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Adaptations to walking on an uneven terrain for individuals with and without Developmental Coordination Disorder

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Abstract

Given the importance of walking in everyday life, understanding why this is challenging for some populations is particularly important. Studies focusing on gait patterns of individuals with Developmental Coordination Disorder (DCD) have shown that whilst increased variability is characteristic of walking patterns for this group, differences in spatio-temporal gait variables seem only to arise when task demands increase. However, these differences occur under rather artificial conditions, for example using a treadmill. The aim of this study, therefore was to examine the step characteristics of individuals with and without DCD whilst walking along an irregular terrain. Thirty-five individuals with DCD aged 8-32 years and 35 age and gender-matched controls participated in this study. Participants were divided into 3 age groups; 8-12years (n = 12), 13-17years (n =12) and 18-32years (n=11). Participants walked up and down a 6m walkway for two minutes on two terrains: level and irregular. VICON 3D motion analysis was used to extract measures of foot placement, velocity and angle of the head and trunk. Results showed that both groups adapted their gait to negotiate the irregular terrain, but the DCD group were more affected than their TD peers; walking significantly slower with shorter, wider steps and inclining their head more towards the ground. This suggests an adaptive approach used by individuals with DCD to preserve stability and increase visual sampling whilst negotiating an irregular terrain.

Key words; Developmental Coordination Disorder; Gait; Balance; Irregular terrain

Highlights;

- Movement control while walking on an irregular terrain was considered in individuals with and without Developmental Coordination Disorder (DCD)
- The irregular terrain had a greater influence on the individuals with DCD compared to their typically developing (TD) peers
- When on an irregular terrain, individuals with DCD walked more slowly, with shorter, wider steps and angled their heads towards the ground more than TD peers.
- Individuals with DCD use an adaptive approach to preserve stability and increase visual sampling while walking over an irregular terrain

1. Introduction

Competence in walking is a core skill necessary for many activities of daily living, and a major contributor to quality of life (Patla & Shumway-Cook, 1999). However, although walking is a mundane skill it is not a simple task. In fact, Winter (1991) argues that walking is one of the most complex and totally integrated movement tasks humans have to master.

Given the complexities of coordinated movement required for efficient walking it is easy to see that walking is a skill that individuals with movement difficulties may struggle with. One group that has received little attention, and yet has everyday movement difficulties are those with Developmental Coordination Disorder (DCD). DCD is an idiopathic movement disorder that affects the development of motor control and coordination in the absence of obvious physical or neurological dysfunction. The movement skills are below what would be expected given the person's age and opportunity to practice, and significantly interfere with activities of daily living, academic productivity and employment (American Psychiatric Association, 2013). These problems manifest in areas such as coordinated movement, riding a bike and learning to drive (Kirby, Edwards & Sugden 2011). It is estimated that DCD affects between 5-6% of children aged 5 to 11 years (APA, 2013), constituting a major childhood disorder which continues to adulthood (Cousins & Smyth, 2003; Kirby, Edwards, Sugden & Rosenblum, 2010; Losse, et al., 1991).

Themes emerging from a limited literature which has considered the walking patterns of individuals with DCD suggest that when children (Cherng, Liang, Chen & Chen, 2009; Deconinck, Savelsbergh, De Clercq & Lenoir, 2010; Wilmut, Du and Barnett, 2016; Woodruff, Bothwell-Myers, Tingley & Albert, 2002;) and adults (Du, Wilmut and Barnett, 2015) with DCD walk in a relatively stable environment (along a level pathway), the mean spatio-temporal gait variables (e.g. step length, velocity) show only subtle differences to those of typical gait. Clear group differences for children with DCD seem to arise in more challenging situations, such as when walking on a treadmill (Deconinck, et al., 2006[a]), or when visual information is removed (Deconinck, et al., 2006[b]). Other studies have also highlighted an increase in variability (i.e. decrease in consistency) of movement during gait in DCD (Du, et al., 2015; Rosengren, et al., 2009; Wilmut et al., 2016).

