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Short report on a 6-week at-home exergaming intervention to improve balance in children with developmental coordination disorder

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ABSTRACT

Background: Previous studies have evidenced balance training for improving postural control in children with DCD, however none have examined how neuromuscular mechanisms controlling balance might be improved with training.
Aims: To assess the neuromuscular control of balance before and after training in children with DCD.
Methods and procedures: Eleven children with DCD completed a six-week, game-based intervention to train balance, and lower-limb and core strength. Six children with DCD formed the control group. Stepping behaviour, centre of mass variability, centre of pressure area, and postural muscle onset latencies, using a continuous oscillating platform paradigm, were assessed at baseline, immediately-post and six-week-post intervention.
Outcomes and results: Both groups showed improvement in the oscillating platform task, indicating a learning effect. However, only the training group showed improvements in MABC-2 balance percentile scores from baseline ($p = 0.008$).
Conclusions and implications: These findings suggest that children with DCD can learn through repeated exposure to challenging situations, regardless whether training is given. However, only the training group were able to transfer these improvements to the MABC-2 balance assessment. This may suggest the intervention exposed children to increased movement variations which could be transferred to a different task.

What this paper adds?

While it is known that balance training is beneficial for children with developmental coordination disorder (DCD), whether benefits are linked to altered neuromuscular control or other factors is not known, limiting our ability to optimise rehabilitation protocols. In this short report, we present findings following a six-week, at-home exergaming intervention to improve balance and postural control in children with DCD, assessed using a continuous moving platform paradigm. Both groups improved their global stabilisation strategy during the platform task, indicating a learning effect. However, only children in the training group improved MABC-2 balance percentile scores, suggesting that the intervention may have exposed children to additional movement variations that allowed for skill

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transfer to a different task. Children who received the training were able to adapt their neuromuscular control strategies in the gastrocnemius to present more like a typically developing child after training, however this only occurred at one platform frequency (0.25 Hz), and did not persist after a retention period of no training. Further work is required to assess how neuromuscular control strategies may be altered through training in children with DCD.

1. Introduction

Developmental coordination disorder (DCD) affects 5–6 % of school-aged children, and is characterised by reduced motor competence and poor motor coordination in the absence of other competing neurological/medical disorders (American Psychiatric Association, 2013). Most children with DCD experience significant difficulties with both static and dynamic balance due to poor muscle activity regulation. This predisposes them to trips and falls due to an inability to appropriately predict and react to postural disturbances. Therefore, as balance is integral in the successful performance of most functional skills (Huxham et al., 2001), it is important to understand how balance deficits may be overcome with targeted training interventions.

Neuroplasticity is a possible mechanism for improved postural control following training, promoting a functional reorganisation of the central nervous system through learning task-orientated skills (Johnston, 2009). However, skill acquisition and development require substantial repetitions (Valvano, 2004), therefore rehabilitation interventions should be varied and motivational to ensure sufficient engagement. Virtual reality systems, and by extension, active video games or 'exergaming', encourage children to actively embrace rehabilitation interventions by motivating them to control games through their own body movements. This facilitates key principles of motor learning and neuroplasticity, maximising skill transfer potential (Tieri et al., 2018). Therefore, as children can now interact with exergaming on readily-available consoles, they are a potentially attractive option as a training tool for children with DCD. Previous work has shown exergaming to be beneficial in improving general balance in children with DCD (e.g., Cavalcante Neto et al., 2020; Smits-Engelsman et al., 2020). However, whether benefits are linked to altered neuromuscular control or other factors is not known, limiting our ability to optimise selection and delivery of rehabilitation protocols.

Thus, the aim of this study was to compare the postural and neuromuscular responses to repeated platform oscillations between children with DCD who 1) received an at-home exergaming intervention and 2) continued their normal daily routine. We hypothesised that children who received the intervention would improve their postural and neuromuscular responses following training.

