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# Task-specificity and transfer of skills in school-aged children with and without developmental coordination disorder

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## ABSTRACT

*Aim:* To compare the effects of two Active Video Game (AVG) protocols on transfer of learning in children with and without Developmental Coordination Disorder (DCD).
*Methods:* Fifty children, aged 6–10 years were randomly allocated to either group A or B. Children in group A participated in a set of Nintendo Wii ball games whereas group B played agility games (8 DCD and 17 typically developing children (TD) per group). Participants in each group practiced Wii games for 20 min twice a week for 10 weeks. All children also practiced ball and agility games in real-world settings, once per week.
*Results:* Both protocols yielded positive effects with the largest effect sizes shown on agility and balance items of the PERF-FIT and KTK tests. No interaction was found on learning real-world games and the virtual protocol, except for a Ping-Pong game. A significant interaction of time by protocol group indicated that the Ball group improved more on BOT-2-Upper-Limb Coordination than the Agility group. Importantly, children with DCD improved comparably with TD peers in virtual and real-world games.
*Conclusion:* Independent of training protocol, both children with DCD and TD children performed better on trained and non-trained ball, balance and agility tasks after 10 weeks of training.

## What this paper adds

Active video games (AVGs) have been recommended as adjunct therapy for children with Developmental Coordination Disorder (DCD). However, we know very little about how task-specific improvements in motor skills induced by training in a virtual environment influence real-world task performance in children with movement difficulties. Ball skills are known to be difficult for children with developmental disorders because of their complexity. For example, to participate in a game of basketball, a child needs to combine running, catching, dribbling, throwing, and jumping while throwing. Furthermore, reading your opponent or teammate through recognizing the moves and circumstances is one of the key components of skilled catching and throwing at a level of being successful to participate in games or sports. Although many aspects of ball games are mimicked in AVG, numerous task constraints,

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such as, bouncing properties, or interception of the ball are not trained in AVG. If transfer from AVG to real life skills were to occur, one would expect that children who play virtual reality ball games will learn the real-world ball games faster than peers who train on agility games. However, participants' scores in the present study do not seem to support this expectation. Overall, there was a large effect of playing active video games on gross motor and agility outcomes. However, playing tennis or golf in an active video game may be a different ballgame given that spatial constraints, and movements pattern are very dissimilar. However, there are some overarching components that could explain more general effects of AVGs, such as the need to constantly predict when and where events of interest may occur, the repetitive nature of games needed to get to higher levels increasing motivation. It might be that the improvements seen in children after both AVG protocols is the result of faster visual perception, better attentional focus and not so much of the specific skill trained. Notably, the relative improvement was comparable for children with DCD and their TD peers. More detailed evaluation of identical elements is required to gain insight into the relation between improvements in virtually trained and real-world tasks.

## 1. Introduction

There has been an explosion of interest in the use of active video games (AVGs) in pediatric rehabilitation in recent years (Blank et al., 2019; Mentiplay et al., 2019) leading to the publication of several studies investigating the effects of AVGs on motor performance in children with movement difficulties (Bonney et al., 2017a; Hickman et al., 2017; Hocking et al., 2019; Howie et al., 2017; Straker et al., 2015). Some previous studies have specifically examined motor learning and skills transfer in children with Developmental Coordination Disorder (DCD) (Bonney et al., 2017; Jelsma et al., 2015; Smits-Engelsman, Bonney et al., 2021; Smits-Engelsman et al., 2015). Motor skill acquisition is evident when an individual's performance is improved through practice (Schmidt, 1982; Seidler & Noll, 2008; Singer, 1980). In the case of transfer, a saving in learning rate or improved performance occurs due to a person's recent experience with a related skill (Lieberman, Biely, Thai, & Peinado, 2014; Schmidt, 1988; Seidler & Noll, 2008; Singer, 1980). The ability to transfer skills across context is necessary for learning and adaptive functioning. While the lack of carryover effect of AVG-based learning was previously highlighted as a major concern (Blank et al., 2019), to date we still have little empirical data to determine whether children with DCD can apply skills acquired in a virtual environment to task variants in their natural environments. One mechanism that is reported to support transfer of motor skills is task-specificity (Bonney et al., 2017a)(Bonney et al., 2017b). However, there is still insufficient data concerning task-specificity and/or transferability after active video game training to make evidence-based decisions.

Developmental Coordination Disorder (DCD) is a neurodevelopmental disorder that affects the development of movement and coordination skills (American Psychiatric Association, 2013). Many scholars tend to view DCD as a motor learning deficit because children with DCD often struggle to acquire and execute motor skills as compared to their typically developing peers who seem to acquire motor skills almost effortlessly (Biotteau et al., 2016; Bo & Lee, 2013; Smits-Engelsman & Verbecque, 2021). However, preliminary data have shown that children with DCD can learn new motor skills when exposed to AVGs and that skills acquired in such environments could be applied to real world contexts (Bonney et al., 2017; Jelsma et al., 2015; Smits-Engelsman et al., 2015). Although AVGs have been recommended as a useful adjunct to therapy for managing DCD (Blank et al., 2019; Smits-Engelsman et al., 2018), the task-specificity of such programs is less investigated. Additionally, the mechanisms underlying AVGs-based learning among children with DCD and typically developing (TD) peers have not been well explored.

AVGs (also known as exergames) are interactive electronic games that encourage active engagement and repetition of task-specific movements to achieve a specific objective (Kim et al., 2012; Vernadakis , 2012; Zeng et al., 2017). AVGs provide diverse tasks or games which can be played in their original form or can be easily adjusted to decrease or increase task difficulty (Kim et al., 2012). Several features contribute to the appeal of AVGs. These include *interactivity* (ability of players to initiate and receive feedback about their actions), *agency or control* (ability of players to manage aspects of their game play using control devices such as a remote), and *identity* (ability of players to create linkages/relationships with game characters or to become game characters via avatar construction) (Blumberg & Blumberg, 2014). Other characteristic features of AVGs are *feedback* (information players receive about the efficacy of their gaming actions) and *immersion* (players' sense of presence or integration within the game) (Blumberg & Blumberg, 2014). These features and elements such as repetitive practice and motivation promote sustained interest during game play and provide more opportunity for learning new skills (Kim et al., 2012). AVGs encourage the use of sports-specific movements that seem similar to actions required in everyday life. However, differences in the "virtual world" and "real world" spaces might hinder transfer of skills. Therefore, it is essential to address the question: will improved performance of a particular motor skill acquired in a virtual environment contribute to faster learning rates of a similar skill in a real-world context?