Wilmut et al. (2016) investigated movement variability in children with DCD, and they argue that elevated variability in medio-lateral velocity and acceleration of the centre of mass may indicate a difficulty integrating sensory information while walking. This argument is supported by other studies that focus on processing sensory information for individuals with DCD; Geuze (2003) and Wilson & McKenzie (1998) highlight how difficulty integrating sensory information could be a potential causal factor for the movement difficulties. Some studies suggest an over-reliance on visual information which may be due to a difficulty integrating streams of information from other sensory inputs (Wann, Mon-Williams & Rushton, 1998). Deconinck, et al. (2006[b]) considered sensory inputs by asking children to walk along a level pathway in a normal light condition and in a dark condition (a target LED was given for heading direction). Children with DCD walked more slowly and swayed more in the dark compared to the light condition while typically developing (TD) children showed no differences in gait across conditions. From these findings it was concluded that the TD group adapted by using other sensory information such as proprioception and/or the vestibular system, while the children with DCD were less able to do this. These findings suggest that differences seen in the walking patterns of children with DCD may be due to difficulty integrating sensory information, specifically, using sensory information other than vision.

Given that the maintenance of dynamic stability whilst walking requires the efficient integration of visual, vestibular and proprioceptive information (Peterka, 2002), it could be argued that in a laboratory setting (i.e. level, clear pathways) visual rather than proprioceptive and vestibular information would be the main focus of attention. However, in a natural setting we have to negotiate a more complex environment and may encounter different ground terrains (poorly finished pavement, cobbled surface, sand or grass), increasing the importance of integrating all three sensory systems. Some studies have considered how typically developing young and older adults walk on uneven terrains. These studies have found that whilst young adults (22-39yrs) maintain (or even increase) their velocity whilst walking on an uneven terrain, older adults (mean age 75-85yrs) walk more slowly with a shortened step length than the young adults (Marigold & Patla, 2008; Menz, Lord, & Fitzpatrick, 2003). The authors argue that this more conservative gait pattern indicates that the older participants perceived the irregular walking surface as a greater risk to dynamic stability, and adapted their gait to accommodate this threat. Furthermore, MacLellan and Patla (2006) argue that walking on some surfaces that are compliant (such as snow, grass or sand) can reduce the information available from the travel surface to the proprioceptive sensors in the body. To investigate this further, they examined the gait adaptations of eight young adults as they traversed a firm and a compliant walkway (compliant walkway comprised medium density foam). MacLellan and Patla (2006) propose that pedestrians increase their base of support to ensure the stability of the Centre of Mass whilst traversing compliant surfaces. These studies demonstrate the increased task demands which come from walking on an irregular terrain, however, it is unclear how a population who already find the integration of sensory information difficult will adapt to walking in on this type of terrain.

The aims of the current study, therefore, were to examine walking patterns in individuals with DCD whilst traversing an irregular terrain, and to determine whether these patterns differed between individuals with and without DCD. In order to determine how each group adapted their walking when traversing an irregular terrain, there were two walking conditions: a *level walking* condition to provide a baseline measure of walking; and an *irregular walking* condition. The percentage change in measures from one condition to the other allowed a direct comparison and thus an examination of the adaptations made. The control of the feet, using traditional spatio-temporal measures of walking and the angle of the head and the trunk were considered. Inclination of the head was taken as a proxy of gaze direction. Due to the findings of Deconinck et al. (2006[b]), who examined walking in the dark, it was hypothesised that individuals with DCD would show a greater adaptation of movement in the irregular walking condition compared to the TD participants and that this would be shown through the adoption of a 'safer' walking style (slower, shorter, wider steps; greater forward incline of the trunk), together with more forward incline of the head. A wide age range was included in this study to allow for the consideration of maturation of walking patterns, given that studies have shown developmental changes in individuals with DCD from childhood to adulthood (Wilmut & Byrne, 2014; Wilmut, Byrne, & Barnett, 2013). It was expected that the irregular terrain would affect the walking pattern of the children to a greater extent than the adults.

2. Methods

2.1. Participants

Thirty-five individuals with DCD (26 male; 9 female) aged 8-32 years and 35 age and gender-matched controls participated in this study. Participants were divided into 3 age groups; *Children* 8-12years (*n*=24), *Teenagers* 13-17years (*n*=24) and *Adults* 18-32years (*n*=22). All participants with DCD were recruited in-line with the DSM-5 (APA, 2013) and the UK guidelines for assessment of adults with DCD (Barnett, Hill, Kirby & Sugden, 2015). Participants with DCD were recruited from a local support group for individuals with coordination difficulties and from a group who had previously taken part in our studies. Please see Table 1 for sample demographics.