2. Methods

2.1. Participants

Seventeen children with diagnosed (n = 11) or suspected (n = 6) DCD were recruited via parental support groups on social media. Prior to data collection, parents/guardians completed the DCD Questionnaire to confirm indication of, or suspected DCD (Wilson et al., 2009). Additionally, parents/guardians confirmed that their child struggled with balance, did not suffer from any general medical condition known to affect sensorimotor function, and did not currently play active video games. Children with DCD were required to score $\leq$ 5th percentile (overall), and $\leq$ 15th percentile (balance subscale) on the Movement Assessment Battery for Children, Second Edition (MABC-2; Henderson et al., 1992). The institutional research ethics committee granted ethical approval. Written informed consent was obtained from parents/guardians and written assent given by children (Table 1).

2.2. Intervention design

Experimental data were collected on three occasions: baseline, six-weeks after baseline (immediately post-training; "post-test"), and twelve-weeks after baseline ("retention-test") by the same researcher. Eleven children with DCD were randomly assigned to the training group. They completed a six-week at-home exergaming intervention consisting of a pre-selected Nintendo Switch game (Ringfit Adventure) which challenged balance, and targeted lower-limb and core strengthening. Games were played for a minimum of 30-minutes, three times per week. Adherence was monitored through written logbooks and checking console activity. Following the intervention, children returned to normal activity for a six-week retention period. The remaining six children with DCD (control group) maintained normal activity throughout the twelve-week study. All seventeen participants returned for post-test, however three participants (1 training, 2 controls), did not return for the retention-test due to scheduling issues.

Table 1
Participant characteristics.

	Training	Control
N (male/female)	11 (8/3)	6 (4/2)
Age (yrs)	9 ± 1	9 ± 1
Height (m)	1.41 ± 0.07	1.42 ± 0.09
Body Mass (kg)	38.4 ± 7.7	42.3 ± 11.5
MABC−2 Overall Percentile (%)	2 ± 2	3 ± 2
MABC−2 Balance Percentile (%)	2 ± 3	4 ± 3

MABC-2; Movement assessment battery for children, 2nd edition.

2.3. Experimental protocol

The experimental protocol for this study has been described in detail previously (Harkness-Armstrong et al., 2023). In brief, participants stood upright with eyes open and feet shoulder width apart in the centre of a moveable platform. The platform translated 10 cm peak-to-peak in the antero-posterior direction at three successive frequencies (0.1, 0.25 and 0.5 Hz). Participants were instructed to maintain balance and avoid taking steps unless necessary. If steps were taken, participants were asked to return to their initial position as quickly as possible. Participants completed the exact same protocol at baseline, post-test and retention-test.

Full body kinematics were collected at 100 Hz using a 10-camera motion analysis system (Qualisys v2021.1, Gothenburg, Sweden). Passive retro-reflective markers were positioned on the whole-body using a modified Plug-in Gait model, with two additional markers placed on the oscillating platform to record its position. Bilateral surface electromyography (EMG; Delsys Inc., Natick, USA) were recorded from eight lower limb muscles at 1000 Hz in Qualisys. Centre of pressure (COP) data were collected using a Kistler force plate (Type 9281B, Kistler Instrument Corp., Winterthur, Switzerland), embedded into the oscillating platform, at 1000 Hz. Force data were recorded in BioWare software (v5.4.3.0), synchronised to motion data by a Qualisys trigger module.

2.4. Outcome measures

All outcome measures are fully defined in Harkness-Armstrong et al. (2023). In brief, the number of cycles containing a step were counted. COP area was calculated using a 95 % confidence ellipse. Centre of mass (COM) displacement variability in the medio-lateral and antero-posterior directions were assessed by calculating the standard deviation (SD), and Entropy Halflife (EnHL; an analysis of the temporal organisation of variability).

EMG intensity envelopes were calculated using an EMG-specific wavelet analysis (Von Tscharner, 2000). Data were sub-divided into 'transition-state' (first 3–5 platform cycles within each frequency) and 'steady-state' (final 5–10 platform cycles without stepping within each frequency). Postural muscle onset latencies were manually identified in respect to the relevant platform change of direction using the *ginput* function in MATLAB (R2022a, MathWorks In., Natick, MS, USA), when EMG intensity surpassed two SDs above baseline (defined during quiet standing) and lasted longer than 50 ms. Data were then standardised using a custom written MATLAB script so that individual muscle onset always occurred at the same threshold. Total excitation time of each muscle was then calculated as the total time between activity onset, and the first subsequent instance that the EMG intensity dropped below the onset threshold. Activity bursts were coded as anticipatory when they occurred before platform change of direction.