Task-specificity of training demonstrates that the greatest performance gains occur when exercises are similar to tasks and context used during testing (Saeterbakken et al., 2016; Thorstensson et al., 1976). This adaptation could be attributed to alterations in both muscular and neural activations (Saeterbakken et al., 2016). Research shows that training specificity is apparent in the movement patterns, joint positions, and types of muscle contractions used in training (Buckthorpe et al., 2015; Saeterbakken et al., 2016; Thorstensson et al., 1976).

Task-specific training involves the selection and actual performance of a meaningful functional task in a repeated manner to enhance performance of the task in one's natural environment (Bayona et al., 2005; Waddell et al., 2017). During task-specific training, spatial and temporal task constraints are gradually increased to target adaptability of the trained task within a wide variety of contexts (Niemeije et al., 2007; Schoemaker et al., 2003; Smits-Engelsman & Verbecque, 2021). So far, the effects of AVGs on motor function in children with DCD show some task-specific advantages for balance and agility tasks (Bonney et al., 2017), but this seems to depend on elements such as task similarity, variability, and intensity of training (Hocking et al., 2019). This may be different for ball skills. Based on the motor learning literature (Biottaeu et al., 2016; Bo & Lee, 2013), we assume that skill transfer is task-specific and limited to the perceptual or motor skills common to both the trained videogame and the real world (transfer) task. Real life ball skills require, in addition to control the ball, planning of concurrent and sequential actions. For example, to catch a ball in the air a child needs to combine moving to the right position at the right time while making the interception movement. Numerous task constraints such as, bouncing properties, or cupping the hands for intercepting the ball, are not trained in AVGs. For transfer to occur, the perceptual-cognitive and motor demands that the child faces in real world environments need to be trained in an active video gaming environment. However, this is only partly true for commercial AVGs such as the Nintendo Wii Fit or Microsoft Kinect. For instance, when playing the Wii sport tennis, no tennis racket is held but instead the player holds a controller and also misses the impact of the ball on the racket. Ball skills are known to be difficult for children with developmental disorders. Moreover, ball skill competency is a prerequisite for active participation in many forms of play and recreational activities (Smits-Engelsman et al., 2022). It is therefore important to know if AVGs trained ball games transfer to real life ball skills.

The underlying premise of shared common task demands between AVG training and real- world tasks provides a hypothesis that can be experimentally tested and, if confirmed, may be translated to clinical settings. The main purpose of this study was to examine the task specificity, transferability and time course (rate) of performance improvements in response to two AVG protocols; one emphasizing ball skills and the other focusing on agility games. In light of the aforementioned considerations, the following specific questions were formulated:

