Dynamic control of balance in children with Developmental Coordination Disorder

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Chapter 4

Short-term motor learning of dynamic balance control in children with probable Developmental Coordination Disorder

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Research in Developmental Disabilities (2015), 38, 213-222

ABSTRACT

Aim: To explore the differences in learning a dynamic balance task between children with and without probable Developmental Coordination Disorder (p-DCD) from different cultural backgrounds.

Methods: Twenty-eight Dutch children with DCD (p-DCD-NL), a similar group of 17 South African children (p-DCD-SA) and 21 Dutch typically developing children (TD-NL) participated in the study All children performed the Wii Fit protocol. The slope of the learning curve was used to estimate motor learning for each group. The protocol was repeated after six weeks. Level of motor skill was assessed with the Movement ABC-2.

Results: No significant difference in motor learning rate was found between p-DCD-NL and p-DCD-SA, but the learning rate of children with p-DCD was slower than the learning rate of TD children. Speed–accuracy trade off, as a way to improve performance by slowing down in the beginning was only seen in the TD children, indicating that TD children and p-DCD children used different strategies. Retention of the level of learned control of the game after six weeks was found in all three groups after six weeks. The learning slope was associated with the level of balance skill for all children.

Conclusion: This study provides evidence that children with p-DCD have limitations in motor learning on a complex balance task. In addition, the data do not support the contention that learning in DCD differs depending on cultural background.

INTRODUCTION

Children with motor coordination problems, such as Developmental Coordination Disorder (DCD), frequently experience challenges in performing motor activities in which balance is required. Evidence suggests that the poor motor performance seen in these children may be partially explained by deficits in postural control (Geuze, 2005; Johnston, Burns, Brauer, Richardson, 2002). Children with DCD also appear to learn differently compared to typically developing (TD) children, which affects their acquisition of balance-related motor skills (American Psychiatric Association, 2013). In particular, these children seem to be delayed in reaching the level of automaticity (Visser, 2003). Consequently, children with DCD need more time, to reach an appropriate level of performance in motor tasks compared to their TD peers (Kirby, Sugden, & Edwards, 2010). There are, however, only a few studies that directly tested skill acquisition in children with DCD (Gheysen, Waelvelde, & Van Fias, 2011; Lejeune, Catale, Willems, & Meulemans, 2013; Marchiori, Wall, & Bedingfield, 1987); and of these only one multiple case study used a skill that required whole body postural control (Marchiori et al., 1987).

Postural control is a prerequisite for skilled motor performance. It is referred to as an active process of control of the body in static or dynamic situations. Postural control manifests in four ways: (i) awareness of the orientation of body segments in relation to the environment or task; (ii) controlling the center of mass within the base of support, also referred to as balance; (iii) preparing for a movement or action by anticipatory postural adjustments; (iv) reacting to an internal or external perturbation of posture also known as reactive postural adjustments (Dusing & Harbourne, 2010; Goldfield, 1995). Poor postural control, including inadequate dynamic balance strategies, delayed anticipatory and slow reactive postural adjustments are commonly seen among children with DCD (Geuze & Wilson, 2008; Johnston et al., 2002).

Studies investigating how children with DCD control the perturbations that arise during goal-directed movements (i.e. dynamic balance) have typically examined performance within tasks such as gait (Rosengren et al., 2009) and obstacle crossing (Deconinck, Savelsbergh, Clercq, & De Lenoir, 2010). Deconinck et al. (2006a) reported that children with DCD make adaptations to their gait pattern on a treadmill. Rosengren et al. (2009) reported more variability, complexity and asymmetry in the movement pattern of gait in children with DCD. However, dynamic balance seems specifically compromised when balance demands increase. Characteristic difficulties that show up are slowing down of gait with increase of the medio-lateral sway, both in the dark (Deconinck et al., 2006b) and during obstacle crossing (Deconinck et al., 2010). Children with DCD seem to rely more on sensory and visual information compared to their peers (Bair, Barela, Whitall, Jeka, & Clark, 2011; Cherng, Hsu, Chen, & Chen, 2007).

