Effects of a highly intensive balance therapy camp in children with developmental coordination disorder - An intervention protocol

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Effects of a highly intensive balance therapy camp in children with developmental coordination disorder - an intervention protocol

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Abstract:	Background: Children with Developmental Coordination Disorder (DCD) often (<87%) experience postural control problems, impacting all levels of the International Classification of Functioning, Disability and Health (ICF) including their daily participation, self-esteem and mental health. Due to the multisystemic nature of postural control, comprehensive therapy should target all systems which is currently not the case. Highly intensive therapy is effective and commonly used in pediatric populations, but has not been explored yet to train postural control in children with DCD. Aims: To investigate the effects of a highly intensive functional balance therapy camp at all ICF levels in children with DCD. Methods and Procedures: The effects on postural control, muscle activity, brain alterations, self-perceived competence, self-identified goals, gross motor activities and participation are evaluated. Participants are assessed pre- and post-intervention, including a 3 months follow-up. Forty-eight children with DCD, aged 6-12 years old, receive 40 hours of comprehensive balance training. This intervention is fun, individually tailored, targets all postural control systems, implements different motor learning strategies and includes both individual and group activities. Conclusion: Novel insights into the effects of a highly intensive comprehensive balance therapy camp designed for children with DCD will be gained at all levels of the ICF.
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Introduction

Developmental Coordination disorder (DCD) is a condition resulting in clumsy, uncoordinated movements (APA, 2013; Blank et al., 2019). With an estimated prevalence of 5-6% in school-aged children, it is the most common neurodevelopmental motor condition in children (Blank et al., 2019). The presence of DCD can result in problems at all levels of the International Classification of Functioning, Disability and Health (ICF) (World Health Organization, 2001) with impairments at the level of functioning (e.g. postural control deficits, muscle weakness, coordination deficits) but also affecting activities and participation (e.g. cycling, self-care, problems in school) (Blank et al., 2019; Magalhães et al., 2011). As sports and physical leisure activities are an essential part of the lives of school-aged children, less participation in these activities can have potential consequences for their self-esteem and mental health (Cairney et al., 2013; Pimenta et al., 2023). One of the important prerequisites for a successful performance of daily activities and participation in school-aged children (e.g. riding a bicycle, playing, rope skipping) is sufficient postural control (Shumway-Cook A. & Woollacot M.H., 2016).

According to the multisystemic framework of Horak et al. (Horak, 2006), postural control is based on the interaction of dynamic sensorimotor processes and can be divided in five different systems. First, the body should be controlled during performance of dynamic movements. Second, adequate movement strategies are required to prepare the body for destabilization during voluntary movements (anticipatory postural adjustments) or to restore stability after perturbation (reactive postural adjustments). Third, the ability to move in different sensory situations requires sufficient integration of sensory stimuli (vision, proprioception and vestibular). During any movement within a posture (e.g. walking or reaching while sitting), an estimation of verticality, the limits of stability and how to move efficiently towards them are needed to move in a safe and controlled way. Finally, cognitive processing and divided attention are needed to successfully perform dual tasks while moving (Horak, 2006).

The multisystemic framework of postural control is situated at the body function level of the ICF. A large variety of motor skills require postural control and when applied in these skills (e.g. walking, running, jumping) this is situated at the activity level of the ICF and referred to as balance. The degree to which sufficient postural control and which postural control systems are needed are determined by the interaction between task, child and environmental factors (Johnson et al., 2023; Kiss et al., 2018).

Literature suggests that heterogeneous postural control problems occur in up to 87% of the children with DCD (Verbecque et al., 2021). They experience problems with anticipatory postural adjustments, moving towards their limits of stability in the backward direction while standing and maintaining a stable standing position in more complex sensory conditions. Conflicting results have been found on reactive postural adjustments and gait parameters (Verbecque et al., 2021).

The performance of balance activities is monitored and regulated by brain and muscle activation patterns. These underlying neuromuscular processes can be categorized into the central nervous system and the peripheral neuromuscular system activity (Fong et al., 2018). Literature on peripheral neuromuscular processes during performance of postural control tasks in children with DCD is limited and mainly suggests that muscle onset latencies tend to be delayed when anticipating for a voluntary movement and when responding to a perturbation, dependent on the perturbation method (Verbecque et al., 2021). In the central nervous system of children with DCD, an underactivation in cerebellar, parietal and prefrontal networks (Subara-Zukic et al., 2022; Wilson et al., 2017) has been reported, which are areas involved in the mirror neuron system (MNS)(Subara-Zukic et al., 2022), as well as a disruption of the cerebello-cerebral network (Fong et al., 2018). However, there is also evidence for altered activity in regions outside the MNS (e.g. left superior frontal gyrus) or enhanced activity in specific regions (e.g. right postcentral gyrus) (Wilson et al., 2017) which indicates that literature is inconclusive and more research is needed, especially during the performance of postural control tasks. By investigating these neuromuscular processes, additional insights can be gained to fully understand what happens during the performance of postural control tasks and after intervention.