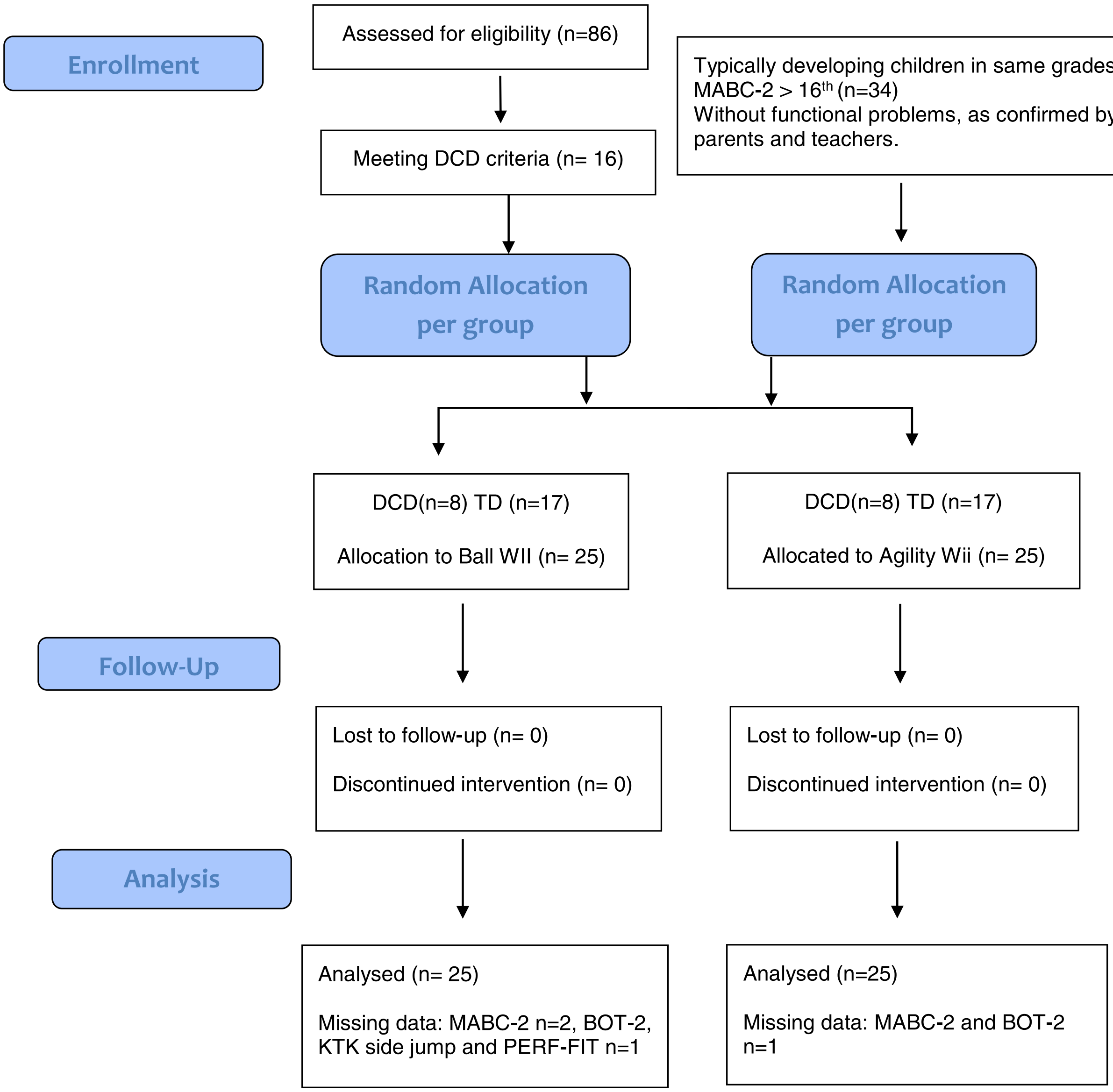

**Fig. 1.** Flowchart of children’s recruitment process of the study.

1) Do children who participate in 10 weeks of training demonstrate improvements in practiced real-world games performance?
    a. Do children who participate in the AVG Ball protocol learn *real-world* ball skills faster than the control group (AVG Agility protocol)?
    b. Do children who participate in the AVG Agility protocol learn *real-world* agility skills faster than the control group (AVG Ball protocol)?
2) Do children who participate in 10 weeks of training improve on non-trained standardized tests measuring ball skills, agility and balance?
    a. Do children who participate in 10 weeks of AVG Ball protocol improve more on non-trained items that have *comparable elements* (ball test items) than control children (AVG Agility protocol)?
    b. Do children who participate in 10 weeks AVG Agility protocol improve more on non-trained items that have *comparable elements* (agility test items) than control children (AVG Ball protocol)?
3) Is the level of motor performance (TD vs. DCD) a mediating factor in the rate of learning?

Based on the principle of task-specificity (Bayona et al., 2005; Waddell et al., 2017), we expected children in the virtual Agility protocol group to improve faster on (trained) real-world agility games and improve more on standardized agility test items (non-trained task with comparable elements) than children in the virtual Ball protocol group. Additionally, we expected children in the virtual Ball protocol group to improve faster on (trained) real-world ball games and improve more on (non-trained) standardized ball tests than children in the virtual Agility protocol group.

## 2. Methods

### 2.1. Participants

Fifty (n = 50) school-aged children (mean age 7.2 ± 1.0 years; grades 1–3) participated in this study and were recruited from a mainstream elementary school in Cape Town, South Africa. Participants' demographic information is summarized in the results section. Eligibility criteria were specified to include children aged 6–9 years, enrolled as a learner in the participating school and willingness to participate in the study. Children were excluded if they had any injury or functional limitations that precluded testing. Written informed consent was obtained from parents of all participants and each child provided written assent before involvement. The study protocol received ethical approval from the Human Research Ethics Committee of the University of Cape Town (HREC #: 139/2019). Permission was also obtained from the principal of the school and designated education authorities in the Western Cape Province of South Africa.

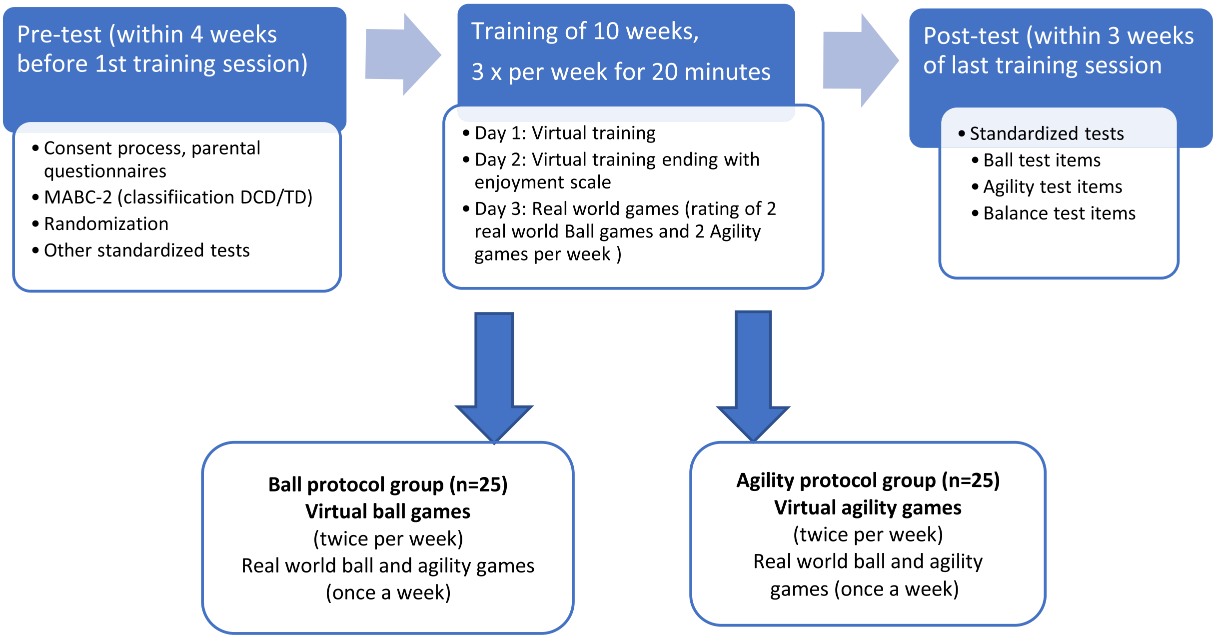

**Fig. 2.** Design of the study. The experimental protocol included 10 weeks of training with 2 weeks of school holidays in the middle. During the ten weeks of training all the real-world games were scored five times (4 games per week). The pre- and post- standardized tests were separated by a 16 – 20-week time period.

### 2.2. Identification of children with DCD and TD children

Identification of children with DCD and TD children followed a two-step process to confirm the four diagnostic criteria for DCD specified in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (American Psychiatric Association, 2013) (see Fig. 1 for flowchart of children's recruitment and randomization process of the study). First, after consent, parents were asked to fill out a parental background questionnaire and DCD-Q to determine the presence of motor problems (Wilson et al., 2009). Secondly, children were tested on the Movement Assessment Battery for Children test-second edition (MABC-2) (Henderson et al., 2007). The criteria used for selecting children with DCD were: at risk for motor problems in early life based on parent reports; a score below the 16th percentile on the MABC-2; no diagnosis of a significant medical condition known to affect motor performance (determined by parent reports); not repeated a grade more than once. The following criteria were used to identify children with typical development: not at risk for motor problems [determined by parent reports], a score above the 16th percentile on the MABC-2, no diagnosis of a significant medical condition known to affect motor performance and not repeated a grade more than once (determined by parent reports).