Adequate postural control is achieved by 'an active process that exploits the reactive forces from the environment by generating appropriate muscle activations' (Geuze & Wilson, 2008, p. 229). This active process of motor control includes the use of a combination of both feed-forward and feedback control strategies (Miall & Wolpert, 1996). Anticipatory postural adjustments (APAs) that accompany goal-directed active movements and are based on feed-forward motor control or internal forward modeling (Wing, Flanagan, & Richardson, 1997). Feed-forward motor control is defined as the ability to estimate the temporal and spatial requirements of a motor task and predict the sensory consequences of the impending action (Miall & Wolpert, 1996). If necessary, rapid online corrections (ROC) in real time can be used if the movement does not match the predicted outcome. The feedback system is reliant on adequate sensory information, error detection and integration (Scott, 2012) and if working well, it will drive reactive postural adjustments (RPAs). RPAs are usually rapid adjustments induced by external perturbations to help re-stabilize the body (Nashner, 1980; Shumway-Cook & Woollacott, 2007). RPAs are reliant on the ability to use sensory information (e.g. visual, tactile, and vestibular) to calculate an adjustment to disturbances.

Wilson, Ruddock, Smits-Engelsman, Polatajko, and Blanks (2013) conclude that children with DCD have a deficit in the forward modeling of movement, referred to as the internal modeling deficit (IMD). Specifically, predictions, based on efferent information and visual feedback, seem unreliable and ROCs are inadequate among children with DCD (Hyde & Wilson, 2011a, 2011b). Whether the postural control problems are caused by deficits in processing sensory information, lack of experience or deficits in motor learning is not known.

Although DCD is a disorder characterized by delayed acquisition of skilled motor actions or deficits in motor learning, remarkably little research focused on how children with DCD learn new motor skills. The few studies that have attempted to study questions relating to deficient or inefficient learning in children with DCD are inconsistent in outcome. For example, Missiuna (1994) examined the impact of explicit instruction on a simple aiming task using a Fitts paradigm (Fitts, 1954). Children were required to move a mouse pointer from a central point on the screen toward a target in response to a visual stimulus. Children with DCD were found to perform more poorly than their peers on measures of motor skill. Interestingly, groups did not differ in their rate of learning, or in the extent to which they were able to generalize the learned skills to other tasks. Lejeune et al. (2013) used adapted touch screen technology as a modification of the keyboard tasks used by Wilson, Maruff, & Lum (2003) and Gheysen et al. (2011). Children were required to respond as quickly and accurately as possible to stimuli appearing at different locations on a computer screen by pressing corresponding keys on the keyboard or the touch screen; participants were not told that the stream of stimuli corresponds to a repeating sequence. Learning of the sequence was demonstrated by improvement in the speed of response across trials and, more specifically, by the difference in response latency between a random block of stimuli and the repeating sequence block, indicating clearly that skill learning was sequence-specific. Their findings revealed no group differences, although Gheysen et al. (2011) found a lack of adaptation to a different sequence in children with DCD. In contrast, when training a more complex skill, Marchiori et al. (1987) found that after extensive training of two boys with poor motor skills on hockey slap shots for six weeks, the performance remained extremely variable in phasing and timing compared to the performance of two age matched boys. Thus, the question whether children with DCD have problems with motor learning remains a complex question, and the problems seem to depend on task and condition.

Based on the knowledge that the majority of children with DCD do experience balance problems, and the fact that no studies thus far have examined the rate at which children acquire balance skills, the aim of this study is to examine the rate of learning a dynamic balance task. Specifically, to examine the progress of learning of a dynamic balance task in typically developing children and in children with balance problems and probable DCD (p-DCD) from the Netherlands (p-DCD-NL) and South Africa (p-DCD-SA). Since the latter group (p-DCD-SA) had no earlier exposure to computer games, we hypothesized that being novice to a task, would influence the amount and rate of learning. Similarly, we hypothesized that children, who were accustomed to playing motion steered computer games, would be faster learners on a Wii Fit system. Further objectives of this study were to examine the retention effect of motor learning after six weeks and to analyze whether the rate of motor learning was related to performance of more general balance skills.

METHODS

Participants

Dutch children between the ages of 5 and 11 years with probable DCD (p-DCD) were selected from referrals through a practice of pediatric physical therapy and through teachers of two primary schools for special education in Groningen, the Netherlands. South African children between the ages of 6 and 10 years were recruited from a primary school located in a low-income community in Cape Town, South Africa. All children were tested using the Movement Assessment Battery for Children-2 (MABC-2) (Henderson, Sugden, & Barnett, 2007). Children were included if their total test score and the Balance component score was ≤16th (≤7th standard score). All included children were reported by their parents and/or teachers as experiencing motor problems in daily life. However, many of them did not have a confirmed medical diagnosis of DCD, therefore the group is referred to as probable DCD (p-DCD). Children with typical motor development were recruited in the Netherlands from a mainstream primary school and also tested on the MABC-2. They were included in the typically developing group (TD group) if their total test score and their Balance component score was >16th percentile (>7th standard score). Children diagnosed with a medical, neurological and mental disorder or IQ < 70 were excluded. Demographic characteristics of all three groups are presented in Table 4.1.

