Running head: The Use of Visually Guided Behaviour in Children with Developmental Coordination Disorder (DCD) when Crossing a Virtual Road

The Use of Visually Guided Behaviour in Children with Developmental Coordination Disorder (DCD) when Crossing a Virtual Road

Catherine Purcell[1], Kate Wilmut[2] and John P. Wann[3]

[1] School of Psychology, Early Years, Education and Therapeutic Studies, University of South Wales, Pontypridd, Treforest, CF37 1DL

[2] Department of Psychology, Social Work and Public Health, Oxford Brookes University, Gipsy Lane, Oxford, OX3 0BP

[3] Department of Psychology, Royal Holloway, University of London, Egham, TW20 0EX

Correspondence concerning this article should be addressed to Dr Catherine Purcell, at University of South Wales, Ferndale Building, Pontypridd, Treforest, Rhondda Cynon Taff CF37 1DL, United Kingdom. Tel: +44 (0)1633 432330 Email: Catherine.purcell@southwales.ac.uk.

Research Highlights

- Primary school children rely predominantly on the optical size (distance) of a vehicle
- Relying on optic size would result in potential collision with vehicles approaching at 40 mph
- Children with DCD may accept insufficient temporal gaps on roads with speed limits of 30 mph

Abstract

The ability to safely cross a road is a perceptual-motor skill that involves coordination between a pedestrian's perception of the approaching vehicles and their locomotive capability to execute the road crossing action. Developmental Coordination Disorder (DCD) is a chronic disorder that is characterised by significant motor difficulties that impact on daily living, including a reduced ability to perform visually guided actions. A total of 25 typically developing primary school aged children and 25 age- and gender-matched children with DCD were presented with a virtual desktop task that required them to select suitable temporal crossing gaps between vehicles a stream of traffic approaching at either 20 mph, 30 mph or 40 mph from the near-side (one-lane) or both near+far-sides (two-lane). A best-PEST staircase procedure was used to measure the temporal gaps that children accepted and the maximum likelihood value was taken after nine reversals as each participant's threshold. Typically developing children accepted temporal gaps that were sufficient to execute a safe crossing for vehicles approaching at 20 mph and 30 mph, but insufficient for vehicles approaching at 40 mph. In contrast, children with DCD selected insufficient temporal crossing gaps across all approach speeds, which if translated to the roadside would have resulted in collision. These findings add to our understanding of the difficulties that children with DCD appear to have with visually guided behaviour and suggest the potential impact on one aspect of daily functioning that could have significant consequences.

1. Introduction

Almost all animals that possess spatial vision exhibit avoidance responses to an object approaching on a direct collision course. Collision avoidance is crucial to an animal's survival and an appealing account of how humans and animals make judgments of impending collision has come from Lee (1976), who proposed that the retinal expansion of an approaching object is sufficient to prompt an appropriate behavioural response. His early work demonstrated that the time-to-passage[1] (TTP) 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 $\dot{\theta}(t)$:

$$TTP = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} = tau$$

The theoretical appeal of this ratio, which Lee (1976) termed tau, is that the information necessary for TTP judgments are perceptually available without the need for higher order computations. Furthermore, the ecological perspective proposes that the environment offers the observer opportunities for behaviour which are directly related to the observer's action capabilities (theory of affordances; Gibson, 1979). Therefore, to safely and efficiently navigate through complex and dynamic environments, observers must choose actions and control their movement in a way that takes into account their locomotor capabilities (Fajen & Matthis, 2011). For example, when catching a ball perception-action coupling requires the observer to extrapolate environmental information relating to the ball's perceptual invariants (spatial and

---

[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 paper describes approaching objects that pass the observer, the term time-to-passage will be used.

temporal properties of the ball's arrival) in order to time and control the catching action (van der Meer, van der Weel, Lee, Laing & Lin, 1995). Of course, the consequence of errors in perception-action coupling in the context of catching a ball carries a relatively low risk of fatality, this is not the case however in the context of road crossing.

