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When an object appears unexpectedly: anticipatory movement and object circumvention in individuals with and without Developmental Coordination Disorder

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Abstract

Obstacles often appear unexpectedly in our pathway and these require us to make adjustments to avoid collision. Previous research has demonstrated that healthy adults will make anticipatory adjustments to gait where they have been told there is the *possibility* of an obstacle appearing. One population that may find this type of anticipatory movement difficult is individuals with Developmental Coordination Disorder (DCD). The current study considered how individuals with and without DCD adjust to the possibility of an obstacle appearing which would require circumvention. Forty four individuals with DCD and 44 age-matched controls (aged from 7-34 years of age) walked down an 11m walkway under three conditions. Initially they were told this was a clear pathway and nothing in the environment would change (1, no possibility of an obstacle, no obstacle). They then performed a series of trials in which a gate may (2, possibility of an obstacle, obstacle) or may not (3, possibility of an obstacle, no obstacle) partially obstruct their pathway. We found that all participants increased medio-lateral trunk acceleration when there was the *possibility* of an obstacle but before the obstacle appeared, in addition the typical adults and older children also increased step width. When describing circumvention we found that the younger children showed an increase in trunk velocity and acceleration in all three directions compared to older children and adults. We also found that the individuals with DCD adjusted their path sooner and deviated more than their peers. The degree of adjustment to step width in anticipation of an obstacle was related to later medio-lateral velocity and timing of the deviation. Therefore, the lack of 'readying' the system where there is the possibility of an obstacle appearing seen in the individuals with DCD and the younger typical children may explain the increased medio-lateral velocity seen during circumvention.

Keywords

Trunk velocity, trunk acceleration, step width, obstacle circumvention, avoidance

Introduction

As part of everyday life we negotiate obstacles as we locomote through the environment. The ability to avoid both static and moving objects is vital for our safety and efficient passage. When confronted with an obstacle a walker needs to adjust and control movement in order to side step, step over, change direction or stop. When we approach a stationary object walkers are able to pre-plan a movement in order to avoid collision (de Silva, Barbieri, & Gobbi, 2011; Higuchi, 2013; Huxham, Goldie, & Patla, 2001; Patla & Vickers, 2003). Pre-planning movement in this way is convenient but not always possible. On many occasions we need to navigate dynamic obstacles that unexpectedly move into our path of travel. For example, when a pedestrian appears from an adjoining road or a ball rolls across our path. A number of cleverly designed studies have examined how healthy adults do just that (Chen, Ashton-Miller, Alexander, & Schultz, 1994; Patla, Beuter, & Prentice, 1991; Patla, Prentice, Rietdyk, Allard, & Martin, 1999; Weerdesteyn, Nienhuis, Hampsink, & Duysens, 2004). The common finding is that participants are able to adjust their movement and react to an obstacle appearing suddenly. However, in all of these studies participants the unexpected element is *when* an object will appear not *if* an object will appear. We know from studies where an obstacle is present in the pathway that participants adjust their walking velocity and step length which may allow more time for necessary adjustments (Chen, Ashton-Miller, Alexander, & Schultz, 1991; Chou & Draganich, 1997; McFadyen & Carnahan, 1997). This raises the question as to whether participants, when knowing an obstacle *may* appear in their pathway, adjust their movement in anticipation.

Pijnappels, Bobbert, & van Dieën (2001) compared the kinematics of walking under two conditions, unobstructed walking and walking when participants were warned that a trip may be induced (forewarning). Participants made no changes to the temporal parameters of walking (velocity, step frequency, swing time double support time) but they did show an increase in step width during forewarning. In a similar vein, Pater, Rosenblatt, & Grabiner (2015) also considered anticipation of a fall while walking on a treadmill. While participants walked a perturbation could be introduced, whereby the speed of the treadmill suddenly increased. One group of participants were warned about this perturbation (expectation group) while another were not (no expectation group). The expectation group fell less often following the perturbation compared to the no-expectation group and when they did fall the recovery of the expectation group was classified as more typical than the no-expectation group. In a recent study we considered this type of 'anticipation' in a lower risk scenario that did not involve the possibility of a trip but rather the possibility of needing to circumvent an obstacle appearing in the pathway (Wilmut, Du, & Barnett, In Press). We compared trials where there was the possibility of an obstacle appearing (a gate which could close and partially block the pathway) with trials where there was no possibility of the obstacle appearing. We found that adults narrowed their steps and increased medio-lateral acceleration in anticipation of the gate closing. It was concluded that these adjustments may enable participants to remain central on the pathway thus allowing for a fast adjustment either to the right or to the left (Wilmut, Du, et al., In Press). These studies provide an important insight into anticipatory control and clearly show some modification of behaviour to ensure safe passage, with typical adults changing their movement pattern when faced with the *possibility* of an event (trip or obstacle appearing). Adjusting away from a typical or preferred pattern of movement has an associated cost (O'Connor, Xu, & Kuo, 2012), but it would appear in this situation, that the benefit of having the motor system ‘ready’ for the event (and therefore, ready to avoid collision / tripping) outweighs this cost even when the event occurs on a small proportion of trials.

