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Variable training does not lead to better motor learning compared to repetitive training in children with and without DCD when exposed to active video games

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ABSTRACT

Background: Little is known about the influence of practice schedules on motor learning and skills transfer in children with and without developmental coordination disorder (DCD). Understanding how practice schedules affect motor learning is necessary for motor skills development and rehabilitation.

Aims: The study investigated whether active video games (exergames) training delivered under variable practice led to better learning and transfer than repetitive practice.

Methods and procedures: 111 children aged 6–10 years ($M=8.0$, $SD=1.0$) with no active exergaming experience were randomized to receive exergames training delivered under variable (Variable Game Group (VGG), $n=56$) or repetitive practice schedule (Repetitive Game Group (RGG), $n=55$). Half the participants were identified as DCD using the DSM-5 criteria, while the rest were typically developing (TD), age-matched children. Both groups participated in two 20 min sessions per week for 5 weeks.

Outcomes and results: Both participant groups (TD and DCD) improved equally well on game performance. There was no significant difference in positive transfer to balance tasks between practice schedules (Repetitive and Variable) and participant groups (TD and DCD). **Conclusions and implications:** Children with and without DCD learn balance skills quite well when exposed to exergames. Gains in learning and transfer are similar regardless of the form of practice schedule employed.

What this paper adds: This is the first paper to compare the effect of practice schedules on learning in children with DCD and those with typical development. No differences in motor learning were found between repetitive and variable practice schedules. When children with and without DCD spend the same amount of time on exergames, they do not show any differences in acquisition of motor skills. Transfer of motor skills is similar in children with and without DCD regardless of differences in practice schedules.

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1. Introduction

Despite the wealth of research on differences in motor behavior and its underlying processes between typically developing (TD) children and those with Developmental Coordination Disorder (DCD), little is known about practice conditions that facilitate efficient motor skill training, and about factors that influence the course of motor learning (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). There is no doubt that children with DCD are able to learn new motor skills or improve upon existing ones when given adequate training (Miyahara, Hillier, Pridham, Nakagawa, & Miyahara, 2014; Zwicker, Missiuna, Harris, & Boyd, 2012). However, investigations of how to effectively manipulate practice conditions to create optimal learning experience are still lacking.

Motor learning refers to the processes that allow individuals to acquire new motor skills and to adjust their movements to changes of the physics of the body and the world (Kroemer, Burrasch, & Hellrung, 2016). Though there is a general consensus that motor learning leads to improvement in motor skills beyond baseline levels, these improvements are not seen as indication of learning (Shmuelof, Krakauer, & Mazzoni, 2012). Rather, improvements observed in retention of acquired skills over time and transfer (ability to apply acquired skills in novel situations) are used as key determinants of motor learning in human subjects (Shea & Morgan, 1979). Also, motor learning is described as a set of internal unobservable processes that occur with practice or experience resulting in permanent changes in movement capacity (Schmidt & Lee, 2011). Acquisition of skilled movements is influenced by various factors such as attention focus, type and frequency of feedback, amount of practice and practice schedules (Wulf, Shea, & Lewthwaite, 2010).

Practice schedules refer to the ways practice and/or training sessions are designed and structured to optimize learning outcomes (Muratori, Lamberg, Quinn, & Duff, 2013; Vera, 2008). Generally, two forms of practice schedules are described in the motor learning literature: repetitive (or constant) and variable practice (Shea, Kohl, & Indermill, 1990). Repetitive practice is the continuous repetition of one skill during an episode of training, whereas variable practice involves the execution of a wider variation of skills (Lage et al., 2015). It is now known that training the task to be learned repetitively (constant practice) leads to improved practice performance but results in poor retention and transfer (Battig, 1966; Shea & Morgan, 1979). The advantage of repetitive practice may be that performing many repetitions leads to automatization of that skill, and enables temporal and spatial adaptations of this specific skill (For example, the skill improves in speed, accuracy, stability and fluency). Nonetheless, variable practice leads to increased retention and transfer (Lee & Magill, 1983; Muratori et al., 2013; Schmidt & Lee, 1988; Shea & Morgan, 1979) and is widely regarded as superior to repetitive practice in terms of enhancing skill learning.

The idea that motor learning benefits more from practicing tasks in a variable rather than repetitive practice context is known as contextual interference (CI) effect (Feghhi, Abdoli, & Valizadeh, 2011; Magill, 2004; Shea & Kohl, 1990). From a neurocognitive perspective, sensorimotor learning involves learning new mappings between motor and sensory variables. Such mappings are termed internal models, as they represent features of the body and the environment. When we learn new movements, we must be able to link them to appropriate contextual cues such as objects, tasks or environments (Wolpert, Diedrichsen, & Flanagan, 2011). For example, expert video game players develop an extraordinary ability to extract information and spread their attention over a wide spatial frame without any apparent decrease in performance (Green & Bavelier, 2003).

One of the prominent hypothesis for the poor motor control in DCD concerns deficit in the internal modeling of movements (Wilson et al., 2013). According to this hypothesis, children with DCD have significant limitations in their ability to accurately generate and utilize internal models of motor planning and control. Since learning is strongly determined by the neural representations and influences how learning generalizes to novel situations, deficits in internal representations will not only hamper skill acquisition but also transfer of motor learning. As an example; when playing a new or untrained computer game on a balance board, after playing many other active computer games during 5 weeks, the relevant inputs stay comparable (the moving and stationary images on the screen) and the task relevant output will be similar, namely rapid weight shifts. It is hypothesized that by playing many different games (variable training), the child extracts general rules for how to control the coveting parameters for different games (Braun, Aertsen, Wolpert, & Mehring, 2009). What differs between the various computer games are the parameters of inputs and outputs, such as the path through which the children have to steer round the obstacles that have to be avoided, and the amount and timing of the weight shifts. Given these comparable task constraints, we can expect transfer of learning, which can be evaluated by the more rapid learning of other comparable tasks. On the other hand, if the child plays one game over and over again, it will become better at that game. However this creates relatively less contextual interference during training because it involves executing the same motor task repeatedly. The child playing many different but comparable games, may also have improved performance on the games played, but will likewise have learned the basic structure of a balance steered computer game and transfer. By playing multiple motor tasks, contextual interference (CI) effect is assumed to create relatively high interference throughout practice because of the rapid changes in task demands from game to game (Shea & Morgan, 1979). In short, it is expected that high levels of CI (variable practice) would result in poorer performance but increased retention and transfer compared to low levels of CI. This is because during acquisition stage of learning, variable practice creates opportunities for more effortful cognitive processing (Lin, Sullivan, Wu, Kantak, & Winstein, 2007) and structural learning (Braun et al., 2009). Previous motor learning research in children with DCD focused on a Serial Reaction Time paradigm (Gheysen, Van Waelvelde, & Fias, 2011; Lejeune, Catale, Willems, & Meulemans, 2013; Wilson, Maruff, & Lum, 2003). To date, no study has examined the impact of practice schedule manipulation in children with DCD. Recent studies have introduced active video games (exergames) in children