In a road crossing situation, TTP must be judged in order to determine when an approaching vehicle will reach the observer; this informs the time available to cross 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. It is of course 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 when the decision to cross the road is made. Onelcin and Alver (2015) demonstrated that participants began crossing when the vehicle was beyond 75 m when the vehicle speed was above 30 km/h. The identification of safe gaps between passing cars when crossing a road is a task most of us accomplish successfully on a daily basis however, the ability to safely cross a road is a complex perception-action coupling task that contains two critical components: 1) selecting a gap in a stream of traffic that affords crossing and 2) coordinating movement through this gap. This requires the determination of the TTP with the planned crossing trajectory and assessment of whether this TTP exceeds the time required to cross the road, taking into account one's own locomotive speed. If a pedestrian over-estimates the gap size or under-estimates 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.

Decisions regarding when to cross the road are usually made by adults with children accompanying them (Van der Molen, Van den Herik, & Van der Klaauw, 1983) however children's vulnerability at the roadside is highlighted by British accident statistics, which report that 27% of all pedestrians killed and seriously injured are children up to 15 years (Department for Transport, 2014). Various studies have investigated the developmental trajectory of perception-action coupling in the context of road crossing and overall the findings suggest that younger participants accept smaller temporal gaps compared to older participants which has been attributed to variations in TTP estimates (Petzoldt, 2014). For example, Plumert and colleagues (2007) examined children's road crossing skills using a real-time bicycling simulator and 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. Plumert et al., (2011, 2014) argue that perception-action skills undergo a prolonged period of development when the task involves integrating self-motion with object motion. A consistent finding across methodologies is that younger children show a limitation in selecting appropriate gaps in traffic. For example, Velde, van der Kamp and Savelsbergh (2008) recruited 5 to 12 year old children and adults and presented them with a small-scale road. The task was to push a doll between two toy vehicles, which approached one after another. They found that younger children (5 to 7 year olds) 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, these 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.

Using a different approach, Simpson, Johnston and Richardson (2003) designed a virtual environment to investigate the temporal gaps that 5 to 19 year old individuals accepted. There were two different types of trials: uniform speed, where all vehicles in the traffic flow had the same speed, and uniform distance trials, where all vehicles in the traffic flow were separated by the same distance. 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 and adolescents used distance as a guide to safe crossing gaps and did not take speed fully into account; this is consistent with previous 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 is supported by previous research which has found that pedestrians who spend more time waiting to cross from the curb 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 curb (Hamed, 2001). This has also been supported by more recent evidence that indicated that, at all ages, pedestrians experience greater exposure to traffic dangers when they cross under time pressure (Morrongiello, Corbett, Switzer & Hall, 2015).

Studies on children’s perceptual judgments at the roadside, such as those mentioned above, have largely focussed on typically developing children, and less so on children demonstrating atypical development. Clancy, Rucklidge and Owen (2006) examined road safety in children with Attention Deficit Hyperactivity Disorder (ADHD). They predicted that participants with ADHD would leave shorter safety margins than the 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, due to the observation that distance information is typically used rather than speed by younger pedestrians. They found that participants with ADHD have poorer perceptual abilities, not explainable by impulsivity alone, in judging the TTP of oncoming vehicles, and tended to focus on distance in anticipating the relative arrival times more than their typically developing peers. This finding is supported by Stavrinos and colleagues (2011) who found that children (aged 7 to 10 years) with ADHD combined type failed to process perceived information adequately to enable safe crossings. In addition, Xiang and colleagues (2006) found that children with a range of physical, mental, sensory or self-care disorders were more likely than their typically developing peers to have experienced a pedestrian injury.

