that could place them at considerably more risk at the roadside. The question that then arises is whether children with DCD are more cautious in their road crossing behaviour as a means of compensating for their perceptual limitations. The following section explored this by presenting children with and without DCD with simulated road crossing tasks.

10.3. Selecting Suitable Action Gaps

In order to achieve a safe road crossing, the TTC of an approaching vehicle must be greater than the time required to cross, otherwise collision will occur. In general, previous research has demonstrated that children tend to ignore the approach speed of oncoming vehicles and predominantly use distance to judge the safety of a potential crossing (e.g. Connelly et al., 1998). In the series of experiments presented in Chapter 6, children were presented with a computer generated perspective correct simulation of a road crossing scene, with a single vehicle approaching at four approach speeds (20, 30, 40 and 50 mph) in the near side lane. The task of the child was to decide whether to cross or not. In line with previous research both typically developing children and children with DCD accepted shorter temporal crossing gaps as speed increased, suggesting that children rely on optical size (distance) in making safe road crossing decisions. The developmental results (experiment one) suggest that children accepted sufficient temporal gaps and were basing their judgments on a mixed model based on optic size with some speed compensation in their crossing decisions. The results for children with DCD suggest that they may rely more heavily on optic size (distance) compared to typically developing children but adopted an overly cautious strategy, selecting much larger temporal and distance gaps than would be necessary for them to execute a safe road crossing, based on their recorded walking speeds. In applied terms, although this overly cautious strategy is reassuring, the inter-vehicle temporal gaps recorded at the roadside suggest that children with DCD would either be standing at the roadside for a long time or would be forced into making a crossing decision when they may be unsure if it is safe to cross or not.

The second paradigm (Chapter 7) assessed the temporal gap thresholds of typically developing children and children with DCD, as well as children with reported motor difficulties combined with more general developmental delays, using a virtual reality environment. In this series of experiments, multiple vehicles approached at three speeds (20, 30 and 40 mph) from either the near-side lane, or bidirectionally from both near and far-side lanes. If the findings from the previous paradigm were due to children with DCD rejecting suitable crossing gaps if they judged a car as approaching from any distance this paradigm, where children were asked to judge if they would cross in between vehicles, controlled for that possibility. The results showed that all children accepted inter-vehicle temporal crossing gaps that if translated to the roadside would result in collision. It could be argued that observers may be less cautious in a virtual environment compared to a real environment, where the consequences of accepting or rejecting crossing gaps for example differ. However, as discussed in the Introductory Chapter, there is a growing body of research that has demonstrated the transferability from virtual environment to real environments (e.g. Schwebel et al, 2008). It is not surprising therefore, that the use of virtual reality technology is being used more and more in research around the world and has huge potential for training and rehabilitation (e.g. Katz et al, 2005). In the case of road crossing or driving, it offers a unique potential to examine complex concepts by creating highly controlled yet realistic scenarios, without any risk to the participant. Some additional benefits include: an active rather than passive experience; an immersive experience minimising distractions and immediate engagement.

10.4. Intercepting Moving Targets

The finding that children with DCD perform equivalently to typically developing children in allocating attention for action reinforces the conclusions of previous chapters, that children with DCD may have a low-level motion processing deficit. The final experimental chapter used a predictive motion task to explore whether children with DCD are able to accurately coordinate their movement with a target that moves across their path to intercept it, during a period of occlusion. The findings suggest that, unlike the findings in Chapter 6, where children with DCD consistently overestimated the TTC of the approach car, when children with DCD were required to coordinate self-motion with object-motion in order to achieve an interception, they underestimated the TTC by 9 cm.

One explanation for the findings reported so far, could be a difference in DCD in how vision is dynamically allocated to facilitate the preparation of goal-directed actions. The following section aimed to assess whether children with DCD have poorly developed strategies for the allocation of dynamic visual attention that could explain some of their perceptual-motor difficulties.

10.5. Dynamic Allocation of Attention in children with Developmental Coordination Disorder

Previous research has suggested that children are at greater risk at the roadside due to attentional lapses rather than perceptual or timing errors (Demetre et al, 1992). As a pedestrian at the roadside, an environment that is unpredictable and dynamic, the ability to allocate visual attention to salient information and modify or inhibit an already executed movement (road crossing) is critical. Given previous findings that have suggested that children with DCD do not use visual information to anticipate movement (e.g. Wilmut & Wann, 2008), a series of conditions that varied in complexity were designed in Chapter 8, to assess whether children with DCD have poorly developed strategies for the allocation of dynamic visual attention. Initial analysis found that children with DCD performed significantly below what would be expected for their chronological age on a standardised battery of attention, further analysis revealed that they performed significantly poorer on the sustained attention component. Overall there were very few significant differences in any of the conditions on any measure, suggesting that children with DCD were equally able to allocate dynamic visual attention in a series of conditions that required simple kinematic responses to simple stimuli.

10.6. Variability Within and Between Groups

Previous research into children with DCD has suggested that it may not be a uniform disorder (e.g. Visser, 2003). The results reported in this thesis emphasis the variability often reported within DCD groups. For example, Figure 4.1 (p.98) illustrates how 44% of children with DCD were able to discriminate the approach rates of two cars with errors within the 95% confidence interval for their typically developing peers (speed difference <60mph), whereas 33% needed a speed difference >120mph to make this judgment. The heterogeneous nature of DCD is now widely accepted within the research community, both in terms of children presenting with different areas of deficit within the same disorder and in the range of deficits each child might present with. The issue of heterogeneity and comorbidity is compounded by inconsistencies in the diagnostic criteria employed by the DCD research community. The lack of any significant differences reported in this thesis between children considered at risk of developing movement difficulties, scoring between the fifth and fifteenth percentile on the MABC-2 and children scoring above the twenty-fifth percentile on the MABC-2 re-emphasises the need to carefully consider the classification of DCD groups within research thoroughly. Group variability is a common underlying finding in all DCD research and suggests that ultimately the emphasis should be on considering the individual performance of each child with DCD.