The study was approved by the Ethics Committee of the Department of Psychology, of the University of Groningen and the Faculty of Health Sciences Human Research Ethics committee of the University of Cape Town (HREC 218/2012) and permission to conduct the study was granted by the designated educational authorities. All parents and children gave their informed consent or assent.

Table 4.1 Demographic characteristics and motor test outcome measures at baseline of all three groups; typically developing children (TD), children with p-DCD from the Netherlands (p-DCD-NL) and South Africa (p-DCD-SA).

Groups	TD (n = 21)	p DCD-NL (n = 28)	p-DCD-SA (n = 17)
Mean age in year; months (SD)	8; 8 (1; 3)	8; 2 (1; 4)	7; 8 (1; 0)
Range	6;4–11;5	5;9 –11;3	6;2–9;77
Sex ratio f/m	.48	.36	.59
Mean MABC-2 total standard score (SD)	13.2 (2.8)[**,^^]	2.5 (1.4)[**]	2.8(1.5)[^^]
Range standard score	9–19	1–6	1–5
Mean MABC-2 balance standard score (SD)	11.4 (2.1)[**,^^]	3.3 (1.6)[**,#]	4.3(1.7)[^^,#]
Range standard score	9–17	1–7	1–7

[#] p-DCD-NL vs p-DCD-SA p < .05.
** p-DCD-NL vs TD p <. 01
^^ p-DCD-SA vs TD p < .01.

Instruments

The Movement ABC-2

The Movement Assessment Battery for Children – second edition (MABC-2) (Henderson et al., 2007) was used to test motor performance. The test consists of three sections: Manual Dexterity (three items), Aiming and Catching (two items) and Balance (three items). The raw scores on each item can be recoded into an item standard score and summed into a total standard score (range 1–19; mean score = 10; SD = 3) and percentile score. Component standard scores can also be derived for each section. Standard scores >7 are regarded as average/normal motor performance, children who achieve scores 6–7 are considered to be at risk for motor problems and scores ≤5 indicate a significant motor problem.

Wii Fit training protocol

The Wii Fit training protocol was developed specifically for this study (Jelsma, Geuze, Mombarg, & Smits-Engelsman, 2014). The Wii is an interactive video computer system (Nintendo®) that uses a Wii balance board (WBB) as a remote controller. A child standing on the balance board can interact with the video game by shifting weight. The WBB software calculates the center of pressure (COP) from the displacements of the child, which causes the virtual character (Mii) to move on the display. The sensitivity of the WBB is normalized according to the child's weight, which is a standard procedure of Nintendo Wii. The WBB has been found to be a valid tool to measure balance compared to a laboratory-grade force platform (Clark et al., 2010).

The Wii Fit training protocol consists of ten repeated runs of the ski slalom game. The goal of the game is to ski through 19 gates along a ski slope without missing a gate and as fast as possible. In the Wii Fit ski slalom game the Mii speeds up or slows down when the child shifts his or her center of mass respectively forward or backward (anterior/posterior), while shifting the center of mass to the left and right (lateral) directs the skier sideways. The spatial layout of the gates on the slope is invariant. The individual gates vary in their distance from the middle of the slope and in distance between consecutive gates along the slope.

Before starting, all children are instructed to pass through as many gates as possible, but speed is not emphasized. The protocol starts when the assessor is sure the child understands the game. No practice trials were included because we wanted to study the learning process from the first trial. Two children of the p-DCD-NL group were excluded from the study because over the first 5 runs they did not seem to understand how to control the Mii, leaving n = 28 in this group for the analyses.