Developmental Coordination Disorder (DCD) describes individuals who present with motor coordination which is below the expected level given their age. Figures suggest that almost 2% of children in the UK present with DCD (Lingam, Hunt, Golding, Jongmans, & Emond, 2009). These children display difficulties with fine and gross motor tasks (Sugden, 2006) which can persist into early adulthood and continue to have a negative impact on everyday life (Kirby, Edwards, Sugden, & Rosenblum, 2010). The generation of anticipatory movement has been considered in this population. Mon-Williams et al. (2005) and later Wilmut & Wann (2008) used a cueing paradigm, whereby participants were either given full cue information (exact target location was cued) or partial cue information (direction was cued thus highlighting two possible target locations). In both studies children with DCD made anticipatory movements following full cues (as did the typically developing participants) but did not make any anticipatory adjustments in response to the partial cue (while the typically developing participants did). From these results it was concluded that for the children with DCD the cost of preparing a movement which then had to be changed outweighed the benefits of moving early (Mon-Williams et al., 2005; Wilmut & Wann, 2008). Essentially this conclusion states that the lack of anticipatory movement in the children with DCD was not due to a deficit per se, but rather a specific choice of movement selection. The time course over which movements are made and adapted are very different in a discrete grasping task as compared an ongoing walking task. Therefore, whether a similar pattern of cost-benefit trade-off is seen in a walking task remains to be seen.

The aims of this study were twofold: Firstly to investigate whether children and adults with and without DCD show anticipatory control when there is a possibility of an obstacle appearing in the pathway. To do this we compared walking across three conditions: 1. 'no gate' where there is no possibility that an obstacle will move across the path; 2. 'gate close' where there is a *possibility* that a gate will move across the pathway and later in the trial the gate does close; and 3. 'gate open' where again there is a *possibility* that the gate will move across the pathway but the gate actually remains open. To consider anticipatory control we considered movement prior to the point at which gate closure or non-gate closure was confirmed. Given that previous studies have highlighted difficulties with anticipatory control in this population (Mon-Williams et al., 2005; Wilmut & Wann, 2008) we expect to either see a lack of anticipatory control or a different type of anticipatory control in this population. Both adults and children with DCD are included in this study because although is it widely acknowledged that these children do not grow out of their difficulties (Kirby et al., 2010) there is a paucity of research studies focusing on adults with DCD. What does exist suggests that the children and teenagers with DCD continue to have difficulties into adulthood and do not simply develop more slowly than typical individuals (Wilmut & Byrne, 2014; Wilmut, Byrne, & Barnett, 2013). The second aim of this study was to describe the nature of circumvention and whether this differs between individuals with and without DCD.

Method

Participants

This project was approved by Oxford Brookes University Research Ethics Committee. Forty-four participants with DCD (aged from 7 to 34 years) and 44 age (to within 6 months) and gender matched typically developing individuals were recruited for this study. These participants took part in a larger study of which this task was just one that they completed. Participants were divided into three age groups: adults (N=30, aged from 18 to 34 years), older children (N=30, aged from 12 to 17 years) and younger children (N=28, aged from 7 to 11 years). Details regarding these participants can be found in Table 1. Participants with DCD were recruited from two sources: from a group known to the authors from previous studies; and from a local support group for individuals with DCD and their families. All participants with DCD were assessed and selected in line with the DSM-5 criteria for DCD and with recent UK guidelines (Barnett, Hill, Kirby, & Sugden, 2015).

To determine motor skill below the level expected for the individual's chronological age (criterion A) we used the test component of the Movement Assessment Battery for Children second edition (MABC-2; Henderson, Sugden, & Barnett, 2007) for individuals ≤17yrs of age and a combination of this and the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition, Brief Form (BOT-2 Brief; Bruininks & Bruininks, 2005) for individuals > 17 yrs. Individuals with DCD scored below the 16th percentile on the MABC-2 and below the 18th percentile on the BOT-2 Brief. To determine that the motor impairment significantly impacted on daily living (criterion B) the MABC-2 Checklist, the DCD-Q (Wilson, Kaplan, Crawford, Campbell, & Dewey, 2000) and a telephone interview with the parent was used for individuals ≤17yrs of age while the Adult Developmental Coordination Disorder Checklist (ADC; Kirby & Rosenblum, 2008) and a telephone interview with the participant was used for individuals >17yrs. Telephone interviews were also used to determine that the onset of the motor difficultly was in early childhood (criterion C) and that the difficulties were not due to a known neurological impairment or intellectual disability (criterion D). The typically developing (TD) individuals or their parents completed a telephone interview and the MABC-2 Checklist / ADC (depending on age) to confirm that no movement difficulties were present.

Given the co-occurrence of motor difficulties and attention difficulties all participants or their parents completed either the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) or the Conners' ADHD adult rating scales (CAARS; Conners, Erhardt, & Sparrow, 1999). Only 10 of the individuals with DCD had high or very high scores on the inattention subscale compared to none of the typically developing individuals. Running analyses both with and without these individuals with high or very high scores did not alter the outcome of the findings and so these individuals were included in the study.