Fig. 1. Research design: Pretest (Criterion test) was conducted for all children, after randomisation they either followed the variable practice schedule (A) or repetitive practice schedule (B), all children underwent the same post test (Criterion test).

with DCD and several other populations (Bonnehère, Jansen, Omelina, & Van Sint, 2016; Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008; Hammond, Jones, Hill, Green, & Male, 2014; Jelsma, Ferguson, Smits-Engelsman, & Geuze, 2015; Lohse, Hilderman, Cheung, Tatla, & Van der Loos, 2014; Mendes et al., 2012; Smits-Engelsman et al., 2013), yet the extent to which practice schedules affect learning during gameplay is unknown. Given that balance problems are common in children with DCD (Cherng, Hsu, Chen, & Chen, 2007; Deconinck, Savelsbergh, De Clercq, & Lenoir, 2010; Geuze, 2003; Grove & Lazarus, 2007), we investigated the influence of practice schedules on motor learning using selected balance games on a commercially available active video game console.

In this study, we designed an experiment to determine what practice schedule would work best in enhancing perceptual-motor learning in children. Specifically, we evaluated the effect of two practice schedules on motor learning and transfer in children with DCD and their typically developing peers. We hypothesized that improvement in game performance score, which encompasses speed and accuracy, would be less when children play 10 different games on the Wii (Variable practice schedule) than when they play only one game repetitively (Repetitive practice schedule). Next, it was expected that the variable practice schedule would enhance learning and facilitate transfer to untrained comparable tasks more effectively than repetitive practice. In light of the aforementioned considerations, the following specific questions were addressed:

- 1) Are there differences in improvement and retention in game performance between repetitive and variable practice schedule *during* 5 weeks of training?
- 2) Are there differences in near transfer to a comparable virtual static balance task between repetitive and variable practice schedule *during* 5 weeks of training?
- 3) Are there differences in performance on the Criterion test between repetitive and variable practice schedule *after* 5 weeks of training?
- 4) Do children learn the criterion test faster *after* they have played many different Wii games for 5 weeks (Variable practice schedule)?
- 5) Is the level of motor competence (TD vs. DCD) a mediating factor in the rate of learning and the amount of transfer?

2. Methods

2.1. Research design

A stratified randomized pre-post single blinded design was used to evaluate changes in performance during and after 10 training sessions (two times per week for 5 weeks) using the Nintendo® Wii Fit games in children with and without DCD.

Pre- and post-test for both groups involved the same Criterion test (see Fig. 1). In this experiment, the Criterion test was followed by practicing either the ski slalom game (same game as used in the Criterion test) repetitively, or variations of 10 other selected computer games (see Appendix A).

In this experiment, we used a design that made it possible to measure retention and transfer in both the repetitive and variable practice schedule groups. To accomplish this, we employed a double transfer design to determine both short-term transfer (differences per practice session in performance on a yoga task) and long term transfer (differences between pre and posttest in the speed of improvement using the untrained Criterion test) among the variable practice group.

2.2. Participants

2.2.1. Identification of DCD and controls

To select participants, teachers and parents were asked to assist in identifying children between the ages of 6–10 years with motor coordination problems based on their observation in class and on the playground by highlighting the child's name on a class roster and returning this list to the researchers. The four DSM-5 criteria were used to identify children with DCD (American Psychiatric Association, 2013). All children who scored ≤ 5 th percentile on the Movement Assessment Battery for Children 2nd edition (Criterion A), who were identified as having a motor coordination problem by the teacher or parent

(Criterion B), whose parents reported no diagnosis of a significant medical condition known to affect motor performance in the parental questionnaire (Criterion C), and whose teacher affirmed the absence of intellectual or cognitive impairment (Criterion D) were included in the study.

A total of 56 children with DCD were selected to take part in the study. They were gender- and age-matched with 56 TD children from the same classes. Matching of children on age was done on half a year basis (± 6 months). Typically developing (TD) children had: 1) no evidence of functional motor problems as observed by their teacher or parent, 2) a score above the 16th percentile on the MABC-2, 3) no diagnosis of a significant medical condition as indicated by a parent and 4) absence of intellectual or cognitive impairment as reported by their teacher. All parents filled a pre-study questionnaire that sought to elicit information on medical history and physical health of their child. This questionnaire was designed by the authors and has been used in earlier studies (Ferguson, Aertssen, Rameckers, Jelsma, & Smits-Engelsman, 2014; Ferguson, Naidoo, & Smits-Engelsman, 2015).

2.3. Instruments

2.3.1. The movement assessment battery for children-2 (MABC-2)

The MABC-2 was used to select the children. The MABC-2 (Henderson, Sugden, & Barnett, 2007) consists of eight physical subtests used to assess motor coordination in children aged 3–16 years. Raw scores for each item are converted into age appropriate standard scores. The sum of all eight item standard scores is recoded into a Total Standard Score (TSS) with a range of 1–19 and a mean of 10 ($SD = 3$) and gives an impression of the overall motor proficiency. The MABC-2 has demonstrated good inter-rater reliability, and criterion validity (Henderson et al., 2007; Wuang, Su, & Su, 2012).

2.3.2. Wii fit

The Wii Fit is a video game designed by Nintendo® for the Wii console. It is an exercise game, featuring four main categories of games that users can choose from: Strength, Aerobics, Yoga and Balance. The Wii Fit Plus uses a platform called Balance Board (BB), on which the user stands during gameplay. The balance board has four force plate sensors, one in each corner, used to measure the child's weight, and to calculate center of pressure (COP) and to estimate weight distribution. The BB software focuses on directly controlling the game using the player's COP displacements via movements of a virtual character called the Mii. The Mii is an on-screen character through which the user interacts with the game interface. The BB is normalized according to the child's weight, which is a standard procedure of Nintendo Wii. In comparison to a laboratory-grade force platform (FP) the BB has been found valid and reliable enough for assessing standing balance (Clark et al., 2010). For this study, we pre-selected several balance games for the variable practice schedule (see Appendix A), the ski-slalom game for the repetitive practice schedule group and one yoga task to evaluate near transfer. The ski-slalom was also used for the Criterion test. The choice of balance games for the study was informed by findings of previous research suggesting that many children with DCD have balance problems necessitating specific interventions targeted at addressing balance issues.