During the game, immediate feedback (audio and visual signal of success or failure) is provided as the child passes through the gates. Immediately after a run, the Wii score is presented on the screen. The children were able to see this feedback and were encouraged to do improve the successive attempts. In the first four trials the children have the opportunity to discover the response of the Mii by changing their COP in a playful setting. Additional instructions and demonstrations were given between the fourth and fifth run, according to protocol. Demonstration was used in order to show the children what to do, or how to improve control over shifting weight to enhance the chance to pass through the gates. The assessor demonstrated the lower limb balance strategy (Michalski et al., 2012), that is, the way to shift weight in a controlled manner by using leg and hip movements while the child observed. The assessor then asked the child to try the movement. When the child could not demonstrate the movement, the weight shift was induced by placing hands on the child's pelvis, giving tactile feedback so that the child could feel the movement. After this the child was free to explore further strategies in the next six trials and find the best way to get a good result.

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Procedure

A self-developed questionnaire was administered to record demographic variables and children were asked whether (yes/no) the child had ever played Nintendo Wii Fit games. All children were tested on the MABC-2 in their own school environment by special trained assessors. Children with p-DCD or TD were selected based on the MABC-2 scores and three groups were established: (1) TD group, (2) p-DCD-NL group for Dutch children and (3) p-DCD-SA for South African children. All children were instructed on the Wii Fit ski slalom game, according to the standardized protocol by two different assessors. The change over the ten runs on the Wii Fit protocol was used to determine short-term motor learning. A second series of runs was recorded six weeks later. All children and parents were instructed and agreed that children would not play on any Wii Fit balance game during this period.

Data analysis

To compare groups for age and weight analysis of variance was used with post hoc Bonferroni tests. Chi^2 was used to test for gender differences. The p-DCD-NL group and p-DCD-SA group were tested for differences on MABC-2 Total Score (TS) and balance component at baseline using *t*-tests (see Table 4.1). The effect of Wii experience was tested within the TD group and within the p-DCD-NL group to determine whether a correction for Wii experience was needed.

Short-term motor learning was estimated from a growth curve model of change in the Wii outcomes over ten runs. Wii outcomes were number of gates missed, the duration of the descent and the Wii score. The Wii software derives a Wii score from the following equation: Wii Score = T + (# × 7 s), where T is the time taken to reach the end of the slope, # is the number of missed gates and 7 s is the penalty in seconds for each gate missed.

The Wii data of 10 runs was fitted by the growth curve $y_n = a - (a - b)/(1 - 1/n)$ in an iterative procedure using the least sum of squares (with $1 \leq n \leq 10$). The curve has a start value (a) at the first run, and would have an end value (b) after endless runs (b is the limit value); (a – b) is the learning potential. For an example of these curves see Fig. 4.1. The least sum of squares represents the variability between the runs relative to the learning curve. The learning slope over 10 runs was determined from the estimated curve as $(Y_1 – Y_{10})/\text{mean } Y_{1–10}$.

For the first research question MANOVA's were used to compare differences in the slope of the learning curve and the least squared fit of (i) missed gates, (ii) duration of the descent and (iii) Wii scores of the repetitive task between groups.

Similarly, the retention effect was tested using GLM repeated measures by comparing the mean missed gates score of run 9 and 10 of the first test with run 1 and 2 of the second test after six weeks. For this analysis the TD group had 19 children as two TD children were lost to follow up due to illness on the days of testing, and the p-DCD-NL group had 14 children because the other 14 started

