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Original Article

Balance in focus: a simple observational scale to monitor the effect of exercises on static balance in case of childhood flexible flat foot

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Abstract. [Purpose] Childhood flexible flat foot is the most common lower limb deformity. Observational evaluation of the underlying elements of reactive balance during static positions is an accepted tool besides the timed measures. We aim to assess the effects of combined balance training on the foot function and to test the usefulness of our observational static balance score. [Participants and Methods] A total of 19 healthy primary school students with flexible flat foot deformity volunteered for the study. We evaluated the foot's dynamic properties and static postural stability before and after a 20-week combined balance training. On the basis of the observational findings, the time vs. quality observational static balance score was developed. All data were subjected to Wilcoxon's test and Friedman's ANOVA to compare the effects of the training on foot trajectory and observational static balance score. [Results] Better strength and endurance in the foot extensors and improved foot function were noted after the training. Using our observational static balance score, the quality of the balance performance remarkably changed. [Conclusion] The quality domain of our new scale seems to be a useful tool in daily clinical practice and a more sensitive measure in eyes-closed situations.
Key words : Balance, Foot, Movement strategy

INTRODUCTION

Postural stability or equilibrium, often referred to as balance, is the ability to control the body's centre of mass (CoM) in relation to the base of support during quiet standing and movement[1]. In standing position the feet act as the base of support, therefore the foot trajectory is a srong predictor of balance. Balance is a basic requirement for function in any age; therefore, balance examination is a vital element of physical therapy evaluation, especially for a school-age child, since the foot trajectory is under development in this age. Moreover, childhood flexible flat foot is the most common paramorphism of the lower limb[2], that may have an impact on postural control as well.

Static and dynamic balance assessment is often applied to determine the neuromusculoskeletal control status after lower leg injury[3]. In many of the published research, movement quality during balancing is assessed with the use of equipment, such as posturography and force-plate measurements[4–6]. Nonetheless, traditional observational evaluation of the underlying elements of reactive balance during static positions is an accepted tool besides the timed measures. Although the quality of a child's balance reaction is considered to be an important indicator of developmental delay or disability, only a few criteria for objectively scoring the qualitative aspects of balance reactions have been developed. Fisher[7] reported an objective scoring

that is restricted for reaching during standing in a tilted and a flat board. Therefore, evaluation of the quality of a balance reaction has remained subjective during observation of other static balance tasks. There is a need in clinical practice to develop simple observational scores, that provides information about quality of balance reactions and movement strategies during static balance tests.

Regarding quality evaluation in holding positions, an important milestone is the work by Nashner et al., which is the strategy concept for reacting for perturbations in static positions[8]. They identified the ankle, hip and stepping strategies by exploring the muscle activation patterns that underlie movement strategies for balance[9–12].

In this paper, we focus on the ankle strategy, which restores the CoM to a stable position through body movement centred primarily around the ankle joints. During single-leg stance for example, the control of upright posture is accomplished largely through corrective movements at the ankle joint[13]. Activation of gastrocnemius muscle, together with synergistic activation of dorsal muscles in a distal to proximal sequence, leads to plantar flexion torque that slows and reverses forward body movement. In the case of response to backward instability, the tibialis anterior is the first muscle to act followed by the synergistic activation of the ventral postural muscles, such as quadriceps and abdominal muscles. This ankle strategy appears to be used most commonly in situations wherein the perturbation to the equilibrium is small and the support surface is firm[1]. During normal development of postural control, around 6 to 7 years of age, the adult-like balance starts to develop[14].

Owing to understanding of movement strategies during balance situation, there is a need to combine observational balance assessment and strategy concept to objectively measure performance quality during static balance tests in daily clinical practice, especially when more expensive posturographic systems are not available.

We hypothesised that combined foot trajectory and static balance training with tools designed to promote instability will positively influence foot function resulting in better outcome during static balance tasks in case of children with mild to moderate flexible flat foot deformity. In addition, we aim to test and assess the usefulness of our newly developed observational static balance score for daily clinical practice.

PARTICIPANTS AND METHODS

A total of 19 healthy primary school students (neurologically intact, with mild to moderate flexible flat foot deformity, aged between 9 and 14 years; mean age=11, SD=1.71 years; mean height=1.5, SD=0.095 metres; mean mass=45.84, SD=8.88 kg; mean BMI=20.09, SD=2.84) volunteered for the study based on the results of a school screening programme that assessed body alignment and foot trajectory. All parents of the participants provided written informed consent before participation. The measurements used and trainings complied with the current laws of the country, wherein the study was conducted, and are in line with the Declaration of Helsinki.