2.3.3. Wii test game

The Wii Fit ski slalom game was used as the Criterion test for all the children. Also, the same game was used as training game for Repetitive Game group. The goal of the game is to allow the Mii (virtual character) ski through 19 gates along a ski slope as fast as possible without missing a gate. The spatial layout of the gates on the slope is invariant and runs are therefore comparable over trials and children. The individual gates vary in their lateral distance from the middle of the slope and their distance along the slope. The number of gates the Mii misses results in 7 s penalty time per miss and is added up to the time between start and finish, together yielding an integrated speed accuracy trade off game score presented on the screen immediately after each run. In this game, the direction of weight shifting of the child's center of mass controlled the movement of the Mii. For instance, when the child shifts his or her center of mass forward or backward (anteriorly/posteriorly) the Mii speeds up or slows down; shifting the child's center of mass to left and right (laterally) directs the skier sideways. The outcome of the Wii test game during pre and posttest is referred to as the Criterion test score, with higher scores denoting poorer performance (more time needed to finish the task and/or more errors made).

2.3.4. Near transfer task

The standing knee pose is one of the game options in the Yoga category. This game was chosen as the near transfer task. We selected this game as it is closely related to the other balance games used to train the children. The standing knee pose involves standing on one leg on the BB, while holding the other leg with flexed knee, using both hands in front of the body. An on-screen personal trainer demonstrates how to acquire this posture and the software detects the efficacy of the performance. The child is required to focus on a representation of the postural sway from their COP holding it as steady as possible within a yellow coloured band displayed on the screen. The time taken to maintain a steady balance is recorded by the computer (maximum execution time of 30 s). A maximum score of 50 points per leg can be earned. This score takes into account the number of seconds and the steadiness of the pose assumed. Like the other balance games, the Yoga task requires the child to stand on the Wii balance board and watch the screen on which augmented dynamic visual feedback related to task performance is presented. To monitor progress the child performed the Yoga task once for each leg per training session. Both legs were tested for all the children.

Fig. 2. Flow diagram of recruitment and randomization process.

2.3.5. Enjoyment rating scale

As motivation might be related to the level of motor proficiency and to practice schedule, we included an enjoyment rating scale to measure the level of enjoyment experienced while playing the games. It was hypothesized that the repetitive game schedule would be experienced as less fun. Children chose from five different smiley faces to rate their gaming experience (0 is “no fun at all”; 1 is “boring”, 2 is “a bit of fun”, 3 is “fun” and 4 is “awesome”), using a scale that was developed for one of our earlier studies (Jelsma, Geuze, Mombarg, & Smits-Engelsman, 2014). We evaluated how much the child enjoyed playing a Wii game on three occasions (after the first, third and fifth week of practice).

2.4. Procedure

Approval for the study was granted by the University of Cape Town, Faculty of Health Sciences Human Research Ethics committee (HREC: 556/2015) and the designated educational authorities. Informed consent for the testing was obtained from all parents and informed assent was also given by each child. Based on teacher’s judgment and responses received from parental questionnaires, 334 children were preselected for testing by a team of qualified physiotherapists and physiotherapy students who had received additional training on the administration of the MABC-2. 56 children with a score $\leq$ 5th percentile of the MABC-2 were selected and age-matched with 56 TD children (randomly selected) from the same classes. These pairs were randomly assigned to either the variable or repetitive practice schedules. Pre- and post-measures of the Criterion test were conducted by two separate teams of assessors, who were blinded to pretest results, group membership (TD/DCD) and the practice schedule to which the children belonged (Fig. 2).

2.5. Training

Four television monitors and four off-the-shelf Nintendo Wii motion-controlled video consoles (Nintendo Co. Ltd., Kyoto, Japan), including the balance boards were set up in an empty classroom on the school premises. Four children trained simultaneously each on their own systems under the supervision and guidance of two trained student therapists. The role of the supervisors was to ensure that Wii fit system works efficiently, to train the children with the correctly calibrated Mii and to instruct, encourage and motivate the children. Besides, supervisors were responsible for documenting the choice of games played, game scores attained and playing time for each child, which consisted of 20 min of active gaming, twice weekly for five weeks.

Each training session comprised of a self-selected choice out of ten games (see Appendix A) in the variable practice schedule (Variable Game group). To enhance diversity within the variable practice schedule, children could only play the same game twice in a session if they wanted (for a short description of the games see Appendix A). Also, children who underwent the repetitive practice schedule had no choice as they were required to play the same game throughout the

entire training period (Repetitive Game group). All the children in the repetitive schedule group played the ski-slalom game for 5 weeks. Two versions of this game were played alternately, the beginner version (consisting of 19 gates) and the advanced version (consisting of 27 gates).

If children missed a training session, they were offered an opportunity to attend a catch-up session, preferably in the same week, if that was not possible they came for an extra session the following week. All children completed 10 practice sessions. None of the children had prior Wii gaming experience. Additionally, no child played any of the Wii games outside the training context.

2.6. Data analysis

Data were checked for normality and equality of variances and appropriate analyses were selected.

2.6.1. Comparability of the groups at pretest

Differences in demographic characteristics between groups (TD and DCD) and the practice schedules were calculated at baseline using Pearson's Chi squared test (sex and handedness) or *t*-test (age, BMI and MABC-2).

2.6.2. Analysis of change in performance, near transfer and enjoyment during 10 training sessions

Since the children played different games during training and earned varied scores, we needed to create an equivalent aggregate score to be able to test if there were differences in improvement and retention in game performance. Therefore, all scores were normalized as the percentage of the maximum (or best score possible) obtained for that game over the whole training period. This was designated as Normalized Game score, with higher scores representing better performance (100% being the maximum score).

To estimate the relationship between repetitions and the Normalized Game score, a linear curve was fitted to the 10 data points (one per session) of each individual child. Regression estimates were used to describe the temporal pattern of performance: steepness of the slope (β) reflects the extent to which performance becomes better as the training progresses (rate of improvement), while linear fit (R^2) shows the variability around this progress and reflects retention between sessions. Estimates of slope (β) and linear fit (R^2) were entered into separate two factor ANOVA (practice schedule and participant group as the between factors) (Smits-Engelsman, Jelsma, Ferguson, & Geuze, 2015). Also the number of children in which the regression line was significantly different from zero was evaluated. The proportion of children with significantly changing slopes (β) in the Repetitive practice schedule group and in the Variable practice schedule group was compared using χ^2 statistics.