Table 1. Descriptive information for the six cohorts

	Adults		7-11years		12-17years	
	TD	DCD	TD	DCD	TD	DCD
N	15	15	15	15	14	14
Mean age (yrs:mo)	23:3	25:5	14:7	14:11	9:3	9:3
Gender ratio (F:M)	2:3	2:3	1:3	1:3	1:6	1:6
MABC-2 test mean percentile (range in brackets)	-	1.54 (0.1-5)	-	2.55 (0.1-5)	-	3.71 (0.5-9)
BOT-2 test mean percentile (range in brackets)		7.07 (1-18)	-	-	-	-
MABC-2 checklist total score	-	-	0.7	27.6	3.0	25.9
DCD-Q total score	-	-	70.2	33.1	65.5	34.6
ADC total score	21.7	65.9	-	-	-	-

2.2 Apparatus and procedure

Participants walked barefoot at a comfortable pace along an 11m by 1m walkway made from high density foam sports mats. Two rectangular ‘gates’, 60cm wide and 30cm high and constructed from the same high density foam material, were positioned on each side of the walkway 8m from the start point (see Fig. 1a). A motion sensor was positioned 5m from the start point (3m in front of the gates) and this, when triggered would cause either the right or left gate to close across the pathway. When the motion sensor was activated there was a delay of ~16ms prior to the gate starting to move and the gate took ~1250ms to fully close.

A Vicon Nexus 3D motion capture system with 16 cameras running at 100Hz was used to track the movement of reflective spherical markers (9mm in diameter) attached to the skin at five bony landmarks: the sacral wand, the second metatarsal head on left and right foot (left and right toe marker), and the lateral malleolus on left and right foot (left and right ankle marker). Initially participants completed 6 ‘no gate’ trials. On these trials the gates and motion sensors were present at the side of the walkway but participants were told that these were to be ignored. Participants were instructed to walk the length of the walkway at a natural pace. Following these ‘no gate’ trials participants were again instructed to walk from the start to the stop point for each trial, and then return to the start by the return path. In ‘gate close’ trials the motion sensor was switched and this was then triggered when the participant walked passed, once triggered one of the gates (randomly selected) closed forcing circumvention (Fig. 1c). Participants were instructed to avoid the gate while continuing their passage along the walkway. On ‘gate open’ trials, unbeknown to the participant, the motion sensor was deactivated so that the gates remained stationary throughout the trial allowing for unobstructed passage (Fig. 1b). Participants completed 6 ‘gate close’ and 30 ‘gate open’ trials with the former interspersed randomly with the latter. This ensured that presence of the obstacle in the pathway was unpredictable and so from a participant’s point of view there was a *possibility* that a gate would close on all 36 of these trials. The start point was varied by ±20cm to avoid the participant starting at a consistent distance from the obstacle.

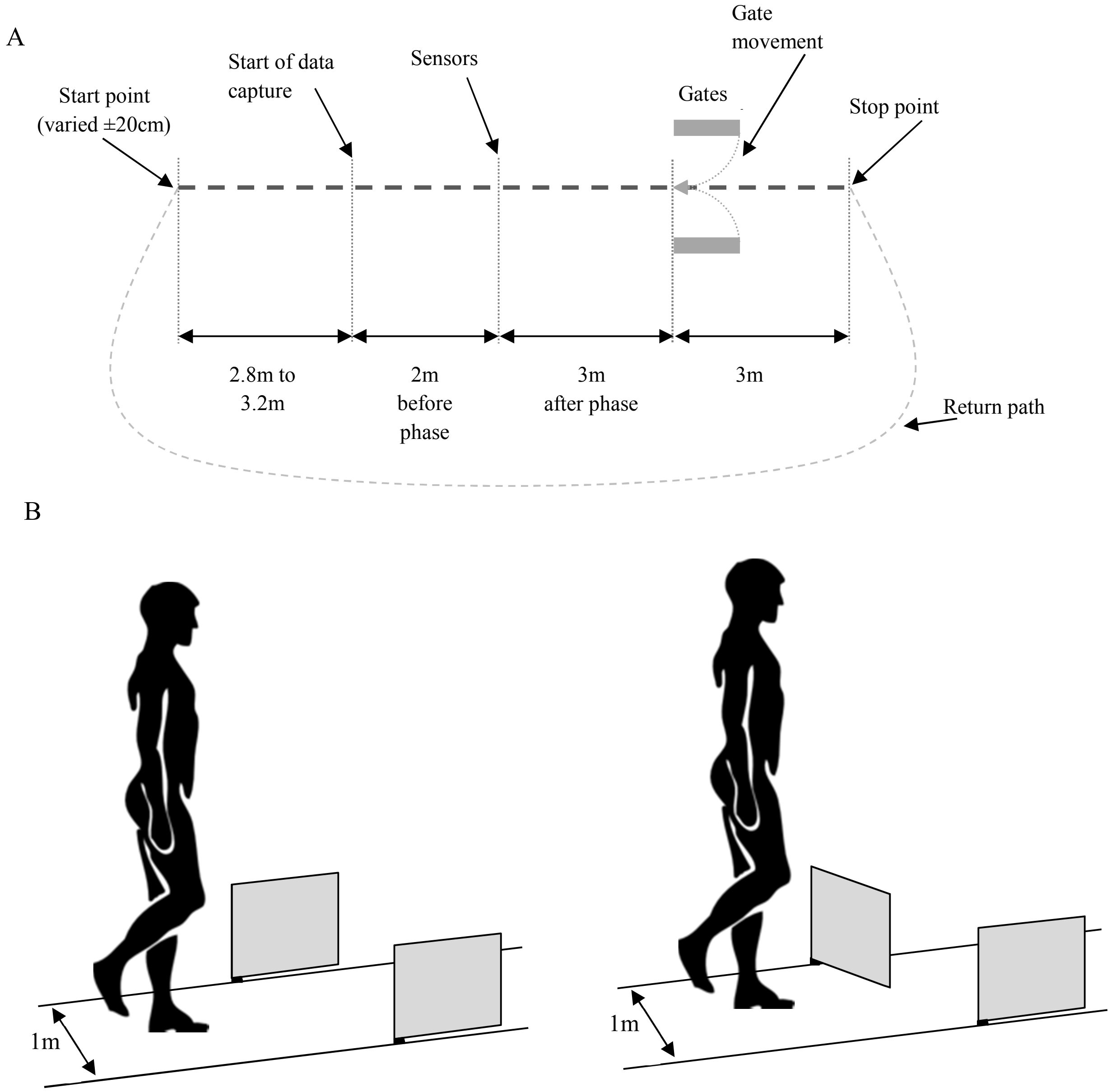

Figure 1. A. bird’s eye view of the set up including the walking path, the return path and the location of the sensors and gates. B. Left - a gate open trial, right - a gate close trial.