A large variety of interventions on postural control therapy in children with DCD has been reported i.e. power training (Kordi et al., 2016), exergames (Smits-Engelsman et al., 2017), taekwondo (Fong et al., 2013), trampoline (Giagazoglou et al., 2015) to vestibular interventions (Dannenbaum et al., 2021). Most studies show improvements in postural control measures after intervention. However, it is clear that none of the interventions target all systems of postural control according to the multisystemic framework. The same holds true for the postural control outcome measures, as most of them only include up to three of the five systems. Therefore, it is possible that potentially affected postural control systems were not targeted nor evaluated. Furthermore, international guidelines recommend that interventions in children with DCD should target activity and participation-oriented activities (Blank et al., 2019). Studies investigating the effect of training these activities on postural control in children with DCD are still limited (Cavalcante Neto et al., 2019; Dannenbaum et al., 2021; Noordstar et al., 2017; Sugden & Chambers, 2007). No studies have yet explored the effects of a multisystemic, comprehensive approach targeting all postural control systems during activity and participation-oriented balance activities in children with DCD.

Besides the heterogeneity in postural control interventions, also the intensity of therapy varies in literature. In other pediatric populations, highly intensive therapy is often applied and proven successful (Bleyenheuft et al., 2017; Klingels et al., 2013). In children with Cerebral Palsy, highly intensive therapy is defined as a minimum of 30 therapy hours with a minimum therapy frequency of three times a week (Jackman et al., 2020). In children with DCD, only a limited number of studies investigated the effect of highly intensive therapy (Dannenbaum et al., 2021; Krajenbrink et al., 2022; Zwicker et al., 2015), but showed improvement of performance and satisfaction of individual goals (Krajenbrink et al., 2022; Zwicker et al., 2015), functional gait and gaze stability (Dannenbaum et al., 2021) which indicates that highly intensive therapy can be feasible. However, the effects of highly intensive therapy on postural control have not yet been investigated in this population.

Furthermore, literature investigating the interventional effects on neuromuscular processes in children with DCD is scarce. To our knowledge only two studies (Cheng et al., 2019; Fong et al., 2016) investigated the effect of training on peripheral muscular systems. Therapy effects when measured analytically show increased time to peak and peak forces in lower limb muscles(Fong et al., 2016), but are conflicting dependent on outcome measure(Cheng et al., 2019). It is not clear how muscle activity may be affected after intervention when measured during functional tasks. Secondly, a recent review on central nervous system deficits reported that physical interventions are able to alter the structure and function of some of the brain correlates in children with DCD (frontal and parietal lobes, cerebellum, basal ganglia and limbic system) and their connections through the corpus callosum (Izadi-Najafabadi et al., 2020). No studies have yet investigated the effect of a postural control intervention on brain activity. In current literature, interventional effects were measured by static neuroimaging methods (e.g. functional magnetic resonance imaging (fMRI) (Gill et al., 2022; Izadi-Najafabadi et al., 2022), event-related potentials (Tsai et al., 2014), electro encephalography (EEG) (Blais et al., 2018)). However, with these methods, it is not possible or more difficult due to movement artefacts (e.g. EEG) to measure cortical activity while performing dynamic tasks. Functional Near-Infrared Spectroscopy (fNIRS) (Owen-Reece et al., 1999) is a portable neuroimaging method that allows assessing brain activity during actual task performance (Menant et al., 2020). Hence, more insights can be gained in neuromuscular processes while performing postural control tasks and the changes after intervention.

The children's difficulties performing motor tasks influence their self-esteem and mental health (Pimenta et al., 2023). Children with DCD have low perceived competence in sports due to their motor coordination problems, therefore often show frustration when performing school-based activities and have less confidence when playing with other children (Cairney et al., 2013). Interventions targeting motor aspects should therefore also aim to let children experience motor successes and fun while moving in order to improve their self-esteem and perceived confidence.

This study protocol is designed to fill current gaps in literature by investigating the effects of a highly intensive six-day, comprehensive balance therapy camp for children with DCD and measuring the effects at different levels across the ICF including postural control performance (body functions), individually chosen goals (activities and participation), neuromuscular processes (body functioning and structure), self-perceived competence (personal factors), perception of parents (environmental factors) and gross motor activities (activities and participation).

Aims and hypotheses

The main objective of this clinical trial is to investigate the short (immediately after intervention) and medium term (three month) effects of a highly intensive, comprehensive postural control 6-day therapy camp in school-aged children (6 to 12 years) at different levels of the ICF framework.

Primary aim and hypothesis

- To explore the effects of the camp on the ***performance of a functional postural control test*** (Balance Evaluations Systems Test for Children; Kids-BESTest) in children with DCD. We hypothesize that the therapy camp will induce greater and longer lasting improvements in postural control performance when compared to usual physical activity and therapy children with DCD after 3 months.

Secondary aims and hypotheses

- To determine the effect of intervention on ***individually identified goals*** by the participants.
    - Hypothesis: An increased performance on the activities selected by the participant (higher scores on the Canadian Occupational Performance Measure; COPM)) after the camp when compared to usual motor activity and therapy.

- To determine the effect of intervention on ***gross motor activities***.
    - Hypothesis: An improved performance of gross motor activities (higher scores on Test of Gross Motor Development – third edition; TGMD-3) after the camp when compared to usual physical activity and therapy.

