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Research paper

Appropriateness of different pedagogical approaches to road safety education for children with Developmental Coordination Disorder (DCD)

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ABSTRACT

Background: In 2016, 29% of pedestrians killed or seriously injured on the roads in Great Britain were under 15 years of age. Children with Developmental Coordination Disorder (DCD), a chronic disorder affecting the acquisition and execution of motor skills, may be more vulnerable at the roadside than typically developing (TD) children. Current methods used to teach road safety are typically knowledge-based and do not necessarily improve behaviour in real traffic situations. Virtual reality road crossing tasks may be a viable alternative.
Aims/Methods: The present study aimed to test the road crossing accuracy of children with and without DCD in virtual reality tasks that varied the viewpoint to simulate the teaching methods currently used in road safety educational programmes. Twenty-one children with DCD and twenty-one age and gender matched TD peers were required to locate the safest road crossing sites in two conditions: allocentric (aerial viewpoint) and egocentric (first-person viewpoint).
Procedures/Outcomes: All children completed both conditions and were required to navigate either themselves or an avatar across the road using the safest crossing route. The primary outcome was accuracy defined as the number of trials, out of 10, on which the child successfully identified and used the safest crossing route.
Results/Conclusions: Children with DCD performed equally poorly in both conditions, while TD children were significantly more accurate in the egocentric condition. This difference cannot be explained by self-reported prior road crossing education, practice or confidence.
Implications: While TD children may benefit from the development of an egocentric virtual reality road crossing task, multimodal methods may be needed to effectively teach road safety to children with DCD.

What this paper adds?

Between July and September 2016, 29% of all UK pedestrian casualties were children under the age of 15 years (Department for Transport, 2016). As only 19% of the population fall within this age range (Office for National Statistics, 2012) it suggests that this group is over-represented in these statistics. Children with Developmental Coordination Disorder (DCD), a chronic disorder affecting the acquisition and execution of motor skills, may be more vulnerable at the roadside than typically developing (TD) children due to differences in perceptual ability. Road safety education is less effective than is desirable; current methods are typically knowledge-

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based and do not necessarily improve behaviour in real traffic situations. To our knowledge, this is the first study that has systematically measured the road crossing accuracy of primary and secondary school aged children with and without DCD in a virtual environment using varying perspectives: allocentric and egocentric. Our results showed that children with DCD performed equally poorly on both tasks, whilst the TD children performed better on the egocentric task. This between group difference cannot be attributed to task understanding, or explained by self-reported history of road crossing education, practice or perceived confidence. This result implies that, while TD children may benefit from the development of an egocentric virtual reality road crossing educational programme, multimodal methods may be needed to effectively teach road safety to children with DCD. Given the inefficacy of current road safety education, and the likely vulnerability of children with DCD at the roadside, we believe that this study is of the utmost importance.

1. Introduction

The cost of preventable road traffic accidents to governments is estimated to be around 3% of Gross National Product and road traffic accidents represent the second largest cause of death for children aged 5–14 years worldwide (Toroyan & Peden, 2007). In the UK, over 13,500 children and young people (aged up to 17 years), were involved, as pedestrians, in reported road traffic accidents in 2015: a stark overrepresentation at 56% of all pedestrian casualties (Department for Transport, 2016). The reasons that children are so vulnerable at the roadside remain unclear, despite the tragic and avoidable cost to human life and the financial cost to public services. Road safety education for children provides the foundation of their knowledge, understanding and behaviour as adults. As such, road safety education programmes underpin a large proportion of road safety efforts. Although the need to teach children how to safely cross the road is widely accepted from the age of 4–5 years until secondary school (Connelly, Conaglen, Parsonson, & Isler, 1998; Dragutinovic & Twisk, 2006), it is unclear whether current methods of teaching road safety are successfully upskilling children in the road crossing task. In addition, road safety education programmes are frequently implemented without evidence of effectiveness (Dragutinovic & Twisk, 2006), and there appears to be a lack of consistency in the methods used to teach road safety in UK schools.

Pedagogical method could be key to the effectiveness of road safety education. Interventions for road safety teaching in the UK include the 'Tufty Club', which promotes the use of illustrated books for road safety education. This teaching method is widely available and classroom-based (therefore not particularly resource intensive) and attempts to improve road safety by increasing the child's rote knowledge of safe crossing areas and other road safety rules. However, past research has shown that increasing knowledge of road safety does not necessarily translate to improved behaviour in real traffic situations (Zeedyk, Wallace, Carcary, Jones, & Larter, 2001).