Data analysis

VICON movement data was smoothed using an optimized low-pass Woltring filter with a 12 Hz cut-off point and was then processed using tailored Matlab routines. Measurements of trunk movement and foot placement were taken. For all trials movement was split into two parts: before obstacle trigger (the before phase) defined as the 2m between start of data capture and the sensor; and after obstacle trigger (after phase) defined as the 3m between the sensor and the gate.

Spatial-temporal parameters of foot placement: Heel strike (HS) and toe off (TO) events were determined based upon an adapted the foot velocity algorithm (O'Connor, Thorpe, O'Malley, & Vaughan, 2007). The algorithm was adapted by using the ankle marker (lateral malleolus) rather than a heel marker. This was used to analyses each step which fell between the start of data capture until the gate was passed. From the timing of HS and TO events two measures pertaining to foot placement were determined: *Step length*: the anterior-posterior distance between the front foot ankle marker and the back foot ankle marker at each HS, this was normalised to leg length; *Step width*: the medio-lateral distance between the two ankle markers at each HS, this was normalised to hip width.

Trunk movement: Movement of the sacral marker was taken as an indicator of trunk movement. For each step sacral root mean squared velocity (ms^{-1}) and acceleration (ms^{-2}) was calculated over the three axes of movement: medio-lateral (ML); anterior-posterior (AP); and vertical (V). All trunk movement measured were normalised to leg length as this factor has been shown to influence trunk movement (Hsue, Miller, & Su, 2009).

Path deviation: In order to describe obstacle circumvention measures were taken for the gate close condition during the after phase; these are described below. Firstly we determined whether or not a deviation occurred, this was done by calculating the medio-lateral position over the course of the trial and if in the after phase ML position deviated from ML position in the before phase by more than three standard deviations it was recorded as a path deviation. From this, proportion of deviation trials was calculated for each participant. For trials where a path deviation was apparent, we calculated three more variables: the time left after deviation, the time between the start of the deviation and the point at which the participant passed the gate; the distance left after deviation, the distance between the participant and the gate at the point at which the deviation started; the size of the deviation, the maximum transverse distance between the average path prior to deviation and path after deviation.

Statistical analysis

Data were analysed in line with the aims of the study. Firstly in order to determine whether participants showed any anticipation we considered movement during the before phase across the conditions (no gate, open gate and close gate). Essentially this is comparing a condition with no possibility of an obstacle (no gate) to two conditions where there is a possibility of an obstacle appearing (open gate and close gate). To do this a three-way ANOVA (age x group x condition) was used to compare the spatial-temporal parameters of foot placement and the trunk movement measures. Secondly, in order to determine how participants moved to circumvent an obstacle, we considered movement during the after phase for the gate close trials only. To do this two-way ANOVA (age x group) was used to compare trunk movement measures and the measures of path deviation. As an attempt to quantify the relationship between the anticipatory adjustments in the before phase and the measures of obstacle circumvention in the after phase we calculated a percentage adjustment variable for measures before the sensor. The mean value of each measure in the possibility conditions (gate open and gate close) was subtracted from the value of the measure in the no possibility (no gate) condition and then divided by the value of these variables in the no possibility (no gate) condition. Correlations were then run between these variables and the measures of object circumvention in the after phase. For all statistical analyses Greenhouse-Geisser was reported when the assumption of sphericity was violated. Significant main effects were followed up with post-hoc tests using a Bonferroni correction to adjust for multiple comparisons and significant interactions were followed up with a Pillai's Trace simple main effects test. Partial eta-squared is reported as a measure of effect size and the significance level set at 0.05.

Results

All participants successfully completed all conditions, in the gate close trials there were no collisions and participants circumvented the obstacle rather than stepping over it.

Anticipation of obstacle appearance

Firstly spatial-temporal parameters of foot placement were considered across age, group and condition, data can be found in Figure 2. For step width we found a significant main effect of condition [F(1.667,36.709)=4.20, p=.017, η_p^2=.05] which was due to a wider step in the gate close and gate open condition compared to the no gate condition. A significant main effect of age was also found for both measures [step length: F(2,82)=7.31, p=.001, η_p^2=.15, step width: F(2,82)=12.23, p<.001, η_p^2=.23], which was due to a relatively longer and wider step in the younger children compared to the older children or adults. In addition, a significant interaction was found for step width between condition and age [F(4,164)=5.18, p=.001, η_p^2=.11]. All other effects were non-significant [F<1]. In order to explore the significant interactions condition and age were considered for each group separately. For the TD group a main effect of condition was found [F(1.398,57.336)=6.03, p=.004, η_p^2=.13], which reflected that described above and a significant interaction between condition and age was found [F(4,82)=4.34, p=.003, η_p^2=.18]. Simple main effects demonstrated that this interaction was due to an effect of condition (no gate < gate close = gate open) for the adults [F(2,40)=5.82, p=.006, η_p^2=.23] and the older children [F(2,40)=3.39, p=.044, η_p^2=.15] but not the younger children [p>.05]. To contextualise this it is a difference in step width of approximately 1.8cm in the TD adults and 1.0cm in the older TD children. For the DCD group no significant effects were found [p>.05].