We evaluated the foot's dynamic properties and static postural stability before and after the training period.

All tests were conducted by the same final-year physiotherapy student under supervision of a more experienced physiotherapist. The foot's dynamic features were evaluated by the sit-to-stand navicular drop test (SSNDT) and the heel-rise test (HRT).

In SSNDT, with the child in sitting neutral position, as the starting position, we marked with a pen the most prominent part of the navicular tuberosity and measured its distance from the floor with a ruler. We repeated the measurement with the child in standing position, after sitting, when there is full weight-bearing in the lower extremity. Then, we calculated the difference between the two navicular height measurements (unloaded and loaded positions).

Timed bilateral HRT was used to characterise the extensor muscle function. It was performed with the child in a standing position, barefooted and in bipedal manner. With light finger touch allowed on a wall to help maintain balance, the child performed plantar flexion with maximum range across all repetitions. We counted the number of repetitions done for 30 seconds.

Single-leg stance (SLS) and tandem stance (TS) are popular tests to ascertain the ability of children (and adults) in maintaining balance with a narrow base of support. Therefore, static balance was assessed during tandem and one-leg standing on left and right foot without holding on to anything for support, arms hanging freely on both sides, with eyes-open (EO) and eyes-closed (EC) situations for 30 seconds. The examiner focused and took notes on the time characteristics and the quality of movement strategies applied to maintain the static position. The examiner also supervised and observed the closed position of the eyes and the applied balance strategies. The static balance parameters were assessed by the same physiotherapists before and after a 20-week balance training module (see subsequent texts). Firstly, the Berg Balance Scale official scoring for tandem standing and one-leg standing issues were quantified in both EO and EC situations, owing to the lack of special scoring for EC condition.

Secondly, a new time vs. quality observational static balance score (TQOSBS) was developed based on the observational written findings on the performance time and quality characteristics to quantify the static balance features in quiet TS and SLS with eyes opened and closed (Table 1)[15]. The study design is summarised in the flowchart (Fig. 1).

During the measurements and training, we preferred the eyes closed instead of being blindfolded considering the different psychological effects of these two situations. Using a blindfold is a kind of constraint, which may create a feeling of uncertainty during balance measurement and result in a negative compensatory balance strategy that we wanted to avoid during testing and training periods, such as fixing or stiffening[16].

The participants took part in a 20-week combined balance training intervention led by a physiotherapist once a week, for

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Table 1. Time vs. quality observational static balance score

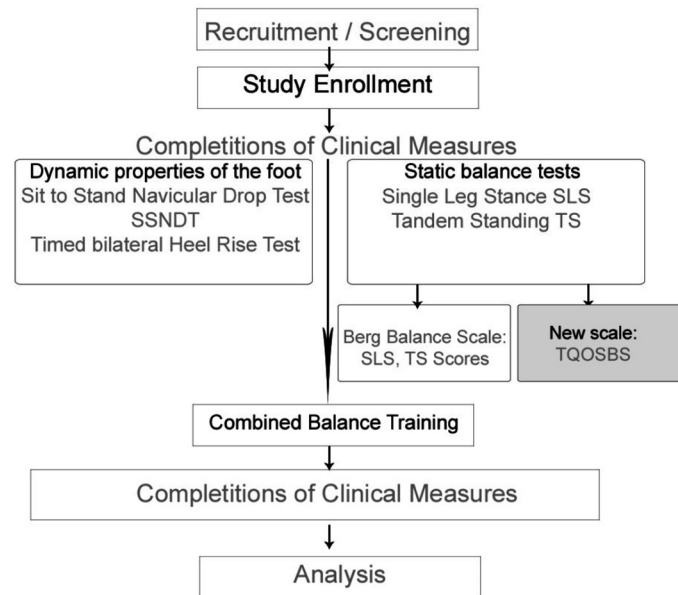| Time(s)	Score	Quality
0–10	0	Stepping out from the position before 10 s or changing the size of base of support anyhow, opening the eye in case of eye closed situation
10–15	1	Using big arm, trunk and/or hip movements, twisting or jumping
15–20	2	Using mainly hip strategy besides ankle/foot movements, postural sway is big
20–25	3	Using mainly ankle strategy for keeping balance, 1–2 hip movements are allowed, postural sway is moderate
25–30	4	Using only ankle strategy for keeping balance, postural sway is minimal

Fig. 1. Flow chart of the study design.