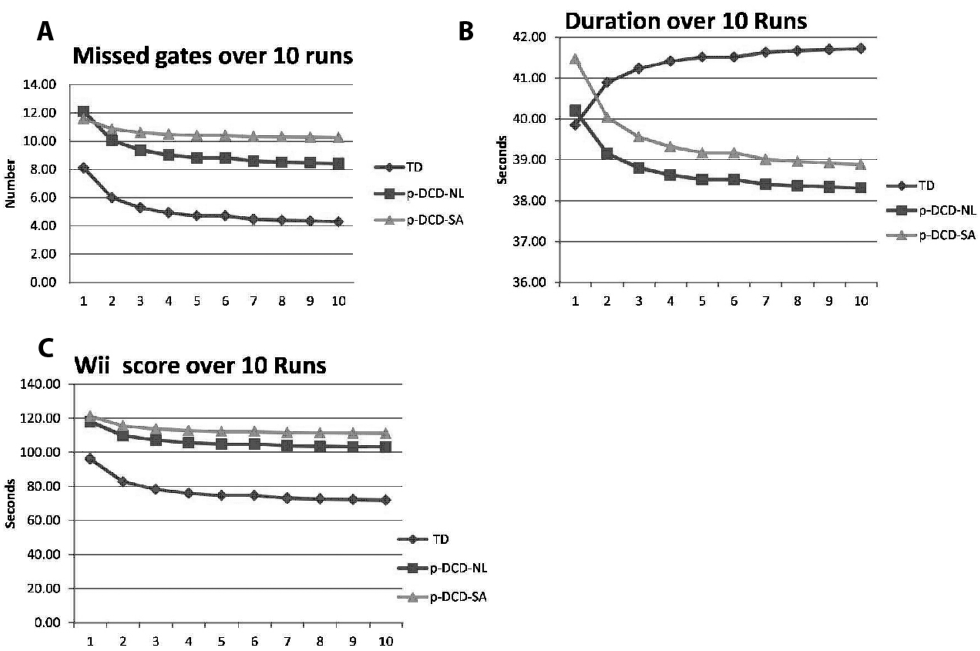

Fig. 4.1. *Model of the learning curves of the 3 groups over 10 runs for: (A) the number of missed gates; (B) the duration of descent; and (C) the combined Wii score.*

intervention immediately after the first assessment. The p-DCD-SA group remained at n = 17. Partial eta squared (η_p^2) was calculated for effect size (interpretation: 0.01–0.05 a small effect; 0.06–0.14 a medium effect; and 0.14 or greater a large effect (Field, 2010)). If appropriate, post hoc Bonferroni tests were applied.

Linear regression analysis was used to test whether the learning slope of the missed gates or the learning slope of the Wii scores was a predictor for motor test outcomes over all groups.

RESULTS

Group differences in demographic data, MABC-2 performance and Wii-experience

Groups were comparable in age and weight ($F(2,63) = 3.0$, $p = .056$; and $F(2,63) = .55$, $p = .579$). Gender was similarly distributed in the groups ($\text{Chi}^2 < 2.3$, $p > .131$).

The MABC-2 total score at baseline were not different between p-DCD-NL and p-DCD-SA ($t(43) = -.70$, $p = .49$). However, the South African group was more proficient on the MABC-2 balance component score than the Dutch group ($t(43) = -2.12$, $p = .04$) (see Table 4.1).

Nine TD children (43%) and eight children of the DCD-NL group (29%) had previous Wii Fit experience. None of the SA children had any experience with the Wii. To check if Wii experience had an impact on Wii outcomes we tested if children with and without Wii experience within the TD group, scored differently on Wii duration and Wii missed gates. No difference was found (multivariate ($F(2,18) = .24$, $p = .789$; univariate all $p > .624$)). Also within the p-DCD-NL group no differences were found for Wii experience both multivariate ($F(2,25) = .91$, $p = .416$) nor univariate (all $p > .357$). Therefore, and given the fact that none of the children in the p-DCD-SA group had any Wii experience at all, Wii experience was not included as covariate in further analyses.

Short-term motor learning

Over a total of ten runs the TD group missed a mean of 5.1 gates per run (SD 2.6; 26.8% miss), the p-DCD-NL group 9.7 (SD 2.6; 51.1%) and the p-DCD-SA group 10.6 (SD 2.1; 55.8%) gates. Fig. 4.1A shows the learning curves of performance of the variable "missed gates" of all three groups.

The groups differed significantly on the multivariate ($F(4,126) = 7.8$, $p = < .001$, $\eta_p^2 = .20$) and univariate test both in slope ($F(2,63) = 11.3$, $p = < .001$, $\eta_p^2 = .26$) and least squared fit ($F(2,63) = 4.9$, $p = .01$, $\eta_p^2 = .13$) based on missed gates. Post hoc tests showed a significant difference in motor learning slope between the TD group and the p-DCD-NL group ($p = <.001$) and the TD group and the p-DCD-SA group ($p = <.001$). No difference was found in motor learning between both p-DCD groups ($p = .48$).

Regarding the least squared fit, post hoc tests only revealed a difference between both p-DCD groups ($p = .02$) with a better least-squared fit of the learning curve in the p-DCD-SA group compared to the p-DCD-NL group (see Table 4.2).

It took the TD group a mean of 41.3 (SD 3.8) seconds, the p-DCD-NL group 38.7 (SD 3.7) seconds

Table 4.2 Slope of motor learning and least squared fit (LSF) per group over ten runs.