### 2.3. Procedure

This experimental study had a stratified randomized pre-post single blinded design and was used to evaluate changes in performance during and after 10-weeks training. Two different AVG protocols were used: Ball protocol and Agility protocol. Groups were stratified so that an equal number of children with and without motor problems were randomly allocated to the two protocols by an independent individual, who was not involved in the study (See Fig. 1 for the stratified randomization and Fig. 2 for the study design).

To compare the performance gains in real world games, each game was scored five times during the 10 weeks of training. Lastly, participants completed pre- and post-tests on non-trained standardized tests to evaluate if motor performance was better after 10 weeks of game play on a number of different standardized tests. The MABC-2, PERF-FIT, BOT-2 and KTK items were administered pre- and post-training by four trained assessors, who were not involved in the training and were blinded to the protocols.

Sample size was calculated by using G*Power v3.1 (Faul et al., 2009) and data from past research. Considering an effect size of 0.80, 23 participants per group were required. To account for possible dropouts, this number was increased to 25.

### 2.4. AVG Protocols

The virtual part of the training consisted of playing different AVGs from the Nintendo Wii Fit. The Wii Fit Plus uses the Wii Balance Board (WBB), on which the child stands and handheld remote controllers. The WBB has four sensors in each corner and is calibrated according to each child's weight. Four television monitors and Nintendo Wii motion-controlled video consoles and WBB (Nintendo Co. Ltd., Kyoto, Japan) were set up in a designated classroom.

Children participated in 20 min of AVG exercises per session, twice weekly for 10 weeks. One group played virtual Ball games that seem related to real-world ball games while the other group played Wii Fit agility games (See Table 1). The video games required whole body movements to steer the avatar, and the child was expected to anticipate the movement direction and speed, based on changes in the visual context. Both protocols provided extensive (visual and auditory) feedback on the child's performance during game play. Additionally, scores were provided for each of the games played. For the Agility protocol group, steering the avatar was done via the WBB. However, in the Ball protocol group, the WBB was only used in 3 games, while in the other games a hand-held remote controller steered the avatar.

### 2.5. Real-World Games

Eight real-world games were also developed for this study. These included Obstacle race, Slalom race, Sack race, Foam path race over 10 m, Cup ping pong, Flip and catch, Golf and Marble putting (See Table 2 for details). These games were performed in a large hall at the school (in small groups of 2–4 children) supervised by two physiotherapists who were not involved in the assessments. The

**Table 1**
Virtual games included in the Ball and Agility games protocol.

| Wii Ball games | Wii Agility games |
|---|---|
| • Soccer heading | • Penguin slide |
| • Snowball flight | • Balance bubble |
| • Big top juggling | • Skateboard |
| • Golf (Wii sports) # | • Obstacle course |
| • Tennis (Wii sports) # | • Table tilt |
| • Bowling (Wii sports) # | • Snowboard |
| • Baseball (Wii sports) # | • Ski jump |
| | • Kong fu # |

Note: The children started each week with Virtual Game 1 and finished all games in their protocol in the two sessions of that week. # Used handheld remote control to steer the games.

**Table 2**
Active Games.

| | |
|---|---|
| **Obstacle course (s)** | Running 10 m while jumping over four 15 cm high obstacles without touching them. At the end line they picked up a ball, put it in the bucket and ran back the same trajectory. |
| **Slalom (s)** | Running a 5-meter super curvy slalom with narrow gates marked by colored bottles. At the end line they picked up a ball, put it in the bucket and ran back the same trajectory. |
| **Sack race (s)** | Children got inside a large burlap sack before the starting signal and had to jump over a 10-meter trajectory without falling. |
| **Foam pads (s)** | Children had to cover a 10-meter distance while staying on two closed cell foam pads (50 ×40×6 cm), normally used for balance testing, without stepping on the floor. At the end line they picked up a ball, put it in the bucket to end the timing. |
| **Flip and catch (#)** | The child was standing next to a small seesaw and propelled a beanbag up in the air by firmly stepping on the higher end of the seesaw. The bean bag had to be caught before it landed on the floor. Number of beanbags caught was counted (10 trials). |
| **Cup Ping-Pong (#)** | The children had to throw a Ping-Pong ball against the wall at 1 m distance and catch it in a plastic beer cup in the other hand. Number of Ping-Pong balls caught was counted (10 trials). |
| **Golf putting (#)** | The golf ball had to be putted using a putter from 1 m distance (10 trials). |
| **Marbles putting (#)** | Marbles had to be putted using the preferred hand in the golf put from 1 m distance (10 trials). |

s: measured in 0.1 s using a stopwatch; # measured in number of times

games were set up before participants arrived and each game was explained and demonstrated before children were allowed to practice. The real-world games were performed once a week, 20 min per session for 10 weeks, and included practice of fundamental movement skills, which are required to perform running and agility, and aiming and catching activities. The therapists provided verbal encouragement to all children during the training. The time taken to complete a game or the number of catches or points was recorded. The best score of two repetitions was used for the analysis.

## 2.6. *Measures*

In the next section, a summary of all the measures used is provided.

### 2.6.1. *Anthropometric variables*

Height, and weight were measured, and BMI calculated using the formula [BMI = weight (kg)/height (m)$^2$]. Height was measured to the nearest 0.1 cm with a wall-mounted tape measure while weight was measured to the nearest 0.1 kg using an electronic scale. Participants' weight was measured in light clothes and without shoes.

### 2.6.2. *Physical activity readiness questionnaire (PAR-Q)*

The PAR-Q was used to screen for safe exercise participation (Quinn, 2018). This questionnaire allows parents to report on medical conditions (e.g., high or low blood cholesterol, asthma or respiratory problems) of their children that will make exercising unsafe. The PAR-Q is now considered to be a global pre-participation screening instrument (Warburton et al., 2011).

### 2.6.3. *Movement assessment battery for children-2nd edition (MABC-2)*

The MABC-2 test consists of eight motor skill items divided over three different domains: Manual Dexterity (three items), Aiming and Catching (two items), and Balance (three items). Raw scores are converted into standard scores and can be summed up and recoded into a Total Standard Score or percentile score. The MABC-2 is known for good inter-rater reliability and criterion validity (Henderson et al., 2007). The total scores were used for classification and component scores for Aiming and Catching, and Balance were used for pre- and post-training comparison. The MABC-2 is considered a reliable and valid measure to assess motor performance (Wuang, Su, & Su, 2012). In children with DCD, internal consistency is reported to be high (alpha = 0.90) and test-retest reliability for the total scores is regarded as excellent (ICC = 0.97) (Smits-Engelsman, 2010).