2.5. Statistical analysis

All statistical analyses were completed in RStudio (RStudio 1.3.959). A linear-mixed model (lme4 package; Bates et al., 2015) was developed to quantify differences for each outcome measure between groups, and between sessions (fixed effects). Participant ID was included as a random effect. Assumptions of linearity and normality distributions of the model were checked visually, and homogeneity of variance assessed using Levene's Test. Estimated means for each variable were derived from the model using the *emmeans* package, and are reported as mean ± standard error (SE). To identify between-group and between-session differences, Tukey's pairwise comparisons were conducted. Statistical significance was set at $p < 0.05$. Effect sizes (ES) were also calculated using the *effsize* package, and considered trivial (< 0.2), small (≥ 0.2), moderate (≥ 0.6), large (≥ 1.2), or very large (≥ 2.0), and are presented as ES ± 90 % confidence intervals. ES were considered unclear if the 90 % confidence intervals included substantial positive and negative values (≥ ± 0.2).

3. Results

All group-level data for all outcome variables can be found in Supplemental Material.

3.1. Intervention

All children in the training group completed a minimum of 15 sessions (total number: 17 ± 2).

3.2. Movement Assessment Battery for Children (Balance Subscale)

Both groups had similar MABC-2 balance percentile scores ($MABC\text{-}2_{BP}$) at baseline ($p = 0.985$). $MABC\text{-}2_{BP}$ was greater at post-test (4.33 ± 1.91; moderate ES: 1.19 ± 0.79; $p = 0.139$) and at retention-test (10.07 ± 1.99; large ES: 1.76 ± 1.12; $p = 0.008$) compared to baseline (1.63 ± 1.91) in the training group, whereas there were no between-session changes in the control group (3.75 ± 2.58 *vs.* 3.92 ± 2.58 *vs.* 2.31 ± 3.09; unclear ES; $p > 0.05$). At retention-test, children in the training group had a greater $MABC\text{-}2_{BP}$ than the control group (large ES: 1.62 ± 1.29; $p = 0.299$).

3.3. Stepping responses

At post-test, the number of cycles where a step was taken at 0.5 Hz reduced by 6 ± 1 in the training group (large ES: 1.89 ± 0.75; $p = 0.007$) and 7 ± 1 in the control group (very large ES: 2.17 ± 1.02; $p = 0.055$) compared to baseline. In both groups, this effect was

maintained at retention-test (post *vs.* retention; unclear ESs, $p > 0.05$). There were no differences between-sessions at 0.1 Hz or 0.25 Hz in either group (unclear ES; $p > 0.05$), and no group differences at any frequency, at any session (unclear ES; $p > 0.05$).

3.4. COM variability

In both groups, medio-lateral COM SD was smaller at post-test (moderate to large ESs; $p > 0.05$) and retention-test (moderate to very large ESs; $p > 0.05$) compared to baseline at 0.5 Hz (Fig. 1a-b). However, there were no between-session differences in either group at 0.1 or 0.25 Hz (unclear ES; $p > 0.05$), and no group differences at any frequency at post-test or retention-test (unclear ES; $p > 0.05$).

In the training group, at 0.25 Hz, antero-posterior COM SD was smaller at post-test (large ES: 1.28 ± 0.75; $p = 0.326$), and retention test (large ES: 1.45 ± 0.78; $p = 0.167$) compared to baseline. At 0.5 Hz, there was no difference between baseline and post-test (unclear ES; $p > 0.05$), however antero-posterior COM SD was smaller at retention-test compared to baseline (large ES: 1.82 ± 0.78; $p = 0.018$; Fig. 1c). In the control group, antero-posterior COM SD was smaller at post-test and retention-test compared to baseline, at all frequencies (moderate to very large ES: 1.03–3.30). There were no group differences at any frequency at post-test or retention test (unclear ES; $p > 0.05$; Fig. 1d).

