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ARTICLE

Short- and Long-Term Changes in Balance After Active Video Game Training in Children With and Without Developmental Coordination Disorder: A Randomized Controlled Trial

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Active video games (AVG) have been used as training tools and are known to ameliorate balance performance in children with Developmental Coordination Disorder (DCD). Our aim was to evaluate balance using clinical tests and by measuring body sway using a force plate with a mixed design of vision (eyes open/eyes closed), surface (rigid/soft), and support (stance/semitandem) before, and after, training and 4 months later (follow-up). Thirty-six DCD children and 40 typically developing children participated in the study, of which 50 children (26 DCD; 24 typically developing) were retested after 4 months. Balance improved on the clinical measures after the training, which was independent of type of AVG (Wii-Fit and Xbox Kinect) used, and this effect was still present after 4 months. The AVG training did not influence general sway behavior, but only sway in the eyes-open condition, corresponding with task demands of the training and indicating a training-specific effect. Overall, DCD children and typically developing children responded comparably to the AVG training, thereby maintaining the gap in performance between the two groups. The changes in postural sway are interpreted as a sign of more confidence and less freezing of the joints, enabling

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greater flexibility of movements and balance strategies as supported by the improved performance on balance tests in the DCD children. This is the first study that showed long-term effects of AVG training on balance performance. However, these follow-up results should be interpreted with caution given that 35% of the children were lost in follow-up.

Keywords: force plate, visual feedback, motor development, follow-up, center of pressure

Static balance is the ability to keep the body stable when the base of support is fixed, keeping adequate alignment and orientation in relation to the environment (Shumway-Cook & Woollacott, 2007). For most children, balance develops easily, although postural control requires complex interactions of musculoskeletal and neural systems (Ivanenko & Gurfinkel, 2018). Information from multiple neural response systems is needed to keep balance when standing, such as the vestibular system for gravity, the somatosensory system for support surface changes, and the visual system for environmental scanning (Ivanenko & Gurfinkel, 2018). With integration of musculoskeletal and neural systems, experiences, and exploration of tasks and skills, children develop flexibility of movements and may use multiple movement solutions to achieve the desired result in tasks (Ranganathan et al., 2020). When sensory information is altered or removed, such as when base of support, vision, or surface is altered, postural demands increase, requiring greater muscle recruitment and compensatory mechanisms (Gebel et al., 2019). The system reacts to these demands by increasing muscle tension to resist the disturbance and maintain balance (Ivanenko & Gurfinkel, 2018).

Children with Developmental Coordination Disorder (DCD) have problems in acquisition and execution of motor skills, like balance, compared with their peers (American Psychiatric Association, 2013). Delays in anticipatory postural adaptations and slow-reactive postural adjustments that diminish timely responses to balance disturbances seem common in these children (Geuze, 2003). Increased postural sway may be due to less efficient supraspinal perceptual control mechanisms and impaired central sensory organization, inducing less efficient internal models' recalibration and peripheral feedback control (Speedtsberg et al., 2017). These difficulties may cause inaccurate adjustments in DCD children, entailing lack of fluidity of movements that demand more energy and more corrections to over- and undershoots (Miller et al., 2019). It is known that DCD children process sensory inputs differently and rely more on the visual system to adapt to environment and control directional oscillations, similar to babies (Hadders-Algra, 2013) and nursery children (Wann et al., 1998). In the absence or alteration of sensory input, children tend to adopt different motor strategies, like freezing joints to keep balance (Cherng et al., 2007; Fong et al., 2012; Geuze, 2003; Speedtsberg et al., 2017; Tsai et al., 2008). An important question is whether, and how, balance deficits can be diminished by training through use of active video games (AVG).

The European Academy of Childhood Disability guidelines (Blank et al., 2019) and recent systematic reviews (Cavalcante Neto et al., 2019; Lino et al., 2021; Mentiplay et al., 2019; Page et al., 2017; Smits-Engelsman et al., 2018) suggest that AVG training can improve DCD children's balance. Commercial AVGs like Xbox Kinect and Nintendo Wii-Fit have been studied as therapeutic resources to improve motor performance. Xbox Kinect provides visual feedback that allows players to control the avatar with wide, free body movements. Studies have shown beneficial effects on motor imagery and motor planning, promoting the development of internal models to predict future states of moving limbs, as studied in girls by Ebrahimisani et al. (2020), and improving motor ability and physical activity levels in DCD children of both genders (Straker et al., 2011). In contrast, the Wii-Fit detects weight shifts of the subject through sensors in the balance board, to move the avatar and provide simultaneous visual feedback of body movements related to game objectives. This visual feedback appears to provide additional information to acquire precise movement adjustments (Jelsma et al., 2014). Several studies reported that visual feedback may help to train balance skills (Jelsma et al., 2014; Mombarg et al., 2013), aerobic and anaerobic fitness (Bonney et al., 2018), motor proficiency, and emotional well-being of DCD children (Hammond et al., 2014). No study so far examined long-term effects of AVG training on balance performance. To our knowledge, only one study (Jelsma et al., 2016) analyzed changes in body sway in a dynamic balance task after no training and after Wii-Fit training in DCD and typically developing (TD) children, revealing that changes in kinetic features were in opposite direction: Both groups improved balance performance, either decreasing the pathlength of the center of pressure (CoP; TD group) or increasing the pathlength (DCD), during the second test and remaining after training. With better dynamic balance, both groups modified CoP displacements to optimize trajectory forces. Wii-Fit's subtle and restricted movements may promote better results on static balance than Xbox Kinect. However, no study has compared how they change sway in static balance tasks or in different standing or balance conditions.