### 2.6.4. *The bruininks-oseretsky test of motor performance, second edition (BOT – 2) upper-limb coordination subtest*

The BOT-2 (Bruininks & Bruininks, 2005) measures an array of motor skills in children of 4–21 years of age. It contains eight subscales: Fine Motor Precision, Fine Motor Integration, Manual Dexterity, Upper-limb Coordination, Bilateral Coordination, Balance, Running Speed and Agility, and Strength. The BOT-2 Upper-limb Coordination was chosen for this study as it is one of the tests with the largest number of Ball skill items. The BOT-2 is a widely used instrument, with an excellent reliability for this age group (ICC = 0.76 – 0.82) (Bruininks & Bruininks, 2005), good test-retest reliability (r = 0.85) and good validity (Brown, 2019).

### 2.6.5. *Korper Koordinations Test fur Kinder (KTK)*

The KTK, developed to examine non-sport-specific gross body coordination in children, was used in this study. The KTK is made up of 4 subtests: (1) walking backwards along a balance beam, (2) moving sideways on platforms, (3) hopping for height on one foot and (4) jumping sideways (Kiphard & Schilling, 2007). Item 2 moving sideways on platforms and item 4 jumping sideways were used for this study because they measure agility and dynamic balance. The KTK showed to have a good reliability (test-retest reliability between.80 and.96 (Kiphard & Schilling, 2007).

#### 2.6.6. PERF-FIT

The Performance and Fitness (PERF-FIT) battery is a valid and reliable test for children aged 5–12 years, with excellent content validity (content validity index ranging from 0.86 to 1.00), good structural validity (Smits-Engelsman et al., 2020; (Smits-Engelsman et al., 2020b). excellent inter-rater reliability (ICC, 0.99), good test-retest reliability (ICC, $\geq$ 0.80) (Smits-Engelsman et al., 2021b).

The PERF-FIT has two subscales: a Performance part; the Motor skill performance subscale (5 Skill Item Series) and a Fitness part; Agility and Power subscale (5 items). The Motor skill performance subscale contains five Skill Item Series (SIS) of increasing difficulty; bouncing and catching, throwing and catching, jumping, hopping (left and right), and balance. The Agility and power subscale contains five items: running, stepping, side jump, long jump, and overhead throw. All children perform two trials for each item with the best score used for the analysis (Smits-Engelsman, 2018).

#### 2.6.7. Enjoyment scale

An enjoyment scale that was previously developed (Jelsma et al., 2014) was used to measure participants' enjoyment during game play. The scale has five smiley faces (0 is not fun at all, 5 is super fun).

### 2.7. Data analysis

Differences in demographic characteristics between the two groups were calculated at baseline using Pearson's Chi squared test (sex) and t-test (age, BMI and MABC-2 total score).

To test for changes during the 10 weeks of training, we analyzed the real-world game scores for each of the ten games using repeated measure ANOVA with Assessment (5), as within group factor and Protocol (Ball versus Agility) and Participant group (TD/DCD) as the between subject factors.

To test for changes after the 10 weeks of training, we analyzed the standardized test scores (transfer tasks) at component/subscale and item-level with repeated measure ANOVA with Time of measurement (Pre versus Post) as within group factors and Protocol group (Ball versus Agility) and Participant group (TD/DCD) as the between group factors.

Partial eta-squared ($\eta_p^2$) effect-sizes were calculated and defined:0.01 as small, 0.06 as medium and 0.14 as large (Cohen, 1988). For ease of comparison to earlier studies eta-squared values for significant changes were also converted to Cohen's $d$ using the formula given by Cohen (1988). and classified as small ($d = 0.3$), moderate ($d = 0.5$) or large ($d = 0.8$) (Sullivan & Feinn, 2012). The statistical analyses were carried out with Statistical Package for the Social Sciences (SPSS 27.0 version, Chicago, Illinois, USA),(IBM Corp., 2017) with a significance level set at $p < 0.05$.

## 3. Results

All children completed training procedures, and no injuries were reported. Both Protocol groups recorded a participation rate of 100% during the training. Data were missing for some post-tests because those children were not in school during the whole post-test period, which took place two weeks after the training, just before the school's vacation (missing data Agility group: MABC-2 (n = 1); BOT-2 (n = 1); and Ball group: MABC-2 (n = 2); BOT-2 (n = 1); KTK (n = 1); PERF-FIT (n = 1).

### 3.1. Participant characteristics

As shown in Table 3, children in the two protocol groups were not different on any of the demographic variables.

**Table 3**
Demographic background information about the participants per group with statistics.

| Variables | All children n = 50 | Ball Protocol group n = 25 | Agility Protocol group n = 25 | Statistics | TD n = 34 | DCD n = 16 | Statistics |
|---|---|---|---|---|---|---|---|
| **# Boys/Girls** | 25/25 | 13/12 | 12/13 | *Chi*= 0.08, $p = 0.77$ | 18/16 | 7/9 | *Chi*= 1.26, $p = 0.53$ |
| **Age (years) mean, (SD)** | 7.16 (1.0) | 7.08 (0.95) | 7.24 (1.05) | $t = -0.563$, $p = 0.576$ | 7.2(0.98) | 7.1 (1.06) | $t = 0.471$, $p = 0.64$ |
| **BMI (kg/m$^2$) mean (SD)** | 15.86 (2.53) | 15.8 (2.44) | 15.9 (2.67) | $t = -0.16$, $p = 0.874$ | 15.9(2.4) | 15.7 (2.8) | $t = 0.269$, $p = 0.79$ |
| **MABC-2 (SS) mean (SD)** | 9.18 (2.95) | 9.2 (3.06) | 9.2 (2.90) | $t = -0.048$, $p = 0.962$ | 10.7 (2.2) | 5.9 (1.0) | $t = 8.55$, $p = 0.001$ |
| **# MABC-2 ≤ P16** | 16 | 8 | 8 | | 0 | 16 | |

#=number; BMI=body mass index; MABC-2=Movement Assessment Battery for Children, second edition; SS=standard score; Chi=Chi squared test; t = independent t-test; p = p-value

### 3.2. *Effect of training*

#### 3.2.1. *Real-world Game scores*

The children improved significantly on the scores of the real-world games, except on Golf (for *p-values* see Table 4). Only for one game, Cup Ping Pong, a significant interaction between Time and Protocol group emerged (Time x Protocol; $F(4,45)= 3.525$, $p = 0.014$, $\eta^2$ 0.24). Against expectations, the Agility group improved more on the Cup Ping Pong game than the Ball group.