In both the medio-lateral and antero-posterior directions, EnHL did not differ from baseline at any frequency in either group (unclear ES; $p > 0.05$). There were also no group differences at any frequency at any session (unclear ES; $p > 0.05$; Fig. 2).

3.4.1. COP area

At 0.1 Hz and 0.25 Hz, there were no between-group differences in any session, or any session differences within either group (unclear ES; $p > 0.05$). At 0.5 Hz, COP area was smaller in both groups at post-test (large ESs: 1.39–1.50; $p > 0.05$) and retention-test (very large ESs: 2.03–2.22; $p > 0.05$) compared to baseline. There were no between-group differences in any session at 0.5 Hz (unclear ESs; $p > 0.05$).

3.4.2. Muscle activity

Postural muscle activity data are presented in Table 2. At 0.1 Hz and 0.5 Hz, there were no clear trends within- or between-groups during transition-state or steady-state cycles. At 0.25 Hz, medial gastrocnemius muscle onset of the training group at post-test was closer to platform change of direction by 11.40 ± 4.21 % half-cycle time ($\%_{HCT}$) during transition-state (large ES: 1.24 ± 0.76; $p = 0.238$), and 8.27 ± 4.21 $\%_{HCT}$ during steady-state cycles (moderate ES: 0.90 ± 0.76; $p = 0.714$) compared to baseline. Total

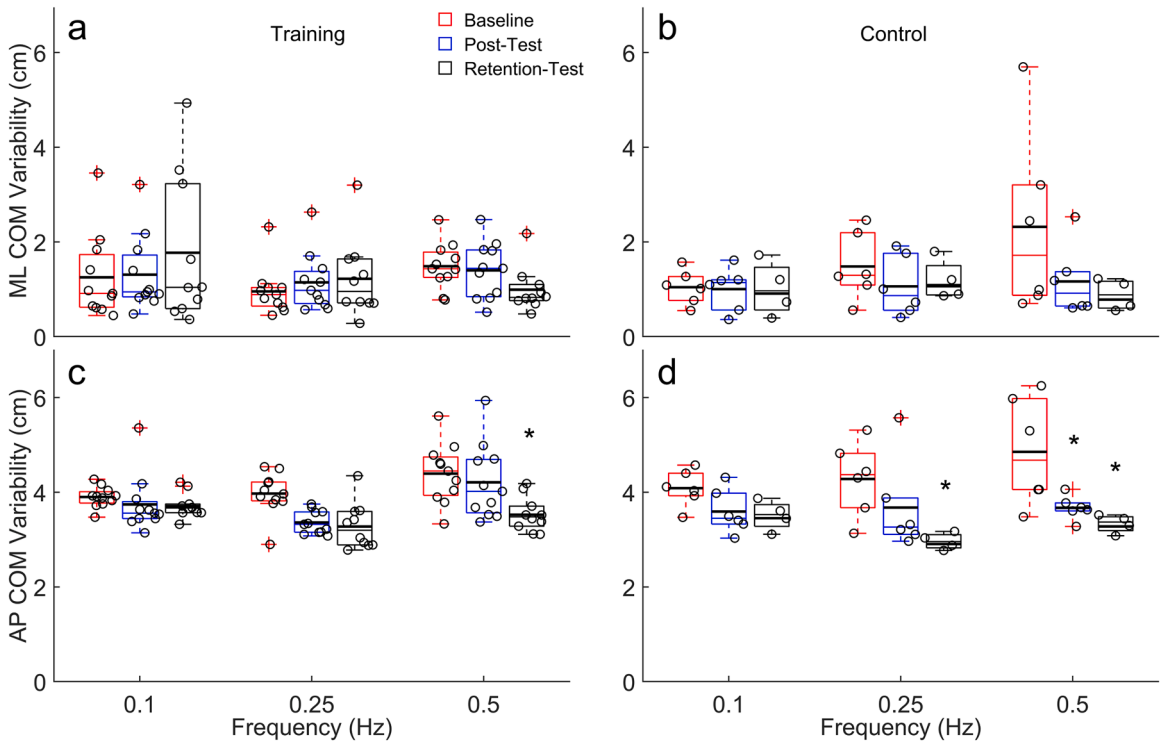

Fig. 1. Linear-mixed model estimated centre of mass variability, based on signal standard deviation in the (a-b) medio-lateral direction in (a) training and (b) control groups, and (c-d) antero-posterior direction in (c) training and (d) control groups. Solid horizontal black lines indicated group averages. *Significant difference from baseline ($p < 0.05$). ML, medio-lateral; AP, antero-posterior; COM, centre of mass.