For near transfer, the Yoga task scores were analyzed in a repeated measure ANOVA with Sessions (10) as within group factors and participant group (TD/DCD) and practice schedule (Repetitive/Variable) as the between factor. We also tested using a χ^2 test if the frequency of the perceived enjoyment expressed on enjoyment rating scale was different between practice schedules and participant groups, since we expected that playing different games might be more fun and perhaps produce higher motivation.

2.6.3. Analysis of pre and posttest performance on the criterion test

Pretest differences on the Criterion test score were analyzed in a repeated measure ANOVA with Trials (10), as within group factor and participant group (TD/DCD) and practice schedule (Repetitive/Variable) as the between factor.

To test for changes after the 5 weeks training period, we analyzed the Criterion test score in a repeated measure ANOVA with Time of test (Pre/Post) and Trials (10), as within group factors and participant group (TD/DCD) and practice schedule (Repetitive/Variable) as the between factor. Post hoc paired *t*-tests were performed if a practice schedule or group by training interactions was found.

To test if the Variable game group learned faster at post-test, the improvement during the 10 trials at pre and post-test was compared using a paired *t*-test. The total sample size (with an effect size of 0.8) required in each group was calculated. Accordingly, it was established that 25 participants per group were required to enter this study in order to detect a difference between the groups at a 0.05 significance level with a power of 0.8. Significance level was set at $p < 0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS Inc., version 23).

3. Results

3.1. Group comparability

Parents of one TD child assigned to the Repetitive practice schedule gave permission for the pretest but did not consent for the training and so that child could not participate in the training. The Repetitive game group therefore consisted of 55 children whereas the Variable game group had 56 children. For one child, a classification error was made (two children with the same first name got the same code which lead to randomization mistake) in the pre-selection process. We left this child with DCD, originally randomized as TD, in the practice schedule it was assigned to. Therefore the TD group that started intervention consisted of 54 ($M = 28$, $F = 26$) and the DCD group of 57 ($M = 29$, $F = 28$) children. Since groups were gender and age matched, no group differences were found with regards to age and gender. No difference was found for BMI

Changes in Normalized Game score over 10 sessions

Fig. 3. Changes during the 10 training sessions on the Normalized Game score (% of the maximum score) for the 2 participant groups and the 2 practice schedules. Error bars indicate standard error.

between the DCD and TD group ($p = 0.34$) or between the Repetitive and Variable game group ($p = 0.42$). Because the children were selected based on motor performance, large differences were shown on the MABC-2 Total Standard Score mean TSS: TD = 10.7 (2.13), DCD = 3.77 (1.30); ($t(109) = 20.81, p < 0.0001$).

3.2. Changes in performance over training sessions

3.2.1. Changes in normalized game scores during the 5 weeks of training

There were large changes in the Normalized Game score for the children during the 5 weeks of training (See Fig. 3; Main effect of practice $F(1,107) = 14.05, p < 0.0001, \eta^2 = 0.56$). It is shown that the DCD group performed worse than the TD group during the training period. Overall, the DCD group was poorer (Main effect of group $F(1,107) = 17.44, p < 0.0001, \eta^2 = 0.14$) but responded in a similar manner to training (no practice schedule by group interaction $p = 0.18$).

When we compared the steepness of the learning curve (slope β), no significant difference between practice schedules ($p = 0.13$) or groups emerged ($p = 0.16$).

However, as can be seen in Fig. 3, the variability in the learning curve (R^2) of the two practice schedules was different ($F(1,107) = 83.78, p < 0.0001, \eta^2 = 0.44$). This larger variability in improvement in the variable practice group confirmed that Normalized Game scores of the children playing many different games were more variable (R^2) than if only one type of game was played but retention over sessions (slope β) was not affected. Although not reaching the chosen level of significance, a trend in the variability for group indicated that the DCD group tended to have a larger variance (R^2) in their learning curve when they played many different games $F(1,107) = 3.73, p = 0.056, \eta^2 = 0.03$. The combination of these two variables ($\beta + R^2$) indicates that even though performance between sessions was more variable, the improvement of the 5 weeks was comparable.

On further exploration of the individual learning curves, differences were found between the numbers of children whose learning curve showed a significant improvement. As can be seen in Table 1, the learning curves had significantly more changing slopes (β) in the Repetitive group than in the Variable group ($\chi^2 = 43.04, p < 0.001$). There was also clear difference in the effect sizes for learning curve in the two practice schedules, which are larger in the Repetitive practice schedule (Table 2). Large variance in the variable practice schedule decreases the effect sizes. The effect of practice in the individual children who could concentrate on one game was more stable than in the children who could choose between 10 games.

3.2.2. Changes in near transfer scores during the 5 weeks of training

The Yoga task was measured 10 times on the left and on the right leg (once per training session). The DCD group had a lower score on the Yoga task (See Fig. 4; Main effect of participant group: Left leg $F(1, 107) = 9.69, p = 0.002, \eta^2 = 0.08$; Right leg $F(1, 107) = 13.37, p < 0.0001, \eta^2 = 0.11$). A large effect of training was found (Left leg $F(9, 99) = 4.06, p < 0.0001, \eta^2 = 0.27$;

Table 1

Number of children per practice schedule who showed significant changes in their individual learning curves.

Group and Practice schedule	Individual Improvement		Total (n)
	Not significant (n)	Significant (n)	
TD Repetitive practice schedule	2	24	26
DCD Repetitive practice schedule	7	22	29
Total Repetitive practice schedule	9	46	55
TD Variable practice schedule	20*	8	28
DCD Variable practice schedule	24*	4	28
Total Variable practice schedule*1 child got significantly worse	44	12	56

Table 2

Effect size per practice schedule and group in the standardized game score over 10 training sessions.

Practice schedule	Eta squared
TD Repetitive practice schedule	0.912
DCD Repetitive practice schedule	0.818
TD Variable practice schedule	0.568
DCD Variable practice schedule	0.461

Changes in Yoga score over 10 sessions

Fig. 4. TD children showed better performance on the Yoga task at the beginning and the end than the children with DCD but no differences were found in the rate of change between the two practice schedules. Error bars indicate standard error.