Increasing the child's involvement in learning and enabling practice of road crossing behaviours could be a more effective way of teaching road safety. The ecological approach to visual perception (Gibson, 1979) underlines the importance of dynamic visual information for both perception and the control of movement, and suggests that physical practice is necessary in order to fine-tune perception. Book-based methods of teaching which rely on increasing knowledge of correct road crossing behaviour do not address this need for physical practice. As far as we are aware, the Kerbcraft initiative (Thomson, Dickson, McBrearty, Motion, & Docherty, 2008) is the only practice-based method of teaching road safety currently used in UK primary schools. The programme involves going to the roadside with the aim of teaching children three practical skills relating to identifying safe crossing sites: recognising safe versus dangerous roadside locations; crossing safely near parked cars; and crossing safely near junctions. This type of roadside behavioural training has been found to be more effective than classroom instruction (Van Schagen & Rothengatter, 1997). However, individualised roadside pedestrian safety training programmes, such as Kerbcraft, are highly time and labour intensive (Schwebel, Davis, & O'Neal, 2012); Kerbcraft specifically, relies heavily on the involvement of parent volunteers, making it unrealistic that the programme can be widely and sustainably implemented in all schools.

It is particularly unclear whether the commonly used methods of road safety education described here are successfully upskilling children with Developmental Coordination Disorder (DCD) in the road crossing task. DCD is an idiopathic developmental condition characterised by marked impairment in fine and/or gross motor coordination, in the absence of any physical or neurological abnormalities, which negatively impacts on activities of daily living. The prevalence of DCD among 7–8 year old children in the UK is estimated at 1.8% (Lingam, Hunt, Golding, Jongmans, & Emond, 2009). Previous visual perception research suggests that children with DCD may have visual perception and perceptual motor deficits that may contribute to their motor function impairment; for example, primary school aged children with DCD have been shown to have reduced sensitivity to looming objects, whereby under certain viewing conditions they may misperceive a vehicle that is 5 s away as stationary, if it is travelling faster than 18 mph (Purcell, Wann, Wilmut, & Poulter, 2012). In addition, children with DCD have been shown to have a deficit in making approach rate judgements, meaning that when presented with two vehicles, with one travelling faster than another, they cannot judge which vehicle will reach them first (Purcell, Wann, Wilmut, & Poulter, 2011) and to leave considerably shorter (and insufficient) temporal crossing gaps compared to their typically developing peers (Purcell, Wilmut & Wann, 2017). Although much of the previous research on children's perceptual judgements at the roadside has focused on typically developing children (e.g. Demetre et al., 1992; Lee, Young, & McLaughlin, 1984), the deficits in visual perception, and particularly in looming sensitivity, observed in children with DCD suggest that these children may be more at risk at the roadside than their typically developing peers. In addition, the perception-action practice discussed above (Gibson, 1979) may be especially important for children with DCD since, if looming sensitivity is impaired, it is logical to assume that more practice would be necessary to fine-tune visual perception.

A less time and labour intensive method of teaching road safety within schools, in a method that allows for perceptual practice, could utilise virtual reality. Virtual reality is defined as an immersive and interactive three-dimensional computer experience occurring in real time (Rose, Attree, & Johnson, 1996). Virtual reality provides a promising strategy for the reduction of pedestrian casualties, as it allows the user to safely undertake a task that may otherwise be dangerous, within an immersive and realistic environment. Some computer-based road crossing games are currently available to schools; Tales of the Road is one such game, but it primarily uses an aerial, third-person perspective (also known as an allocentric perspective). Previous research has demonstrated that virtual tasks using an allocentric perspective are more cognitively demanding than first-person tasks (tasks undertaken from an egocentric perspective, where the subject sees the scene from their own viewpoint) (Vogeley et al., 2004). Egocentric perspective tasks have been found to increase neural activity in the medial frontal and parietal regions (Vogeley et al., 2004) which may be reflective of an "inner rehearsal (p. 4263)" of real-world visual perception (Gusnard, Akbudak, Shulman, & Raichle, 2001). This aligns egocentric virtual reality tasks with the ecological approach to visual perception (Gibson, 1979), suggesting that these types of virtual reality tasks may be comparable to real-world practice and therefore a useful tool for teaching road safety in schools.

Given that virtual reality is only a viable tool if behaviour in a virtual environment matches behaviour in the real world, Schwebel, Gaines, and Severson (2008) tested the validity of virtual reality as a tool in pedestrian road safety education. Their experiment involved participants (both adults and children) completing simulated road crossings in both an egocentric virtual environment and an identical natural environment, and found a high level of correlation between participants' behaviour in the real versus immersive environments, demonstrating good construct validity of the virtual reality tasks.