In the absence of visual impairments or neurological abnormalities, children with pronounced atypical development of motor function may be classified as having Developmental Coordination Disorder (DCD). This condition can be described as a chronic disorder which impacts on activities of daily living where the acquisition and execution of motor skills is substantially below that expected given the individual’s age and opportunity for learning (American Psychiatric Association, 2013). 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 (American Psychiatric Association, 2013). DCD is a common disorder, and although varying prevalence rates have been cited, largely as a result of the definition used and the tools chosen to assess the child, a UK-based large population study recently showed a prevalence of 1.7% in 7–8-year-old children (Lingam, Hunt, Golding, Jongmans, & Emod, 2009). One of the characteristics of DCD is a reduced ability to adjust visually guided behaviour in response to sudden changes in object position, reflecting abnormal patterns of on-line control (Hyde & Wilson, 2011). An inability to make quick on-line adjustments at the roadside could place children with DCD at more risk.

In a previous study (Purcell, Wann, Wilmut, & Poulter, 2011), we presented primary school aged typically developing children and children with DCD a perspective-correct road scene image, with a single car approaching in the near-side lane and found that children with DCD selected significantly larger temporal and distance gaps compared to their typically developing (TD) peers. Furthermore, taking into account locomotive speed and a safety margin of 1.5 seconds (criterion set on the basis of Simpson et al., 2003), to allow for unexpected changes in the behaviour of an individual (e.g. tripping) or in the approaching vehicle (e.g. accelerating), 89% of children with DCD missed safe 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 at any speed or from any distance. At face value this appears reassuring. However, a single vehicle approaching from only the near-side, is one of the simplest scenarios faced by a pedestrian and our previous study did not assess the ability of children with and without DCD to determine suitable crossing gaps in an environment where multiple vehicles are approaching from either the near-side or both near+far-sides. The current study is the first to systematically measure the temporal gaps that children with DCD accept when undertaking a virtual desktop task that requires them to select safe crossing gaps between vehicles in a stream of traffic. Previous research has found that an increase in traffic flow reduces the gap size that pedestrians accept (Lobjois, Benguigui & Cavallo, 2013) therefore, when faced with a more realistic scenario of a constant stream of vehicles and forced to make a safe crossing judgment between vehicles it is possible that rather than selecting overly cautious crossing gaps, children with DCD would accept insufficient temporal gaps. To test this hypothesis we presented children with a novel task which involved a constant stream of vehicles either approaching from the near-side (one-lane) or the near+far-side (two-lane) and children were asked to select sufficient crossing gaps between vehicles. If children use rate of looming in addition to optic size, this gives them access to an estimate of TTP, in which case the temporal gaps accepted would not vary with approach speed; however, if children rely predominantly on just optic size, the time gaps accepted would be an inverse function of approach speed.

2. Methods

2.2.1. Participants

A total of fifty participants took part in this study: twenty-five typically developing (TD) children aged between 6 to 11 years and twenty-five participants with significant motor difficulties aged between 6 to 11 years (see Table 2.1. for group information). Children were recruited from a local primary school, and screened in accordance with DSM-5 guidelines (American Psychiatric Association, 2013). To assess DSM-5 Criteria A and B, teachers were initially asked to identify children who they had identified as having motor difficulties that interfered with school activities and those who did not, 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 ≥ 25th percentile, indicating typical motor development; children identified as DCD scored ≤ 16th percentile, denoting movement difficulties. Criterion A of the DSM-5 does not indicate a cut-off point quantifying how much a child’s performance should deviate from the norm in order to be considered ‘substantially below’ that expected for age. The European Academy for Childhood Disabilities (EACD) recently published a consensus statement suggesting that the 15th percentile should be used as a cut-off for identifying DCD (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012) and a similar approach is retained in the UK adaptation of these guidelines (Barnett, Hill, Kirby & Sugden, 2014).