- To determine the effect on ***neuromuscular processes*** involved in postural control tasks. Neuromuscular processes will be assessed while performing postural control tasks and include lower limb muscle activity and cortical brain activity.
    - Hypothesis: Neuromuscular processes measured while performing postural control tasks will resemble more those of typically developing peers (less co-contraction and less variable onset latencies) after the therapy camp compared to usual physical activity and therapy. Cortical brain activity, measured with fNIRS, will chang after

intervention and will also resemble more those of typically developing peers (more focal and increased activity in brain regions related to postural control and MNS (motor and parietal cortex)).

- To determine the effect on ***self-perceived competence*** of participants.
    - Hypothesis: A higher self-perceived competence (higher scores on Self Perception Profile for Children questionnaire; SPPC) after the camp when compared to usual physical activity and/or therapy.

- To determine the effect on the ***perception of the parents***.
    - Hypothesis: A higher self-esteem and less fear of moving in their child as reported by the parents after the camp when compared to usual motor activity and therapy (conducted with a qualitative questionnaire and interview).

- To investigate whether age, activity profile and baseline postural control can ***predict*** the outcome after intervention
    - Hypothesis: The intervention will have greater effects on postural control if children: (a) are aged between 8 and 10 years old, we expect that children in this age range have the most potential to progress due to motivational and motor learning conditions, (b) have lower baseline activity scores, (c) have lower baseline Kids-BESTest scores.

Materials and methods

<u>Ethics</u>

This study was approved by the Committee for Medical Ethics of ***BLINDED FOR REVIEW***. Detailed information is provided to the parents in forms of a website, flyer and digital information sessions. If parents agree on the participation of their child, a written consent is signed by the parents before the first assessment. Children sign assent on an age-appropriate assent form.

<u>Current status of the protocol</u>

The recruitment and data-collection for this study has started.

<u>Study design</u>

This study is a clinical trial with a single group pre-post interventional test design with a triple, non-training baseline and follow-up (Figure 1), and is reported following the Tidier checklist (Hoffmann et al., 2014). After inclusion, participants are followed for six months prior to the intervention using a triple baseline consisting of six months pre-assessment (T1), a three-months pre-assessment (T2) and a pre-interventional assessment (T3). After the camp, patients perform a post-interventional assessment (T4) and a three-month follow-up assessment (T5) (Figure 1). During the pre-interventional follow-up children perform their usual physical activity and therapy. Physical activity (e.g. leisure and sport activities), content and frequency/intensity of therapy throughout this period is registered and considered in the analysis.