Building on this, the present study aimed to test the road crossing ability of children with DCD and typically developing (TD) children in two virtual reality tasks with varying perspectives. The tasks used an egocentric and allocentric perspective, and were designed to simulate the different methods currently used to teach road safety in UK schools. Based on previous research demonstrating that the neural activity that occurs during egocentric virtual reality tasks is much like an "inner rehearsal" or a "continuous simulation of behaviour" (Vogeley et al., 2004, pp. 822), we designed an egocentric perspective virtual reality road crossing task to simulate real-world road crossing practice. As a control condition, we designed an identical virtual reality road crossing task using an allocentric perspective which may be more comparable to other teaching methods such as Tufty Club and Tales of the Road. Based on previous research showing that egocentric virtual reality tasks are less cognitively demanding than allocentric tasks, we hypothesised that the children would be more accurate in the road crossing task that utilised an egocentric perspective, which would demonstrate the potential suitability of egocentric perspective virtual reality tasks as a road safety education resource. We hypothesised that both the children with DCD and the TD children would have higher accuracy on the egocentric perspective task, which would demonstrate that this task is a viable road safety resource for both typically developing children and children with DCD.

2. Method

2.1. Design

The study used a repeated measures design, all participants completed 10 road crossing trials in two conditions (allocentric and egocentric viewpoint) using a desktop computer-based simulated virtual environment. The study received ethical approval from the University of South Wales Faculty Research and Ethics Committee.

2.2. Participants

A total of 158 participants aged between 6 and 12 years were recruited directly from schools in the South East Wales Consortia. Of these, 23 children were identified who met the criteria for DCD. Following written opt-in parental consent and children's assent, all children were screened for DCD in accordance with DSM-5 (American Psychiatric Association; APA, 2013) guidelines. To assess DSM-5 criterion A (APA, 2013), children completed the age-appropriate sections of the test component of the Movement Assessment Battery for Children, Second Edition (MABC-2; Henderson, Sugden, & Barnett, 2007). Children scoring below the 5th percentile on the MABC-2 were included in the DCD group, and teachers confirmed that the children identified had difficulty with school-based motor activities (DSM-5 criteria B). To assess DSM-5 criterion C and D (APA, 2013), the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman & Kaufman, 2004) was administered to all children to obtain an overall IQ score and parents were asked about their child's medical history. Children scoring below 80 on the KBIT-2 were considered to have below average IQ and excluded from both experimental groups. None of the children had any reported history of behavioural or neurological problems that would qualify as exclusion criteria. Given reported comorbidity rates between DCD and ADHD, parents were asked to complete the Swanson, Noland and Pelham Questionnaire (SNAP-IV; Swanson, 1992) to measure children's attentional ability. A higher score on the SNAP-IV indicates a higher level of attention difficulties, as such only children scoring below the top 5% (within the normal range) were included in the present study. With parents' consent, teachers of participating children were informed of any scores below what might be expected for chronological age on any administered tests to enable follow-up. The TD group was comprised of participants scoring above the 25th percentile on the test component of the MABC-2 (indicating typical motor coordination) who were matched with the DCD group on age (within 9 months) and gender by case-control matching. Case-control matching took place after the exclusion of participants who failed to complete at least one correct trial in each condition (DCD, $N = 2$; TD, $N = 14$). The remaining TD participants ($N = 121$) were entered into a case-control matching process using SPSS v22, to identify a TD control group by randomised matching on age and gender to the remaining DCD participants ($N = 21$). The final sample ($N = 42$) consisted of a DCD group of 21 children, and 21 age and gender matched TD controls. Of the children included in the final sample, 34 children were in primary school (17 per group).

Fig. 1. Screen shots from the virtual reality road crossing task in allocentric condition (a) and egocentric condition (b).

2.3. Simulations

Participants were seated in front of a Dell flat LCD monitor (34 × 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 7. All simulations were scripted in Python using Vizard 3D simulation tools (WorldViz, Development Edition, USA). The Vizard libraries interface with OpenScene-Graph, enabling highly realistic 3D simulations at the maximum screen refresh rate (60 Hz). There were two conditions: the virtual reality tasks in each condition were identical but presented from two different viewpoints: an aerial perspective (allocentric condition, with the avatar in view); and a first-person perspective (the child's perspective is that of the avatar; egocentric condition) (see Fig. 1a and b for a screen shot of both conditions). The virtual reality scenes were realistic and 3D, with moving objects and traffic.

2.4. Road crossing questionnaire

A road crossing questionnaire was administered to participating children which assessed self-perceptions of safety, experience and confidence relating to road crossing. Prior independent road crossing experience was assessed with the question *"Have you ever crossed the road by yourself?"* (Yes/No). The frequency of independent road crossing experience was measured using the questions "*Thinking about the last week:* '*Did you cross the road on your own?*' (Yes/No) and (if yes) *"How often did you cross the road on your own?"* (Every day/Four to six days/Two to three days/Once). Competence at road crossing was assessed using the following questions*: "Think about when you last crossed the road on your own and the road was busy: Did you start crossing and have to run because the car was closer than you thought?"* (Yes/No) and *"Think about when you last crossed the road on your own and the road was busy: Did you have to wait for a long time before you were happy to cross?"* (Yes/No). Children were also asked *"Some children are confident at crossing the road alone, others are not. Which do you think you are?"* (Very confident; Confident; Slightly confident; and Not confident at all) and *"Some children think they are good at crossing the road alone, others don't think this. Which do you think you are?"* (Very good/Good/Bad/Very bad). The road crossing questionnaire also included the question *"Where do you think it is safe to cross the road?"* (Zebra crossing/ Traffic lights/Footbridge/Underpass/Other), which was included to ensure an existing level of knowledge of safe crossing areas, and questions about road crossing education at school *("Have you done any road safety at school?"* Yes/No; *"If yes, was it in the classroom or outside?"* Classroom/Outside).