2.1.1. Selection and assessment for individuals with DCD >17 years of age

A range of assessments were used to ensure the four diagnostic criteria for DCD were met. Both the Movement Assessment Battery for Children-2 test component (M-ABC-2; Henderson, Sugden & Barnett, 2007) and the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition, Brief Form (BOT-2 Brief; Bruininks, & Bruininks, 2005) were used to determine whether significant movement difficulties were present (criterion A). All individuals with DCD >17 years of age scored below the 15th percentile on the M-ABC-2 and below the 18^{th} percentile on the BOT-2 Brief. Criterion B (impairment on everyday life) was assessed using a telephone interview and the Adult Developmental Coordination Disorder/Dyspraxia Checklist (ADC; Kirby, et al., 2010). The telephone interview was also used to determine that the onset of motor difficulties was during early childhood (criterion C) and could not be attributed to a sensory or neurological disorder or intellectual impairment (criterion D). Given the high rate of co-occurrences between DCD and ADHD (Blank, Smits-Engelsman, Polatajko, Wilson, 2012; Kadesjö & Gillberg, 1999), and the affect that increased levels of distractibility and impulsivity can have on motor skills, additional assessments were performed to check for attentional difficulties. The Conners Adult ADHD Rating Scales (CAARS, short version; Conners, Erhardt & Sparrow, 1999) was used for individuals >17 years of age. Only one participant >17 years with DCD scored highly on these rating scales, however subsequent analyses including and excluding this participant failed to affect the results and all participants were subsequently included in the study.

2.1.2. Selection and assessment for individuals with DCD ≤17years

As above, a range of assessments were used to ensure the four diagnostic criteria for DCD were met. Criterion A was assessed using M-ABC-2 test (Henderson, et al., 2007), all children with DCD scored below the 15th percentile. Criterion B was assessed using a telephone interview and the M-ABC-2 Checklist (Henderson et al, 2007) completed by parents of children 8-15 years and the ADC (Kirby, et al., 2010) completed by individuals aged 16-17 years; The telephone interview also established that the movement difficulty was apparent from early childhood (Criterion C) and that the difficulties could not be attributed to a sensory or neurological disorder or intellectual impairment (Criterion D). As above, additional assessments were performed to check for attentional difficulties. The Strengths and Difficulties Questionnaire, (SDQ; Goodman, 1997) is a brief behavioural screening tool for children aged 4-16 years, and was completed by parents to identify any behavioural problems. A total of 9 participants with DCD (<17 years) scored highly on the SDQ, however subsequent analyses including and excluding these participants failed to affect the results and all participants were subsequently included in the study.

2.1.3. Selection and assessment for typically developing participants

All typically developing (TD) participants were recruited from the local area and were age- (to within 6 months for children and 1 year for adults) and gender-matched to the participants with DCD. Inclusion criteria stipulated a self-report (or parental report where appropriate) of no motor difficulties or previously diagnosed medical conditions that might impact on movement skill, together with a score >16th percentile on the M-ABC-2 balance sub-section (this measure was most relevant to walking, and indicated balance performance within the typical range).

INSERT TABLE 1 HERE

2.2. Materials and Procedure

This research was approved by the Oxford Brookes University Research Ethics Committee and informed consent was obtained from all participants. A VICON 3D motion analysis system with 6 infrared cameras, operating at 120Hz, tracked the motion of small reflective markers attached to the skin at 11 bony landmarks: centre forehead, chin, chest (manubruim of the sternum), hips (trochanter major), knees (lateral epicondyle), ankles (lateral malleolus) and toes (caput for the 5th metatarsal). A flat walkway was laid out comprising six $1m^2$ interlocking high density, non-slip sports mats. The walkway was edged in a contrasting colour (red) to clearly delineate the path (blue) for participants to walk along. A cone was placed at the start and end of the walkway for participants to walk around. The VICON system was set up to capture the middle 4m x 1m area of the walkway to eliminate deceleration effects whilst navigating around the cones.

There were two conditions; *Level,* where the walkway was as described above, and *Irregular*, where rectangular pieces of foam (9cm wide x 10cm long x 2cm high) were stuck at irregular intervals and positions on to the middle 4m of the walkway. There were approximately 190 of these pieces of foam, made of the same non-slip material as the sports mats and were spaced at a minimum distance of 4cm and maximum distance of 10cm apart. The spacing essentially forced participants to walk on these foam rectangles rather than between them. All other materials remained the same as for level walking. For both conditions participants walked barefoot at a self-selected pace, for two minutes around the cones placed at either end of the walkway. They walked in a clockwise direction and in as straight a line as possible. All participants were given a demonstration and one practice trial (one walk from start to end cone) to familiarise themselves with each experimental condition. Measurements of leg length (greater trochanter to floor) and hip width (left trochanter major – right trochanter major) were taken, as these dimensions are known to affect some gait variables such as stride length (Stansfield, et al., 2003).