To assess DSM-5 Criterion D, the majority[2] of children (*n* = 36; TD 18 and DCD 18) were assessed on the Coloured Progressive Matrices (CPM; Raven, 1956). Twenty-six children (86%) fell at or above intellectually average for their chronological age (between 25th - 100th percentile), and one TD child and four children with DCD (16%) fell below intellectual capacity for their age (between 10th - 25th percentile). The data for these five children for all tasks were looked at individually and were not found to be significantly different from the group means and so were included in the final sample. Teachers did not report any known neurological condition or difficulties with attention that might affect movement or concentration on the task and all children were in mainstream primary schools suggesting no early onset of difficulties in accordance with Criterion C.

-Insert Table 2.1 about here-

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

---

[2] Due to school timetables and limited time with each child in the school environment, it wasn’t possible to run the Coloured Progressive Matrices with all participants. However, all children were recruited from mainstream schools and none of the children were receiving any additional support in school, suggesting that none of the children had any cognitive impairments.

approved by the ethics committee of University of South Wales (formerly the University of Wales, Newport).

2.2.2. 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.

2.2.3. Stimuli

In all conditions, a virtual road which consisted of a straight flat section of road within a virtual city was presented to all children. The road was marked with a continuous white line nearest the viewpoint and a pavement (sidewalk) was visible furthest from the viewpoint. There were dashed white centre lines that divided the road into two 3.5m wide lanes. 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; children were seated in front of the heading viewpoint. At the start of each trial, the heading viewpoint simulated a road crossing at 0.93 m/s to demonstrate the approximate time that it would take the child to execute a road crossing at a normal walking pace (7.5 seconds; Purcell, Wann, Wilmut & Poulter, 2011). Vehicles were represented as blocks, sized to be equivalent to a typical car found on UK roads (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 six road crossing conditions. In three conditions they encountered six vehicles approaching in succession in the near-side lane (one-lane condition) at either 20 mph, 30 mph or 40 mph and in the other three 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 (see Figure 2.1. for example of experimental set up).

-Insert Figure 2.1 about here-

At the end of the experimental session, each child walked a distance equivalent to the width of one-lane of road (3.5 m) at two walking paces (preferred pace and as fast as possible). This was used to estimate a walking time for each child in order to compare the time it would have taken them to cross the virtual road to their gap acceptance thresholds. Each child completed four trials at each walking pace from which their average crossing time was obtained. It is possible that children based their judgments on the simulated crossing time of 0.93 m/s and this is considered in the results.

2.2.4. Psychophysical Procedure

In both near-side and near+far-side conditions, the child’s task was to verbally indicate whether they would ‘cross the road’ or ‘not cross the road’ between the traffic stream. 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. If a child indicated they would accept the available temporal gap the PEST would select the next smallest temporal gap in the range for the next trial, if however the child indicated that they would not accept the available temporal gap, the PEST would select the next largest temporal gap in the range for the next trial. The maximum TTP 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 TTP 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 temporal gap acceptance threshold.

2.3. Results

2.3.1. Temporal Gap Acceptance Thresholds

Mean temporal data for all approach speeds and groups are presented in Figure 2.2 for all conditions.

A three-way mixed ANOVA [TD and DCD], lane [one-lane and two-lane] and vehicle approach speed [20mph, 30mph and 40mph] was used to compare gap acceptance thresholds. All effects are reported as significant at $p < .05$. There was a significant main effect of the vehicle approach speed on gap acceptance thresholds, $F(2,96) = 30.51$, $p < .001$, $n_p^2 = .39$. A weak trend was found between conditions ($F(1,48) = 2.417$, $p < .127$, $n_p^2 = .05$) suggesting participants left longer temporal gaps for the two lane condition compared to the one lane condition. Repeated linear contrasts using Bonferroni multiple comparison adjustments revealed that temporal gap acceptance thresholds for the vehicles approaching at 20mph were significantly longer compared to the vehicles approaching at 30mph ($F(1,48) = 33.92$, $p < .001$, $n_p^2 = .41$) and significantly shorter for vehicles approaching at 40mph compared to 30mph $F(1,48) = 5.39$, $p = .03$, $n_p^2 = .10$. A significant main effect of group on gap acceptance thresholds was also found $F(1,48) = 8.85$, $p = .005$, $n_p^2 = .16$ whereby children with DCD left significantly shorter temporal gaps than their typically developing peers. There were no significant interactions.