2.5. Procedure

After informed consent/assent had been obtained and assessments completed, participating children completed the road crossing questionnaire with the researcher present to ensure that the children understood all questions. Children were then asked to complete the two virtual reality computer-based tasks, both of which required the children to use the arrow keys on a keyboard to navigate across a series of ten road crossing trials.

The child's task on each trial was to cross the road in the safest possible place. In each road scene, a safe crossing route (zebra crossing) was available regardless of whether the child chose to turn left or right. If the child crossed the road without locating and using the zebra crossing they were considered to have failed that trial. If a child failed to find the safest crossing route on their first attempt on either condition, they were prompted that their task was to find the safest crossing route to ensure task understanding ("Don't forget that your task is to find the safest place to cross"). If a participant had a further three consecutive failed attempts at any point throughout either condition the same prompt was reiterated, and participants were only included if they completed at least one correct trial in each condition.

2.6. Statistical analysis

All analyses were completed using IBM SPSS v23. The primary outcome measure was accuracy, defined as the number of trials, out of 10, on which the child successfully identified and used the safest crossing route (a zebra crossing). Normality of variables was tested using Shapiro-Wilk tests and Q–Q plots. Baseline variables were compared between groups using *t*-tests for normally distributed variables and Mann-Whitney *U* tests for non-normally distributed variables. Results for normally distributed variables are presented as mean and standard deviations. Results for non-normally distributed data are presented as median and interquartile range (IQR), with mean and standard deviation data also presented for comparison. Due to non-normally distributed outcome variables, Mann-Whitney *U* tests and Wilcoxon signed-rank tests for related samples were used to analyse accuracy between conditions (entire sample), and between groups and within groups on each condition. Effect sizes (*r*) were calculated for Mann-Whitney *U* tests using the formula:

$$r = \frac{Z}{\sqrt{N}}$$

and for Wilcoxon signed-rank tests using:

$$r = \frac{Z}{\sqrt{n_x + n_y}}$$

as described by Office for National Statistics (2012). Pallant (2017, p. 255), with effect sizes being defined as small ($r = 0.1$), medium ($r = 0.3$) and large ($r = 0.5$). Secondary analyses involved using Mann-Whitney *U* tests and Kruskal Wallis tests to determine whether accuracy varied between primary and secondary school aged children, or among age groups. Road crossing questionnaire data were analysed using Chi square tests. Pearson's *r* correlations, point-biseral correlations (dichotomous vs continuous variables) and Chi square tests were used to compare other variables. All tests were two tailed and *p*-values of less than 0.05 were considered significant.

3. Results

3.1. Study population

In total, 42 children were included in the study: 21 children who met the criteria for DCD; and 21 age and gender matched TD controls, age matched to within 9 months. Normality testing of baseline variables showed that MABC-2 standard and percentile variables were non-normally distributed. All other variables were normally distributed. See Table 1 for characteristics of both groups.

3.2. Primary outcome: accuracy

Normality testing showed that accuracy variables were non-normally distributed (see supplementary information). Wilcoxon signed-rank test showed that, in the entire sample, accuracy was higher on the egocentric condition (Mdn = 3) compared to the allocentric condition (Mdn = 1.5) with a large effect size, $Z = -3.31, p = 0.001, r = 0.51$. Non-parametric (Mann-Whitney *U*) tests to investigate the accuracy between groups on each condition showed that accuracy of the DCD group (Mdn = 1) did not differ significantly from the TD group (Mdn = 2) on the allocentric condition, $U = 214, Z = -0.175, p = 0.86, r = 0.03$. However, on the egocentric condition, accuracy was significantly higher in the TD group (Mdn = 6) compared to the DCD group (Mdn = 2) with a medium effect size, $U = 144$, $Z = -1.99$, $p = 0.047$, $r = 0.31$ (see Fig. 2).

Within groups accuracy (Wilcoxon signed-rank test) did not differ between the allocentric (Mdn = 1) and egocentric (Mdn = 2) conditions for the DCD group, $Z = -1.27, p = 0.20, r = 0.20$. However, in the TD group, accuracy was significantly higher on the egocentric condition (Mdn = 6) than the allocentric condition (Mdn = 2) with a large effect size, $Z = -3.26, p = 0.001, r = 0.50$ (see Fig. 2).

Table 1
Characteristics of study population by group.