2.3. Data analysis

The VICON movement data were labelled and smoothed using a Butterworth low-pass filter (cut-off 10 Hz) and processed to extract the gait variables of interest using tailored Matlab™ routines. The Foot Velocity Algorithm (O'Connor, Thorpe, O'Malley & Vaughan, 2007) was chosen to determine the timing of Heel-strike (HS) and Toe-off (TO) which was used to identify complete strides. The maximum number of complete strides completed within the data collection area was identified for each participant (mean strides extracted; *Level* TD 8.86, DCD 7.83; *Irregular*; TD 8.40, DCD 6.66). Foot placement measures were taken from the ankle and toe markers from each foot and were used to identify three spatial measures; *Proportional step length:* anterior-posterior distance from lag ankle to lead ankle at their respective heel-strike, then normalised by leg length; *Step width ratio (SWR):* medio-lateral distance between ankle markers at heel-strike, then normalised by hip width; *Percentage gait cycle in double support (%DS):* amount of time during one gait cycle spent with both feet on the ground, expressed as a percentage of the whole stride, measured from ankle markers. *Velocity* was measured in meters per second (taken from the chest marker). Finally, the *angle* *of the head and trunk* were calculated at both heel-strike and toe-off marking the transition between stance and swing (Perry & Burnfield, 2010; Whittle, 2012). Pitch rotations between the front segment (*Head*; measured from markers on the forehead and chin: *Trunk*; measured from markers on the chest and midpoint between the hips) and the horizontal plane are presented, as recommended by Winter (1991). For all measures we report mean percentage differences between walking conditions: [(measure during level condition – measure during irregular condition) / (measure during level condition) x100)]. This approach was taken as it provides more informative data about the *adaptation* of walking patterns between conditions. Absolute values for the level condition are provided for reference.

2.4 Statistical Analysis

Two-way independent ANOVA's were used to investigate any percentage differences between *Group* (DCD, TD), and *Age* (Child, Teenage, Adult). Significant interactions were explored using simple main effects and significant main effects were investigated using post-hoc tests. Bonferroni corrections were applied to protect against Type I error. Statistical significance was set at the 5% level.

3. Results

3.1. Percentage change in spatio-temporal measures

Data for spatio-temporal measures can be found in Table 2. There were significant main effects of group for walking velocity ($F(1,62) = 12.65$, $p = .001$, $\eta^2 = .17$), proportional step length ($F(1,63) = 13.07$, $p = .001$, $\eta^2 = 0.18$), and step width ratio ($F(1,61) = 10.18$, $p = .002$, $\eta^2 = .14$), with the DCD group showing a greater reduction in percentage change in velocity and step length and a greater increase in percentage change in step width compared to the TD group. In addition, there were significant main effects of age for walking velocity ($F(2,61) = 3.86$, $p = .026$, $\eta^2 = .11$). Post hoc tests reveal a significant difference between children and teenagers ($p = .021$), but no significant difference between children and adults or teenagers and adults. This finding demonstrates that the children showed a greater reduction in percentage change compared to the teenagers. Finally, there was a group-by-age interaction for step width ratio ($F(2,61) = 6.80$, $p = .002$, $\eta^2 = .18$), simple main effects show this is due to a larger percentage change in Step Width Ratio (SWR) for children ($p = .049$) and adults ($p < .001$) with DCD compared to their TD controls, no difference was seen between the two teenage groups ($p > .05$). This interaction is illustrated in Figure 1. The percentage of time in double support (%DS) showed no significant effects of age, group or interaction between the two.

INSERT FIGURE 1 HERE

INSERT TABLE 2 HERE

3.2. Percentage change in Angles of the head and trunk

Data for percentage change in head and trunk angle can be seen in Table 3. There were significant group effects for head angle ($F(1,51) = 6.15$, $p = .016$, $\eta^2 = .11$), with the DCD group showing a greater percentage change reduction in head incline compared to their TD peers. In addition, there was a significant main effect of age for trunk angle ($F(2,51) = 4.62$, $p = .014$, $\eta^2 = .15$). Pairwise comparisons (using the Bonferroni correction) indicated that children showed a greater reduction in percentage change of trunk angle compared to teenagers ($p = .039$). No difference was seen between the children and adults or the teenagers and adults. No significant interactions were found.