The aim of this study was to compare short- and long-term changes in balance performance in DCD and TD children after Wii-Fit and Xbox Kinect training. We evaluated changes using clinical tests and FP. The patterns of change of body sway were assessed in anterior/posterior (AP), and mediolateral (ML) directions with a mixed design of vision (eyes-open/eyes-closed), surface (rigid/soft), and support (stance/semitandem).

First, we tested whether balance improved on clinical measures after training and whether it remained after 4 months. Subsequently, we tested whether changes in postural sway followed opposite or similar patterns in DCD children and TD. Next, we examined whether soft surface, eyes-closed, and semitandem stance conditions were more challenging, and whether changes after training were condition or group dependent. Additionally, we explored whether changes in sway pattern differed between Wii-Fit and Xbox Kinect training.

Methods

Participants

Children were recruited from two public schools with similar socioeconomic backgrounds. Children were considered to have DCD if they fulfilled all four criteria of Diagnostic and Statistical Manual of Mental Disorders—Fifth Edition (American Psychiatric Association, 2013): percentile score ≤16 on the Movement Assessment Battery for Children—Second Edition (MABC-2), ≤5 percentile score on the balance component, score below the cut-off on the Developmental Coordination Disorder Questionnaire (DCD-Q), and no other associated pathology or disorder. Children from the same classes who scored above the 16th percentile on MABC-2 and did not have difficulties in daily living activities, development delays, or mental, neurological, and/or orthopedic pathologies, indicated by their parents, were classified as TD. After selection, 81 children aged 7–12 years were assigned to one of four groups (DCD-Wii, DCD-Kinect, TD-Wii, and TD-Kinect). Five of them were excluded for missing more than three training sessions without catching up, resulting in a total of 76 children (40 TD and 36 DCD). Fifty children (24 TD and 26 DCD) were retested after 4 months at follow-up (Figure 1).

Sample size was defined by G*Power (version 3.1.9.2) based on a previous study by Jelsma et al. (2014), considering balance as the main outcome with an effect size of 0.68, a power of 0.95, and an alpha of .05, resulting in a sample size of 16 children per group, totaling 64 children.

Instruments

Developmental Coordination Disorder Questionnaire

The DCD-Q was used to assess whether the deficit in coordination interfered with daily activities (Diagnostic and Statistical Manual of Mental Disorders—Fifth Edition Criterion B). Containing 15 items, it is validated in Brazil with high internal consistency (alpha = .92; Prado et al., 2009). Cut-off points indicating signs of DCD were established according to age and score: ≤46 points (5–7 years), ≤55 points (8–9 years), and ≤ 57 (10–15 years; Prado et al., 2009).

Demographic Questionnaire

A self-developed questionnaire was used to identify whether motor deficit was present since childhood (questions regarding motor acquisition—Criterion C) and that this deficit was not attributed to neurological, intellectual, and visual acuity not correctable with glasses (Criterion D). For Criterion D, we also confirmed that school records did not indicate intellectual deficits.

Movement Assessment Battery for Children—Second Edition

The MABC-2, applied to assess motor performance (Criterion A), contains three components that evaluate manual dexterity (three items), aiming and catching (two items), and balance (three items). The Balance Standard Score (BSS) is based on one static balance task (one-board balance) and two dynamic balance tasks (walking heel-to-toe and hopping on mats on one leg). MABC-2 scores are converted into component scores and Total Standard Score (TSS), with good test–retest reliability ($r = .97$; Wuang et al., 2012). TSS above the seventh Standard Score indicates "normal range," "at risk for motor problems" from sixth to seventh Standard Score, and "a significant motor problem" at or below the fifth Standard Score (Henderson et al., 2007).

