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Effects of Different Balance Training Volumes on Children's Dynamic Balance

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ABSTRACT

Concerning balance training, the most effective design of several load dimensions (e. g., training frequency, volume) is unclear. Thus, we determined the effects of different balance training volumes on dynamic balance in healthy children. Three groups of 20 children (age: 11.0 ± 0.7 years; 47 % females) were randomly assigned to a balance training group using a low or a high training volume or an active control group that performed regular physical education lessons. All groups trained for 8 weeks (2 sessions/week), whereby balance training volume amounted to 4 min/session and 18–24 min/session for the low- and high-volume group, respectively. Pre- and post-training, balance performance was assessed using the Lower Quarter Y-Balance Test and the Timed-Up-and-Go Test. Fifty-five children completed the study and significant Test x Group interactions were detected for both outcome measures in favor of the two balance training groups. Additionally, improvements in the high-volume group were significantly larger for some measures (Y-balance test anterior reach distance: $p < .001$, $d = .94$; Timed-Up-and-Go time: $p = .003$, $d = .81$) compared to the low-volume group. The results indicate that balance training is effective to improve balance performance in healthy children and it seems that a 36–48 min/week compared to an 8 min/week training volume provides additional effects.

Introduction

In childhood, well-developed balance performance is the foundation for successfully mastering everyday life and sports activities [1] and is associated with a lower risk of sustaining a lower extremity injury [2]. Particularly, schools offer good opportunities for promoting balance performance, as children of different physical activity and fitness levels are required to mandatorily attend physical education classes regularly several times a week. The effectiveness of balance training to promote measures of balance performance in children and adolescents has been demonstrated in several studies [3–5]. Moreover, the existing findings were summarized in a narrative review [6] and a systematic review with meta-analysis [7]. In addition, the meta-analysis by Gebel et al. [7] quantified dose-response relations for several balance training load dimensions (e. g., training period, frequency, volume). It turns out that when considered individually and not as complete protocol, balance training programs with a period of 12 weeks, a frequency of 2 sessions per week, a total number of 24–36 sessions, durations of 4–15 min of a single session, and total durations of 31–60 min of exercise per week were the most effective single training modalities for improvements in overall balance.

However, this gain in knowledge is based on an indirect comparison, as the effects were compared between studies of short (4 weeks) vs. long (12 weeks) training duration [4, 8], small (2 times/

week) vs. large (7 times/week) training frequency [9, 10], and low (~4 min/session) vs. high (~9 min/session) training volume [8, 11]. Further, the reported differences in balance training effectiveness may result from discrepancies in the applied training approach (i. e., training sessions in a sports club or physical education lessons at school), the investigated cohorts (i. e., children or adolescents), the performed balance tests (i. e., biomechanical or fitness test), and the used outcome measures (i. e., static or dynamic balance), in addition to differences in load dimension. Consequently, a direct comparison of differently designed training loads within a study is necessary to prove reliable statements regarding a lower or higher effectiveness of balance training on balance performance in youth. To date, there has been only one study on this topic with adolescent girls [12], but the observed training-related changes were not significantly different between the low- and high-volume group.

Therefore, the aim of the present study was to investigate differences in the effectiveness of balance training on measures of dynamic balance performance in children for the "training volume" modality (i. e., number of exercises × number of sets × duration per exercise). Since a high compared to a low training volume means a longer exposure to balance-demanding stimuli, we hypothesized to find greater effects for the former than for the latter. From a practitioner's point of view, it is important to investigate the effects of different balance training volumes in order to determine whether only a high volume or a low volume already causes significant effects on balance performance. In the first case, it would suffice to include balance training in the warm-up part of a PE lesson, whereas in the second case the main part of the PE lesson should be used for balance training.