-Insert Figure 2.2 about here-

2.3.2. Sufficiency of Temporal Gaps

An independent samples t-test between groups [TD and DCD] comparing walking times was conducted. The results showed a significant difference in walking times between groups in the preferred walking condition ($t(46) = -2.01, p = .05$), with children with DCD walking significant slower than their TD peers. The interesting question is whether the temporal gaps between cars accepted by each individual child allowed them to cross the road safely given their individual walking times. To assess whether children were accepting sufficient temporal gaps, the difference between the gap acceptance thresholds and their crossing time (based on their preferred walking pace) was calculated, such that a score of zero would indicate just enough time to cross, a negative difference would indicate that the crossing would result in collision and a positive difference would indicate that sufficient time was left to cross (please see Figure 2.3).

-Insert Figure 2.3 about here-

A series of one sample t-tests were conducted against a test value of zero seconds indicating just enough time to cross. A value of zero therefore, should be considered a near miss and with the recommended margin for error is 1.5 seconds (criterion set on the basis of Simpson et al, 2003) any values below zero would indicate collision. For the typically developing group there were no significant differences in the sufficiency of their temporal gaps for any of the conditions that were below zero. There were two significant differences in the sufficiency of their temporal gaps that were above zero for the 20mph one-lane $t(23) = 2.86$, $p = .009$ condition and two-lane 20mph $t(23) = 2.51$, $p = .02$ condition, whereby they were leaving significantly longer temporal gaps compared to zero. For the DCD group, the sufficiency of their temporal gaps for all conditions were significantly below zero (20mph one-lane $t(22) = -2.68$, $p = .014$ condition; 30mph one-lane $t(22) = -3.60$, $p = .002$ condition; 40mph one-lane $t(22) = -5.19$, $p < .001$ condition; 30mph two-lane $t(22) = -3.79$, $p = .001$ condition and 40mph two-lane $t(22) = -4.35$, $p < .001$ condition) except the 20mph two-lane condition.

It is possible that participants based their required crossing time on the simulated crossing presented at the beginning of each condition (7.5 seconds). A series of one sample t-tests against the value of 7.5 seconds were conducted to explore this possibility. For typically developing children, the temporal gaps accepted were not significantly different to 7.5 seconds except in the 40mph two-lane condition ($t(24) = -3.382$, $p = .002$) suggesting at lower approach speeds they may have been basing their judgments on the simulated walking speed. However, for the children with DCD the temporal gaps accepted for all conditions were significantly less than the simulated walking time of 7.5 seconds, suggesting that they were not using this to aid their crossing judgments.

2.4. Discussion

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. In applied terms, these results demonstrate that the strategy used by TD children would result in collision for vehicles approaching at 40mph and at any speed above 20mph for children with DCD. This is further compounded by the knowledge that as vehicle speed increases, crashes result in more serious injury with the average risk of death increasing from 25% to 75% with a 15 mph increase in impact speed (Tefft, 2012). It could be suggested that primary school aged children are less likely to have experience of crossing roads where the speed limit is above 30 mph, which coincides with urban speed limits. The results from this study suggest that the majority of TD children may accept sufficient temporal gaps for speeds up to 30 mph and as such these results may reflect their experiences at the roadside, this is in stark contrast to age and gender matched children with DCD who may be more likely to accept insufficient temporal gaps on roads with speed limits that they are likely to be exposed to in urban areas.