Figure 1. Overview study design and outcome measures

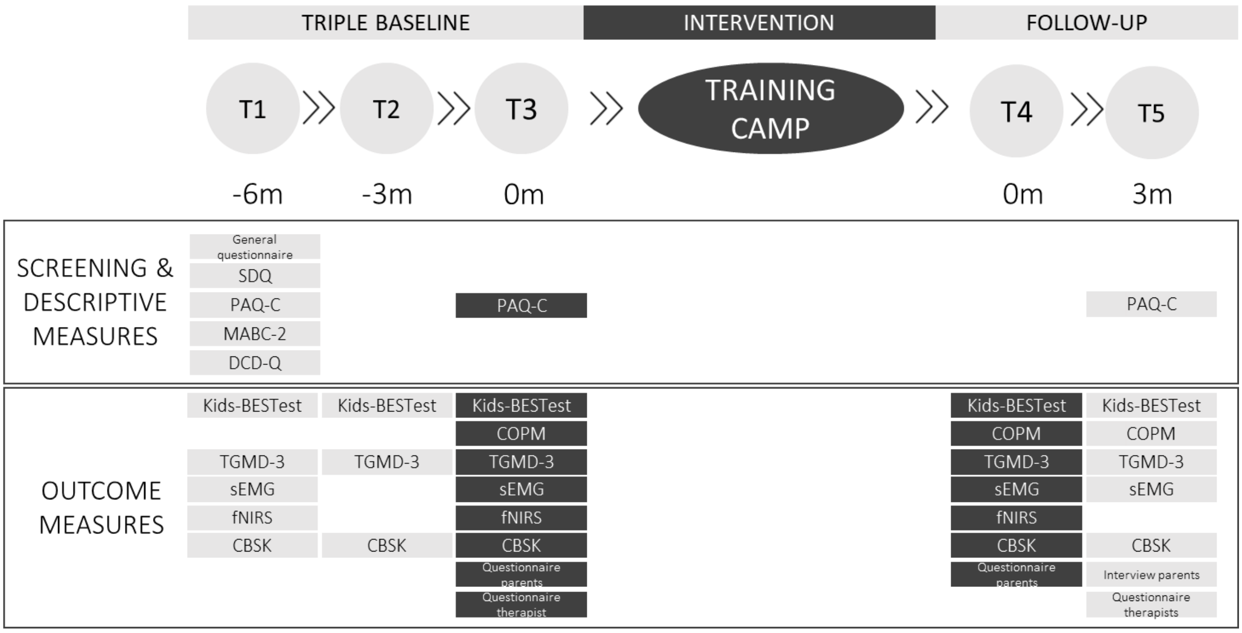


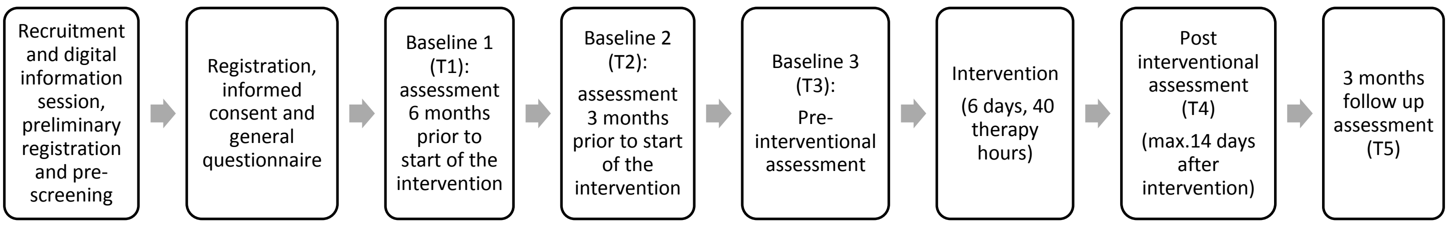
Figure 1. Overview assessments and outcome measures. Abbreviation list: SDQ: Strengths- and Difficulties Questionnaire; PAQ-C: Physical Activity Questionnaire for Children; MABC-2: Movement Assessment Battery for Children 2nd edition; DCD-Q: Developmental Coordination Disorder Questionnaire; Kids-BESTest: Balance Evaluation Systems Test for children, COPM: Canadian Occupational Performance Measure; TGMD-3: Test of Gross Motor Development 3th edition; sEMG: Surface Electromyography; fNIRS: functional Near InfraRed Spectroscopy; CBSK: Competentiebelevingsschaal voor Kinderen,

Recruitment

Participants

Children with DCD between 6 and 12 years old (at T1) are included. Children are recruited through pediatric physical therapists in the region of ***BLINDED FOR REVIEW*** via a recruitment campaign, the ***BLINDED FOR REVIEW*** non-profit organization for parents of children with DCD ***BLINDED FOR REVIEW***, flyers, social media and website. Spontaneous applications or applications of other regions are considered (Figure 2).

Figure 2. Recruitment and study protocol



The sample size was estimated using unpublished data from our pilot study on 12 children aged between 5 and 12 years old (primary outcome measure: the total score of the Kids-BESTest). A total of 38 participants is required to reach a power of 0.90 and a margin of error of 5%, which was calculated with G*Power 3.1. To account for potential drop outs a maximum of 12 children are included in each camp with a maximum of 48 children.

Inclusion criteria

Participants are included when diagnosed with DCD by a pediatrician, using the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) criteria (APA, 2013): (i) motor skill acquisition and performance is at an age-inappropriate level (Criterion A), objectified with the total MABC-2 score at or below the 16th percentile or subscale score at or below the 5th percentile; (ii) the motor skills deficit significantly and persistently interferes with the activities of everyday living (Criterion B), objectified with the DCD Questionnaire 2007 (DCD-Q) ; (iii) Onset of symptoms in early childhood (Criterion C) evaluated by anamnesis with parents; (iv) The motor skills deficits are not better accounted for by any other medical (neurological, intellectual, visual, etc.), neurodevelopmental, psychological, social condition, or cultural background (criterion D), evaluated by a neuromotor examination performed by an acknowledged pediatrician.

Children who have no formal diagnosis are evaluated by the research team using the diagnostic criteria as outlined in the inclusion criteria. In this case, Criterion D is evaluated based on anamnesis and clinical examination. If criterion A, B, C are met and other intellectual, visual or neurological conditions have not been reported, they are included as having “probable” DCD (Blank et al., 2019).

Due to the interventional focus on postural control, children are only included if they score below the 50th percentile for the balance subscale of the MABC-2 and below 80% on the Kids-BESTest total score.

Due to the high comorbidity rate in children with DCD, such as attention deficit hyperactivity disorder (ADHD), autism spectrum disorder (ASD) and dyslexia, the comorbidities are listed through thorough anamnesis and the Strengths and difficulties questionnaire (SDQ) is used (Goodman, 1997).

Exclusion criteria

Children are excluded if they are not able to follow instructions or cooperate sufficiently due to behavioral problems or when they do not meet all the aforementioned criteria.

<u>Location and materials</u>

The camp is held in an accommodation that meets the requirements (e.g. school, sports accommodation). Materials are provided by the research team and include general sports equipment (e.g. different types of balls, cones, mats, trampolines) and specific circus materials (e.g. circus barrel, walking ball)

<u>Intervention</u>

Program

Four camps are organized between April 2023 and August 2024. Each camp consists of six days of therapy, with a total therapy time of 40 hours. The central camp theme is “Circus”, due to the attractiveness for children and the link with postural control.

The intervention is functional (Geijen et al., 2020), and divided in six activity categories: jumping, sitting balance, walking and running, circus, individual goals and group activities with focus on social interaction (Table 2). Each category should: 1. partially or fully cover the multisystemic framework of Horak (Horak, 2006), with the overall program covering the entire framework , 2. be fun and focusing on collaboration rather than competition (Figure 3).

Schedule

Activities are performed in different formations (individually, in duo, in small groups or with the total group). All children perform the same activities except from the individual goal sessions. Each activity is individually tailored. After each day a short relaxation session is held. An example of a day schedule can be found in Figure 4.