The relative changes in the real-world games were not different between the TD and DCD children (no significant interaction between Time and Participant group was found). Fig. 3a gives one example of the changes in a real-world ball game and Fig. 3b an example of a real-world agility game.

#### 3.2.2. *Standardized tests for Ball skills*

Large significant effects of time were found on the subscales BOT-2 Upper-limb Coordination ($F(1,47) = 13.03$; $p = 0.001$, $\eta_p^2 = 0.22$), PERF-FIT bounce ($F(1,47)= 22.37$; $p < 0.01$, $\eta_p^2 = 0.32$) and MABC-2 aiming and catching ($F$ $(1,47) = 7.46$; $p < 0.01$, $\eta_p^2 = 0.14$), but not on PERF-FIT throw ($p = 0.27$). The relative changes in Ball skills were not different between the TD and DCD children (no significant interaction between Time and Participant group was found). Only one Time by Protocol group interaction occurred ($F$ $(1,47) = 4.22$; $p = 0.045$, $\eta_p^2 = 0.08$) for the subtest BOT-2 Upper-limb Coordination (see Fig. 4).

To gain insight regarding which items changed most between pre- and post-tests and which items may have changed differently between the two protocols, we analyzed the significant sub scores (MABC-2, BOT-2 and PERF-FIT-bounce) at item level (see Table 5). The interaction on the sum score of the BOT-2 subtest Upper-limb coordination was caused by item 6 ($F(1,47)= 5.12$; $p = 0.028$, $\eta_p^2 = 0.098$), which did not show a significant main effect of time. As can be seen in Fig. 4 this was caused by a decline in the number of dribbles in the Agility protocol group while the Ball protocol group improved.

#### 3.2.3. *Standardized tests for agility and balance*

Large to very large effect sizes were seen for all agility test items of the PERF-FIT and KTK. Against our hypothesis, no interaction with Protocol group was found. Both the Ball and Agility groups responded similarly in the effect on agility test items (see Table 5). Moreover, no interaction with Participants group was found, except for the item Stepping ($F(1,45) = 6.37$; $p = 0.015$, $\eta_p^2 = 0.12$), indicating that the DCD groups improved less than the TD group.

No progress was measured on the MABC-2 sub scores or individual balance items. Large main effects of Time were found for the PERF-FIT balance items (see Table 5). Importantly, no interaction with Protocol or Participant group was found. Both the Ball and Agility groups responded similarly in the effect on Balance items.

#### 3.2.4. *Enjoyment of AVGs*

Overall, the children liked playing the Wii games; the median score was 4 (Awesome). However, the Ball games were rated lower than the Agility games ($z - 2.31$; $p$ 0.021) See Fig. 5).

## 4. Discussion

Although the use of virtual reality for skill training is well documented and recommended as adjunct form of intervention for managing motor performance in children with DCD, there is limited information about how motor skills acquired in virtual environments lead to improvement in real life skills. This study investigated the task-specificity and transferability of skills acquired in a virtual environment to real-world contexts. It was hypothesized that children participating in the study would show improvement in the trained real-world games and that the greatest improvements in non-trained skills would occur in the task most similar to the ones in the AVG training program (task specificity). Moreover, we expected that training would induce task specific changes in the learning rate of real-world activity. The results demonstrate that children who participated in 10 weeks of training (either via the Ball or Agility protocol) exhibited improved performance in various trained and non-trained motor skills. Also, children's level of motor performance (TD vs DCD) did not affect the rate of learning the real-world games or transfer to non-trained tasks, except for the PERF-FIT stepping

**Table 4**

Main effect of training on each of the real-world games for all children ($n = 50$) over the five measurements. No Time by Participant group (TD/DCD) interaction was present for any of the games.

| Active games | | *df* | *F* | *p* | *Polynomial* | *Eta squared* $\eta^2$ |
|---|---|---|---|---|---|---|
| Catching | Cup Ping Pong* | 4,45 | 5.61 | 0.001 | linear | 0.333 |
| | Flip and catch | 4,45 | 14.51 | 0.0001 | quadratic | 0.563 |
| Aiming | Marble putting | 4,45 | 3.83 | 0.009 | linear | 0.254 |
| | Golf | 4,45 | 2.18 | 0.087 | linear $p = 0.024$ | 0.053 |
| Running | Obstacle race | 4,45 | 18.998 | 0.0001 | cubic | 0.628 |
| | Slalom race | 4,45 | 15.39 | 0.001 | quadratic | 0.578 |
| Balance | Foam path race | 4,45 | 5.85 | 0.001 | quadratic | 0.342 |
| | Sack race | 4,45 | 4.419 | 0.004 | cubic | 0.282 |

* Time by Protocol group interaction

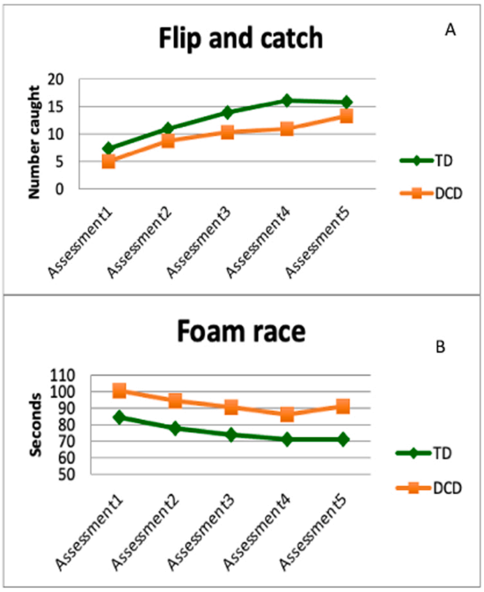

**Fig. 3.** Panel A shows an increase in the number of catches in the Flip and catch task over 10 weeks (5 assessments) and panel B displays that children became faster in the Foam race over 10 weeks for TD and DCD groups.