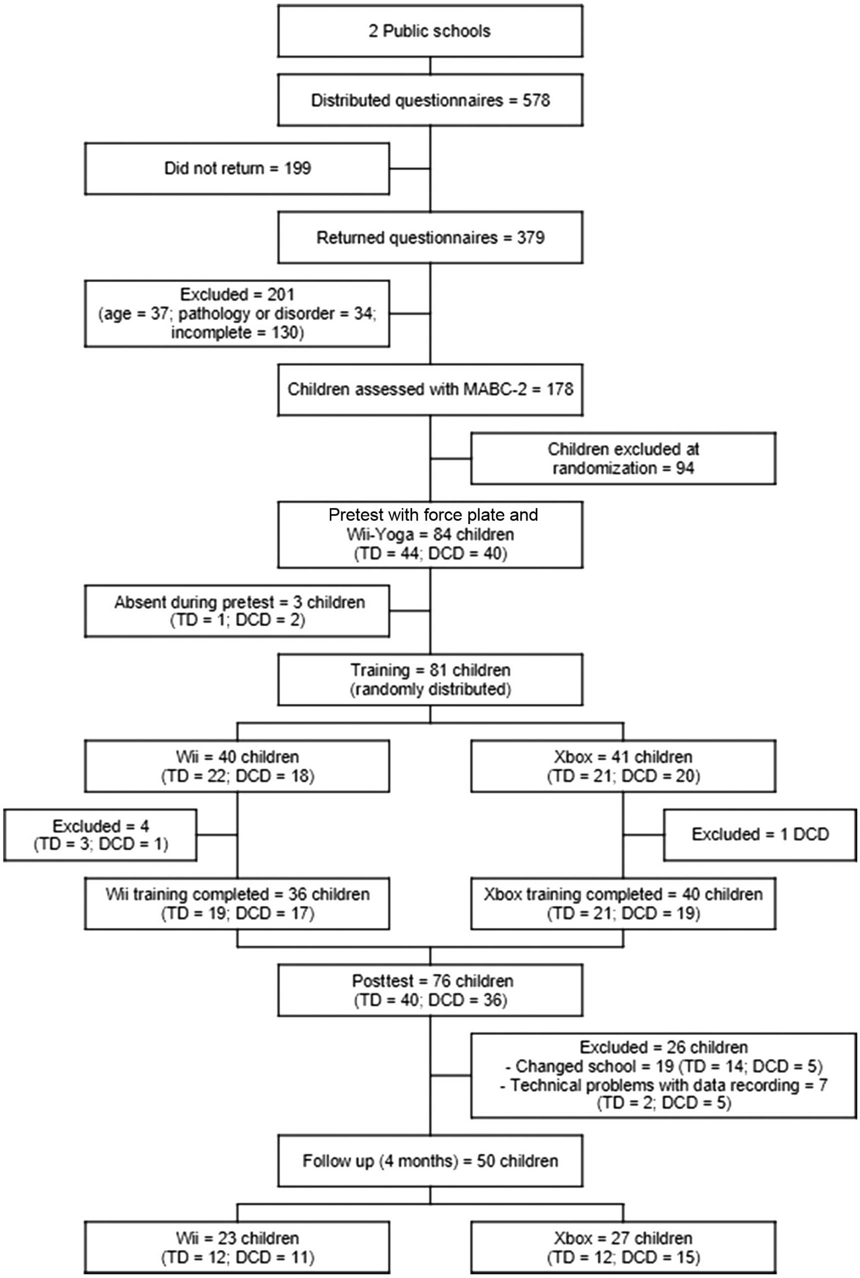

Figure 1 — Design and flow of participants through the study. DCD = Developmental Coordination Disorder; TD = typically developing children.

Body Mass Index

To characterize anthropometric profile, body mass index (BMI) was calculated using height and body weight (in kilograms per meter squared), measured with a stadiometer and a portable scale.

Wii-Yoga

The Wii-Fit Yoga game was used to analyze child's balance on one leg with hands linked together and elbows stretched to hold the flexed knee of the nonsupporting leg without contact with the standing leg. The on-screen instructor guided the child to stand as still as possible, and the representation of their CoP was shown on the screen as a red dot within the predetermined base of support (yellow area). The number of seconds (maximum of 30) and the steadiness of the pose, detected by the software, were converted into a maximum of 50 points score per leg. Both legs were tested twice, and the mean of the four trials was used for analysis. The game always started on the right leg.

FP Protocol

Postural control was assessed during standing and semitandem position (support conditions). For the standing position, participants were asked to maintain upright position barefoot on the FP with their feet shoulder-width apart, and for the semitandem, they were asked to stand with the hallux of one foot positioned behind the other foot, touching the medial edge of the calcaneus of the front foot. Children were asked to feel which foot they would like to have in front, which was noted, and the same foot was used during pre- and postfollow-up. Participants were instructed to stand as still as possible for 30 s on the FP (Advance Mechanical Technology Inc.—AMTI—AccuGait). All participants were first familiarized with the equipment by standing barefoot with their arms positioned at their sides. Two trials (10-s rest intervals) started when the child was standing in the conditions: eyes open or closed (visual condition) on a rigid or soft surface (surface condition) in both support conditions. The soft surface was a foam of $0.5 \times 0.5 \times 0.1$ m (width × length × height/thickness), density of 35 kg/m^3, and elastic modulus of 50,000 N/m^2. The order of conditions was: (a) eyes-open, stance, rigid; (b) eyes-open, semitandem, rigid; (c) eyes-open, stance, soft; (d) eyes-open, semitandem, soft; (e) eyes-closed, stance, rigid; (f) eyes-closed, semitandem, rigid; (g) eyes-closed, stance, soft; and (h) eyes-closed, semitandem, soft.

FP signals were recorded at 200 Hz and filtered using a second-order zero-lag low-pass Butterworth filter, with a 12.5-Hz cut-off. Global analysis from CoP displacements was employed in AP and ML directions to describe postural control performance. The descriptors chosen were root mean square (RMS) and mean velocity (VEL). RMS was calculated by subtracting the mean values from the original signal (using a de-trending operation) and then by calculating the standard deviation (in centimeters). VEL is the VEL of the CoP displacement (in centimeters per second; Prieto et al., 1996).

Procedure

This study used an assessor-blinded randomized comparator-controlled trial. It was approved by the Human Research Ethics Committee of the Federal University of

São Carlos, protocol number 89993118.8.000.5504/2018. Parents and children signed the Informed Consent Form and Informed Assent Form, respectively, before the study started.