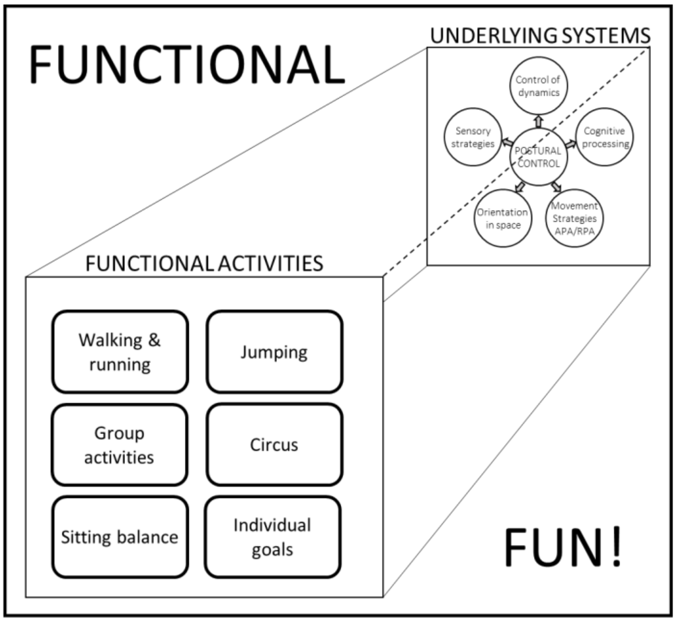
Table 2. Activity categories

Activity category	Description	Examples
Jumping	Activities involve jumping in a broad context and different sensory situations (stable and unstable surfaces), unipedal and bipedal jumping, with and without different dual tasks (cognitive, motor, auditive).	• Personate different animals while jumping on a trampoline • Relay race on an airtrack on one leg while keeping a balloon in the air
Sitting balance	Activities are divided in static and dynamic sitting balance. Static sitting balance activities are performed on the ground, stools or benches with a stable or unstable surface and without backrest. While children sit, games, crafting, cooking activities are performed. In the dynamic sitting balance activities children sit on a moving surface such as sitting on a moving burlap bag or riding a balance bike (unicycle with small steering wheels). Dual tasks (cognitive, motor, auditive) are added to increase complexity.	Static • Sitting on a gymball and crafting juggling balls • Cutting vegetables while sitting on a bench without backrest Dynamic • Performing a complex trail on a balance bike while catching balls that are thrown unexpectedly • Sitting on a burlap bag that is pulled by the individual therapist and remember puzzle pieces
Walking and running	Activities consist of games where children have to reach goals by walking and running. This can be on stable or unstable surface, eyes open or closed, with or without dual tasks, forward, backward or sideward etc.	• Relay with different running activities. Children have to remember puzzle pieces at the end to reconstruct a puzzle. • Perform a complex trail backwards
Circus	Activities include specific circus activities and are performed individually, in duo or in group. Manual circus activities, such as plate spinning or juggling, can be performed as a dual task.	• Barrel walking, if possible combined with throwing a ball • Stand or walk on a firm circus ball
Individual goals	Children choose up to three individual balance goals before the camp. Therapy starts from task performance analysis and is individually adapted using motor learning principles.	• "I want to learn rope skipping" • "I want to learn how to inline skate"
Group activities with focus on social interaction	The focus is on social interaction, children have to work together to reach goals or win games.	• Perform a complex and unstable trail with the whole group • Playing tag and remember memory cards at the same time

Therapists

Therapy is provided by physical therapists and master students in a 1:1 ratio (participant: therapist), allowing individual therapy adjustments for each activity. The activities and program are designed and prepared by an experienced research team of physical therapists with the aid of master students "Rehabilitation and physiotherapy" ***BLINDED FOR REVIEW***.

Figure 3. Overview interventions and underlying systems



Functional therapy, motor learning principles and child specific tailoring

Therapy targets all postural control domains in a functional way (Geijen et al., 2020). Based on the international guidelines for children with DCD, therapy is goal directed, task specific, based on the activities/participation level of the ICF, requires active involvement of the child and focus on functionality rather than normality (Blank et al., 2019). Implicit and explicit motor learning principles are applied. Implicit motor learning is defined as learning without awareness and with no or minimal increase in verbal knowledge (Kleynen et al., 2014) and was proven successful in typically and atypically developing children (van Abswoude et al., 2021). Explicit motor learning is defined as learning which generates verbal knowledge of movement performance, involves cognitive stages within the learning process and is dependent on working memory involvement (Kleynen et al., 2014). Implicit and explicit motor learning strategies and child-specific tailoring is applied based on the child factors (e.g. age, individual abilities and learning phase), type of task and environment (Kleynen et al., 2014; van Abswoude et al., 2021; van der Veer et al., 2022). Instructions and feedback are child-tailored by adapting content (general/specific), focus (internal/external), form (verbal, visual, tactile, auditive) and dosage (frequency, amount, timing). Progression is implemented in the program, tailored to child characteristics and added by changing (i) temporal factors (reaction time, speed execution, speed changes, movement initiation by child/therapist), (ii) spatial factors (precision task, direction changes, base of support), (iii) sensory conditions (visual, vestibular, proprioceptive), (iv) components (simple, complex, dual tasks (motor, cognitive, auditive) or (v) composition (individual, duo, group) (Blank et al., 2019).