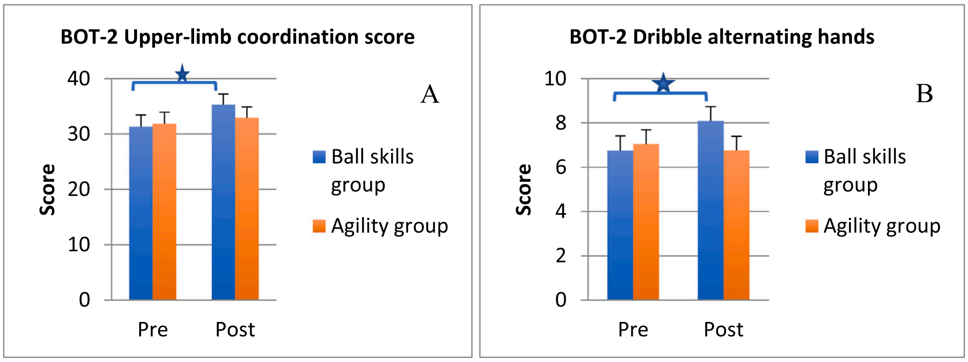

**Fig. 4.** Pre-post changes for the two Protocol groups: panel A shows the score of the BOT-2 subtest Upper-limb coordination and panel B the score of item 6; Dribbling a ball with alternating hands. The Ball skills group improved more than the Agility group* .

item. Our results regarding the real-world games during 10 weeks of practice, lend support to our earlier research which demonstrated that DCD and TD children learn motor skills at comparable rates on tasks trained in virtual environments (Bonney et al., 2017b; Jelsma et al., 2015; Smits-Engelsman et al., 2021a). Although DCD is defined as a deficit in skill acquisition, few studies have addressed the process of motor learning in fundamental motor skills (Bo & Lee, 2013; Smits-Engelsman et al., 2020c; Subara-Zukic et al., 2022). However, it does appear that in the current training program the children with DCD and TD have comparable learning rates when acquiring complex skills in real-world contexts.

### 4.1. *Task specificity*

#### 4.1.1. *Learning real-world games*

It was hypothesized that the greatest skill improvement in the trained real-world games would occur in the ones most similar to the AVG training program (task specificity). Against our expectations, it did not seem very important which AVGs the children played as we found no task-specific advantages in learning the real-world games. This might indicate that transfer of learning from virtual environments to real-world settings shows limited task-specificity. The children who took part in AVG Ball protocol did not learn the real-world ball games faster than the children who participated in the Agility protocol or vice versa. Thus, the type of video games protocol followed had little benefits on improving performance in real-world games.

An explanation for this lack of task specificity might be weaknesses in the underpinning of the principle of task similarity for the chosen WII games and the real-world ball games. The real-world ball handling movement in tennis or golf is a complicated multiple-

**Table 5**
Transfer effect (pre-post intervention) of the ball skill and agility related item scores of the standardized tests. Items with significant p-values between pre and post tests are presented in **Bold.** Cohen's d is calculated for the significant differences between the means of the pre and post values.

| Ball items (df) | *F-value* | *P-value* | *Eta squared* | *Cohen's d* |
|---|---|---|---|---|
| *BOT-2* | | | | |
| **Bot 1 (1,46) Bounce catch 2 hands** | 3.08 | 0.09 | 0.06 | |
| **Bot 2 (1,46) Catch 2 hands** | 2.01 | 0.16 | 0.04 | |
| Bot 3 (1,46) Bounce catch 1 hand | 6.97 | 0.01 | 0.13 | 0.77 |
| Bot 4 (1,46) Catch 1 hand | 12.08 | < 0.01 | 0.20 | 1.01 |
| **Bot 5 (1,46) Dribble 1 hand** | 1.88 | 0.18 | 0.04 | |
| **Bot 6 (1,46) Dribble alternating hands** | 2.18 | 0.15 | 0.04 | |
| **Bot 7 (1,46) Aiming** | 0.94 | 0.34 | 0.02 | |
| *PERF-FIT* | | | | |
| Item 1 (1,47) Bounce catch 2 hands | 4.54 | 0.04 | 0.09 | 0.62 |
| **Item 2 (1,47) Bounce catch preferred hand** | 3.05 | 0.09 | 0.06 | |
| **Item 3 (1,47) Bounce catch non-preferred hand** | 3.10 | 0.09 | 0.06 | |
| Item 4 (1,47) Bounce clap catch preferred hand | 21.37 | < 0.01 | 0.31 | 1.35 |
| Item 5 (1,47) Bounce clap catch non-preferred hand | 17.34 | < 0.01 | 0.27 | 1.21 |
| *MABC-2* | | | | |
| Item 4 (1,44) Catch | 8.74 | < 0.01 | 0.16 | 0.88 |
| **Item 5 (1,44) Aim** | 1.22 | 0.28 | 0.03 | |
| Agility items (df) | | | | |
| *KTK* | | | | |
| KTK 1 (1,48) Platforms | 7.75 | < 0.01 | 0.14 | 0.80 |
| KTK 2 (1,47) Side jump | 61.52 | < 0.01 | 0.57 | 2.29 |
| *PERF-FIT* | | | | |
| Item 1 (1,47) Run | 26.48 | < 0.01 | 0.36 | 1.50 |
| Item 2 (1,47) Step | 26.61 | < 0.01 | 0.36 | 1.51 |
| Item 3 (1,47) Side jump | 65.35 | < 0.01 | 0.58 | 2.36 |
| Item 9 (1,47) Hop | 4.88 | 0.032 | 0.09 | 0.64 |
| Item 10a (1,47) Static balance | 8.18 | < 0.01 | 0.15 | 0.83 |
| Item 10b (1,47) Dynamic balance | 16.75 | < 0.01 | 0.26 | 1.20 |