45 minutes each. It comprised 10-minute general mobilising exercises (warming-up period) and combination of exercises for lower extremity strength and flexibility, closed kinetic chain weight-bearing exercises, and static (holding a position) and dynamic (creating perturbations) balance exercises. The focus was on the ankle and foot, trunk and hip mobility and control and self-generated trunk perturbations, which are exercises generally accepted for balance training. To influence the foot muscles both intrinsically and extrinsically, the short-foot exercise and the toe standing positions were frequent used as starting positions with EO condition[17]. To narrow and specify the perceptual aspects in our programme, we limited visual sensory information throughout the training by having participants kept their eyes closed for as long as possible, especially during trunk and hip mobility exercises and balance exercises. We did not use blindfold to avoid any external constraint on the postural control. Thus, even though we instructed the participants to keep their eyes closed, they can open their eyes. We supposed that the option of free eye opening in situations wherein they would lose balance gave participants sufficient confidence to avoid relying on an eye-fixation strategy, which would cause them to stiffen the body by voluntary overt muscle co-contractions and freezing. Stiffening leads to inadequate acquisition of needed sensory information for planning and executing dynamic and interactive movements[18] and thus interferes with selective balance reactions. During the training, we also maximised proprioceptive sensory information through ongoing perturbations and challenges to the somatosensory and vestibular system by having participants stand on an unstable foam surface (Airex Balance Pad) rather than on a firm surface[16].

All data were subjected to Wilcoxon's matched-pair test to compare the effects of training on foot trajectory and observational static balance score. Analysis of Friedman's ANOVA and Kendall's coefficient of concordance was applied to find differences between the different static balance scores (Statistica 13.1 TIBCO software). We adopted $p < 0.05$ as the level of probability for all statistical analyses of the data.

RESULTS

In foot trajectory during weight-bearing, the SSNDT results revealed significant improvement after the training in case of both left (p=0.01) and right (p=0.01) feet based on the Wilcoxon's matched-pair test results (Table 2).

Similarly, the results of bilateral HRT referring to the strength and endurance of plantar flexors revealed significant improvement after the training; this difference was statistically discernible (p=0.0002; Table 2).

On the basis of the static balance scores in tandem standing in EO situation, this condition was less challenging for our participants. We thus did not observe any change in the performance (data are not shown). Nonetheless, in observing and evaluating tandem standing in more challenging EC situation, the Berg Tandem score did not reveal any difference before and after the training, whereas the new TQOSBS seems to be a more sensitive score to demonstrate differences after the training procedure. The Wilcoxon's matched-pair test in the TQOSBS quality domain revealed a statistically significant improvement after the training (p=0.02). The Wilcoxon's matched-pair test in the TQOSBS time domain also showed an improved tendency but not a significant change (p=0.106). Friedman's ANOVA and Kendall's coefficient of concordance (p=0.005, coefficient of concordance=0.178) demonstrated statistically significant differences among the various scores for qualifying the tandem standing performance (Table 3).

Regarding SLS observational scores, in the EO conditions, there were no significant differences with the Wilcoxon's matched-pair test neither left nor right leg standing before and after (Table 4). Nonetheless, Friedman's ANOVA and Kendall's coefficient of concordance revealed statistically significant differences (p=0,008, coefficient of concordance=0.163) among the various scores in the case of standing on the left leg.

Regarding the EC situations, in the case of standing on the right leg, there were statistically significant differences before and after the training based on the Wilcoxon's matched-pair test and among the various scores on the Friedman's ANOVA tests (p=0.000, coefficient of concordance=0.345). The TQOSBS quality domain appeared to be the most sensitive measure to reveal significant differences (p=0.008) of the effects of the training, and the changes in TQOSBS time domain after the training were close to the significant level (p=0.07) based on the results of the Wilcoxon's test (Table 4).

In the case of standing on the left leg with EC, the Wilcoxon's tests revealed no significant differences after the training,

Table 2. Dynamic foot properties

Sit to Stand Navicular Drop Test SSNDT		
Left	Pre training	7.7 ± 1.21
	Post training	3.86 ± 0.73*
Right	Pre training	6.6 ± 1.05
	Post training	3.5 ± 0.61*
Heel Rise Test		
	Pre training	17.74 ± 0.65
	Post training	34.21 ± 2.29*

*Significant Wilcoxon's matched-pair test (p<0.05).