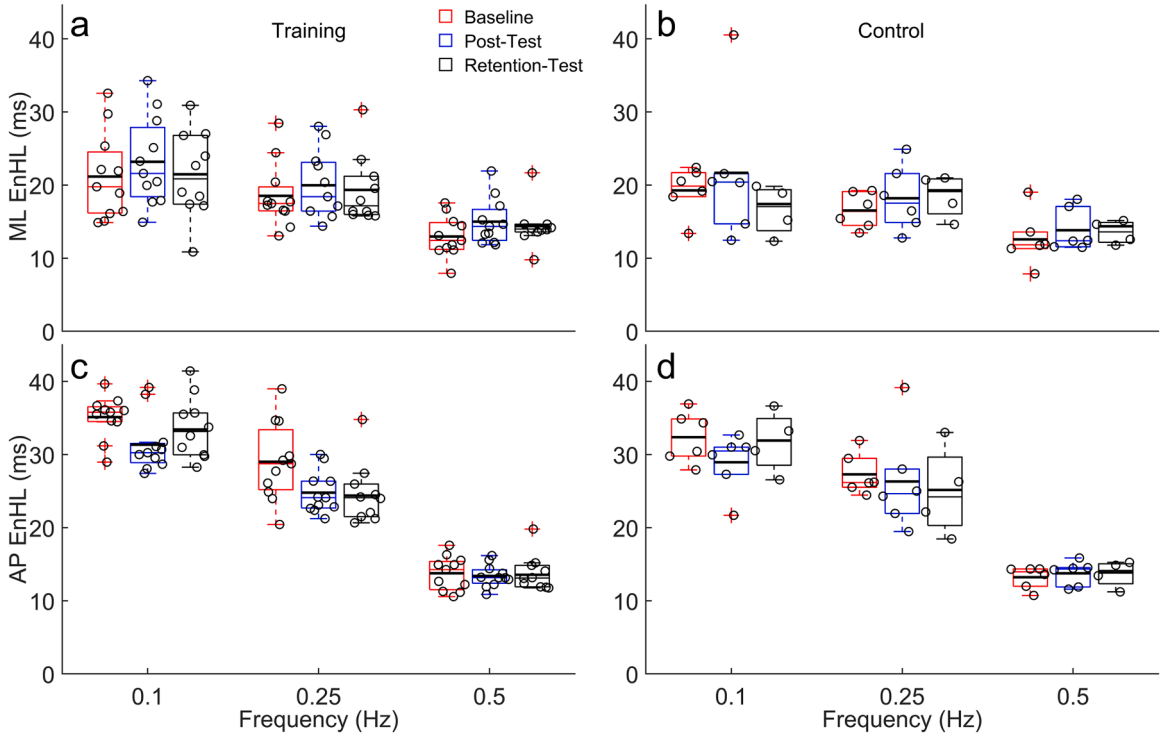

Fig. 2. Linear-mixed model estimated Entropy Halflife, expressed in milliseconds, in the (a-b) medio-lateral direction in (a) training and (b) control groups, and (c-d) antero-posterior direction in (c) training and (d) control groups. Solid horizontal black lines indicated group averages. ML, medio-lateral; AP, antero-posterior; EnHL, entropy halflife.

excitation time of the medial gastrocnemius muscle was also shorter at post-test by 4.85 ± 3.25 $\%_{HCT}$ in transition-state (moderate ES: 0.68 ± 0.76; $p = 0.939$), and by 5.47 ± 3.25 $\%_{HCT}$ (moderate ES: 0.77 ± 0.76; $p = 0.872$) in steady-state cycles, compared to baseline in the training group. There were no differences in onset time or excitation duration between baseline and retention-test (unclear ES; $p > 0.05$). In the control group, there were no differences in gastrocnemius onset time between sessions for transition-state cycles (unclear ES; $p > 0.05$). However, onset time was closer to platform change of direction at both post-test and retention-test compared to baseline for steady-state cycles (moderate to large ES: 0.97–1.33; $p > 0.05$). In both transition-state and steady-state cycles, total gastrocnemius muscle excitation time increased at post-test compared to baseline in the control group (moderate to large ES: 1.09–1.47; $p > 0.05$).