Figure 1 shows the selection procedure. First, we sent the DCD-Q (to verify Diagnostic and Statistical Manual of Mental Disorders—Fifth Edition Criterion B), the demographic questionnaire (to verify Criteria C and D), and informed consent form to parents/guardians of children aged 7–12 years through schools. From the returned questionnaires, we checked whether children repeated a grade or had any pathology, disorder, or condition that compromised identification of DCD and TD. To further investigate Criterion D, school records were checked for any disability/disease/pathology. After this, the project was divided into five stages: (a) identification of level of motor performance (Criterion A) through the MABC-2 and BMI determination. All assessments were performed individually in a quiet room by trained evaluators, who were not involved in the intervention and blinded to children's motor performance level. After classified as DCD, children were paired with the closest TD child in age. Next, each pair was allocated to either Wii-Fit or Xbox protocol through stratified randomization, (b) pretest on FP was performed by the evaluator, Wii-Yoga was performed with the child following the game instructor's guidelines on the television screen, with scores obtained from Wii device, and (c) training was carried out in the same room, equipped with four television monitors connected to two Nintendo Wii-Fit and two Xbox Kinect consoles. Children could not see the results on the other screens. The time schedule for each session fitted the best options for children at school in agreement with the pedagogical team. Intervention was performed only during school hours. All sessions were supervised by two trained therapists blinded to children's diagnosis. Training protocol was published in Jelsma et al. (2022) and summarized in Figure 2. Children who missed a training session had the opportunity to catch up, preferably during the same or next week, (d) posttraining: MABC-2, Wii-Yoga, and FP protocol were repeated, and (e) follow-up: after 4 months of no AVG training, as confirmed by parents, all tests were administered again.

Training

Training was based on Wii-Fit and Xbox Kinect games that require displacements and body movements to control the avatar. The most similar games, in which balance control was the main feature on the two devices, were selected. Both protocols consisted of two sessions of 20 min per week, totaling nine sessions spread over 5 weeks. Children played the selected games at a predefined sequence, according to their device group.

Data Analysis

Mann–Whitney *U* test was used to compare the group that remained in the study and those lost to follow-up, and TD and DCD groups on DCD-Q, TSS, BSS, Age, BMI, and, additionally, Wii and Xbox groups. Chi-squared test was used to compare gender distribution between TD and DCD and between Wii and Xbox groups. There were no differences in demographic data between Wii and Xbox groups, but there was an age difference between TD and DCD groups. Therefore, age was used as covariate in general linear model (GLM) repeated-measures

Figure 2 — Training protocol.

analysis. In the follow-up subgroup (50 children), no differences were found in demographic data between Wii and Xbox and TD and DCD groups.

GLM repeated measures were used to compare pre- and posttraining Wii-Yoga outcomes between groups and AVGs (with age as covariate) for all children and, additionally, to compare pre- and postfollow-up outcomes of children who remained in the study. Bonferroni post hoc analysis was used for significant interactions. Wilcoxon signed-rank test was used to analyze BSS and TSS of MABC-2, for pre- and posttraining comparison and differences between posttraining and follow-up. Mann–Whitney *U* test was used to analyze the differences in change between groups.

GLM repeated measures were used, with age as covariate, to test for changes in visual, support, and surface conditions at pre- and posttraining between groups and AVGs on RMS_AP, RMS_ML, VEL_AP, and VEL_ML scores. Bonferroni post hoc analysis was used for significant interactions.

Subsequently, GLM repeated measures were performed on pre-, posttraining, and follow-up moments to check for consistency of changes and interactions after 4 months. Control for age was not necessary in this subgroup. Follow-up data showed five outliers (values higher than three standard deviations) in eyes closed, semitandem, and soft surface condition (four TD and one DCD) for RMS_AP and VEL_AP. Their data were replaced by the median (Arning et al., 1996; Hawkins, 1980) of their respective group and condition. Statistical analyses were carried out with Statistical Package for the Social Sciences (version 25.0) with significance level set at $p < .05$.

Results

Table 1 presents the demographic characteristics of the groups (TD vs. DCD; Wii versus Xbox) at pre- and posttraining and of the subgroup at follow-up. Children lost to follow-up were older than the remaining children ($p < .001$), but there was no significant difference with the remaining group on DCD-Q ($p = .268$), BMI ($p = .314$), TSS ($p = .167$), BSS ($p = .575$), and gender ($p = .750$).

Effects on Clinical Tests After AVG Training and at Follow-Up

Overall, a significant difference between pre- and posttraining was found on MABC-2 BSS ($Z = -4.993$, $p < .001$), and no change was found between post-training and follow-up ($Z = -0.115$, $p = .909$). Balance scores improved between pre- and posttraining, being significant for DCD ($Z = -4.702$, $p < .001$) and TD children ($Z = -2.032$, $p = .042$), independently of AVG training ($Z = -0.005$, $p = .996$). Although both groups improved, a significant difference in change was found ($Z = -3.164$, $p = .002$), showing that the DCD group improved more than the TD group (Figure 3a).

Effect of time in the general sample was also found for MABC-2 TSS ($Z = -5.512$, $p < .001$), and no change occurred between posttraining and follow-up ($Z = -0.571$, $p = .568$). Motor performance scores improved between pre- and posttraining, being significant for DCD ($Z = -4.160$, $p < .001$) and TD children ($Z = -3.483$, $p < .001$), independently of AVG training ($Z = -0.440$, $p = .660$). There was also a difference between groups ($Z = -2.128$, $p = .033$), and DCD children improved more than TD children (Figure 3b).

The children we lost to follow-up had similar behavior to the remaining children, both in pre- and posttraining in relation to TSS ($p = .258$ and $p = .601$) and BSS ($p = .619$ and $p = .175$).