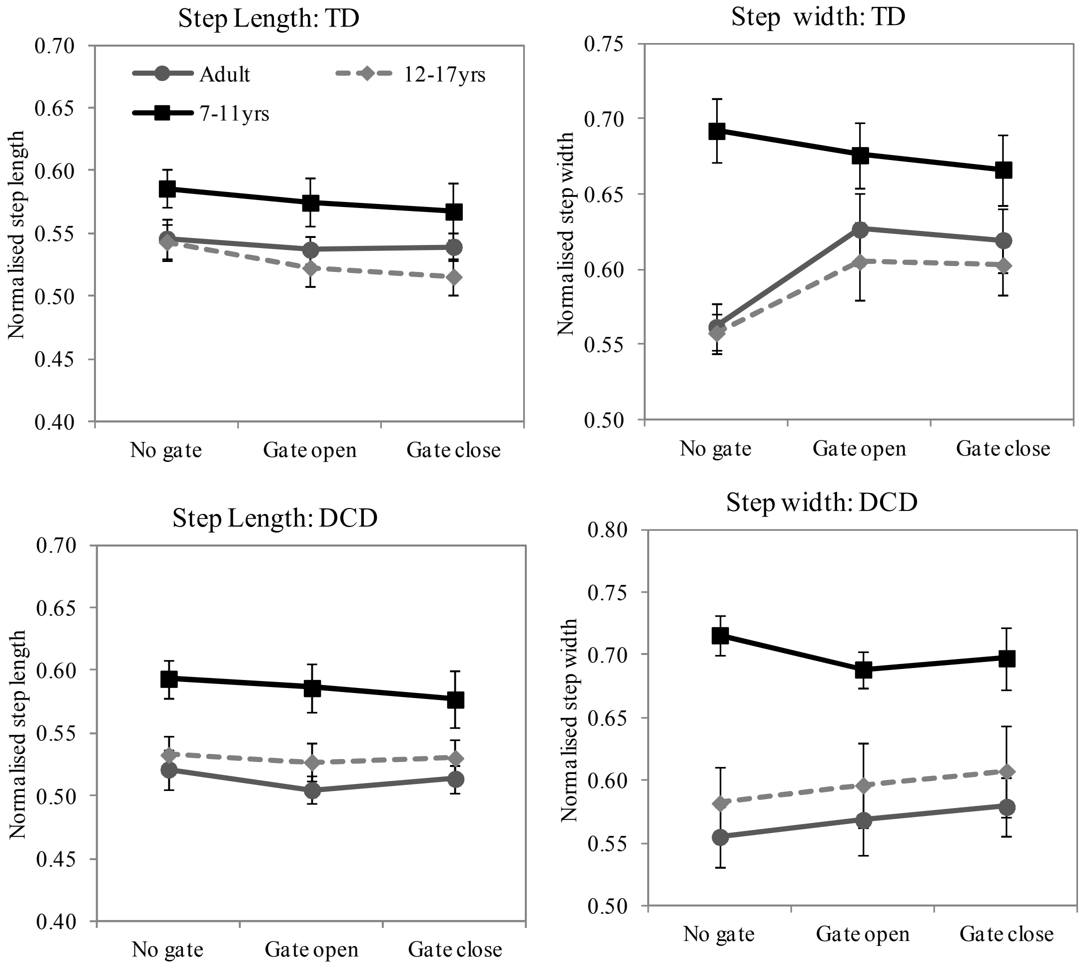

Figure 2. Normalised step length and step width across the three conditions before the sensor. Error bars show standard error.

Secondly we considered trunk movement measures across the same parameters. Data can be found in supplementary tables with illustrations of the significant effects of condition in Figure 3 (which is collapsed across group). A significant main effect of condition was found for ML acceleration [F(1.683,138.03)=25.09, p<.001, η_p^2=.23] due to a higher acceleration in the gate open and gate close compared to the no gate condition (no gate < gate open = gate close). For ML, AP and V velocity and AP and V acceleration the effect of condition was non-significant [F<1]. A significant effect of age was found for all measures of velocity [ML: F(2,82)=6.96, p=.002, η_p^2=.15, AP: F(2,82)=10.94, p<.001, η_p^2=.21, V: F(2,82)=5.89, p=.004, η_p^2=.26] and acceleration [ML: F(2,82)=8.25, p=.001, η_p^2=.17, AP: F(2,82)=33.97, p<.001, η_p^2=.45, V: F(2,82)=21.39, p<.001, η_p^2=.34]. Post-hoc tests indicated that all of these effects were due to a larger normalised velocity and acceleration in the younger children compared to the older children and adults (7-11yrs > 12-17yrs = adults). Finally, a significant main effect of group was found for ML velocity [F(1,82)=4.404, p=.039, η_p^2=.05] with the individuals with DCD showing a higher velocity compared to the TD individuals. For AP and V velocity and MP, AP and V acceleration the effect of group was not significant [F<1]. No significant interactions were found [F<1].