Table 3. Tandem standing

Tandem Standing TS with eyes closed			
TQOSBS Time	EC	Pre training	3.32 ± 0.32
		Post training	3.68 ± 0.19
TQOSBS Quality		Pre training	3.16 ± 0.3
		Post training	3.74 ± 0.13*
Berg Tandem Score		Pre training	3.53 ± 0.26
		Post training	3.53 ± 0.26

*Significant Wilcoxon's matched-pair test (p<0.05).
EC: eyes closed.

Table 4. Single leg standing

Single Leg Standing SLS				
TQOSBS Time	Left	EO	Pre training	3.89 ± 0.1
			Post training	3.95 ± 0.05
TQOSBS Quality			Pre training	3.74 ± 0.13
			Post training	3.95 ± 0.05
Berg SLS Score			Pre training	4 ± 0.00
			Post training	4 ± 0.00
TQOSBS Time		EC	Pre training	2.74 ± 0.41
			Post training	2.89 ± 0.39
TQOSBS Quality			Pre training	2.05 ± 0.34
			Post training	2.74 ± 0.36
Berg SLS Score			Pre training	4 ± 0.00
			Post training	4 ± 0.00
TQOSBS Time	Right	EO	Pre training	4 ± 0.00
			Post training	4 ± 0.00
TQOSBS Quality			Pre training	3.95 ± 0.05
			Post training	4 ± 0.00
Berg SLS Score			Pre training	4 ± 0.00
			Post training	4 ± 0.00
TQOSBS Time		EC	Pre training	2.74 ± 0.41
			Post training	3.53 ± 0.25
TQOSBS Quality			Pre training	2.26 ± 0.37
			Post training	3.2 ± 0.24*
Berg SLS Score			Pre training	3.47 ± 0.26
			Post training	3.84 ± 0.16

*Significant Wilcoxon's matched-pair test (p<0.05).
EO: eyes open; EC: eyes closed.

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but the results of Friedman's ANOVA (p=0.000, coefficient of concordance=0.323) revealed statistically remarkable differences between the different observational scores. These indicate that the TQOSBS quality domain is more sensitive among the scores tested to reveal changes in static balance performance (Table 4).

DISCUSSION

The main finding of this study was an improved foot function after the training as revealed by the SSNDT results indicating better controlled alignment and posture in both feet. In addition, the HRT results suggest better strength and endurance in the foot extensors.

Childhood flexible flat foot is the most common lower limb deformity. Its cause is not a bony foot malformation but a functional deficiency of the anatomic structures that support the plantar arch. Therefore, foot trajectory changes are considered an acquired entity wherein weakness of the extensors (mainly tibialis posterior muscle) causes a flexible flat foot deformation[2]. Because the medial longitudinal arch (MLA) is determined by the navicular position, the navicular drop test (NDT) is a well-known static assessment tool of the foot's posture. NDT is intended to examine the sagittal plane displacement of the navicular tuberosity from a neutral position[19, 20]. Our results further support that SSNDT provides more information about MLA during foot loading and thus is more useful in testing midfoot dynamic properties[21].

Because the muscular control of navicular position is strongly dependent on foot extensors, mainly tibialis posterior and soleus, HRT is an available simple method to characterise the ankle extensor muscle function. It evaluates various properties of the triceps surae, such as strength, endurance, fatigue, muscle function and performance. Strength and endurance of the triceps surae muscle are essential for walking, maintaining balance and performing activities of daily living[22–24]. Therefore, HRT is a reliable tool for monitoring changes in the muscle function, which may influence the functional performance of individuals. We conclude that our training influenced the underlying impairments, such as ankle extensor muscle weakness, at functional and structural levels.

Regarding balance, which is the basis of our daily functions, the foot, as a base of support and an important sensory information resource, has a huge impact on postural control and balance by providing constant sensory information and reacting to postural sway changes. The amount of mediolateral (ML) postural sway mostly depends on body weight distribution over the feet[25]. Plantar sole manual stimulation caused better control of body weight distribution over the two feet[26, 27]. Aside from the sensory intake function of the foot, with its structure and muscular control, it plays an essential role in balance motor strategies.