Figure 4. Example of day schedule

Time	Activity
8u00 - 9u00	Pre camp care
9u00 - 9u45	I1: Balance bikes (C: Sitting balance)
9u45 - 10u00	Break
10u00 - 10u45	I2: Individual goals (C: individual goals)
10u45 - 11u00	Break
11u00 - 11u45	I3: Circus barrel walking (C: Circus)
11u45 - 12u45	Lunch break (passive)
12u45 - 13u30	I4: Airtrack jumping games (C: Jumping)
13u30 - 13u45	Break
13u45 - 14u30	I5: Parcours with obstacles (C: group activities)
14u30 - 14u45	Break
14u45 - 15u30	I6: Obstacle relay with dual tasks (C: walking and running)
15u30 – 15u45	Break
15u45 – 16u30	I7: Rope jumping game (C: Jumping)
6u30 – 17u00	Relaxation + day closing
16u00 - 17u30	After camp care

I = Intervention, C = Category

<u>Outcomes</u>

An overview of the data collection procedure and assessment tools can be found in Figure 1.

Descriptive and screening measures

- The ***general questionnaire*** consists of questions about general characteristics (name, age, birth date, length and weight), comorbidities, medical history, pregnancy and motor performance.

- The ***SDQ*** is a brief parent questionnaire comprising 25 questions about socio-emotional functioning. In this study the baseline double-sided version is used, suitable for children between 2 and 17 years old. Twenty-five attributes distributed over five scales (emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behavior) are evaluated (Goodman, 1997). In this study, the Dutch version with acceptable to good psychometric properties is used (van Widenfelt et al., 2003).

- The activity profile of the children is assessed using ***Dutch Physical Activity Questionnaire for Children,*** a self-report questionnaire for children between 5 and 17 years old (Bervoets et al., 2014;

Kowalski et al., 2004). This version has an excellent content validity, an acceptable inter-item reliability and a moderate to good strength of inter-rater agreement (Bervoets et al., 2014).

- The ***MABC-2***: The Dutch version of the MABC-2 (Smits-Engelsman, 2010) is a standardized performance-based motor scale for children between 3 and 16 years old with good reliability and fair to excellent content validity (Griffiths et al., 2018). The test contains three age bands (3-6 years, 7-10 years and 11-16 years), each with eight age-specific items across three domains: manual dexterity (3 items), aiming and catching (2 items) and balance (3 items). The raw item scores are converted to standard scores and summed to calculate domain and total scores.

- The ***DCD-Q*** is a parent report for children between 5 and 15 years old that consists of 15 questions regarding the motor functioning of the child when compared to peers, with a high overall sensitivity, a good specificity and a high internal consistency (Wilson et al., 2009). Items are scored on a 5-point Likert scale total score ranges between 15 and 75. Age-specific cut-off values have been established to identify an indication of DCD. In this study the Dutch version is used (Schoemaker et al., 2006).

Primary outcome measure

- The ***Kids-BESTest*** is a standardized performance tool to assess postural control in children aged between 5 and 18 years old (Dewar et al., 2017; Horak et al., 2009). The test has excellent reliability (Dewar et al., 2019) and consists of 36 items divided over 6 domains (Table 3). The total and domain scores of the test are expressed as a percentage, with a cut off value of 80% (Horak et al., 2009).

Table 3. Overview of Kids-BESTest domains

Domain	Domain description	Items
I	Biomechanical constraints	Base of support, center of mass alignment, ankle strength, hip/trunk lateral strength, sit on floor and stand up
II	Limits of stability and verticality	Lean (L+R)*, verticality (L+R)*, forward functional reach, lateral functional reach (L+R)
III	Transitions and anticipatory postural adjustments	Sit to stand, rise to toes, stand on one leg (L+R)*, alternate stair touching*, standing arm raise
IV	Reactive postural responses	In place response forward & backward, compensatory stepping correction forward, backward and lateral (L+R)
V	Sensory orientation	Modified CTSIB (standing on ground eyes open and eyes closed, standing on foam eyes open and eyes closed), incline eyes closed
VI	Stability in gait	Level walking*, change in gait speed, walk with horizontal head turns*, pivot turns, step over obstacle*, Timed up and Go test with and without dual tasks

L: left; R: right; CTSIB: Clinical Test for Sensory Interaction in Balance; *: preselected tasks with simultaneous recording of sEMG and fNIRS.

Secondary outcome measures

- The ***COPM*** is a client-centered outcome measure to determine and evaluate individual treatment goals (Law, 2019). Measurement properties are satisfactory to excellent (Carswell et al., 2004). In a semi-structured interview between therapist and child (over 8 years) or parents (under 8 years) balance-related problems in daily living are determined. After scoring for importance on a 10-point rating scale, up to 3 self-selected treatment goals are identified. Each goal is self-rated based on the level of performance and satisfaction. In this study the Dutch version is used (Eijssen et al., 2017).

- The ***TGMD-3*** is a functional process-oriented test to assess fundamental motor skills in children between 3 and 10 years old, with high test-retest reliability and validity (Webster & Ulrich, 2017).

The test consists of 13 fundamental motor skills, subdivided across two subscales: locomotor and object control skills. Each skill is assessed with three to five performance criteria reflecting the developmental stage of the movement pattern. The scaled domain and total scores are considered for analysis.