INSERT TABLE 3 HERE

4. Discussion

The current study aimed to examine the adaptation to gait in individuals with and without DCD whilst traversing on an irregular terrain compared to a level one. It is clear that both groups made adaptations to their gait pattern whilst walking on the irregular, compared to the level terrain. However, it appears that the impact of the irregular terrain was greater for individuals with DCD compared to the control group. This was demonstrated by the individuals with DCD showing a greater reduction in step length, velocity and head angle and a greater increase in step width compared to the TD group. In other words, when walking on the irregular terrain the individuals with DCD shortened their step length, decreased their velocity, angled their head to the ground and increased step width more than the TD group.

The shortening of step length, widening of step width and slowing walking speed have been seen in combination previously (Bierbaum, Peper, Karamanidis & Arampatzis, 2010; Deconinck, et al., 2006[a]; Maki, 1997; Menz, et al., 2003) and are thought to help to preserve stability when there are environmental and/or internal challenges to balance. In fact, in their study looking at walking on an irregular terrain Menz, et al. (2003) and Marigold & Patla

(2008) found very similar adaptive walking in healthy older adults (75-85years), they concluded that this conservative walking strategy enables these older adults to accommodate the greater risk of falling in this complex environment. It seems that the adaptations in individuals with DCD in the current study serve a similar purpose, allowing these participants to maintain forward propulsion while reducing the risk of falling by increasing base of support.

In the introduction, we suggested that one reason individuals with DCD may find walking on an irregular terrain more challenging is an apparent difficulty they have with integrating sensory information while walking (Wilmut et al., 2016) and an over-reliance on visual information (Smits-Engelsman, et al., 2003; Wann, et al., 1998). To some extent the greater change in head angle in the individuals with DCD supports this. Whilst walking on an irregular terrain the individuals with DCD angled their heads more towards the ground than the TD individuals. If this is taken as a proxy for eye gaze, then it may suggest that these individuals are visually sampling the terrain more in the complex environment. This greater reliance on visual information, may be due to the difficulties these individuals have with integrating sensory information, both while walking (Deconinck et al., 2006[b]; Wilmut et al. 2016) and while performing other motor tasks (Geuze, 2003; Wilson & McKenzie, 1998). In the irregular terrain, the proprioceptive feedback from the feet becomes more unstable and difficult to interpret for both groups (as shown by MacLellan & Patla, 2006). It would seem that the TD participants were better able to adapt movement in order to accommodate environmental demands. This may support previous studies which have shown typical populations can manage different sensory inputs (Oie, Kiemel & Jeka, 2002; Peterka, 2002). However, the DCD group seem less able to do this and looked down to utilise additional visual information to help interpret the changing environmental constraints. These findings could be extended with further research using an eye tracker to investigate whether head angle is indeed a good proxy for eye gaze. Furthermore, making the walkway more complex by introducing changes in direction would add ecological validity to the investigation and provide a clearer picture of how individuals with DCD forge a path to their destination in the real environment.

In addition to the group differences described above, we found some effects of age, whereby children walked significantly slower than teenagers and leant their torsos more towards the ground than adults. These gait adaptations have been previously argued to assist with balance constraints for pedestrians in challenging situations (Deconinck et al 2006[a]; Maki, 1997; Menz, et al 2003). It could be argued that the reduced velocity gives the children additional time to process the complex environmental information as they are subject to the constraints of maturational processes of the central nervous system involved with the organisation of movement (Duysens & Van de Crommert, 1998). They are also heavily reliant upon perceptual processes, particularly visual, vestibular and proprioception (Hulme & Snowling, 2009) and their reduced speed may give additional processing time to assimilate this information. Thus, whilst the motoric demands of the walking task are mature by 7 years (Sutherland, Olshen, Cooper, Woo, 1980), the sensory processing needed to effectively interact with a complex environment may not be mature until later in development.