4. Discussion

This study is the first to assess the postural and neuromuscular responses of children with DCD using a continuous balance perturbation paradigm after an at-home exergaming intervention. Both groups showed improvements on the platform balance task. However, only children in the training group showed improvements in MABC-2_{BP} from baseline. Therefore, data from the current study indicate that children with DCD can learn through repeated exposure to challenging situations, regardless whether separate training is given. However, the exergaming training prescribed in this study may have exposed children to increased and/or different movement variations which could be transferred to a different task.

At the fastest platform frequency, both groups showed a reduction in the number of cycles where a step was taken, medio-lateral and antero-posterior COM variability, and COP area, indicating improved balance control regardless whether exergaming training was prescribed. While this limits our ability to assess the effectiveness of our intervention, it does suggest that children with DCD can learn to successfully deal with balance perturbations through repeated exposure to challenging situations (Bonney et al., 2017), and that these learning effects remain after a period of 6-weeks with no exposure. Therefore, future research should consider that the use of the continuous moving platform paradigm may not be most appropriate to assess the effectiveness of intervention-based studies, due to the strong learning effect associated with its use.

Children who received the intervention showed improvements in MABC-2_{BP} immediately after training and following a six-week retention period, that were not observed in the control group. Improvements were also observed across both static and dynamic components of the MABC-2_{BP}. Therefore, either the MABC-2_{BP} was more sensitive than the platform task to detect group-level improvements in balance performance after training, or the exergaming training prescribed in this study exposed children to increased and/or different movement variations that allowed skill transfer to the MABC-2_{BP} (Smits-Engelsman et al., 2020). The latter may, in

Table 2
LMM estimated mean ± standard error timing of muscle activity during transition-state and steady-state cycles. Negative onset latencies indicate muscle excitation occurred before platform change of direction.