	TD Typically Developing ≥25 Percentile MABC-2	Developmental Coordination Disorder < 5th Percentile MABC-2
N	21	21
Mean decimal age on test day (SD)	9.14 (1.68)	9.69 (1.82)
Median MABC-2 centile (IQR)	37 (37–79)	5 (2–5)*
Mean MABC-2 centile (SD)	*54.43 (25.23)*	*3.60 (1.89)*
Median MABC-2 standard test score (IQR)	9 (8–12)	5 (5–6)*
Mean MABC-2 standard test score (SD)	*10.52 (2.27)*	*4.52 (1.12)*
Mean KBIT composite standard score (SD)	98.24 (15.00)	87.90 (12.62)
Mean KBIT verbal standard score (SD)	97.76 (15.00)	95.24 (9.89)
Mean KBIT non-verbal standard score (SD)	98.67 (15.01)	86.10 (13.58)
Gender ratio (f:m)	9:12	9:12
School stage (primary:secondary)	17:4	17:4

N.B. Information in *italics* is for comparison only.
* Significantly different from TD group (MWU test: $p < 0.05$).

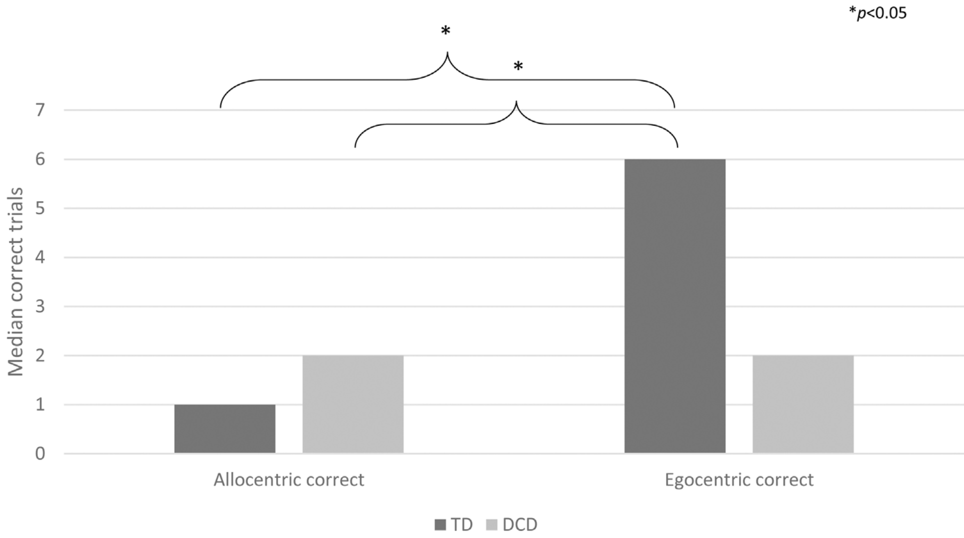

Fig. 2. Median accuracy on both conditions by group.

3.3. Secondary analyses

There was no significant difference in accuracy between primary (N = 34) and secondary school children on either condition: allocentric, $U = 89.00$, $Z = 1.61$, $p = 0.11$; egocentric, $U = 97.5$, $Z = -1.27$, $p = 0.20$. A Kruskal-Wallis *H* test showed that there was no significant difference in accuracy among different age groups (6–7 years (N = 12), 8–9 years (N = 16), 10–11 years (N = 6) and 11–12 years (secondary)) on either condition: allocentric, $\chi^2_3 = 3.36$, $p = 0.34$; egocentric, $\chi^2_3 = 2.53$, $p = 0.47$.

3.4. Preference of condition

Self-reported preference of condition data were available for 37 participants, who responded to the question *"Which task did you prefer?"* at the end of the experimental session. The group overall showed a strong preference for the egocentric condition over the allocentric condition (N = 37, ratio 23:14). There was no difference in preference between groups, with both the DCD and TD groups preferring the egocentric condition over the allocentric condition, $\chi^2_1 = 1.51$, $p = 0.22$. There was also no gender difference in self-reported preference, $\chi^2_1 = 0.22$, $p = 0.64$.

3.5. Road crossing questionnaire

The results of the road crossing questionnaire (see Table 2 for breakdown of relevant data) showed no difference between the DCD and TD groups in prior road crossing experience, TD = 10:9; DCD = 11:9, $\chi^2_1 = 0.02$, $p = 0.88$.

There was a significant difference in independent road crossing experience by school stage, with more primary than secondary school children reporting that they had never crossed the road by themselves, $\chi^2_1 = 8.63$, $p = 0.003$. Independent road crossing experience also varied by age group, $\chi^2_3 = 13.93$, $p = 0.003$ (Fig. 3).

Self-reported prior independent road crossing experience was not associated with any significant difference in accuracy on either condition (allocentric, $U = 162.00$, $Z = -0.82$, $p = 0.41$; egocentric, $U = 148.50$, $Z = -1.18$, $p = 0.24$).