	Slope missed gates	LSF missed gates	Slope duration	LSF duration	Slope Wii Score	LSF Wii Score
TD group (n = 21)	.94	41.0	–.03	10.8	.34	204.3
p-DCD-NL group (n = 28)	.28	56.8	.06	13.7	.17	245.5
p-DCD-SA group (n = 17)	.15	35.4	.07	10.0	.10	175.4

and the p-DCD-SA group 39.4 (SD 4.9) seconds to complete a run. Fig. 4.1B shows the learning curves based on the duration to finish the runs. It seems in Fig. 4.1B that the TD group was slower than the p-DCD groups.

The groups did not differ in duration on the multivariate ($F(4,126) = 1.6$, $p = .18$, $\eta_p^2 = .05$) test. For the univariate test there was a trend to differ for slope ($F(2,63) = 2.6$, $p = .08$, $\eta_p^2 = .08$) but not for least squared fit ($F(2,63) = .7$, $p = .51$, $\eta_p^2 = .02$) between the groups (see Table 4.2). Pairwise comparison (without Bonferroni correction) showed near significant differences between the TD and the p-DCD groups ($p = .051$ and $p = .053$ for p-DCD-NL and p-DCD-SA groups respectively).

The Wii score that takes into account the speed–accuracy trade off, showed a mean score for the TD group of 77 s (18.4 SD), the p-DCD-NL group 106 (17.9 SD) and the p-DCD-SA group 113 s (12.6 SD). Fig. 4.1C shows the learning curves based on the Wii score. Because the TD group slowed down slightly during their repetitive runs while the DCD groups speeded up, this integrated value was analyzed. The curve shows a comparable pattern as the missed gates curve in Fig. 4.1A, even though it is corrected for the difference in time it took the children to complete the runs.

The groups differed significantly multivariate ($F(4,126) = 3.0$, $p = .022$, $\eta_p^2 = .09$) and univariate only in motor learning slope of Wii score ($F(2,63) = 4.0$, $p = .02$, $\eta_p^2 = .11$) and not in least squared fit ($F(2,63) = 2.0$, $p = .145$) (see Table 4.2). Post hoc tests showed a significant difference in motor learning slope of Wii score between the TD group and p-DCD-SA ($p = .03$). No differences were found in motor learning curve variables based on Wii scores between the TD group and p-DCD-NL group ($p = .12$), nor between both p-DCD groups ($p = 1$).

Retention effect

There was no difference between the mean number of missing gates of run 9 and 10 of the first measurement compared to the mean of run 1 and 2 after six weeks. An interaction effect of time x group was found ($F(2,47) = 3.5$, $p = .039$) caused by the small loss in performance in the TD group ($F(1,18) = 6.1$, $p = .024$) (see Table 4.3).

Moreover, for duration the time x group interaction was marginally non-significant ($F(2,47) = 3.0$, $p = .06$) with a faster performance after 6 weeks in the TD group but not in the p-DCD groups ($p = .037$).

On the Wii score no effect of time was found ($p = .58$) indicating that the performance did not deteriorate over 6 weeks (no time by group interaction; $p = .089$). Within the TD group the loss of retention was marginally non-significant ($p = .053$).

Within the p-DCD groups there was full retention over 6 weeks over all three measures (all p > .16).

In summary, over the retention period the different Wii outcomes showed that the p-DCD groups kept their performance at the same level, while the TD group showed a strategy of slightly faster runs while missing more gates compared to their last performance at T0. This did not lead to a significant poorer performance on the Wii score.

Table 4.3
Retention of performance level after 6 weeks on mean missed gates, duration and Wii score of run 9&10 of the first measurement and of run 1&2 after six weeks second measurement.

	TD group (n = 19)		p-DCD-NL (n = 14)		p-DCD-SA (n = 17)	
Missed gates (SD)						
T0 run 9&10	3.4	(2.2)*	10.4	(4.0)	10.3	(2.9)
T1 run 1&2	4.9	(2.6)	9.0	(4.0)	10.9	(3.3)
Duration (SD)						
T0 run 9&10	41.3	(4.3)*	38.0	(5.1)	39.2	(4.7)
T1 run 1&2	39.0	(3.7)	39.7	(5.5)	39.5	(5.1)
Wii-score (SD)						
T0 run 9&10	64.9	(15.5)	110.8	(25.2)	111.2	(18.1)
T1 run 1&2	73.2	(18.7)	102.9	(29.1)	115.7	(21.7)

* Difference run 9&10 and 1&2 p < .05.