In addition to considering age we also found that the adaptations to changing environments were different across age for the two groups for step width ratio. Specifically, the children and adults demonstrated clear group differences (with a greater percentage increase in step width ratio in the DCD compared to the typically developing group), but there was no group difference for the teenage group. However, whilst there was no difference in percentage change between teenagers with and without DCD, the response to the cobbled terrain differed when compared to the other age groups (i.e. a smaller percentage increase in step width ratio for teenagers with DCD compared to children and adults with DCD , a larger percentage increase in step width ratio for typically developing teenagers compared to typically developing children and adults). Whilst the phenomenon of the adolescent growth spurt was not a focus of the present study, and any conclusions drawn are purely speculative, it may offer an explanation for these results. Beunen and Malina (1988) argue that the rate of development during the adolescent growth spurt is inversely proportional to the level of motor performance before the spurt. Thus it could be argued that children who are well coordinated at the start of the growth spurt, (i.e. the typically developing teenagers) are more at risk of the negative effect on motor skills (and subsequent wider SWR to accommodate the cobbled terrain) than poorly coordinated children (such as the teenagers with DCD). These findings are supported by research by Visser, Geuze and Kalverboer (1998) who investigated the relationship between the adolescent growth spurt and motor competence for individuals with and without DCD. Results suggested that rapid growth during the teenage years has a negative effect on motor skills, but this affect was more apparent in the typically developing teenagers than the DCD group, who actually improved their motor competence during this time. Clearly caution is needed when interpreting cross-sectional data and our findings suggest that more research is needed to better understand these age effects.

5. Conclusions

The results from the current study suggest that all participants adopted a 'safer' walking strategy whilst traversing the irregular compared to the level terrain. However, the DCD group showed even greater adaptations to the irregular terrain, walking more slowly with shorter, wider steps, and inclined their head more towards the ground than their TD peers. These strategies suggest an adaptive approach used to preserve stability and increase visual sampling whilst negotiating the irregular terrain.

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Table 1. Means, (standard deviations) of demographic data for participants in this study. Significant group differences (TD, DCD) for each measure are also reported.

Measure	Age group	DCD group Mean (SD)	TD group Mean (SD)	p value
Gender ratio M: F	Child	10:2 (N=12)	10:2 (N=12)	
	Teenage	9:3 (N=12)	9:3 (N=12)	
	Adult	7:4 (N=11)	7:4 (N=11)	
Age	Child	10y 4m (1.25)	10y 3m (1.31)	$p > 0.05$
	Teenage	16y 2m (1.27)	16y 0m (1.65)	$p > 0.05$
	Adult	24y 2m (5.08)	27y 7m (4.97)	$p > 0.05$
Leg length (cm)	Child	74.60 (107.81)	75.17 (34.86)	$p > 0.05$
	Teenage	90.83 (67.13)	92.50 (41.23)	$p > 0.05$
	Adult	88.45 (39.59)	91.72 (75.77)	$p > 0.05$
M-ABC balance (%)	Child	2.59 (1.90)	69.75 (25.50)	$p < 0.001$
	Teenage	2.99 (3.01)	61.58 (25.21)	$p < 0.001$
	Adult	2.78 (2.84)	54.27(25.36)	$p < 0.001$
SDQ	Child	High risk N =6	High risk N = 0	
	Teenage	High risk N =3	High risk N = 0	
CAARS	Adult	High risk N =1	High risk N = 0	

Key; **M=male; F=female; M-ABC=Movement Assessment Battery for Children; SDQ= The Strengths and Difficulties Questionnaire; CAARS= The Conners Adult ADHD Rating Scales**

T**able 2.** Means of absolute values for level terrain, standard deviations (in brackets) and percentage change in spatio-temporal measures from level (L) to irregular (I) terrain.

Measure	**Age**	DCD Mean		TD Mean		
		Level	% change L: I	Level	% change L: I	Significant results [post hoc]
Velocity	Child	0.99	-44.30	1.05	-29.57	
(ms^{-1})		(0.20)	(17.44)	(0.17)	(12.61)	
(*n* = 68)	Teenage	1.06	-24.02	1.12	-21.51	Group ** [DCD < TD]
		(0.22)	(9.15)	(0.12)	(21.82)	Age * [C < T]
	Adult	1.06	-38.98	1.10	-11.75	
		(0.17)	(13.10)	(0.18)	(24.20)	
Prop	Child	0.61	-14.55	0.66	-9.38	
step		(0.08)	(18.52)	(0.05)	(10.13)	
length	Teenage	0.58	-11.72	0.62	-2.93	Group* [DCD < TD]
		(0.09)	(17.43)	(0.05)	(4.78)	
	Adult	0.63	-19.69	0.64	-3.39	
		(0.05)	(7.58)	(0.07)	(11.30)	
SWR	Child	0.83	32.59	0.92	10.58	
(*n* = 68)		(0.17)	(20.15)	(0.12)	(16.34)	
	Teenage	0.63	5.91	0.68	15.20	Group* [DCD > TD]
		(0.17)	(19.45)	(0.13)	(36.95)	Group-by-age interaction*
	Adult	0.66	41.42	0.75	-4.81	
		(0.20)	(30.58)	(0.13)	(23.67)	
%DS	Child	15.65	44.60	15.05	35.08	
		(3.05)	(28.39)	(1.39)	(19.74)	
	Teenage	17.67	18.01	15.80	24.10	ns
		(4.46)	(46.21)	(2.19)	(17.42)	
	Adult	16.74	29.74	16.04	18.22	
		(5.66)	(49.15)	(1.13)	(12.47)	