No significant effect of time was found on the Wii-Yoga task between pre- and posttraining when corrected for age differences between TD and DCD groups,

Table 1 Characteristics of DCD and TD Children Per Device at Baseline

	Baseline ($n = 76$) sample present at pre- and posttraining				Baseline ($n = 50$) sample present at pre-, posttraining, and follow-up			
	Wii group ($N = 36$)		Xbox group ($N = 40$)		Wii group ($N = 23$)		Xbox group ($N = 27$)	
	DCD ($n = 17$)	TD ($n = 19$)	DCD ($n = 19$)	TD ($n = 21$)	DCD ($n = 11$)	TD ($n = 12$)	DCD ($n = 15$)	TD ($n = 12$)
Mean age in years (*SD*)	9.06 (1.25)*	9.84 (1.12)*	9.00 (1.05)*	9.43 (0.87)*	8.73 (0.79)	9.17 (0.72)	8.93 (1.10)	9.00 (0.60)
Mean BMI (*SD*)	16.96 (5.38)	17.40 (2.07)	17.77 (3.83)	18.29 (4.08)	18.36 (4.18)	16.98 (1.97)	17.30 (2.96)	17.70 (4.38)
Gender								
Number of girls (%)	7 (41%)	10 (53%)	9 (47%)	13 (62%)	5 (45%	5 (42%)	7 (47%)	8 (67%)
Number of boys (%)	10 (59%)	9 (47%)	10 (53%)	8 (38%)	6 (55%)	7 (58%)	8 (53%)	4 (33%)
Mean DCD-Q score (*SD*)	46.06 (6.97)**	62.89 (9.27)**	44.37 (9.30)**	61.48 (9.88)**	47.55 (5.45)**	60.42 (9.68)**	45.33 (8.74)**	60.33 (9.69)**
MABC-2								
Mean MABC-2 TSS (*SD*)	4.65 (1.50)**	9.84 (1.26)**	4.63 (1.54)**	10.10 (1.34)**	4.64 (1.63)**	9.92 (1.08)**	4.33 (1.59)**	9.92 (1.16)**
Min–max MABC-2 TSS	2–6	8–12	2–6	8–13	2–6	9–12	2–6	8–12
Mean MABC-2 BSS (*SD*)	5.29 (1.61)**	12.00 (2.36)**	5.26 (1.88)**	10.95 (2.42)**	5.73 (1.42)**	12.17 (2.52)**	4.93 (1.91)**	11.33 (2.61)**

Note. n = number of children; DCD = Developmental Coordination Disorder; TD = typically developing children; MABC-2 = Movement Assessment Battery for Children Second Edition test, second edition; TSS = Total Standard Score; BSS = Balance component Standard Score; DCD-Q = Developmental Coordination Disorder Questionnaire; BMI = body mass index; Min = minimum; Max = maximum.

*Statistically significant differences were found <.05 between TD and DCD groups and no significant differences between Wii and Xbox groups. **Statistically significant differences were found <.01 between TD and DCD groups and no significant differences between Wii and Xbox groups.

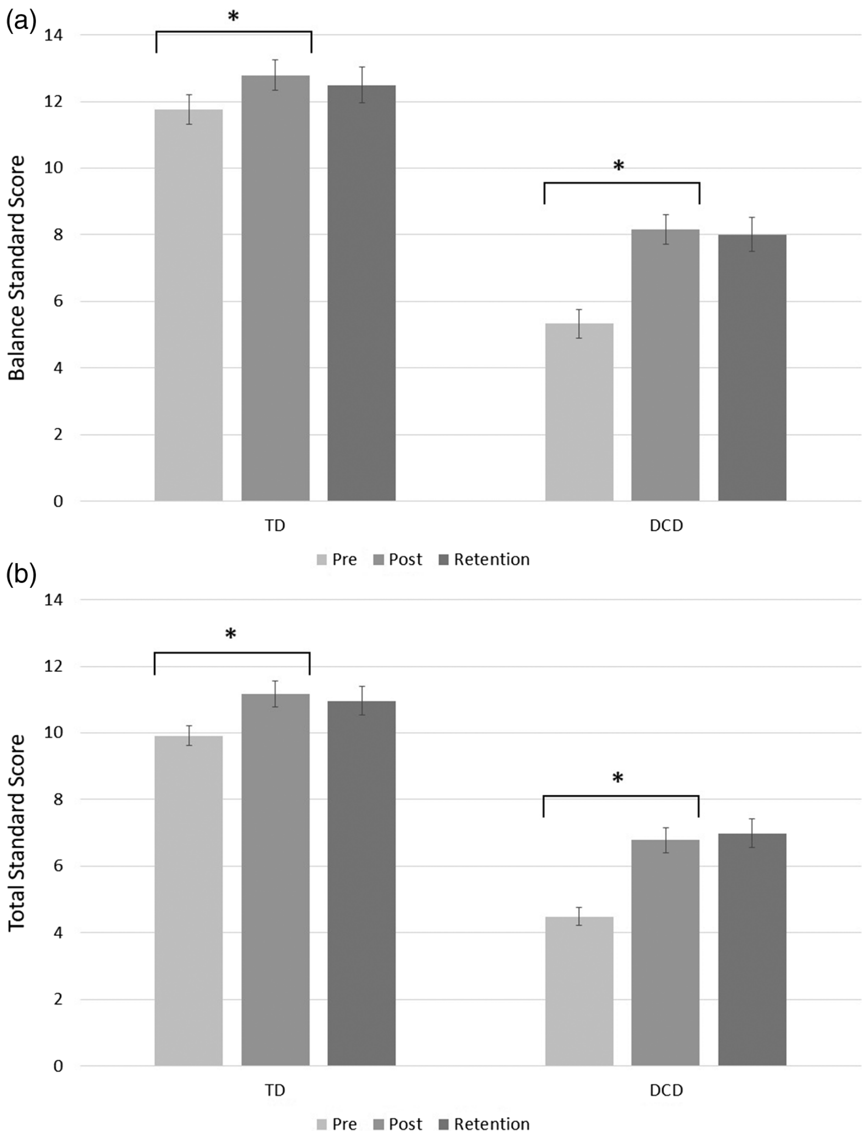

Figure 3 — Mean and standard error of data preand posttraining, and follow-up BSS (a) and TSS (b) for the TD, and DCD groups. TSS = Total Standard Score; BSS = Balance component Standard Score; DCD = Developmental Coordination Disorder; TD = typically developing children.