			Training Group						Control Group					
			Onset Latency (%)			Total Excitation Time (%)			Onset Latency (%)			Total Excitation Time (%)		
			Baseline	Post	Retention	Baseline	Post	Retention	Baseline	Post	Retention	Baseline	Post	Retention
Transition-State	**0.1 Hz**	**RF**	14.28	2.68	−18.10	12.34	16.91	33.02	9.86	11.53	1.96	7.23	11.11	11.17
			(8.79)	(7.83)	(7.05)†††	(11.19)	(10.32)	(10.07)††	(8.60)	(12.48)	(18.04)	(2.75)	(15.53)	(19.53)
		TA	−6.62	−8.49	−9.60	6.17	3.40	6.60	3.48	−6.76	−8.27	9.90	3.93	2.83
			(6.18)	(5.77)	(5.43)	(2.19)	(2.05)	(1.94)	(8.15)	(7.28)	(8.15)	(2.91)	(2.60)††	(2.91)††
		BF	6.41	−2.16	−18.96	8.00	10.03	3.22	−5.02	−7.06	−25.45	4.64	13.36	12.96
			(6.28)	(5.22)	(6.28)††	(3.94)	(3.31)	(3.93)	(16.62)	(9.59)	(11.80)	(10.54)	(5.04)	(7.38)
		MG	−4.03	−9.29	−15.11	5.20	8.39	7.49	−8.03	−1.46	−14.96	7.47	8.13	12.92
			(4.29)	(4.29)	(4.51)†	(1.94)	(1.94)†	(2.03)	(6.39)	(5.82)	(7.17)	(2.86)	(2.62)	(3.18)*
	0.25 Hz	**RF**	−1.33	−12.67	−6.33	16.67	11.57	21.64	−14.91	−6.46	−12.85	30.67	19.53	8.48
			(7.17)	(6.38)	(3.74)	(5.25)	(4.77)	(5.00)	(10.15)	(9.04)	(11.77)	(7.37)**	(6.72)	(8.38)
		TA	−5.08	−9.59	−9.97	9.66	7.14	21.12	−25.53	−2.07	−7.20	12.41	15.36	25.10
			(4.98)	(4.98)	(5.22)	(2.66)	(2.66)	(2.81)	(7.00)**	(6.46)	(7.76)††	(3.76)	(3.42)*	(4.22)
		BF	−19.17	−15.34	−23.05	17.54	11.24	23.21	−6.39	−29.00	−14.38	24.14	51.34	41.70
			(4.21)	(4.20)	(4.73)	(4.19)	(4.18)	(4.71)	(7.75)*	(5.95)* ††	(9.53)	(7.71)	(5.92)*** †††	(9.48)** †††
		MG	−23.24	−11.84	−16.76	12.51	7.66	17.27	−14.81	−14.58	−18.36	13.32	21.07	23.80
			(3.06)	(3.06)††	(3.21)†	(2.31)	(2.31)†	(2.43)†	(4.14)*	(4.14)	(5.09)	(3.13)	(3.13)** ††	(3.86)* ††
	0.5 Hz	**RF**	−15.16	−16.96	−24.16	31.78	35.42	36.58	−19.86	−15.00	−16.72	40.70	17.49	46.18
			(5.09)	(7.32)	(5.09)	(11.44)	(6.44)	(11.44)	(6.56)	(7.22)	(9.40)	(14.74)	(16.23)**	(21.13)
		TA	−16.27	−12.35	−29.46	28.41	30.20	23.59	−25.77	−17.64	−25.00	22.45	28.90	30.76
			(4.29)	(4.29)	(4.42)††	(5.36)	(5.36)	(5.59)	(5.81)	(5.81)†	(6.68)	(7.26)	(7.26)	(8.73)
		BF	−18.99	−12.75	−27.54	30.88	48.02	40.73	−25.20	−19.36	−32.74	55.13	37.07	47.86
			(4.60)	(4.60)	(4.84)††	(13.02)	(9.02)	(13.71)	(6.50)	(7.27)	(8.37)	(18.40)	(20.60)	(13.77)
		MG	−26.14	−22.00	−28.52	33.92	30.23	41.05	−26.43	−31.48	−23.48	29.92	27.58	36.39
			(2.80)	(2.80)	(2.93)	(5.55)	(5.55)	(5.82)	(3.80)	(3.80)**	(4.59)	(7.52)	(7.52)	(9.21)
Steady-State	**0.1 Hz**	**RF**	1.56	−13.25	−17.23	19.39	16.11	9.68	6.39	3.64	−0.79	7.62	5.60	5.30
			(6.07)	(7.75)†	(8.71)††	(9.15)	(10.74)	(11.61)	(8.65)	(10.05)	(8.60)	(12.57)	(13.72)	(12.75)
		TA	4.17	0.10	−3.96	6.21	9.23	5.97	8.46	−15.69	−13.39	6.08	7.64	8.31
			(5.13)	(4.88)	(5.77)	(1.84)	(1.76)†	(2.05)	(6.61)	(7.26)* ††	(8.15)††	(2.38)	(2.61)	(2.91)
		BF	5.86	−7.91	−13.77	5.00	18.67	3.55	−1.16	−8.60	−18.33	5.62	19.83	16.46
			(6.80)	(5.51)†	(6.80)††	(4.23)	(3.50)††	(4.23)	(11.78)	(8.26)	(11.80)	(7.36)	(5.26)††	(7.38)**
		MG	−3.67	−11.20	−9.91	9.39	6.27	10.73	−4.03	−1.02	−16.37	6.92	12.83	14.77
			(4.29)	(4.29)†	(4.77)	(1.94)	(1.94)†	(2.13)	(6.39)	(6.40)*	(7.17)	(2.86)	(2.85)* †	(3.18)††
	0.25 Hz	**RF**	1.52	−7.88	−2.18	18.13	14.06	22.64	−16.32	−15.01	−12.38	18.01	22.88	38.82
			(6.75)	(6.07)	(8.32)	(4.98)	(4.59)	(5.93)	(9.04)*	(9.04)	(14.49)	(6.72)	(6.72)	(10.04)††
		TA	−6.56	1.47	−5.43	11.34	12.26	11.40	−5.28	−1.72	−18.48	11.35	23.68	19.74
			(4.77)	(4.77)†	(5.22)	(2.53)	(2.53)	(2.81)	(6.46)	(6.46)	(7.63)* †	(3.42)	(3.42)** ††	(4.22)* †
		BF	−12.30	−9.12	−17.81	18.16	6.36	19.16	−16.57	−14.96	−0.12	14.21	16.74	11.83
			(4.20)	(4.20)	(4.73)	(4.18)	(4.18)†	(4.71)	(6.67)	(6.67)	(9.53)**	(6.64)	(6.64)	(9.48)
		MG	−19.50	−11.23	−11.91	15.14	9.67	19.82	−26.97	−18.06	−14.68	14.40	24.39	15.53
			(3.06)	(3.06)†	(3.21)†	(2.31)	(2.31)†	(2.43)†	(4.14)*	(4.14)* †	(5.09)††	(3.13)	(3.13)*** ††	(3.86)
	0.5 Hz	**RF**	−15.53	−9.01	−9.09	50.28	44.46	51.26	−16.19	−10.40	−11.22	29.77	59.42	16.45
			(5.10)	(5.09)	(6.14)	(11.46)	(11.44)	(13.80)	(8.10)	(6.56)	(16.59)	(18.20)	(14.74)	(37.19)**
		TA	−16.79	−15.82	−17.74	18.17	29.48	35.23	−25.55	−22.14	−17.69	23.18	32.33	30.63
			(4.42)	(2.49)	(4.42)	(5.59)	(5.36)†	(5.59)†	(6.67)	(5.81)	(6.68)	(8.71)	(7.26)	(8.73)
		BF	−15.97	−13.78	−14.73	36.23	41.81	47.52	−32.53	−16.53	−27.90	50.40	34.87	44.08
			(4.84)	(4.39)	(5.47)	(13.70)	(12.42)	(7.72)	(6.51)**	(7.27)††	(10.22)	(18.42)	(20.60)	(29.05)
		MG	−27.43	−25.74	−28.87	26.87	46.56	42.42	−33.88	−35.28	−33.40	33.66	48.44	40.75
			(2.93)	(2.80)	(2.93)	(5.82)	(5.55)††	(5.82)†	(4.13)	(3.80)**	(4.59)	(8.23)	(7.52)†	(9.21)