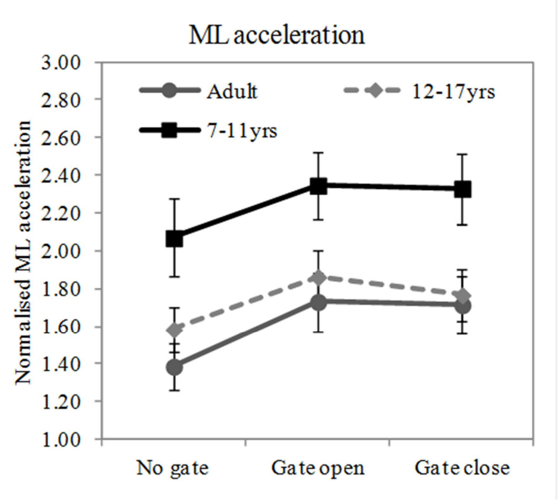

Figure 3. Trunk movement measures before the sensor, data points are collapsed across group. Error bars depict standard error.

Circumvention of an obstacle

Measures were now only considered for gate close trials in the after phase as in the other conditions participants passed along the walkway unobstructed. In terms of trunk movement a significant main effect of age was found for all measures of velocity [ML: F(2,82)=47.46, p<.001, η_p^2=.54, AP: F(2,82)=7.86, p=.001, η_p^2=.16, V: F(2,82)=9.05, p<.001, η_p^2=.18] and acceleration [ML: F(2,82)=14.16, p<.001, η_p^2=.26, AP: F(2,82)=14.69, p<.001, η_p^2=.26, V: F(2,82)=24.09, p<.001, η_p^2=.37]. Post-hoc tests indicated that these effects were due to a larger normalised velocity and acceleration in the younger children compared to the older children or adults (7-11yrs > 12-17yrs = adults). In addition, a significant main effect of group was found for ML velocity and acceleration [F(1,82)=7.33, p=.008, η_p^2=.08, and F(1,82)=4.13, p=.045, η_p^2=.05 respectively], in both cases this was due to a higher value in the individuals with DCD compared to the TD individuals (DCD > TD). No other significant effects of group or interactions between age and group were found [F>1]. These data can be found in Table 2.

Table 2. Data for gate open condition only in the after phase between the sensor and the gate. Values are given for the three age groups and the two groups (DCD and TD). Standard deviation is given in brackets.

			Adult	12-17yrs	7-11yrs	Significant effects
Normalised velocity	ML	TD	0.12 (0.03)	0.17 (0.04)	0.23 (0.04)	Age
		DCD	0.13 (0.05)	0.19 (0.05)	0.27 (0.08)	Group
	AP	TD	1.43 (0.18)	1.29 (0.10)	1.61 (0.25)	Age
		DCD	1.31 (0.16)	1.40 (0.46)	1.82 (0.79)	
	V	TD	0.19 (0.03)	0.171 (0.04)	0.23 (0.06)	Age
		DCD	0.17 (0.05)	0.17 (0.05)	0.25 (0.13)	
Normalised acceleration	ML	TD	1.78 (0.54)	1.69 (0.50)	2.15 (0.44)	Age
		DCD	1.77 (0.56)	1.83 (0.42)	2.75 (0.82)	Group
	AP	TD	2.42 (0.74)	2.27 (1.70)	3.74 (1.45)	Age
		DCD	2.00 (0.75)	1.73 (0.40)	3.56 (1.82)	
	V	TD	2.66 (0.54)	2.59 (0.87)	3.88 (0.94)	Age
		DCD	2.38 (0.63)	2.36 (0.64)	3.71 (1.15)	

For measures of path deviation a significant main effect of age was found for the distance to the gates after the deviation started [F(2,82)=5.52, p=.006, η_p^2=.12], with the younger children starting their deviation while significantly further from the gates than the older children or adults (7-11yrs > 12-17yrs = adults). In addition, a significant main effect of group was found for time left after the deviation started [F(1,82)=6.21, p=.015, η_p^2=.07] and the size of the deviation [F(1,82)=4.66, p=.034, η_p^2=.05]. These effects demonstrate that the individuals with DCD started their deviation earlier in their movement compared to their peers and they deviated to a greater extent than their peers. No other significant effect of age or group was found for the proportion of deviation trials [F<1]. Data can be found in Table 3.

Table 3. Path deviation variables for the three age groups and both the TD and DCD participants. Standard deviation is in brackets.

		Adult	12-17yrs	7-11yrs	Significant effects
Percentage of trials where a path deviation was seen (%)	TD	94 (16)	99 (4)	95 (10)	
	DCD	96 (10)	96 (8)	96 (11)	
Time remaining at start of path deviation (s)	TD	2.57 (0.99)	2.99 (0.36)	2.94 (0.35)	Group
	DCD	3.28 (0.47)	3.18 (0.40)	2.99 (0.69)	
Distance remaining at start of deviation (m)	TD	1.05 (0.31)	1.18 (0.26)	1.28 (0.24)	Age
	DCD	1.03 (0.28)	1.04 (0.23)	1.24 (0.17)	
Size deviation (cm)	TD	31.3 (7.40)	31.1 (5.81)	33.8 (5.39)	Group
	DCD	37.3 (7.83)	34.8 (6.25)	37.3 (7.84)	

Relationship between anticipatory adjustments and obstacle circumvention

The percentage adjustment values for step width and medio-lateral acceleration in the before phase were used to consider the relationship between adjustment and circumvention. These variables were chosen as they are the two variables which showed anticipatory adjustments. Correlations were then run between these variables and the measures of object circumvention in the after phase. For step width, the percentage adjustment in the before phase was shown to correlate significantly with medio-lateral velocity in the after phase [r=.215 N=88 p=.044] and distance from the gates at start of deviation [r=.235 N=88 p=.027]. Scatter plots of these significant correlations can be found in Figure 4. No significant correlations were found between the percentage adjustment of medio-lateral acceleration and the measures of object circumvention.