$F(1, 72) = 0.16$, $p = .692$; pretraining $M = 54.03 \pm 28.31$; posttraining $M = 66.77 \pm 19.52$. When testing the subgroup, without age correction, a significant change between pre- and posttraining was found ($p < .001$), remaining at follow-up (pretraining $M = 50.49 \pm 26.51$; posttraining $M = 62.87 \pm 20.34$; follow-up $M = 63.03 \pm 23.43$). There was no interaction effect of Time × Group, $F(2, 45) = 0.63$, $p = .537$, Time × AVG, $F(2, 45) = 0.04$, $p = .962$, or Time × Group × AVG, $F(2, 45) = 0.085$, $p = .919$, revealing that scores improved, independently of group and AVG training.

Children who remained in the project performed similarly to those lost at follow-up ($p = .294$) on the Wii-Yoga task at pretraining, but at posttraining the behavior was different ($p = .033$), with children lost to follow-up having better scores.

Effects on FP Outcomes After AVG Training and at Follow-Up

No main effect of time was found in any of the variables between pre-, posttraining, and follow-up. Likewise, no interaction effect of Time × Group and Time × AVG was found. However, interactions with group emerged for Time × Visual × Group in RMS_AP, $F(1, 72) = 6.116$, $p = .016$, and VEL_AP, $F(1, 72) = 7.073$, $p = .010$. When we analyzed the subgroup at three moments, this interaction was no longer significant for RMS_AP, $F(2, 46) = 2.525$, $p = .091$, but remained for VEL_AP, $F(2, 46) = 4.218$, $p = .021$.

When examining this interaction, RMS_AP increased for DCD group after training only in the eyes-open condition, $F(1, 72) = 15.219$, $p < .001$, which was different from the TD group, $F(1, 72) = 0.525$, $p = .471$, or eyes-closed condition, DCD $F(1, 72) = 0.155$, $p = .695$; TD, $F(1, 72) = 0.349$, $p = .557$ (Figure 4a).

For VEL_AP, the same interaction appeared, with increased values at posttraining with eyes-open for DCD group, $F(1, 72) = 6.249$, $p = .015$, but not for TD group, $F(1, 72) = 1.463$, $p = .230$. Again, there was no significant difference over time in eyes-closed condition, DCD $F(1, 72) = 1.931$, $p = .169$; TD, $F(1, 72) = 1.245$, $p = .268$ (Figure 4b).

No significant interaction was found for Time × Support × Group (stance vs. semitandem) or Time × Surface × Group (rigid vs. soft). The means and standard deviation of all conditions and times are presented in the Supplementary Material (available online).

Though no main effect of AVG was found, a Time × Visual × AVG interaction was found for pre- and posttraining for RMS_AP, $F(1, 72) = 6.216$, $p = .015$, but not for VEL_AP, $F(1, 72) = 2.578$, $p = .113$. Analyzing the subgroup at three moments, for RMS_AP, this interaction remained, $F(2, 46) = 3.728$, $p = .032$, and became significant, $F(2, 46) = 6.485$, $p = .003$, for VEL_AP. The interaction Time × Visual × AVG revealed that both AVGs promoted increases in RMS_AP values between pre- and posttraining, Wii $F(1, 72) = 7.301$, $p = .009$; Xbox $F(1, 72) = 4.284$, $p = .042$, with eyes open but not with eyes closed, Wii $F(1, 72) = 0.692$, $p = .408$; Xbox $F(1, 72) = 3.598$, $p = .062$ (Figure 5a). Analyzing the subgroup at three moments, this interaction remained in eyes-open condition for children trained on the Wii ($p = .038$ between pre- and posttraining), but it was no longer significant for the Xbox group ($p = .738$ between pre- and posttraining; Figure 5b).

Regarding the other conditions (support and surface), no significant interactions were found.

For ML direction, no main or interaction effects were found for RMS or VEL.