10.7. Future Directions

10.7.1. Public Engagement

In the UK alone there are over 6,500 pedestrian casualties per annum, of which 30% are children aged 0 to 15 years old (DfT, 2010). Globally, road traffic accidents are the third leading cause of death for 5 to 9 year olds, with children’s visual limitations in judging speed and distance cited as a contributory factor (Toroyan & Peden, 2007). At the other end of the age range, the incidence of mis-judgments at junctions increases significantly for drivers over the age of 70 years and this population is predicted to double in the next 20 years. Public safety messages can be effective, but on an individual level they are often mediated by a drivers "optimistic bias" and their own perceived capability. In short the majority of drivers, when asked, feel they are significantly better/safer than the average driver, which logically cannot be the case. Funding has been obtained from the ESRC to modify the existing "virtual reality" perceptual tests making them suitable for use as online "test-games", that after completion show not only the individual drivers results but the pattern that occurs across the age range (6 years of age to 80 years of age).

10.7.2. Assessing Motion Processing in DCD

It has been proposed that some of the findings reported in DCD, could be due to dorsal stream vulnerability. The dorsal stream radiates from the occipital lobe to the parietal lobe, and has two distinct functional characteristics, spatial awareness and the guidance of actions. The ventral stream stretches from the occipital lobe to the temporal lobe and is associated with object recognition and form representation (Milner & Goodale, 1995). It has been suggested that tests of form coherence assess ventral stream function (Braddick et al, 2000), while tests of motion coherence assess dorsal stream function (Scase et al, 1996). Atkinson and colleagues have found that both ventral and dorsal stream functions mature during the early school years (Atkinson et al, 2003). Studies using form and motion coherence tests in children with DCD, however, have yielded contrasting results. Sigmundsson, Hansen, and Talcott (2003) found that "clumsy" children were less sensitive in the detection of both global visual motion and form, whereas Wilmut and Wann (2008) found no evidence for this despite children with

DCD having impaired performance on their motion cued action tasks. Nevertheless, it is necessary to assess participants with DCD on measures that truly tap into ventral and dorsal stream processing , in order to establish whether this population exhibit a dorsal stream deficit, as found in other developmental disorders, for example Williams syndrome (Atkinson et al, 1997).

10.7.3.Assessing Dynamic Visual Attention in DCD

The disproportionately high number of child pedestrian accidents could be attributed to children not appreciating the potential risks, or not following safe road crossing procedures, although in the UK both of these factors are strongly promoted and tend to be instilled from a young age. It has also been suggested that attentional lapses rather than perceptual skills could explain children’s mis-judgments about gaps in traffic (Demetre et al, 1992). Dunbar, Hill and Lewis (2001) identified concentration and attentional switching as useful pedestrian skills. Although performance in their frog game may relate to roadside skills, it is not clear that there is a direct equivalence to the type of attentional search and detection that is required at the roadside. A break down of some of the attentional skills is required to measure components such as visual motion “pop-out” in complex scenes and attentional switching that explicitly addresses the issue of attentonal disengagement from distractors in the scene, using highly realistic simulated road scenes.

In addition, Wilmut, Brown and Wann (2007) used the gap/overlap attentional paradigm (Saslow, 1967) and found reaction time and accuracy deficits in children with DCD aged 7 years that could be explained as an interference between attentional processes and motor system, they suggest that DCD have a deficit in allocating attention for action at the level of execution. Although informative, these tasks were not designed to assess the allocation of dynamic attention in naturalistic complex contexts, and although useful in explaining some aspects of how visual perception is affected in DCD, are unable to tell us anything about the role of dynamic visual attention in the types if tasks that are performed on a day-to-day basis, specifically road crossing.

10.8. Closing Comments

The findings presented in this thesis suggest that observers from the general population make significant errors in judging the approach rates of two vehicles, and these errors are inflated in younger children and significantly poorer in children with DCD, placing them at more risk at the roadside. Children with DCD have significantly reduced sensitivity to looming visual stimuli, suggesting an immaturity in the dorsal stream network and explain some of the difficulties that characterise DCD. The crossing gaps that children with DCD accepted were considerably larger than they would need in order to execute a safe road crossing, but inter-vehicle crossing gaps that typically developing children, children with DCD and children with comorbid motor difficulties accepted were shorter than the time it would take them to cross. These results cannot be explained by a deficit in the allocation of visual attention for action.

As a closing comment, in the UK there is a 20 mph speed limit in force outside some schools, but this often only extends for about 100 meters around the school. In many cases schools have been unable to get such a zone implemented. Current UK government advice (DfT, 2005) suggests that only a zone > 500 meters would have the desired effect of significantly reducing traffic speed and they recommend that a 20 mph limit should be imposed over an area consisting of several roads close to a school, but there are very few instances of this being adopted by local authorities. As a result children often need to cross roads that are not regulated at 20 mph. The data on speed judgments reinforce the UK government recommendation that a 20 mph limit should be imposed over an area consisting of several roads close to a school.

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