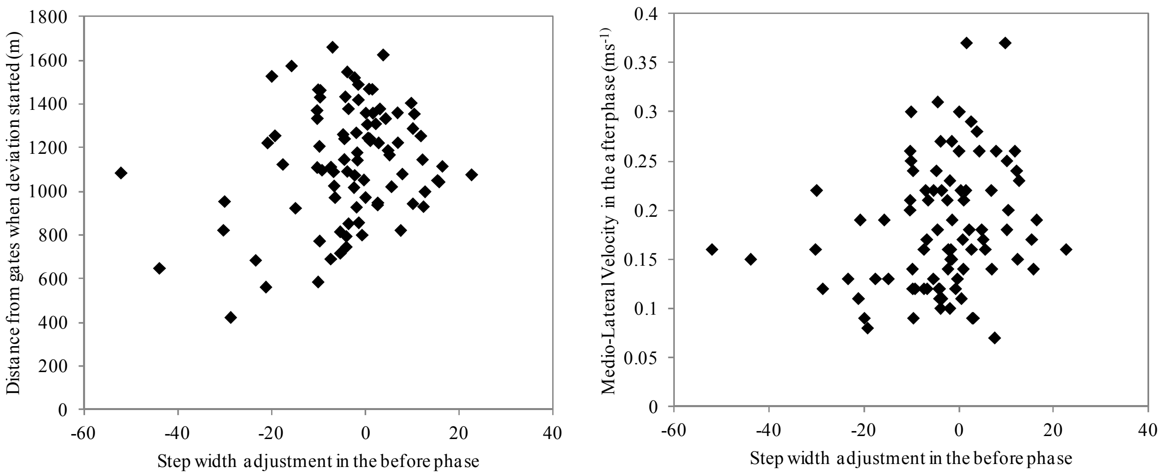

Figure 4. Scatter plots of significant correlations between step width adjustments in the before phase and variables in the after phase

Discussion

The current study considered aspects of anticipation and obstacle circumvention in individuals with and without DCD. The first aim of the study was to determine whether these individuals show anticipatory adjustments during a walking task when there is a possibility of an obstacle appearing. All of the participants (DCD and TD) showed an increase in medio-lateral acceleration when there was the possibility of an obstacle appearing compared to when there was not. In addition, the typical adults and typical older children showed a widening of their steps when there was the possibility of an obstacle appearing. These changes to movement are similar to adjustments we have seen previously in a study of healthy adults using the same methodology (Wilmut, Du, et al., In Press). These adaptations may allow participants to ready themselves for a movement to the left or the right. The participants with DCD and the youngest typical children only showed a change to medio-lateral acceleration and not to step width. This suggests a difference in how these populations ready the motor system for a potential event. From their work Mon-Williams et al. (2005) and later Wilmut & Wann (2008) concluded that for the children with DCD the cost of preparing a movement which then had to be changed outweighed the benefits of moving early (Mon-Williams et al., 2005; Wilmut & Wann, 2008). Essentially this conclusion states that the lack of anticipatory movement in the children with DCD was not due to a deficit per se, but rather a specific choice of movement selection. In the introduction we stated that the benefit of 'readying' the motor system for action in light of the *possibility* of an event was greater than the cost of altering the typical pattern of locomotion in typical adults. We see that again here, where the typical adults and typical older children do change their movement for the gate open and gate close trials. However, it seems that in the less mature motor systems of the younger typical children and the atypical motor systems of the individuals with DCD this is not the case and in fact the benefit of 'readying' the motor system for action in light of the *possibility* of an event does not out-weigh the cost of altering a typical pattern of locomotion. This conclusion suggests an inflexibility of the motor system (in terms of adjustments to step width) in these populations and is one that merits further consideration.

The second interesting question is whether the anticipatory adjustments we saw in the before phase relate to the nature of the circumvention in the after phase. We attempted to quantify this and demonstrated that the degree of step width adjustments related to both medio-lateral velocity and the distance from the gates when deviation started. Participants who showed a greater adjustment to step width demonstrated a smaller medio-lateral velocity and smaller distance from the gates. Given that previous studies have linked increased medio-lateral velocity to poor balance control (Deconinck et al. 2010) this would seem to indicate that the anticipatory adjustments are functional in supporting balance control during circumvention. The fact that we see no relationship between the change in medio-lateral acceleration in the before phase and the measures of circumvention makes it difficult to determine whether the one anticipatory change the individuals with DCD do make is linked to a more effective circumvention strategy or not.