Right leg $F(9, 99) = 4.59$ $p < 0.0001$, $\eta^2 = 0.30$) indicating transfer to a task close to the game situation but requiring static balance instead of faster dynamic changes as practiced during the practice. No interaction with practice schedule was found. It can be concluded that both practice schedules lead to a transfer effect on a different balance task for both TD and children with DCD, though on a different level.

3.2.3. Changes in enjoyment rating scale during the 5 weeks of training

Given the results on the enjoyment scale, it is clear that the children liked to play the exergames. After the first week, 91% and 93% children reported the training to be “awesome”, for the repetitive and variable practice schedule group, respectively. After five weeks, 89% and 93% of the children rated the training as “awesome” and “0” rated it “not fun” or as “boring”. Only two children rated their repetitive practice as “a bit of fun” in the last week of the practice. Remarkably, this shows that children also liked doing the same game over and over again. Frequencies of rating were not different for the practice schedules ($\chi^2 = 1.564$, $p = 0.668$; $\chi^2 = 2.668$, $p = 0.263$, $\chi^2 = 2.901$ $p = 0.234$, for the first, third and fifth week of the practice, respectively).

3.3. Criterion test game

3.3.1. Analysis of criterion test game at pretest

At pretest, children assigned to Repetitive and Variable practice schedule groups did not differ on the score of the Criterion test game over ten runs ($p = 0.34$). There were however differences in the initial levels on the score of the 10 runs between

Changes over 10 repetitions in Pre and Post Criterion Test Performance

Fig. 5. Changes during the 10 trials of the pretest (left side) and the 10 trials of the posttest (right side) on the Criterion test for the 2 participant groups and the 2 practice schedules. Error bars indicate standard error.

Table 3

Pretest and posttest comparison of Criterion test scores.

Multivariate tests of the Criterion test				
Effect	F	df	Sig	η^2
Time (pre/post)	279.871	1.107	0.0001	0.723
Time* Practice schedule (Repetitive/Variable)	84.526	1.107	0.0001	0.441
Time*Participant Group (TD/DCD)	1.202	1.107	0.275	0.011
Time*Practice schedule*Participant Group	0.461	1.107	0.499	0.004
Trials (10 runs of the computer game)	11.596	9.99	0.0001	0.513
Trial* Practice schedule	1.967	9.99	0.051	0.152
Trial*Participant Group	0.813	9.99	0.358	0.092
Trial*Practice schedule*Participant Group	1.117	9.99	0.358	0.092
Time*Trial	0.807	9.99	0.611	0.068
Time*Trial*Practice schedule	2.995	9.99	0.003	0.214
Time*Trial*Participant Group	0.983	9.99	0.459	0.082
Time*Trial*Practice schedule*Participant Group	1.065	9.99	0.395	0.088

TD and DCD ($F(1, 106) = 13.40, p < 0.001$; TD mean = 155.83 (39.03), DCD = 175.57 (37.29)), even though all children played the game for the first time. The effect size for this comparison was small-to-moderate, partial $\eta^2 = 0.11$.

All groups displayed an increase in Criterion test performance during 10 trials of the pretest, leading to a decreased score, because less time was needed and less errors were made during the repetitions of the game, indicating that they learned to respond according to the game constraints (Main effect of Trial ($F(9, 99) = 6.22, p < 0.0001, \eta^2 = 0.36$). The magnitude of change was not different between participant groups during these first 10 trials during the pretest (no significant Trial by Participant interaction; $p = 0.64, \eta^2 = 0.067$). The rate of improvement during the pretest was comparable between the TD and DCD groups (See Fig. 5-left side).

3.3.2. Pre-post comparison on criterion test game

Table 3 displays the large improvement in scores on the Criterion test game after children had played active video games for 5 weeks (Fig. 5; $F(1, 107) = 279.871, p < 0.0001, \eta^2 = 0.72$). However the practice effect of the two practice schedules was different (Time of test x Practice schedule; $F(1, 107) = 84.53, p < 0.0001, \eta^2 = 0.44$). The Criterion test score was significantly better for the children in the Repetitive game group after the training. Importantly, no interaction with participant group was found (Time of test x Participant group, $p = 0.28; \eta^2 = 0.011$). Both the TD and DCD group responded similarly to the two-practice schedules. This also means that the differences between the participant groups were still there after the practice (post hoc test for group differences $F(1, 107) = 6.32, p = 0.013, \eta^2 = 0.056$; See Fig. 5 right side).

As expected, the children who had played the Criterion test game for 5 weeks (Repetitive group) improved more than the variable group (Table 4). It is shown in Fig. 5 that the DCD group performed worse than the TD group during pre and posttest. Fig. 5 also displays the change during the gap between pre and posttest trials, in which the Repetitive practice schedule group, kept playing the Criterion test game, while the Variable practice schedule group only played other games. It can also be seen that the variable practice schedule group had not improved on the Criterion test score immediately

Table 4

Mean and SD of the pre and posttest scores on the Criterion test.

Mean Criterion test score over 10 trials	Pretest (Mean $\pm$ SD)	Posttest (Mean $\pm$ SD)	Cohen d for the change
TD Repetitive practice schedule	155.83 $\pm$ 35.56	66.36 $\pm$ 34.99	2.52
DCD Repetitive practice schedule	175.77 $\pm$ 36.12	83.37 $\pm$ 41.07	2.56
TD Variable practice schedule	142.14 $\pm$ 41.44	121.93 $\pm$ 42.43	0.49
DCD Variable practice schedule	175.36 $\pm$ 39.21	142.70 $\pm$ 38.75	0.83

*Lower scores indicate improvement; less mistakes and less time to finish a run.

at run 11, after 5 weeks of playing other games, but improved fast once they started playing the game during run 11–20. Fig. 5 also shows that the children in the repetitive practice schedule, who played the same game for 5 weeks, no longer improved during the 10 trials of the posttest procedure, due to a ceiling effect. On the other hand, children who had not played the Criterion test game during the training (Variable game group), showed large improvement during the 10 trials of the posttest (Interaction Time of test $\times$ Trial $\times$ practice schedule $F(9, 99) = 3.00$, $p = 0.003$, $\eta^2 = 0.21$). As can be seen in the steepness of the lines, these improvements were larger in the Variable game group.