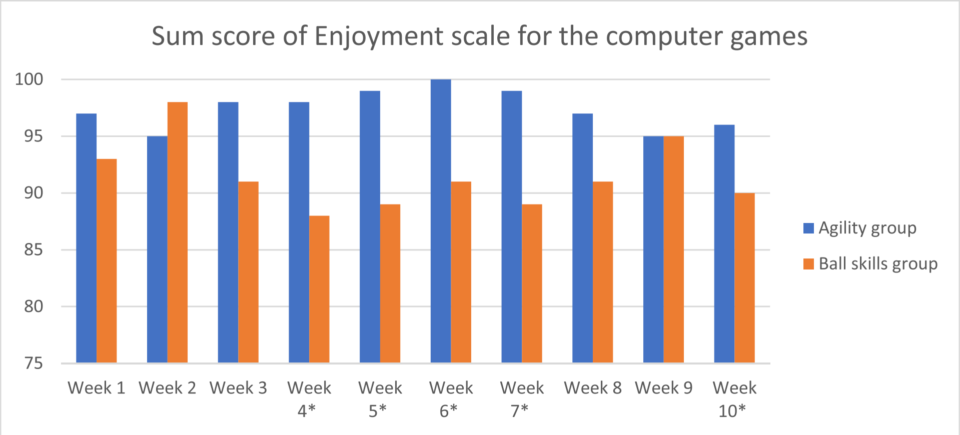

**Fig. 5.** Sum of Enjoyment scores for the AVGs. Note: If all 25 children would rate the games as "Good fun" the total score would by 75, if all children would rate the games as "Awesome" the sum score would be 100 (which is the case for the Agility group in week 6). * indicates significant different sum scores between Protocol groups.

joint motion which requires precisely timed accurate movements. Conversely, hitting a tennis ball in an AVG with a controller in your hand does not require you to run to the right spot (no spatial requirements) only to make a movement with the controller at the right moment (temporal requirement) either with arm or only hand (no motor pattern requirement). Thus, many aspects of skilled behavior that need to be integrated and coordinated to perfectly hit the ball (e.g., the trajectory of the racket head during the swing, the position and motion of the racket at impact, the speed of the arm and wrist movement, the force needed to hit the ball) are not mimicked in the used off-the-shelf video games. It is plausible that aspects of these large differences in task and environmental constraints may well explain lack of specific transfer between virtual environments and real-world settings.

Additionally, games may look alike but might rely on different underlying subskills that may even change with different level of skill learning in the same task. For instance, in the Cup Ping Pong game the children had to throw a ping-pong ball (10 times) against the wall and catch it in a plastic cup in the other hand. We may think this is an aiming and catching task but if you are not (yet) able to throw the ping pong ball with the right force and in the right angle to the wall it may become an agility task because you must move fast to be at the spot where you can still catch the ball in your cup.

### *4.1.2. Improvement of non-trained tasks*

The fact that children from both AVG protocols showed large improvements on tests measuring aspects of ball skills, agility and balance confirms the well-documented effect of AVG on general motor skills and fitness (Blank et al., 2019; Mentiplay et al., 2019; Smits-Engelsman et al., 2018, 2021a). It was hypothesized that the greatest skill improvement in non-trained skills would occur in the tasks most similar to the ones in the AVG training program (task specificity of transfer). However, the lack of interactions on most of the outcomes it is not indicative of task specificity. Only among the children in the AVG Ball protocol a larger improvement in one ball skill item was observed: specifically dribbling with alternating hands, the most difficult item of upper-limb coordination tasks of the BOT-2. Hence our assumption that the largest transfer would occur to items of the non-trained standardized test items that share similar task elements with the AVG protocol was at most incompletely supported.

At first sight these results are not indicative of task specificity of the AVG's effect. However, by choosing our games (real and virtual) we may have overlooked their complexity. To explain this line of thought we will take a closer look at two examples. The games used for this study combined many motor (sub) skills and agility components as this is the inherent complexity of every day games played on a playground and in the virtual world. Catching a propelled beanbag in the *Flip and catch* game after giving a forceful stamp with the foot on the higher part of the seesaw (while standing on the other leg) is not just a catching game but a fast-adaptive agile movement to a partly unpredictable trajectory of the bean bag. Hence transfer from the chosen Wii ball games (like Soccer heading or Golf) is not as obvious as it may look at first site. Also, the *Foam game* may seem a balance game, but besides stepping and moving on these large closed cell foams, the foams needed to be picked up with two hands while crouching down and to be positioned in a way that the child could make a step on to them without touching the floor and the child also needed to select the shortest trajectory to the ball on the cone indicating the end of the trajectory.

Although, one can argue that the complexity of the tasks could be an explanation for the lack of straightforward carryover effect of AVGs-based learning, there could also be some more general effects that are less dependent of the specific skill trained that may have caused this general learning effect. The virtual reality (VR) environment provides a variety of sensory information that could guide the scope of attention to the results of movement (external focus). In the beginning of exploring a new task the individual learns how to correct his actions and then gradually anticipates the effects of his/her actions. Moreover, virtual environments provide opportunities of both action observation via the avatar and motor imitation, and thus may assist motor learning in general (Bieber et al., 2021). AVG play is positively associated with several visuospatial memory skills, (visual discrimination, visual memory), enhanced attentional capabilities and multisensory temporal processing (Bavelier et al., 2015). However, none of these processes were specifically tested in our study. Given that there is still lack of data to back this up, it is necessary that further studies be conducted in children with DCD to provide clarity on this topic, so optimal training circumstances can be developed. At the moment, it is difficult to ascertain the relationship between training exposure and effect on transfer of motor skills.

### *4.2. Limitations of the study*

Several limitations of the study need to be considered. Because we aimed to study if AVG training would help the children in learning real-world games, we ended up with a mixed design. All children were participating in the real games, so we could test if they learned games with more identical elements faster. By doing this, we trained all children for one session per week on both Ball and Agility real-world games. Therefore, it is harder to explain the results on the non-trained test items, since children may have learned partly from the AVG games and partly from the real-world games. However, the intensity of the AVG was at least double the time of the real games, so if the effect would have been very task specific, one would still expect a larger effect on the tasks with the largest similarity to the trained tasks. However, this was not the case.

## 5. Conclusion

In summary, our findings show that a combined training program of AVG and real-world games focusing on gross motor skills demonstrate both learning and transfer effects for children with and without DCD. However, transfer of learning from a virtual environment to real-world contexts does not appear to be very task-specific.

Future studies are needed to explain the lack of specificity of AVG training and gain insight into the potential underlying mechanisms of motor learning to formulate the optimal mode of training for transfer. Therefore, there is a need for more studies on how task-specific gains made in a virtual environment transfer to daily life activities and also if these gains are related to changes in action observation, motor imitation, working memory and attentional capabilities.

## CRediT authorship contribution statement

**Bouwien Smits-Engelsman:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft. **Emmanuel Bonney:** Project administration, Supervision, Writing – review & editing. **Dorothee Jelsma:** Project administration, Supervision, Writing – review & editing.

## Data Availability

Data will be made available on request.

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