***Key*; * *p* = significant to 0.05 level; ***p* = significant to 0.001 level; ns = not significant. SWR=Step Width ratio; %DS= Percentage gait cycle in double support.** N.B. For two measures, values are only reported for 68 participants in both cases this was due to 1 teenager with DCD and their matched pair being removed from analysis as the chest (walking speed) or hip (step width ratio) marked was occluded throughout a number of trials.

Table 3. Means of absolute values for level terrain, standard deviations (in brackets) and percentage change in in head and trunk angles whilst walking on the level (L) to irregular (I) terrain.

Measure	**Age**	**DCD**		**TD**		
		Level	% change L: I	Level	% change L: I	Significance
Head angle ^{o} (*n=58*)	Child	72.63 (4.45)	-37.46 (14.24)	75.93 (5.35)	-27.30 (14.44)	Group* [DCD<TD]
	Teenage	69.52 (11.04)	-30.72 (15.07)	72.10 (10.54)	-18.59 (11.63)	
	Adult	72.86 (8.83)	-28.32 (17.50)	78.83 (9.72)	-23.06 (11.51)	
Trunk angle ^{o} (*n=64*)	Child	90.63 (3.93)	-12.54 (13.84)	88.82 (4.44)	-9.34 (6.90)	Age* [C<A]
	Teenage	86.62 (3.97)	-3.96 (4.02)	89.17 (4.17)	-6.39 (6.55)	
	Adult	91.39 (4.15)	-2.92 (5.06)	92.04 (4.48)	-5.86 (7.57)	

***Key*; * *p* = significant to 0.05 level; ***p* = significant to 0.001 level; ns = not significant.** N.B. For head angle, values are reported for 58 participants (2 children, 3 teenagers with DCD; 1 TD adult and matched controls removed). For trunk angle, values are reported for 64 participants (2 children, 2 teenagers with DCD and matched controls removed). In all cases this was due to obscured markers (head – forehead marker; trunk = chest marker) for a number of trials.

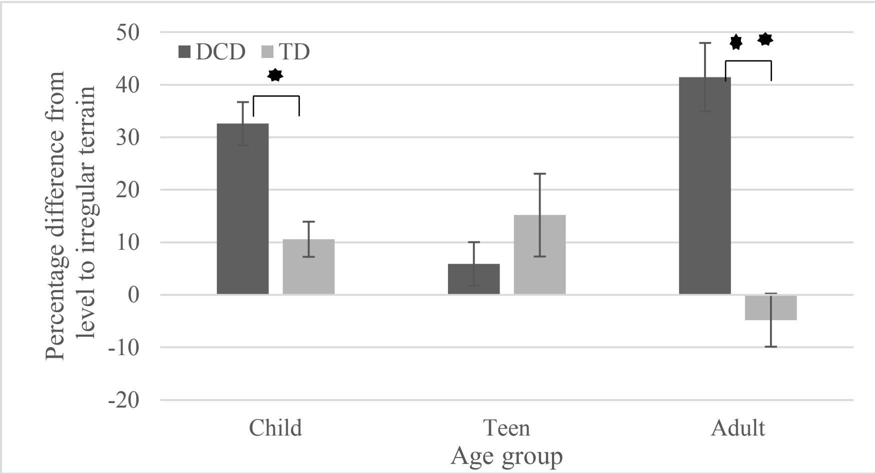

Figure 1. Percentage difference in step width ratio from level to irregular terrain. Error bars represent standard error. ***key*** ✸ *p* = significant to 0.05 level; ✸✸ *p* = significant to 0.001 level.