3.3.3. Comparison on rate of change in the pre and post criterion test

To answer the question if children learn the Criterion test game faster after they had played many different Wii games for 5 weeks, the extent of the change in the pre and post test trials was compared (transfer of skills). For the children in the Variable practice schedule, the difference in the change in the pre and posttest showed that they improved more in the posttest trials than during the pretest ($t(55) 2.56$; $p = .013$). At pretest, their Criterion test game score started at 178 in the first run and changed to 152 points in the last run (difference between trial 1 and 10 is 25.6 points, 15% improvement) and this change was from 161 at pretest to 112 at the posttest (difference between trial 1 and 10 is 48.6 points, 30% improvement). This confirmed a higher gain in the Criterion test score after playing other games in the Variable game group.

4. Discussion

In this study, we sought to ascertain if variable or repetitive practice schedule enhances sensorimotor learning best. The findings were based on changes brought about by participating in a 5-week active video games using two-practice schedules, either playing the same game over and over again, or engaging in a free choice of 10 different games. The data gave the following answers to our research questions:

1. There is no difference in improvement in the mean standardized game scores in Repetitive and Variable practice schedule during 5 weeks of training. Although variability of the individual learning slopes is larger in the variable practice schedule, which led to less significant changes in the individual game score during the variable practice (retention), this does not lead to differences in the transfer of learning.
2. Both practice schedules have a comparably positive effect on a near transfer task (the yoga task) tested during the 5 weeks of training.
3. There were large differences in performance on the criterion test between repetitive and variable practice schedule after 5 weeks of training, confirming task specificity of the training effect.
4. Children in the Variable practice schedule group learn the untrained criterion test faster during the posttest session *after* they have practiced other games, compared to the changes in pretest (transfer of learning).
5. The level of motor performance (TD vs. DCD) was not a mediating factor in the rate of learning or the amount of transfer. There are no differences in improvement in the Normalized Game scores between children with DCD and TD children or in the transfer tasks.

Although children improved on the trained and less trained tasks, the conclusion is that we could not show in the present study that playing variable games enhanced complex motor-skill learning more compared to the repetitive practice of playing the same game.

4.1. Motor learning

In this study, predictions associated with motor learning research were confirmed using active video games. First of all, performing a particular task over and over again makes one better at it. By playing games repetitively scores get better; this was the case in both TD children as well as in children with poor motor coordination. The specificity of learning hypothesis predicted that learning is most effective when practice sessions include environment and movement conditions, which closely resemble those required during performance of the task. In this study the replication of the target skill for the Repetitive practice group showed the largest effects ($ES = 2.5$), compared to the effect size ($ES = 0.66$) of the children who played many different games. Secondly, if you train longer you improve more on the skill trained as was shown in the learning curve based on the changes in scores of the 10 training sessions. Thirdly, after a certain time, learning levels off. No

learning occurred within the ten runs during the post-test after 5 weeks of training in the group that repetitively practiced the Wii test game (Criterion test game). That does not imply that longer practice will not improve the skills further, it could just be that we entered the less steep part of the learning curve. Lastly, learning of variable games influences the rate of learning of a relatively new comparable game both aimed at dynamic balance.

4.2. Active computer games and near transfer

In this study, we decided to look at two forms of near transfer: the speed of improvement in a different active video game and a near transfer task, while being challenged during a static balance task which poses different challenges than that presented by the dynamic balance games trained in our study.

Transfer of learning is the dependency of learning on practice or performance on prior experience. The underlying thought is that the application of skills that were learned in one situation will increase the speed of learning of a new skill in another situation. So one can consider transfer achieved when the learning of untrained related skills happens faster based on prior experience. If this were true, one would predict that by training many games (Variable practice schedule) one would have improved their score also on Criterion test game and that they would learn the Criterion test game faster. The first was not the case, the children in the variable practice schedule group had not improved significantly on the Criterion test game at the beginning of the posttest compared to the last trials of the pretest (see Fig. 5; the score on run 11 after the training is slightly worse than on run 10 before the training). But once the children in the variable practice schedule group were able to repeat the Wii test game, they seemed to catch up for a large part in one session while playing the game 10 times. So indeed they were learning faster, indicating transfer of learning.

Improvement on the Yoga task was comparable between practice schedules. Based on motor training principles, performing a task twice a week for a maximum of 30 s per leg cannot be called practice as such. To explain transfer from dynamic to static balance, we argue that the tasks selected must share common demands with the trained videogames, e.g., postural control guided by immediate visual feedback given on the screen. In contrast with our hypothesis, both practice schedules were equally successful, in the near transfer Yoga task. Apparently, both practice schedules elicited focus on the virtual character (Mii) as augmented feedback tool to control balance in a similar way; whether they repeated the same game or whether the child played different games. In short, the central finding is that near transfer is not different between the two-practice schedules.

4.3. Active computer games and learning in DCD

Does exergaming help children with DCD in the acquisition of skills? Based on our results and outcomes of recent studies (Ashkenazi, Weiss, Orian, & Laufer, 2013; Hammond et al., 2014; Smits-Engelsman et al., 2015), one could state that for some skills, specifically ones that require fast postural adaptations, the answer is yes. However, there is a risk that exergames might give an “overdose” of feedback, which may make performance dependent on that feedback which is usually unavailable in real life situations. Augmented feedback helps to develop a reference of correctness and to detect errors during motor learning. Importantly, these error signals provided by the excursion of the Mii act as a practice signal for refining the accuracy of predictive models; this iterative process is thought to be fundamental for motor learning (Davidson & Wolpert, 2005) and is hypothesized to be impaired in children with DCD. According to the guidance hypothesis (Schmidt, 1991), during acquisition, the learner's intrinsic error detection and correction processes remain undeveloped due to the readily and constantly available augmented feedback. Thus, the individual's experience attributes normally used to develop representations to shape the internal models are supplanted by the guidance properties of the feedback. Quite a number of studies strongly suggests that children with DCD have a deficit in motor prediction and online control encapsulated under the internal modeling deficit hypothesis (Adams, Lust, Wilson, & Steenbergen, 2014; Wilson et al., 2013). Especially in children with DCD this abundance of augmented feedback in active computer games might therefore be an important point for further studies. The fact that we did not find any differences in learning or transfer between TD and DCD does not confirm these hypotheses (guidance hypothesis or internal modeling deficit hypothesis) nor does it refute them. Given the huge amount of augmented feedback the DCD group seems to thrive and learn at a comparable rate. The children with DCD showed a comparable amount of transfer to a Yoga task without the need of anticipatory control in a simple context. Whether these skills can be applied in an everyday living environment without the bells and whistles provided by the computer games needs to be scrutinized in future learning studies. Although 89% of the children still thought playing the same game was awesome by the end of the practice, versus 96% of the variable group, the supervisors observed discussions and excitement in the children in the variable game group on which games to play on subsequent sessions. However, this was not the case for the repetitive practice schedule group as they did not have that option. Therefore, we would recommend giving children the choice to select their own games depending on the goal of the practice.