There was no difference between the TD and DCD groups in self-reported prior exposure to road safety education at school, $\chi^2_2 = 0.00$, $p = 1.00$; whether road safety education took place in the classroom or outside, $\chi^2_2 = 2.18$, $p = 0.14$; knowledge of safe crossing places, $\chi^2_2 = 0.12$, $p = 0.73$ (zebra crossing), $\chi^2_2 = 0.36$, $p = 0.55$ (traffic lights); confidence in road crossing skills, $\chi^2_2 = 0.67$, $p = 0.72$; perceived road crossing ability, $\chi^2_3 = 4.51$, $p = 0.21$; or frequency of recent independent road crossing practice, $\chi^2_4 = 1.58$, $p = 0.81$. There was also no difference in self-reported road crossing competence between the DCD and TD groups: misjudging traffic gap, $\chi^2_1 = 0.04$, p = 0.84; long wait to cross, $\chi^2_1 = 0.22$, p = 0.64.

4. Discussion

The present study aimed to test the road crossing ability of both children with DCD and TD children in virtual reality tasks with varying perspectives (allocentric and egocentric), designed to simulate the different methods currently used to teach road safety in UK schools. Our first hypothesis was that children would be more accurate in the road crossing task from an egocentric perspective, which would demonstrate the suitability of egocentric perspective virtual reality tasks as a road safety resource. Confirming this hypothesis, we found an overall relationship between condition (perspective) and accuracy scores, with accuracy being higher in the egocentric condition. However, further investigation demonstrated that the TD children performed significantly better on the

Table 2
Breakdown of questionnaire data by group and school stage (where relevant).

Question	Answer	Group		School stage	
		TD	DCD	Primary	Secondary
Have you ever crossed the road by yourself?	Yes	10	11	13*	8
	No	9	9	18*	0
If yes, how often did you cross the road on your own?	Every day	4	3		
	Four to six days	1	2		
	Two to three days	1	1		
	Once	0	1		
Some children think they are good at crossing the road alone, others don't, which do you think you are?	Very good	1	4		
	Good	6	8		
	Bad	2	0		
	Very Bad	0	1		
Some children know when it is safe to cross the road, others don't, which do you think you are?	Always know	5	5		
	Sometimes know	4	6		
	Sometimes don't know	0	0		
	Never know	0	2		
Some children are confident crossing the road alone, others are not, which do you think you are?	Very confident	2	5		
	Confident	5	6		
	Slightly confident	2	2		
	Not confident at all	0	0		
Did you start crossing and have to run because the car was closer than you thought?	Yes	2	2		
	No	8	10		
Did you have to wait a long time before you were happy to cross?	Yes	6	6		
	No	4	6		
Where do you think it is safe to cross the road? (Multiple answers possible)	Zebra crossing	6	5		
	Traffic lights	2	1		
	Underpass	0	0		
	Other	0	0		
Have you done any road safety at school?	Yes	12	12		
	No	7	7		
If yes, was it in the classroom or outside?	Classroom	10	12		
	Outside	2	0		

* Significantly different to secondary ($p < 0.05$).

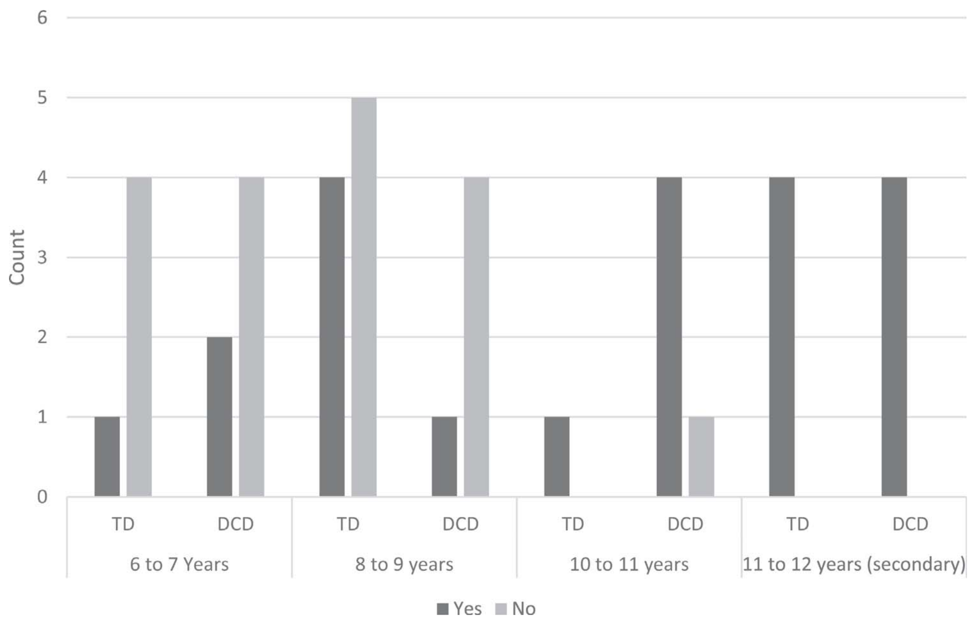

Fig. 3. Answers to the question *"Have you ever crossed the road by yourself?"* (Yes/No) by age group and group.

egocentric task than on the allocentric task, but that this difference was not observed in the children with DCD, who performed equally poorly in both conditions. This result was contrary to our second hypothesis, that both the children with DCD and the TD children would have higher accuracy on the egocentric perspective task. From this preliminary testing, the egocentric virtual reality task in the present study has the potential to be developed into a viable road safety resource for typically developing children, but not necessarily for children with DCD.