In clinical practice, static measures are often used to obtain information of the dynamic functional movements. Therefore, our results add to the evidence that combined balance training with the focus on foot alignment, mobility and strength positively influences the foot dynamic properties. It has been described that decreased MLA height is a remarkable etiological factor for several lower extremity overuse injuries, such as plantar fasciitis[28, 29] and medial tibial stress syndrome[30], in later ages with higher level of physical activity. Therefore, effectively influencing childhood flexible flat foot is an essential issue in prevention of later overuse injuries and posture-related alteration in the neuromusculoskeletal system.

The use of training tools designed to promote instability[31] is popular in balance trainings. For example, ankle disc (unstable surface) training can positively affect the ankle muscle motor performance in a unipedal balance task, most likely through improved strength, coordination and possibly endurance[32]. Our results further support these positive effects on strength and coordination of the ankle muscles.

Moreover, the above-mentioned findings were further supported by the better balance performance in activity level that we found in our new observational static balance score focusing on the quality domain of the static balance performance. This is the second important finding of our study derived from our new observational static balance score, which revealed that balance performance quality changed remarkably after our training indicating positive changes at the body's functional and structural levels as manifested in behavioural changes during balancing.

A critical issue in prevention and rehabilitation is how training transfers either to a new task or to a new environment[1]. In our investigation, we provided further evidence that better muscle strength and control over the foot trajectory resulted in better balance performance and static balance situation, standing on firm surfaces with eyes closed. With the results of our training, we postulate that a better ankle strategy was developed with the balance control. The higher scores of our TQOSBS quality domain, which was developed on the basis of Nashner's strategy concept, are associated with smaller postural sway. Because smaller sway and perturbations are controlled primarily by ankle muscles, we suggest that a higher score on TQOSBS quality domain after the training indicates better ankle strategy, less postural sway and better static balance performance in the case of our participants.

A Paediatric Balance Scale (PBS) by Franjoine et al. was suggested to evaluate paediatric population[33], which is a modified version of the Berg Balance Scale (BBS)[34] adapted for school-age child with mild to moderate motor impairment. Nonetheless, SLS and TS item scoring in both scales is similar. Tandem standing, which is standing unsupported on one foot in front (item no. 13 in BBS, item no. 8 in PBS), is assessed in EO situation. The scoring is focused on the ability of placing the foot tandem independently and the time issue, but no information has been given about the movement strategy adopted to maintain the position, which is associated with the static balance performance quality. In case of children with mild to moderate foot trajectory changes, this item for scoring static balance performance is not informative enough. Moreover, it

appeared to be not sensitive enough at activity level to reveal changes exerted by our training.

SLS, which is standing on one leg (item no. 14 in BBS, item no. 9 in PBS), is also assessed with EO condition. The observational score is focused on the ability to lift the leg and hold the position for 10 seconds, and this issue is also lacking in information about the quality issues during holding the position[33, 34].

In the available static balance scores, there is a lack of quality scoring, especially in EC conditions. Because our results revealed statistically remarkable changes in EC conditions in the more challenging situation, such as the SLS and TS, we propose that the TQOSBS is a possible tool to measure balance performance quality and is applicable in both EC and EO conditions in daily clinical practice.

The TQOSBS is a simple-to-use and inexpensive tool to qualify movement strategies applied to hold a more challenging balance situation in case of neurologically intact school-aged children with mild to moderate functional foot trajectory changes and decreased MLA. As for the TQOSBS time domain of our scale, it appeared to be less sensitive to reveal the training effects than the quality domain. Therefore, we conclude that time domain needs reconsideration; the 30-second time cut might be replaced by other timeframes, such as 90 or 120 seconds, as suggested by Ruhe et al[35].

On the basis of our finding, we reinforced our hypothesis that combined foot trajectory and static balance training with tools designed to promote instability has positively influenced the foot function resulting in better outcomes during static balance tasks. We also revealed that the TQOSBS, especially the quality domain, seems to be a useful and practical tool to evaluate the more challenging static balance tests in daily clinical practice.

There are several limitations of this study, one of them is the relatively low number of participants. Therefore further investigations are necessary to support the study results in different and larger populations, including a control group, since this population changes continuously due to the developmental nature of this age

The TQOSBS inter- and intra-rater reliability and validity were also not tested in this phase of the investigation. Nonetheless, in comparison with other available scores, it seems to be a promising tool for simple static balance assessment. Further investigations may focus on the comparison of posturographic postural sway analysis with the results of this score to find more evidence of their correlation.

Funding and Conflict of interest

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