Relationship between motor learning and motor performance at baseline

Linear regression analysis over all children (n = 66) showed that the learning slope of the missed gates is a good predictor of the MABC-2 component balance (B = 3.4, CI 2.1; 4.7, r_p = .55, p < .001). Similarly, the learning slope of the Wii score was also a predictive value for the MABC-2 component balance (B = 5.3, CI 2.0; 8.7, r_p = .37, p = .002), with a moderate relation. The results indicate that the rate of learning accuracy of the timing to get through the gates was highly related to the level of balance measured by the MABC-2 balance items.

DISCUSSION

In this study we examined short-term motor learning using a dynamic balance task in children with probable DCD and those who are typically developing. The main findings are that (i) short-term motor learning rate and performance level on the ski slalom game is less in children with p-DCD in comparison with typically developing children; (ii) no differences in performance and learning were found between the Dutch and South African children with p-DCD and balance problems; (iii) retention was comparable across the three groups on the Wii score.

The present study shows that short-term motor learning of typically developing children is faster than the learning of children with p-DCD. By fitting a learning curve to ten repeated trials, two main learning parameters were derived; the slope of the curve, representing the rate of learning, and the least squared fit, representing the variability between the runs relative to the learning curve. The magnitude of the learning effect (number of missed gates) was significantly larger in the TD group compared to both p-DCD groups (see Table 4.2).

The Wii-score is derived from the number of missed gates and the duration of the run. When we look in more detail at these constituent measures, over the first 10 runs the TD group slows down about 2 s while reducing the number of missed gates by 4. In this task there are two sources of knowledge of results (KR) which drives the learning, (i) a high or low tone at each gate passed or failed; (ii) the Wii-score, the number of missed gates and the duration of the run presented at the end of the run. A reduction of missed gates leads to a greater improvement of the Wii-score than a faster descent because the computation of the Wii-score uses a penalty of 7 s for each missed gate. Therefore, the speed–accuracy trade-off of the TD group seems an efficient strategy. No speed–accuracy trade-off was seen in the p-DCD groups. Rather, the p-DCD groups seem to persist more in their less efficient strategy. The group difference is unlikely to be caused by a group bias as all groups received the same instructions and feedback. They improved both on missed gates and speed, with less steep learning curves for Wii-score and missed gates as a consequence. Future studies might investigate whether in the long run p-DCD children will adapt to the strategy of the TD children, or continue to use their initial strategy.

In sequence learning tasks it has been shown that children with DCD have comparable performance to matched controls (Wilson et al., 2003; Lejeune et al., 2013). These results contrast with our findings and may be due to the differences in tasks used. The former studies evaluated the change in reaction time during simple movement tasks involving a series of key presses (serial reaction time tasks) with low spatial accuracy and timing demands. The current study evaluated learning a computer-based balance task requiring complex whole-body movements, anticipatory postural control and temporal accuracy. Evidently, tasks requiring a series of key presses are different from dynamic balance tasks in which postural control and weight shift based on visual input is involved.

Interestingly, the rate of motor learning between p-DCD groups (SA and NL) was not significantly different despite differences in backgrounds and movement experience. All children in the SA group confirmed not to be familiar at all with any motion steered computer game. We hypothesized that being novice to a task, may influence the amount and rate of learning. On the one hand children, who are accustomed to playing motion steered computer games for example, may therefore be faster learners on a Wii Fit system. On the other hand, children without experience may start the learning process on a different level and may have more learning potential available to use. Despite the fact that the SA group was novice to computer games, it appeared that Dutch and South African children with p-DCD learned at a comparable rate. Apparently, motion steered computer gaming is easily understood by children from multi-cultural backgrounds, which makes it suitable for examining learning or training balance. We conclude that slower motor learning rate in children with DCD appears to be independent of the cultural background of the children and of their level of experience with the Wii.