The reasons for the lack of a difference between conditions for the DCD group are not immediately apparent. It is clear from the results of the road crossing questionnaire that these results cannot be explained by prior independent road crossing experience or frequency of independent road crossing practice, which were not significantly different between the TD and DCD groups. There was also no group difference in self-reported perceived road crossing ability, prior exposure to road safety education at school, confidence in own road crossing skills, or self-reported road crossing competence.

The most likely explanation appears to be that children with DCD may need more than either allocentric or egocentric methods can provide separately: it is therefore likely that multimodal teaching methods may be required to improve road crossing behaviour among children with DCD, and potentially other children who are not typically developing. This aligns with previous research which has detected deficits in visual perception (particularly in looming sensitivity) in children with DCD, which suggest that these children may be more at risk at the roadside than their typically developing peers, and thus may need more intensive, or different, educational intervention.

Another possibility is that the use of virtual reality for road crossing tasks is not appropriate for children with DCD. Schwebel et al. (2008) only tested the construct validity of their virtual reality scenarios in TD children; children with DCD may show a marked difference in road crossing learning between, for example, book-based learning and actual roadside learning (i.e., Kerbcraft) but it may be that this difference was not detectable using virtual reality paradigms. A replication of the Schwebel et al. (2008) study validating virtual reality road crossing tasks for children with developmental disorders is warranted, as well as further testing to analyse road crossing learning in children with DCD without using virtual reality.

Although lack of task understanding may be a factor in the difference in accuracy rates between the TD and DCD groups, it does not appear likely that this could fully explain the low accuracy scores among the DCD group, since there was no difference in IQ between the TD and DCD groups. Given the additional precautions taken to ensure task understanding as outlined in the method section (repeated verbal prompting, exclusion of participants with a KBIT standard score of < 80, and the exclusion of participants with no correct trials on either condition) it appears unlikely that task understanding would fully explain the lack of any observable difference between conditions for the DCD group. Another potential limitation of the present study linked to task understanding is the lack of a practice trial. In future studies, a practice trial may be of significant benefit.

Overall, the children in the present study self-reported a preference for the egocentric condition, suggesting that this task may be more intuitive. This is consistent with previous research demonstrating that egocentric virtual reality tasks are less cognitively demanding than allocentric viewpoint tasks (Vogeley et al., 2004). However, perhaps unexpectedly, there was no difference in preference of condition between the TD and DCD groups, in spite of the group difference in accuracy on the egocentric condition. The fact that a majority of children preferred the egocentric condition, despite no difference in accuracy for the DCD group, suggests that egocentric methods may be more intuitive than allocentric methods for both TD and DCD children, and as such egocentric learning should be included in multimodal approaches for children with DCD.

The sample size of the present study is relatively small, which may have reduced statistical power. The small sample size, combined with skewed outcome variables, rendered multivariate statistics impossible; with a larger sample size multivariate statistical tests (such as binary logistic regression) could have been used. However, children in the DCD group in the present study met the diagnostic criteria which, when considered alongside the age and gender matched control group, means that this study is highly rigorous regardless of size. It is unlikely that the lack of a detectable difference between conditions for the DCD group was due to a lack of power alone, given that the difference in the TD group was detectable at this sample size, and because of the absolute similarity in accuracy between the two conditions for the DCD group ($r = 0.03$).