Materials And Methods

Participants

Sixty children from three secondary school classes participated in this study after experimental procedures were explained. Because the classes were rigid in their composition, randomization was only possible on a class but not on an individual level. Consequently, each class was randomly defined to be either an active control group (CON), a balance training group using a low training volume (BT-LV), or a balance training group using high training volume (BT-HV). For this purpose, before the pretest the physical education teachers had to assign a sealed envelope to each class, which contained a slip of paper with the group designation (i. e., CON, BT-LV or BT-HV). The examiners were blinded to group allocation and the participants were aware only of their own training program but did not know how other participants trained. ▶ **Fig. 1** provides an overview of the progress of the study and the group-specific participants' characteristics are shown in ▶ **Table 1**. Maturity offset was calculated in terms of years from peak height velocity (PHV) for each participant by using the formulas provided by Moore et al. [13]. For girls, the formula for the calculation is: –7.709133 + (0.0042232 × (age × height)), and for boys, the corresponding formula is: –7.999994 + (0.0036124 × (age × height)). None of the participants had any history of diagnosed intellectual disabilities and/or musculoskeletal or neurological disorders that might have affected their ability to execute the balance training programs, the physical education lessons, and/or the balance tests. Participants' assent and parents' written informed consent was obtained before the start of the study. The study protocol was approved by the local ethics committee (reference number: TM_29.11.2018).

Testing procedures

The pre- and post-testing was conducted in a gym hall by the same skilled assessors (degreed sport scientists) before and after the 8-weeks of training. All participants received standardized verbal instructions and a visual demonstration regarding the testing procedure that included assessment of anthropometric variables and balance performance. All subjects conducted a standardized 10-minute warm-up prior to each test that consisted of submaximal running (e. g., skipping, hip in/out) and balance exercises (e. g., single leg stance on unstable devices, forward/backward beam walking).

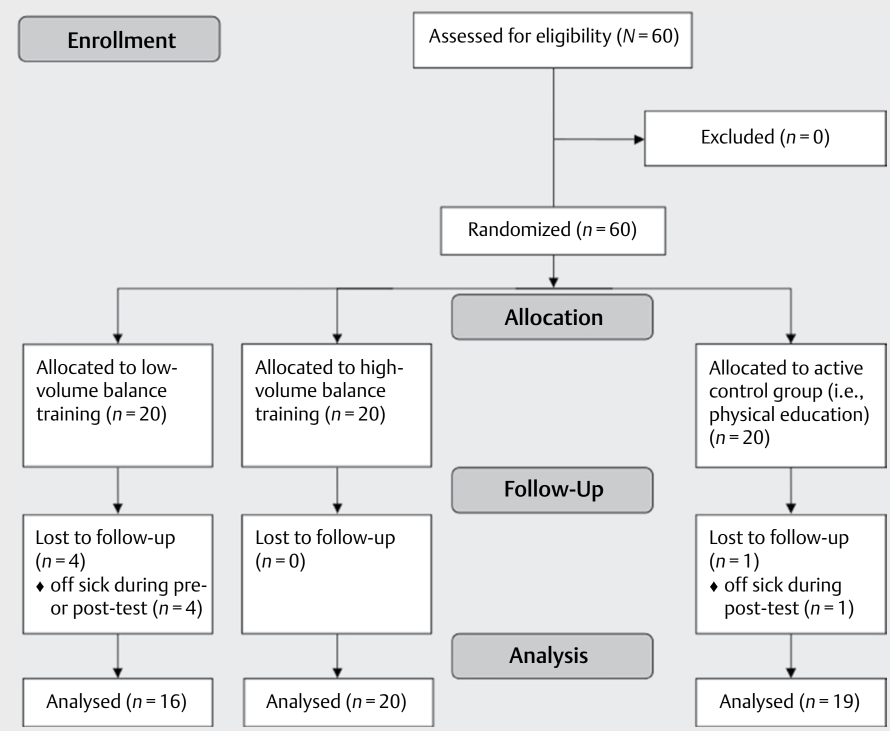
Assessment of anthropometric variables

The anthropometric variables body height, body mass, and length of the non-dominant leg were assessed. Body height was registered with a Seca 217 (Basel, Switzerland) linear measurement scale without shoes to the nearest 0.1 cm. Body mass was determined without shoes using an electronic Seca 803 (Basel, Switzerland) scale to the nearest 100 g. Leg length was measured via tape measure as the distance from the distal end of the anterior superior iliac spine to the most distal point of the medial malleolus to the nearest 0.5 cm [14]. In addition, the participants were asked to self-report their non-dominant leg (i. e., "On which leg do you stand on when kicking a ball?").