- Surface ***EMG*** is a reliable tool that can be used to measure muscle activity in lumbar and lower limb muscles (Grigoriu et al., 2021; Steele et al., 2019). Muscle activity is registered using sEMG Trigno^{TM}, Delsys Inc., USA. Registered muscles are: m. gastrocnemius medial head, m. tibialis anterior, m. rectus femoris, m. biceps femoris, m. gluteus medius and mm. erector spinae. Outcome measures regarding sEMG are onset latencies (time in ms), time to peak activity (time in ms) and co-contraction (percentage). Sensor placement and locations are performed in accordance with the SENIAM guidelines (Stegeman & Hermens, 2007). Muscle activity is registered simultaneously with fNIRS during performance of Kids-BESTest tasks (Table 3).

- To register cortical brain activity, ***fNIRS*** is applied simultaneously with preselected Kids-BESTest tasks (Table 3). This optical neuro-imaging technique uses infrared light to monitor changes in the concentration (µmol/l) of oxygenated (HbO_2) and deoxygenated hemoglobin (HHb) between the task and baseline condition (Menant et al., 2020). It is a reliable tool for within subject measurements (Dravida et al., 2018) and can be reliably applied in children (Eng et al., 2022). Due to its portability, it can be used during postural control tasks and gait measurements. The NIRSport 2 (NIRx Medical Technologies, GE) with continuous wave (760nm; 850nm) imaging is used.
  The region of interests (ROI) targeted with fNIRS were determined based on evidence of brain areas responsible for adequate postural control tasks in healthy individuals (Dijkstra et al., 2020) and affected brain areas in children with DCD in a variety of tasks (Subara-Zukic et al., 2022; Wilson et al., 2017). The ROI include the inferior (IPL) and superior parietal lobe (SPL), premotor cortex (PMC) and the supplementary motor area (SMA). Optode placement on the head caps is standardized and relative to specific anatomical landmarks following the international 10-10 system and developed in the fOLD Toolbox based on Brodmann area's (Zimeo Morais et al., 2018). More details on the cap, configuration and hardware are presented in Appendix 1.

- Self-perceived competence is assessed with the modified self-perception profile for children (SPPC)(Harter, 1982) or ***"Competentiebelevingsschaal voor kinderen (CBSK)"*** in Dutch translation (J.W. Veerman, 2004). The CBSK is a self-report instrument for children between 8 and 12 years. The scale has acceptable reliability and consists of 36 items on six domains: scholastic competence, social acceptation, athletic competence, physical appearance, behavioral conduct and global self-worth (J.W. Veerman, 2004). Each item is scored on a 4-point ordinal scale. Raw subscale scores are converted to percentile scores.

- Self-perceived competence is assessed with ***Pictorial scale of perceived competence and social acceptance in young children (PSPCSA)*** in children aged 6 and 7 years. The PSPCSA, a self-report instrument, is reliable (Harter & Pike, 1984) and consists of 4 domains (cognitive competence, physical competence, peer acceptance and maternal acceptance) each comprising 6 items. Items are scored on a 4-point ordinal scale. Raw subscale scores can be calculated, with higher scores indicating higher competence.

- ***Qualitative questionnaire and interview parents:*** Parents' perception of their child is questioned with 14 open questions on the child, parents, family and social contacts. Before intervention, parents list their baseline findings, changes are questioned after intervention. Based on these answers, a focus group with the parents is organized at follow-up.

- ***Questionnaire therapists:*** Details (goals, frequency, duration) on the participants' therapy and potential changes in content since the first baseline measurement were questioned with the therapists before intervention. If during the therapy time before and after the camp, postural control goals were set, training methods were inventoried. On follow-up, changes in therapy goals and potential changes in performance are questioned.

Blinding procedure

The Kids-BESTest and TGMD-3 performances are videotaped and scored on video by an experienced assessor. Assessors are blinded for the pre-post condition and timing of the assessment.

Data processing

EMG and accelerometry data are resampled to 500Hz to use in further analysis. EMG data processing is performed in MATLAB using custom-made codes. The raw EMG data are rectified, filtered using a band-pass filter and the linear envelope is calculated. The fNIRS data are pre-processed using the Homer3 software in MATLAB (Huppert et al., 2009). Raw data are transferred to optical density data. Motion and physiological artifacts are removed using wavelet and bandpass filtering. Afterwards, the Beer-Lambert law will be applied to obtain meaningful (de-)oxy hemoglobin levels (HbO_2/HbE) (Menant et al., 2020).

Statistical analysis

Descriptive statistics will be applied to characterize the participants. Means and standard deviations or medians and interquartile ranges, as appropriate, are used to describe the sample at different assessment times (T1-T6). To analyze the interventional effect on the different outcome measures (Kids-BESTest, fNIRS, sEMG, TGMD-3, COPM, CBSK/PSPCSA), a linear mixed model (LMM) analysis is performed. The LMM corrects for the correlation among repeated observations within subject using random effect(s). A first LMM analysis is performed to compare the immediate interventional effect (T4) compared to the triple baseline measurements (T1-T3). A second LMM analysis is performed to investigate the follow-up period, at zero (T4), three (T5) and six months (T6), compared to baseline (T3). To determine which child benefits most of intervention, covariates are added in the LMM analyses. Covariates are "age", "Kids-BESTest baseline scores" and "activity profile". Qualitative parental interviews and the focus groups are analyzed using a qualitative analysis. The 5% level of significance is used. Data analysis is performed in IBM SPSS Statistics Version 28.01.1.1. and SAS Version 9.4. (SAS Institute, Inc., Cary, NC).