Based on a conservative estimate of 1% prevalence, children with DCD represent approximately 43,000 primary school aged children in England (Department for Education, 2013). Children with DCD typically have difficulty with fine and/or gross motor skills, with motor performance that is usually slower, less accurate, and more variable than that of their typically developing peers (Zwicker, et al., 2012). Although the etiology of DCD is largely unknown, it has been hypothesized that children with DCD demonstrate a mismatch between sensory input and motor output (Zwicker, et al., 2012). The findings from the current study support this view by demonstrating a deficit in the visually guided behaviour of children with DCD in the context of road crossing. In line with previous research (Plumert et al., 2007) as approach speed increased the temporal gap acceptance thresholds that both typically developing children and children with DCD accepted decreased. This pattern was the same for both one and two lane conditions. This decrease suggests that children rely predominantly on the optical size of the vehicle (distance) in making judgments of safe crossing gaps, regardless of the speed of the approaching vehicle. One consequence of this strategy is that as speed increases the temporal crossing gaps that children leave decrease as do the margins for error that children leave themselves.

One of the limitations of this study is that it wasn't possible to explore whether participants would speed up if they realized they had accepted an insufficient temporal crossing gap. This could be important because one of the additional challenges facing children with DCD at the roadside relates to lack of inhibitory control, the suppression of behaviour in response to either internal or external influences (Fuster, 1997). It is often necessary to suppress an initiated action in the context of road crossing when required to quickly prevent ourselves from executing an inappropriately prepared action. Deficits in inhibitory control have been confirmed in many studies in children with DCD (Mandich, Buckolz & Polatajko, 2003). In the current study, children with DCD walked significantly slower than their TD peers and this coupled with consistent findings showing a deficit of inhibitory control raises concerns as to whether children with DCD would be able to quickly increase their walking speed or inhibit a planned crossing and this needs further exploration.

Of course, selecting suitable temporal gaps in traffic is just one aspect of road crossing but the current study suggests that it needs to be considered when working with children who have DCD. Given the findings of this study it is possible that the differences between the TD and DCD temporal gap thresholds are related to opportunities to practice road crossing and future research could explore the road crossing experiences of both typically and atypically developing children. It could also be argued that the participants in this study were less cautious in a virtual environment compared to a real environment, where the consequences of accepting or rejecting crossing gaps differ. However, there is a growing body of research that has demonstrated the transferability from virtual environments to real environments (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 (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.

The findings from this study add to our understanding of the difficulties that children with DCD appear to have with visually guided behaviour and suggests the potential impact on one aspect of daily functioning that could have significant consequences.

Acknowledgements

The research reported in this paper was supported by UK ESRC award RES-062-23-0842 to John P. Wann and Kate Wilmut. We thank the children, parents and schools who participated in this project.

Figures

Figure 2.1. 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.

Figure 2.2. Mean temporal gap acceptance thresholds (in seconds) and standard errors, for vehicles in the one-lane and two-lane conditions, approaching at 20, 30 and 40 mph.

Figure 2.3. The difference between temporal gap acceptance thresholds (in seconds) and crossing time for vehicles in the one-lane and two-lane conditions, approaching at 20, 30 and 40 mph.

Tables

Table 2.1. Participant information for each group, information provided includes number in each group, mean decimal age, age range, mean MABC-2 percentile, MABC-2 total standard test score mean and range and gender ratio (female to male).

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (fifth ed.).* Arlington, VA: American Psychiatric Publishing.

Barnett, A. L., Hill, E. L., Kirby, A., & Sugden, D. A. (2014). Adaptation and Extension of the European Recommendations (EACD) on Developmental Coordination Disorder (DCD) for the UK context. *Physical & occupational therapy in pediatrics*.

Blank, R., Smits-Engelsman, B., Polatajko, H., & Wilson, P. (2012). European academy for childhood disability (EACD): Recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version)*. *Developmental Medicine & Child Neurology, 54*(1), 54-93.