When considering the nature of circumvention we see that medio-lateral velocity and acceleration was higher in the individuals with DCD compared to the typical individuals and that the individuals with DCD also started their path deviation earlier in the movement and tended to deviate more. These findings demonstrate a clear difference in object circumvention in young typically developing children and in individuals with DCD. These findings are in line with other observations of obstacle avoidance in this population. Deconinck et al., (2010) demonstrate increased medio-lateral velocity in children with DCD while stepping over obstacles and we have shown that when navigating through an aperture, both children and adults with DCD started their movement adjustment (shoulder rotation to fit through the aperture) sooner and rotated to a greater extent than their peers (Wilmut, Du, & Barnett, 2015; Wilmut, Du W., & Barnett, In Press, the same group of child participants were used in the latter paper as are in the current study). The combination of these findings may suggest that individuals with DCD attach higher costs to collision as compared to their peers. This may reflect poor motor control within this population or at the very least compensatory behaviour in a group of individuals who have become accustomed to their higher propensity for collision. This conclusion sits nicely with a recent explanation of DCD which is based on the constraints-based model of motor control (Newell, 1986); Wade & Kazeck (2016) state *"For children with DCD, the functional constraints of task, environment and their understanding of their own limited motor abilities may be a key element in accounting for their documented motor difficulties"* (pg 9). One final observation regarding circumvention is that velocity and acceleration in all three dimensions is higher in younger children compared to older children and adults. This may simply indicate a lack of ability in young children to specifically control momentum in one direction.

Prior to obstacle trigger, although not related to anticipatory control, we have also shown that regardless of the possibility of an obstacle medio-lateral velocity is higher in individuals with DCD compared to typical individuals. This mirrors a previous finding that medio-lateral velocity (and acceleration) is higher in this same group of children with DCD compared to their peers (Wilmut, Du, & Barnett, 2016). In our previous paper we concluded that this increased medio-lateral velocity may suggest a deficit in the integration and use of sensory information to control gait (this is in line with the suggestion that medio-lateral movement during walking relies on the integration of sensory information while anterior–posterior movement relies on lower-level propriospinal actions (O'Connor & Kuo, 2009). Functionally this suggests that individuals with DCD may have less control over walking as they have difficulty integrating information about the environment.

In the current study we have shown differences in the anticipatory mechanisms in individuals with DCD compared to typical individuals, with the individuals with DCD failing to show key components of anticipatory movement which we suggest are due to a cost-benefit trade off. Furthermore, we have provided preliminary evidence that a lack of anticipatory adjustments to step width may result in object circumvention which is less controlled.

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Supplementary Table. Data for the three conditions before the sensor. Values are given for the three age groups and the two groups (DCD and TD). Standard deviation is given in brackets.

		No gate			Gate open			Gate close		
		Adult	12-17yrs	7-11yrs	Adult	12-17yrs	7-11yrs	Adult	12-17yrs	7-11yrs
Normalised velocity										
ML	TD	0.12	0.10	0.14	0.12	0.10	0.14	0.12	0.11	0.14
		(0.04)	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.06)	(0.03)
	DCD	0.12	0.13	0.17	0.12	0.13	0.19	0.12	0.13	0.17
		(0.04)	(0.04)	(0.08)	(0.04)	(0.05)	(0.11)	(0.03)	(0.03)	(0.08)
AP	TD	1.41	1.38	1.72	1.44	1.41	1.73	1.44	1.45	1.73
		(0.20)	(0.12)	(0.19)	(0.18)	(0.24)	(0.16)	(0.18)	(0.38)	(0.22)
	DCD	1.41	1.39	1.76	1.32	1.39	1.97	1.44	1.38	1.91
		(0.20)	(0.27)	(0.89)	(0.17)	(0.20)	(0.82)	(0.18)	(0.21)	(0.78)
V	TD	0.19	0.20	0.25	0.18	0.22	0.25	0.19	0.26	0.25
		(0.03)	(0.06)	(0.05)	(0.03)	(0.14)	(0.05)	(0.04)	(0.23)	(0.06)
	DCD	0.19	0.20	0.26	0.17	0.18	0.24	0.19	0.18	0.24
		(0.03)	(0.06)	(0.10)	(0.04)	(0.05)	(0.09)	(0.04)	(0.05)	(0.10)
Normalised acceleration										
ML	TD	1.46	1.47	1.84	1.78	1.79	2.18	1.76	1.71	2.14
		(0.54)	(0.45)	(0.49)	(0.52)	(0.68)	(0.45)	(0.53)	(0.62)	(0.59)
	DCD	1.46	1.69	2.26	1.68	1.93	2.49	1.76	1.83	2.49
		(0.55)	(0.47)	(1.09)	(0.68)	(0.43)	(0.91)	(0.53)	(0.42)	(0.88)
AP	TD	1.65	2.37	3.06	1.94	2.13	3.33	1.97	2.07	3.34
		(0.32)	(0.20)	(0.48)	(0.37)	(1.00)	(0.57)	(0.38)	(0.84)	(0.68)
	DCD	1.60	2.24	3.29	1.65	2.02	3.57	1.65	1.99	3.42
		(0.38)	(0.53)	(0.84)	(0.30)	(0.52)	(1.50)	(0.31)	(0.43)	(1.47)
V	TD	2.51	2.84	3.81	2.61	2.74	3.92	2.65	2.66	3.91
		(0.60)	(0.39)	(0.79)	(0.58)	(1.36)	(0.74)	(0.57)	(1.42)	(0.90)
	DCD	2.51	2.85	3.53	2.41	2.39	3.82	2.64	2.39	3.85
		(0.59)	(0.74)	(1.31)	(0.59)	(0.51)	(1.30)	(0.57)	(0.59)	(1.68)