*Moderate, **large or ***very large effect size difference between training and control group. †Moderate, ††large, or †††vary large effect size difference from baseline within-group. *† Significant difference, $p < 0.05$. RF, rectus femoris; TA, tibialis anterior; BF, bicep femoris; MG, medial gastrocnemius

part, be supported by the training group being able to achieve a similar global stabilisation strategy (e.g., COM control), by utilising a different neuromuscular control strategy than the control group. At 0.25 Hz, children who had received the training activated their gastrocnemius muscle closer to how typically developing children did when performing the same task (Harkness-Armstrong et al., 2023). However, this was only observed at the middle platform frequency and the effect was not maintained at retention-test. Therefore, future work should explore alternative, and potentially more sensitive measures of assessing neuromuscular control mechanisms in children with DCD. This could target the communication between the brain and postural muscles (e.g., Parr et al., 2022) in relation to balance perturbations, to gain a more holistic understanding of neuromuscular control and/or motor learning processes.

To conclude, findings from the current study support the notion that children with DCD can learn to overcome balance perturbations through repeated exposure to challenging situations, such as the moving platform paradigm, regardless of whether separate training is given. However, through specific training interventions, such as those available through accessible gaming platforms, children with DCD may be exposed to increased movement variations that facilitate sufficient motor development and importantly, can be transferred to a different task. Finally, while there appears to be some evidence that neuromuscular control strategies may be altered through training in children with DCD, further work is required to substantiate this notion.

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CRediT authorship contribution statement

Carla Harkness-Armstrong: Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Emma Hodson-Tole:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Greg Wood:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Richard Mills:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ridd.2024.104900.

Data availability

The datasets generated for this study are available on request to the corresponding author.

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