The present study found that TD children performed more accurately on an egocentric virtual reality road crossing task than an allocetric task, but found that children with DCD performed equally poorly on both conditions. The results of the present study highlight the value of a first-person, realistic virtual environment (egocentric) over a less immersive, aerial viewpoint task for road safety accuracy for typically developing children, and suggests a need for multimodal teaching for children with DCD. However, it is important to note that the present study did not aim to teach the children any road crossing skills and there was no feedback incorporated into the task. Future research should aim to expand on the preliminary findings of the present study by incorporating feedback (and therefore learning) into a realistic, egocentric virtual reality road crossing task. This task would need to be thoroughly tested for learning potential in different populations, particularly in children with DCD. Previous research has found a virtual reality computer game replicating a multimodal, real-world learning experience to be effective for teaching children with developmental delay (caused by foetal alcohol exposure) about road and fire safety (Coles, Strickland, Padgett, & Bellmoff, 2007). However, the learning involved in this study was rote learning of safety skills, as opposed to the egocentric condition task in the present study, which could be developed into a more realistic perceptual-motor road crossing practice environment. With further testing, a realistic, egocentric computer-based virtual reality road crossing education programme with audio and/or visual feedback, may be a valuable tool in teaching children how to cross the road whilst remaining safely in the classroom. A programme such as this could be used as a cost effective alternative to Kerbcraft, and could be used to supplement current road safety education for TD children throughout the UK and beyond. The development and testing of such a programme is warranted; however, given the results of the present study, there would need to be significant additional testing of the programme to assess whether it could be an appropriate learning resource for children with DCD. Despite the findings of the present study it is possible that a VR road crossing education programme may be appropriate for children with DCD if, for example, they had longer or more frequent periods of exposure to the programme, or were given additional (multimodal) teaching methods alongside. Given the overall vulnerability of children at the roadside, the perceptual and perceptual-motor deficits observed in DCD, and the widespread availability of virtual reality technology, developing new and innovative methods of teaching road safety is of the utmost importance.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ridd.2017.08.010.

References

Coles, C. D., Strickland, D. C., Padgett, L., & Bellmoff, L. (2007). Games that work: Using computer games to teach alcohol-affected children about fire and street safety. *Research in Developmental Disabilities, 28*(5), 518–530.

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.

Demetre, J., Lee, D., Pitcairn, T., Grieve, R., Thomson, J. A., & Ampofo-Boateng, K. (1992). Errors in young children's decisions about traffic gaps: Experiments with roadside simulations. *British Journal of Psychology, 83*(2), 189–202.

Department for Transport (2016). *Reported casualties by road user type, age and severity, Great Britain, 2015*UK: Department for Transport.

Dragutinovic, N., & Twisk, D. (2006). *The effectiveness of road safety education.* The Netherlands: SWOV Institute for Road Safety Research.

Gibson, J. (1979). *The ecological approach to human perception.* Boston: Houghton Mifflin.

Gusnard, D. A., Akbudak, E., Shulman, G. L., & Raichle, M. E. (2001). Medial prefrontal cortex and self-referential mental activity: Relation to a default mode of brain function. *Proceedings of the National Academy of Sciences of the United States of America, 98*(7), 4259–4264.

Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement assessment battery for children* (2nd ed.). London: Harcourt Assessment.

Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman brief intelligence test.* Wiley Online Library.

Lee, D. N., Young, D. S., & McLaughlin, C. M. (1984). A roadside simulation of road crossing for children. *Ergonomics, 27*(12), 1271–1281.

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

Office for National Statistics (2012). *2011 Census: Population and household estimates for the United Kingdom.* London: Office for National Statistics.

Pallant, J. (2017). *SPSS survival manual: A step-by-step guide to data analysis with SPSS.* New York: McGraw-Hill.

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

Purcell, C., Wann, J., Wilmut, K., & Poulter, D. (2012). Reduced looming sensitivity in primary school children with developmental co-ordination disorder. *Developmental Science, 15*(3), 299–306. http://dx.doi.org/10.1111/j.1467-7687.2011.01123.x.

Purcell, C., Wilmut, K., & Wann, J. P. (2017). The use of visually guided behaviour in children with Developmental Coordination Disorder (DCD) when crossing a virtual road. *Human Movement Science, 53*, 37–44.

Rose, F., Attree, E., & Johnson, D. (1996). Virtual reality: An assistive technology in neurological rehabilitation. *Current Opinion in Neurology, 9*(6), 461–468.

Schwebel, D. C., Gaines, J., & Severson, J. (2008). Validation of virtual reality as a tool to understand and prevent child pedestrian injury. *Accident Analysis & Prevention, 40*(4), 1394–1400.

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.

Swanson, J. (1992). *School-based assessments and interventions for ADD students.* Irvine, CA: University of California Child Development Center.

Thomson, J., Dickson, M., McBrearty, L., Motion, A., & Docherty, J. (2008). *Kerbcraft training manual: A handbook for road safety professionals.* London: Department for Transport.

Toroyan, T., & Peden, M. (2007). *Youth and road safety.* Geneva: World Health Organization.

Van Schagen, I., & Rothengatter, T. (1997). Classroom instruction versus roadside training in traffic safety education. *Journal of Applied Developmental Psychology, 18*(2), 283–292.

Vogeley, K., May, M., Ritzl, A., Falkai, P., Zilles, K., & Fink, G. R. (2004). Neural correlates of first-person perspective as one constituent of human self-consciousness. *Journal of Cognitive Neuroscience, 16*(5), 817–827.

Zeedyk, M. S., Wallace, L., Carcary, B., Jones, K., & Larter, K. (2001). Children and road safety: Increasing knowledge does not improve behaviour. *British Journal of Educational Psychology, 71*(4), 573–594.