While the two p-DCD groups did not differ on learning slope, they did show a difference in variability between the runs relative to the learning curve when it was based on missing gates. However, this difference was not seen on the variability of the learning curve of the Wii score, when the slope was corrected for the time it took the children to finish the task. The lower fit in the Dutch group may represent the exploration of different strategies (shifting weight sideways farther or faster) in order to find ways to improve their score, but may also indicate more variable kinetics and kinematics. This result is consistent with the view of Hadders-Algra (2002) and O'Hare and Khalid (2002), who reported that children with DCD show large variability over learning trials and have greater difficulty producing consistent movement patterns (Rosengren et al., 2009). However, one would expect a similar degree of variability in the South African group of children and this was not the case. We assume this may be the result of being novice toward the Wii Fit, resulting in a lack of exploring all the possibilities of the balance board and how the game can be played. It would be of interest to determine if the exploratory behavior would change during a longer period of training. We would expect the variance to decrease in the Dutch group when optimal strategies have been discovered resulting in a more coordinated and consistent execution of the task (Bernstein, 1967). For the SA group we expect an increase of variance due to more exploratory behavior at first, once the children feel more secure with the ways the game can be controlled, later to be followed by a reduction again when they have found more optimal control strategies (Herzfeld & Shadmehr, 2014).

Remarkably, there was no regression in the level of Wii performance after six weeks in both p-DCD groups. The level of control of the game remained the same, which is promising for interventions aimed at children with p-DCD. Our findings suggest that children with p-DCD show evidence of learning and retention, although performance and learning is on a different level than TD children and more practice is needed to reach a satisfactory performance level. A small loss in performance was found in the TD group after 6 weeks not playing with the Wii, but they were still much better than the p-DCD groups. It would be of interest to evaluate the learning curve and Wii scores after a longer period of training balance games of the Wii Fit, to determine whether children with p-DCD would reach the same level as children with TD. Marchiori et al. (1987) established that children with DCD had great difficulty performing a skilled hockey slap shot, even after explicit instructions and intensive training. Recent studies of Hammond, Jones, Hill, Green, & Male (2014), Jelsma et al. (2014) and Mombarg, Jelsma, & Hartman (2013) showed that children with DCD seem to increase their balance performance through intensive practice on the Wii Fit balance board, as shown by a transfer effect on motor test outcomes of dynamic balance tasks. We suggest this type of training may influence anticipatory or reactive postural adjustments. Therefore, practicing with Wii

Fit balance games or other motion steered computer games may support intervention of children with DCD.

An important finding of our study is the fact that the learning slopes of both the missed gates and the Wii score, when duration was included, were associated with the level of motor balance performance of the children. The more learning (the steeper slope of the curve), the higher scores were on the MABC-2 balance component. While acknowledging that an association does not allow causal reasoning, there may be two interpretations of this association. One is that the restricted learning rate results in poor performance levels of balance tasks. The other is that poor balance with inconsistent outcomes hampers skill learning. Longitudinal research of development and learning along with experimental work that manipulates the learning process may shed light on which is the better explanation.

Strengths, limitations and recommendations

In this study, we explored short-term learning in a complex motor task. The task requires anticipatory planning of timed weight shifts in order to pass through the gates of the ski slalom game. The game is challenging, as the fast changing circumstances require the player to make quick adaptations to postural balance. As such, it links to natural activities of children in daily life.

A limitation is the relatively small sample size. The design of the study would have been stronger, if a group of TD children from South Africa had been included in the study to control for differences in more general level of motor proficiency and exposure in the population that may exist between SA and NL. Lastly, motor learning may involve both a change in performance within the same strategy as well as a change for a more efficient strategy. To fully understand learning of motor skills in children (with DCD) both improvement in performance and change of strategy should be studied. The current study was not designed to study the effect of previous exergame experience. It would be interesting to investigate the relationship between different aspects of previous movement experience and rate of learning of new motor tasks.

Finally, we recommend further research of the effect of a much more extensive training in children with p-DCD to find out whether the children will reach the level of performance of TD children. We also recognize that the underlying processes that facilitate learning should be subject to further research.

Conclusion

Children with p-DCD learn at a lesser rate than TD on a Wii Fit ski slalom game in which anticipatory planning of timed weight shifts is needed. This result adds to evidence that poor acquisition of motor skills is a core feature of DCD. Speed– accuracy trade off was only seen in the TD children, indicating that TD children and p-DCD children used different strategies. Taking a positive perspective, it is evident that children with p-DCD are able to learn, albeit at a different rate and the learned level of performance can be retained over six weeks. Cultural background and experience did not influence the rate of learning.

Competing interest

The authors declare that they have no competing interests.

Acknowledgements

We would like to thank all children, parents and the staff of participating schools for their time and cooperation. The work done by the paediatric physical therapists and students of the University of Applied Sciences; Hanze, Groningen and Avans+, Breda, the University of Groningen, and the University of Cape Town in helping to collect the data for this study, is highly appreciated.

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