5. Conclusion

Our findings suggest that playing active video games enhances sensorimotor learning and yields superior performance. Effect of active video gaming is large, whether children follow repetitive or variable practice schedule. There are clear indications of transfer after active computer training to tasks that share common elements. Variable practice schedule does

not enhance the transfer effect. Although we are replicating previous findings that children with DCD perform poorer on exergames, the learning effect is comparable for children with different levels of motor proficiency.

Conflicts of interest

The authors have no conflict of interests to declare.

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Appendix A.

See [Table A1](#)

Table A1
Description of games played by the children in the variable practice schedule group.

Number (#)	Name of Game	Brief Description	Total number of games played over 10 sessions (n = 56)
1	Soccer heading	The player is supposed to head soccer balls and avoid other objects by shifting body weight to the left and right sides.	364
2	Table tilt	The player is expected to move balls into a hole by shifting his body weight forward, backward, left side and right side.	323
3	Ski jump	The player skis around obstacles by stepping on and off the balance board and shifting his body weight from forward to backward and left side to right side.	639
4	Bubble Balance	The player steers a water bubble through a narrow water course without allowing the bubble to touch the river bed. This is achieved by carefully shifting of his/her body weight on the balance board.	475
5	Penguin slide	The player is expected to catch fishes flying over iceberg by shifting his/her body weight in several directions (forward, backward and sideways).	280
6	Snow board	The player moves through gates by shifting his/her body weight from forward to backward on the balance board.	247
7	KungFu	The player follows the instruction on the TV screen and executes the correct movement pattern by repeating the gestures of the Mii (an avatar character)	405
8	Obstacle course	The player runs over gaps and around obstacles through vertical displacement of his center of mass. The player is neither required to fall into a ditch nor be hit by the moving obstacles	482
9	Perfect 10	The player is expected to hit numbers that sum up to 10 by shifting his/her body weight forward, backward and sideways.	396
10	Skateboard	Player moves over elevated obstacles by shifting his/her body weights in several directions (anterior-posterior/sideways).	359
Total Number of Games			3970
Mean Number of games per session			7.1 (SD: 2.0)

References

- Adams, I. L. J., Lust, J. M., Wilson, P. H., & Steenbergen, B. (2014). Compromised motor control in children with DCD: A deficit in the internal model?—A systematic review. *Neuroscience & Biobehavioral Reviews*, 47, 225–244. <http://dx.doi.org/10.1016/j.neubiorev.2014.08.011>
- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.
- Ashkenazi, T., Weiss, P. L., Orian, D., & Laufer, Y. (2013). Low-cost virtual reality intervention program for children with developmental coordination disorder: a pilot feasibility study. *Pediatric Physical Therapy*, 25(4), 467–473.
- Battig, W. F. (1966). *Facilitation and interference. Acquisition of Skill*, 215–244.
- Bonnechère, B., Jansen, B., Omelina, L., & Van Sint, J. (2016). The use of commercial video games in rehabilitation: a systematic review. *International Journal of Rehabilitation Research*, 39(4), 277–290.
- Braun, D. A., Aertsen, A., Wolpert, D. M., & Mehring, C. (2009). Motor task variation induces structural learning. *Current Biology*, 19(4), 352–357 [<http://dx.doi.org/10.1016/j.cub.2009.01.036>].
- Cherng, R.-J., Hsu, Y.-W., Chen, Y.-J., & Chen, J.-Y. (2007). Standing balance of children with developmental coordination disorder under altered sensory conditions. *Human Movement Science*, 26(6), 913–926.
- Clark, R. A., Bryant, A. L., Pua, Y., McCrory, P., Bennell, K., & Hunt, M. (2010). Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. *Gait & Posture*, 31(3), 307–310. <http://dx.doi.org/10.1016/j.gaitpost.2009.11.012>
- Davidson, P. R., & Wolpert, D. M. (2005). Widespread access to predictive models in the motor system: a short review. *Journal of Neural Engineering*, 2(3), S313.
- Deconinck, F., Savelsbergh, G., De Clercq, D., & Lenoir, M. (2010). Balance problems during obstacle crossing in children with Developmental Coordination Disorder. *Gait & Posture*, 32(3), 327–331.
- Deutsch, J. E., Borbely, M., Filler, J., Huhn, K., & Guarrera-Bowlby, P. (2008). Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy. *Physical Therapy*, 88(10), 1196–1207.