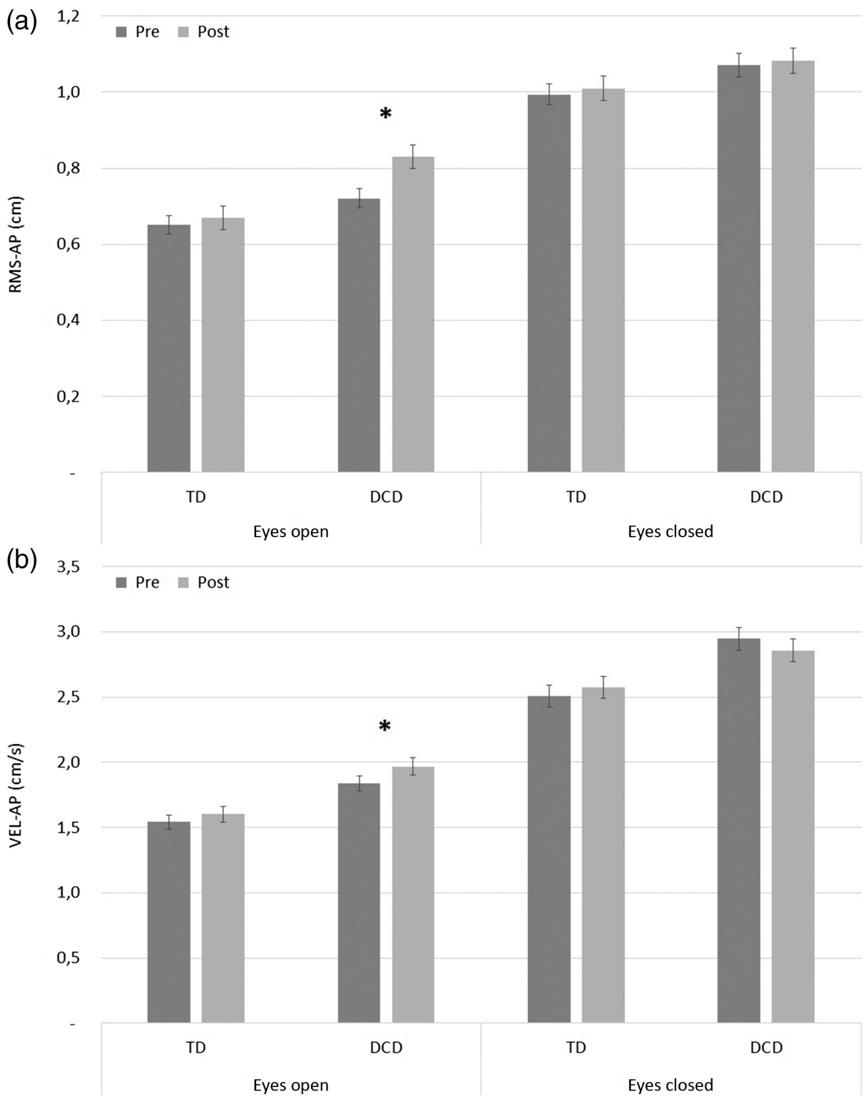

Figure 4 — Mean and standard error of data pre- and posttraining about Time × Group × Visual on RMS_AP (a) and VEL_AP (b). AP = anterior/posterior; VEL = mean velocity; RMS = root mean square.

Results of the remaining group and the lost to follow-up group were similar regarding pre- and posttraining on FP outcomes (Time × Condition × Remaining/lost: RMS_AP $p = .453$; RMS_ML $p = .388$; VEL_AP $p = .447$; and VEL_ML $p = .277$).

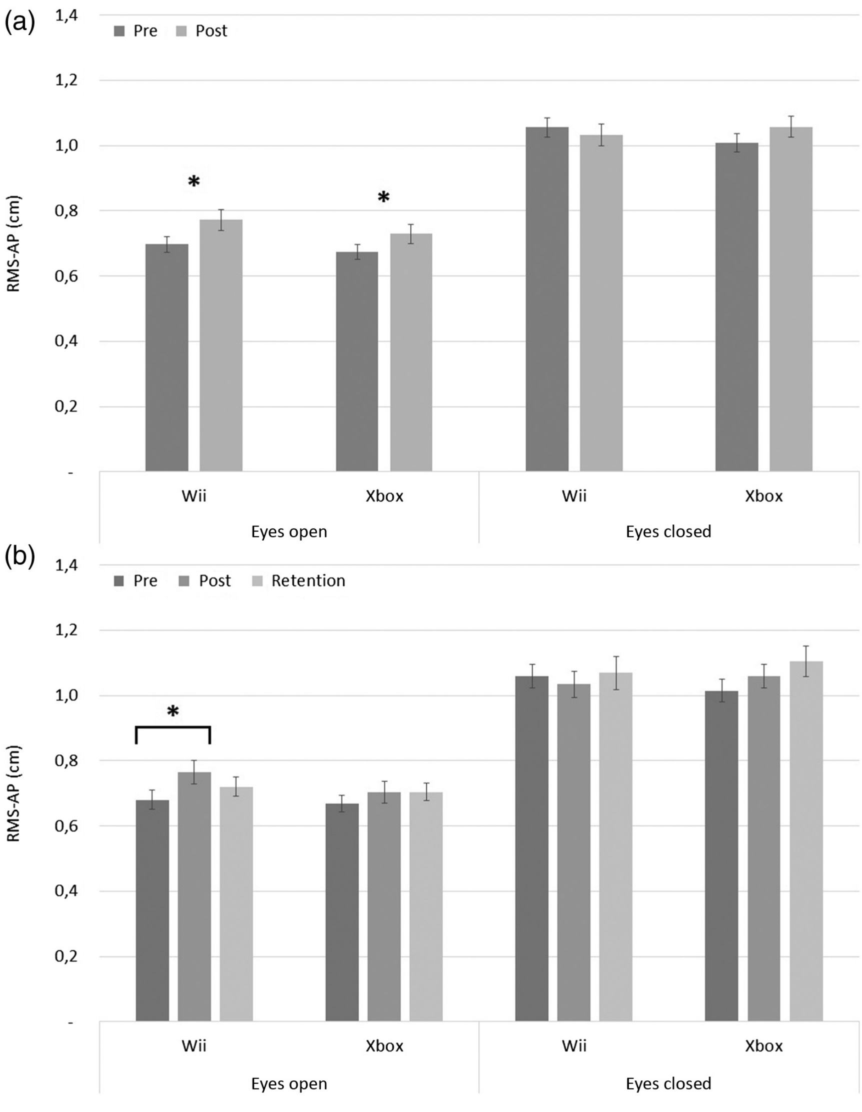

Figure 5 — Mean and standard error about Time × AVG × Visual of data pre- and posttraining on RMS_AP (a) and of data pre-, posttraining, and follow-up on RMS_AP (b). AP = anterior/posterior; VEL = mean velocity; RMS = root mean square; AVG = active video games.