Clancy, T. A., Rucklidge, J. J., & Owen, D. (2006). Road-crossing safety in virtual reality: A comparison of adolescents with and without ADHD. *Journal of Clinical Child and Adolescent Psychology*, *35*(2), 203-215.

Connelly, M. L., Conaglen, H. M., Parsonson, B. S., & Isler, R. B. (1998). Child pedestrians' crossing gap thresholds. *Accident Analysis & Prevention*, *30*(4), 443-453. doi:DOI: 10.1016/S0001-4575(97)00109-7.

Department for Education (DfE). (2013). *Schools, pupils and their characteristics: Statistical first release.* London: Department for Education.

Department for Transport (DfT). (2014). *Reported road casualties in Great Britain: Main results 2013 report*. London: Department for Transport.

Dougherty, G., Pless, I. B., & Wilkins, R. (1989). Social class and the occurrence of traffic injuries and deaths in urban children. *Canadian journal of public health - Revue canadienne de sante publique*, *81*(3), 204-209.

Fajen, B. R., & Matthis, J. S. (2011). Direct perception of action-scaled affordances: the shrinking gap problem. *Journal of Experimental Psychology: Human Perception and Performance, 37*(5), 1442.

Gibson, J. (1979). *The ecological approach to visual perception*. New Jersey, USA: Lawrence Erlbaum Associates, Inc. Publishers.

Hamed, M. M. (2001). Analysis of pedestrians' behavior at pedestrian crossings. *Safety Science, 38*(1), 63-82. DOI: 10.1016/S0925-7535(00)00058-8.

Henderson, S., Sugden, D., & Barnett, A. (2007). *Movement assessment battery for children (2nd ed.)*. Oxford: Pearson.

Hyde, C., & Wilson, P. H. (2011). Dissecting online control in Developmental Coordination Disorder: A kinematic analysis of double-step reaching. *Brain and cognition*, *75*(3), 232-241.

Jonah, B. A., & Engel, G. R. (1983). Measuring the relative risk of pedestrian accidents. *Accident Analysis & Prevention*, *15*(3), 193-206.

Katz, N., Ring, H., Naveh, Y., Kizony, R., Feintuch, U., & Weiss, P. L. (2005). Interactive virtual environment training for safe street crossing of right hemisphere stroke patients with unilateral spatial neglect. *Disability and rehabilitation*, *27*(20), 1235-1244.

Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception, 5*, 437-459.

Lieberman, H. R., & Pentland, A. P. (1982). Microcomputer-based estimation of psychophysical thresholds: the best PEST. *Behavior Research Methods & Instrumentation, 14*(1), 21-25.

Lingam, R., Hunt, L., Golding, J., Jongmans, M., & Emod, A. (2009). Prevalence of developmental coordination disorder using the DSM-IV at 7 years of age: A UK population–based study. *Paediatrics, 123*(4), e693-e700.

Lobjois, R., Benguigui, N., & Cavallo, V. (2013). The effects of age and traffic density on street-crossing behavior. *Accident Analysis & Prevention*, *53*, 166-175.

Mandich, A., Buckolz, E., & Polatajko, H. (2003). Children with developmental coordination disorder (DCD) and their ability to disengage ongoing attentional focus: More on inhibitory function. *Brain and Cognition*, *51*(3), 346-356.

Morrongiello, B. A., Corbett, M., Switzer, J., & Hall, T. (2015). Using a virtual environment to study pedestrian behaviors: how does time pressure affect children's and adults' street crossing behaviors?. *Journal of pediatric psychology*, jsv019.

Onelcin, P., & Alver, Y. (2015). Illegal crossing behavior of pedestrians at signalized intersections: Factors affecting the gap acceptance. *Transportation Research Part F: Traffic Psychology and Behaviour*, *31*, 124-132.

Petzoldt, T. (2014). On the relationship between pedestrian gap acceptance and time to arrival estimates. *Accident Analysis & Prevention*, *72*, 127-133.