Discussion

Due to the high prevalence of postural control problems in children with DCD (Verbecque et al., 2021), affecting different levels of the ICF (Blank et al., 2019; Magalhães et al., 2011), there is need for a comprehensive postural control therapy. Current literature aiming to improve postural control is limited in the postural control systems that are included in both assessment and intervention and therefore potentially missing specific postural control problems. Furthermore, no highly intensive studies aiming to improve postural control in children with DCD have been performed yet. However, this type of intervention was proven successful in other populations (Bleyenheuft et al., 2017; Klingels et al., 2013) and feasible in children with DCD (Dannenbaum et al., 2021; Krajenbrink et al., 2022; Zwicker et al., 2015). This study will be the first to implement all postural control systems in a highly intensive therapy camp model in this population. Children train functional balance activities based on essential postural control skills. A large range of individual and group activities are individually tailored with a 1:1 therapist-child ratio and based on implicit and explicit motor learning principles. The quantitative and qualitative measurements performed before and after the camp are filling the gap in current literature by providing a broad insight in the underlying mechanisms related to postural control deficits in children with DCD and their impact on different ICF levels. The study protocol is easily transferable towards clinical practice in children with DCD and other populations and can therefore reach a large number of clinicians. Confirmation of the hypotheses will result in a new comprehensive, intensive therapy model to target postural control deficits and thereby improve balance in children with DCD.

Declaration of interest

The authors report no conflict of interest.

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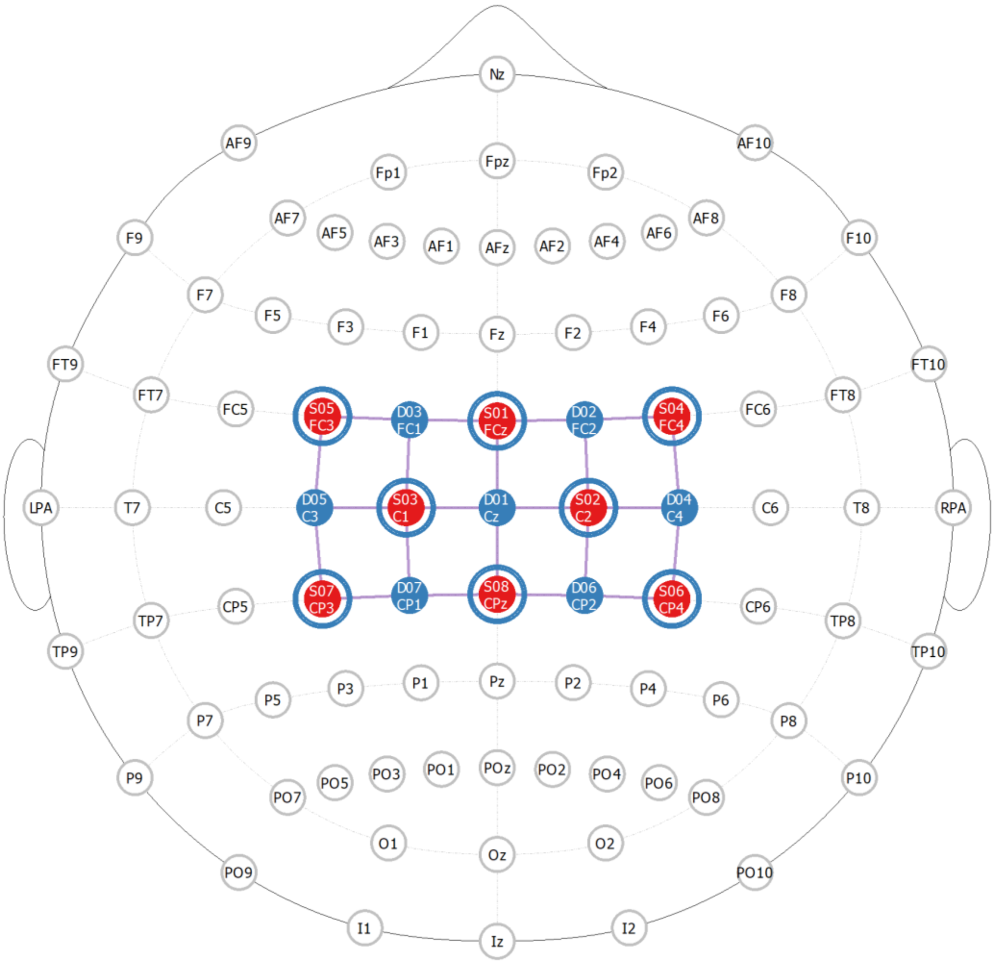
Appendix 1. Details on fNIRS hardware and configuration

fNIRS is registered via an NIRSport2 device provided by NIRX. An 8-source/8-detector configuration is used with an 8-8 optode bundle and short detectors. Based on the ROI a configuration was build using the fOLD (fNIRS Optodes Location Desider) toolbox and based on Brodmann areas. Final configuration is:



EFFECTS OF A HIGHLY INTENSIVE BALANCE THERAPY CAMP IN CHILDREN WITH DEVELOPMENTAL COORDINATION DISORDER – AN INTERVENTION PROTOCOL

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