Discussion

This study aimed to test whether AVG training improves balance and whether this improvement perpetuates after the training stopped. It showed that balance improved on clinical measures (MABC-2 and Wii-Yoga) after training, and this effect remained after 4 months, independently of AVG used.

Additionally, body sway was evaluated before and after AVG training and after 4 months, in different standing or balance conditions, in children with and without DCD. Overall, DCD children and TD responded similarly to training, thereby maintaining the gap between the two groups in sway performance. Although older children were lost to follow-up, they responded similarly to the remaining children at the pre- and posttraining on FP outcomes. Sway did not change significantly after training, except for an interaction effect for Time × Vision × Group, showing that DCD children swayed more in the eyes-open condition after training. This interaction revealed that both Wii and Xbox training increased sway in the eyes-open condition, with Wii training having a larger retention effect. Moreover, standing on different support and surface conditions was not significantly influenced by AVG used. Interaction effects were significant in AP but not in ML direction.

Our study is the first to compare long-term effects of AVG on balance performance in DCD and TD children. Although children clearly improved on balance after training, this was not reflected in all conditions measured on FP. DCD and TD groups presented similar lack of changes in sway behavior on nontrained conditions. The significant interaction revealed that the training effect occurred in eyes-open condition, and importantly, a significant increase of the dispersion of the CoP and VEL_AP was found in the DCD group but not in the TD group.

To our knowledge, our study is also the first to compare AVG training effects on balance on FP in DCD children. Sway patterns of individuals with poor postural control are mostly reported to be more dispersed. From this perspective, one might conclude that DCD children deteriorated after training because their sway increased. However, training may have provided the opportunity to experience displacement in various directions and speeds and to explore their limits of stability in a safe environment. Moreover, they seemed to increase the speed of reactive postural adjustments. Training may have caused children to loosen up with visual input available, leading to more forward and backward sway. As a result, both groups, but especially DCD, stood less rigidly, allowing spontaneous, more natural sway, independent of standing on small or large base of support and rigid or compliant surface. This increase in dispersion could be a sign of more balance in confidence in these simple tasks, making children more relaxed, and standing with less joint stiffness. Playing with their weight shifts during AVG training may have increased their degrees of freedom, leading to greater flexibility of movements, enabling individuals to find new solutions that optimized the performance of the task (Loram et al., 2005; Posa et al., 2020), which would fit our clinical test results. Similar increase in sway path after balance training was found by Posa et al. (2020) with healthy young adults and by Nagy et al. (2007) with elderly, explained as a sign of increased confidence and less joint freezing, enabling greater flexibility of movements and balance strategies.

Interestingly, game scores increased in the more difficult task, standing on one leg in Yoga position, suggesting longer time spent in this position without large oscillations, supporting the idea of more sway (defreezing) only in a controlled condition (Bernstein, 1967). The clinical implication may be that AVG training affects processes related to optimizing degrees of freedom, promoting more balance confidence.

Regarding yoga scores from pre- and posttraining of both total group and subgroup, age and motor proficiency seemed to be important factors. When comparing the performance of children lost at follow-up and remaining ones, results showed similar scores at pretraining, but different at posttraining, indicating that older children increased more on their Yoga scores. However, we can only speculate whether these scores would be robust or still improved at follow-up. Nonetheless, the subgroup, without older children and with more DCD, presented significant improvements on the Yoga task, still consistent after 4 months without training. Complex single-leg stance like the yoga task may be more sensitive to change in comparison with simpler bipedal FP tasks, and outcomes may depend on factors like task experience and maturation.

The observation of changes only in the AP direction is probably caused by the position over FP. In bipedal stance, balance strategies are mainly used in AP direction through ankle movements (Shumway-Cook & Woollacott, 2007). In ML direction, DCD children combine hip strategies with opposite head displacement for compensation (Jelsma et al., 2016; 2020), resulting in around zero ground reaction forces. Future studies may use video recordings to analyze children's responses.

Our multiple outcomes provided new insights in changes after training. Adding FP data, we made a first step in understanding the changes in sway dynamics. Increased sway may relate to decreased ankle tension. Standing with less rigid joints and less calf muscles' activation will make it easier for children to react to disturbances (Loram et al., 2005). New studies are needed to compare motor performance tasks with FP data in more challenging positions, combined with kinematic and electromyography data, to expand knowledge on balance performance, muscle activation, and degrees of freedom, extending our understanding of the dynamics of muscles, balance strategies, and changes after training. In addition, new studies should include analysis of effects of BMI, since its increase is associated with poorer balance ability in children (Kolic et al., 2020).

We highlight some limitations of our study. First, due to change from primary to secondary school, our follow-up group was smaller, with approximately 35% loss to follow-up results should be interpreted with caution. Second, a no-treatment control group was missing in the design, mainly due to ethical and power concerns: (a) For ethical reasons, if a control group was included, children would have to be enrolled in an intervention program after the postmeasurement of the trained children. This would have extended the study for which there was no funding or personnel. Therefore, we enrolled all children that met the inclusion criteria in the study, (b) a control group would reduce the DCD group size, resulting in a loss of power, and (c) the order of conditions was not randomized for practical reasons (easy variant was always performed first).

Conclusions

AVG training resulted in long-term effects on balance performance of evaluated children and elicited changes in global descriptors of sway, indicating increased balance confidence but only in the trained condition (eyes-open). This change may result from the increase in degrees of freedom and decrease of body freezing, being beneficial for motor performance and balance, as confirmed by improvements in clinical test outcomes.

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