Plumert, J. M., Kearney, J. K., & Cremer, J. F. (2007). Children's road crossing: A window into perceptual–motor development. *Current Directions in Psychological Science*, *16*(5), 255-258.

Plumert, J. M., Kearney, J. K., Cremer, J. F., Recker, K. M., & Strutt, J. (2011). Changes in children’s perception-action tuning over short time scales: Bicycling across traffic-filled intersections in a virtual environment. *Journal of experimental child psychology*, *108*(2), 322-337.

Plumert, J. M., & Kearney, J. K. (2014). Linking decisions and actions in dynamic environments: how child and adult cyclists cross roads with traffic. *Ecological psychology*, *26*(1-2), 125-133.

Purcell, C., Wann, J. P., Wilmut, K., & Poulter, D. (2011). Roadside judgments in children with developmental co-ordination disorder. *Research in Developmental Disabilities, 32*(4), 1283-1292. doi:10.1016/j.ridd.2010.12.022.

Raven, J. C. (1956). *Coloured progressive matrices*. Oxford: Oxford Psychologists Press

Schwebel, D. C., Davis, A. L., & O’Neal, E. E. (2012). Child pedestrian injury a review of behavioral risks and preventive strategies. *American Journal of Lifestyle Medicine, 6*(4), 292-302.

Simpson, G., Johnston, L., & Richardson, M. (2003). An investigation of road crossing in a virtual environment. *Accident Analysis & Prevention, 35*(5), 787-796.

Stavrinos, D., Biasini, F. J., Fine, P. R., Hodgens, J. B., Khatri, S., Mrug, S., & Schwebel, D. C. (2011). Mediating factors associated with pedestrian injury in children with attention-deficit/hyperactivity disorder. *Pediatrics, 128*(2), 296-302.

Tefft, B. C. (2013). Impact speed and a pedestrian's risk of severe injury or death. *Accident Analysis & Prevention, 50*, 871-878.

Tresilian, J. R., Mon-Williams, M., & Kelly, B. M. (1999). Increasing confidence in vergence as a cue to distance. *Proceedings of the Royal Society B: Biological Sciences, 266*, 39-44.

Van der Meer, A.L.H., van der Wee, F.R., Lee, D.N., Laing L.A., & Lin, J.P. (1995). Development of prospective control of catching moving objects in preterm at risk infants. *Developmental Medicine and Child Neurology*. 37, 145-158.

Van der Molen, Hugo H., Van den Herik, J., & Van der Klaauw, C. (1983). Pedestrian behaviour of children and accompanying parents during school journeys: An evaluation of a training programme. *British Journal of Educational Psychology, 53*(2), 152-168.

Velde, A. F., Kamp, J., & Savelsbergh, G. J. (2008). Five-to twelve-year-olds' control of movement velocity in a dynamic collision avoidance task. *British Journal of Developmental Psychology, 26*(1), 33-50.

Wazana, A., Krueger, P., Raina, P., & Chambers, L. (1997). A review of risk factors for child pedestrian injuries: are they modifiable?. *Injury Prevention*, *3*(4), 295-304.

Whitall, J., Getchell, N., McMenamin, S., Horn, C., Wilms-Floet, A., & Clark, J. E. (2006). Perception–action coupling in children with and without DCD: frequency locking between task-relevant auditory signals and motor responses in a dual-motor task. *Child: care, health and development*, *32*(6), 679-692.

Xiang, H., Zhu, M., Sinclair, S. A., Stallones, L., Wilkins, J. R., & Smith, G. A. (2006). Risk of vehicle–pedestrian and vehicle–bicyclist collisions among children with disabilities. *Accident Analysis & Prevention*, *38*(6), 1064-1070.

Zwicker, J. G., Missiuna, C., Harris, S. R., & Boyd, L. A. (2012). Developmental coordination disorder: a review and update. *European Journal of Paediatric Neurology*, *16*(6), 573-581.