- Feghhi, I., Abdoli, B., & Valizadeh, R. (2011). Compare contextual interference effect and practice specificity in learning basketball free throw. *Procedia—Social and Behavioral Sciences*, 15, 2176–2180. <http://dx.doi.org/10.1016/j.sbspro.2011.04.075>
- Ferguson, Aertssen, Rameckers, Jelsma, & Smits-Engelsman. (2014). Physical fitness in children with developmental coordination disorder: Measurement matters. *Research in Developmental Disabilities*, 35(5), 1087–1097. <http://dx.doi.org/10.1016/j.ridd.2014.01.031>
- Ferguson, Naidoo, N., & Smits-Engelsman. (2015). Health promotion in a low-income primary school: Children with and without DCD benefit, but differently. *Physical & Occupational Therapy In Pediatrics*, 35(2), 147–162. <http://dx.doi.org/10.3109/01942638.2015.1009230>
- Geuze, R. H. (2003). *Static balance and developmental coordination disorder*. *Human Movement Science*, 22(4), 527–548.
- Gheysen, F., Van Waelvelde, H., & Fias, W. (2011). Impaired visuo-motor sequence learning in developmental coordination disorder. *Research in Developmental Disabilities*, 32(2), 749–756.
- Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, 423(6939), 534–537.
- Grove, C. R., & Lazarus, J.-A. C. (2007). Impaired re-weighting of sensory feedback for maintenance of postural control in children with developmental coordination disorder. *Human Movement Science*, 26(3), 457–476.
- Hammond, Jones, Hill, Green, & Male. (2014). An investigation of the impact of regular use of the Wii Fit to improve motor and psychosocial outcomes in children with movement difficulties: A pilot study. *Child Care Health Dev*, 40(2), 165–175. <http://dx.doi.org/10.1111/cch.12029>
- Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement assessment battery for children-2: Movement ABC-2: Examiner's manual*. São Paulo: Pearson.
- Jelsma, Geuze, Mombarg, & Smits-Engelsman. (2014). The impact of Wii Fit intervention on dynamic balance control in children with probable Developmental Coordination Disorder and balance problems. *Human Movement Science*, 33, 404–418. <http://dx.doi.org/10.1016/j.humov.2013.12.007>
- Jelsma, Ferguson, Smits-Engelsman, & Geuze. (2015). Short-term motor learning of dynamic balance control in children with probable developmental coordination disorder. *Research in Developmental Disabilities*, 38, 213–222. <http://dx.doi.org/10.1016/j.ridd.2014.12.027>
- Kroemer, N., Burrasch, C., & Hellrung, L. (2016). To work or not to work: Neural representation of cost and benefit of instrumental action. *Progress in Brain Research*, 229, 125–157.
- Lage, G. M., Ugrinowitsch, H., Apolinário-Souza, T., Vieira, M. M., Albuquerque, M. R., & Benda, R. N. (2015). Repetition and variation in motor practice: A review of neural correlates. *Neuroscience & Biobehavioral Reviews*, 57, 132–141. <http://dx.doi.org/10.1016/j.neubiorev.2015.08.012>
- Lee, T. D., & Magill, R. A. (1983). The locus of contextual interference in motor-skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 9(4), 730.
- Lejeune, C., Catale, C., Willems, S., & Meulemans, T. (2013). Intact procedural motor sequence learning in developmental coordination disorder. *Research in Developmental Disabilities*, 34(6), 1974–1981. <http://dx.doi.org/10.1016/j.ridd.2013.03.017>
- Lin, C.-H. J., Sullivan, K. J., Wu, A. D., Kantak, S., & Winstein, C. J. (2007). Effect of task practice order on motor skill learning in adults with Parkinson disease: a pilot study. *Physical Therapy*, 87(9), 1120–1131.
- Lohse, K. R., Hilderman, C. G., Cheung, K. L., Tatla, S., & Van der Loos, H. M. (2014). Virtual reality therapy for adults post-stroke: A systematic review and meta-analysis exploring virtual environments and commercial games in therapy. *PLoS ONE*, 9(3), e93318.
- Magill, R. A. (2004). *Motor learning and control: concepts and applications*. Boston: McGraw-Hill.
- Mendes, F. A. D. S., Pompeu, J. E., Lobo, A. M., da Silva, K. G., Oliveira, T. D. P., Zomignani, A. P., et al. (2012). Motor learning, retention and transfer after virtual-reality-based training in Parkinson's disease—Effect of motor and cognitive demands of games: a longitudinal, controlled clinical study. *Physiotherapy*, 98(3), 217–223. <http://dx.doi.org/10.1016/j.physio.2012.06.001>
- Miyahara, M., Hillier, S. L., Pridham, L., Nakagawa, S., Miyahara, M. (2014). Task-oriented interventions for children with developmental co-ordination disorder. 10.1002/14651858.cd010914.
- Muratori, L. M., Lamberg, E. M., Quinn, L., & Duff, S. V. (2013). Applying principles of motor learning and control to upper extremity rehabilitation. *Journal of Hand Therapy*, 26(2), 94–103. <http://dx.doi.org/10.1016/j.jht.2012.12.007>
- Schmidt, Lee (1988). *Motor control and learning: Human kinetics*.
- Schmidt, & Lee. (2011). *Motor control: a behavioral emphasis*. Champaign, IL: Human Kinetics.
- Schmidt. (1991). *Frequent augmented feedback can degrade learning: evidence and interpretations Tutorials in motor neuroscience*. Springer.
- Shea, & Kohl. (1990). Specificity and variability of practice. *Research Quarterly for Exercise and Sport*, 61. <http://dx.doi.org/10.1080/02701367.1990.10608671>
- Shea, & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory*, 5(2), 179.
- Shea, Kohl, R., & Indermill, C. (1990). Contextual interference: Contributions of practice. *Acta Psychologica*, 73(2), 145–157. [http://dx.doi.org/10.1016/0001-6918\(90\)90076-R](http://dx.doi.org/10.1016/0001-6918(90)90076-R)
- Shmuelof, L., Krakauer, J. W., & Mazzoni, P. (2012). How is a motor skill learned? Change and invariance at the levels of task success and trajectory control. *Journal of Neurophysiology*, 108(2), 578–594.
- Smits-Engelsman, Blank, R., van der Kaay, A. C., Mosterd-van der Meijs, R., Vlught-van den Brand, E., Polatajko, H. J., & Wilson, P. H. (2013). Efficacy of interventions to improve motor performance in children with developmental coordination disorder: A combined systematic review and meta-analysis. *Developmental Medicine & Child Neurology*, 55(3), 229–237. <http://dx.doi.org/10.1111/dmcn.12008>
- Smits-Engelsman, Jelsma, L. D., Ferguson, G. D., & Geuze, R. H. (2015). Motor learning: An analysis of 100 trials of a ski slalom game in children with and without developmental coordination disorder. *PLoS ONE*, 10(10), e0140470.
- Vera, J. G. (2008). Effects of different practice conditions on acquisition and Retention.
- Wilson, Maruff, P., & Lum, J. (2003). *Procedural learning in children with developmental coordination disorder*. *Human Movement Science*, 22(4), 515–526.
- Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank. (2013). Understanding performance deficits in developmental coordination disorder: A meta-analysis of recent research. *Developmental Medicine & Child Neurology*, 55(3), 217–228. <http://dx.doi.org/10.1111/j.1469-8749.2012.04436.x>
- Wolpert, D. M., Diedrichsen, J., & Flanagan, J. R. (2011). Principles of sensorimotor learning. *Nature Reviews Neuroscience*, 12(12), 739–751.
- Wuang, Y. P., Su, J. H., & Su, C. Y. (2012). Reliability and responsiveness of the movement assessment battery for children—second edition test in children with developmental coordination disorder. *Developmental Medicine & Child Neurology*, 54(2), 160–165.
- Wulf, G., Shea, C., & Lewthwaite, R. (2010). Motor skill learning and performance: a review of influential factors. *Medical Education*, 44(1), 75–84.
- Zwicker, J. G., Missiuna, C., Harris, S. R., & Boyd, L. A. (2012). Developmental coordination disorder: A review and update. *European Journal of Paediatric Neurology*, 16(6), 573–581. <http://dx.doi.org/10.1016/j.ejpn.2012.05.005>