Assessment of dynamic balance performance

Dynamic balance performance was assessed by means of the Lower Quarter Y-Balance Test Kit (Functional Movement Systems, Chatham, VA, USA). The test kit consists of a centralized stance platform to which three pipes were attached that represent the anterior, posteromedial, and posterolateral reach directions. Each pipe is marked in 1.0-cm increments for measurement purposes and equipped with a moveable reach indicator. The participants were asked to reach with the dominant leg as far as possible in the anterior, posteromedial, and posterolateral directions while standing with their non-dominant leg on the centralized stance platform. A total of six trials (three practice trials followed by three data-collection trials) were executed. The maximal absolute reach distance (cm) per reach direction was used for further analysis. In this regard, the maximal relative reach distance (% leg length) per reach direction was calculated by dividing the maximal absolute reach distance (cm) by leg length (cm) and then multiplying by 100. In addition, the normalized (% leg length) composite score was computed as the sum of the maximal absolute reach distance (cm) per reach direction divided by three times leg length (cm) and then multiplied by 100 and used for analysis as well. The Y-balance test is a reliable tool to assess balance performance in youth [15].

Dynamic balance performance was further assessed using the Timed-Up-and-Go Test (TUG) [16]. In this regard, the participants



▶ **Fig. 1** Flow diagram of the progress of the study according to the CONSORT statements [25].

were asked to rise from a chair, walk three meters, turn around, walk back to the chair, and sit down. The time (s) needed to perform the TUG was manually recorded with a stopwatch to the nearest 0.01 s by the same skilled assessors (degreed sport scientists). Each participant performed two trials (one practice trial followed by one data-collection trial) with 60 s in between and the best trial (i. e., shortest time) was used for further analysis. The Timed-Up-and-Go test is a reliable test of balance performance in children [16].

Balance training programs

Each group trained separately for eight weeks (two times per week) at the school gym supervised by their respective physical education teacher but the same graduate student. The first lessons lasted 90 min and the second lessons amounted to 60 min. Each training session started with a 10- to 15-minute warm-up and finished with a 5- to 10-minute cool down. In between, participants in the two balance training groups conducted different types of balance exercises while the pupils in the CON group underwent their regular physical education lessons including gymnastics and swimming (▶ **Table 2**). The balance training volume amounted to 4 min/session (i. e., four exercises with two sets of 30 s per exercise) and 18–24 min/session (i. e., six exercises with four sets of 45–60 s per exercise) with 90-s rest periods between exercises for the BT-LV group and the BT-HV group, respectively. The chosen distinction was based on the results of Gebel et al. [7]. Although the authors found an equal effectiveness of both balance training volumes, this finding was based on an indirect study comparison. It may therefore be confounded by other variables (e. g., training period, frequency, exercises etc.), which is why a direct comparison was made in the present study where all other variables were the same. The lower balance training volume in the BT-LV group compared to the BT-HV group was filled with gymnastic exercises. After balance training, the remaining class time in the BT-LV group as well as in the BT-HV group was filled with the same gymnastic exercises as in the CON group.

Statistical analyses

Descriptive data are presented as group mean values and standard deviations. After normal distribution was examined via Shapiro–Wilk Test and showed p-values > .05, a univariate analysis of variance (ANOVA) was conducted to test for significant differences in pretest values between the groups. Significant group differences at the pretest were detected for all balance parameters and were thus included as covariates in the analyses. Thereafter, a 2 (Test: pre, post) × 3 (Group: CON, BT-LV, BT-HV) ANCOVA with repeated measures on Test was used. In the case of a significant ($p < .05$) Test × Group interaction, differences between pretest and posttest values were analyzed for each group separately using paired t-tests. Further, effect size (Cohen's d) was calculated and reported as small ($0 \le d \le .49$), medium ($.50 \le d \le .79$), and large ($d \ge .80$) [17]. All statistical analyses were performed using Statistical Package for Social Sciences version 27.0 (IBM Corp., Armonk, NY, USA).

Results

All participants received intervention (i. e., balance training lessons) or control (i. e., regular physical education lessons) conditions as

▶ **Table 1** Group-specific characteristics of the study participants (N = 55)

Characteristic	CON (*n* = 19)	BT-LV (*n* = 16)	BT-HV (*n* = 20)	*p*-value
Age (years)	11.7 ± 0.5	10.6 ± 0.5	10.5 ± 0.4	.001
Sex (f, m)	9/10	9/7	8/12	–
Maturity offset[1] (years from PHV)	− 0.83 ± 0.82	− 1.62 ± 0.72	− 1.69 ± 0.80	.002
Body height (cm)	154.2 ± 7.5	148.8 ± 6.8	152.1 ± 6.4	.075
Body mass (kg)	47.7 ± 10.9	41.9 ± 11.2	40.6 ± 5.5	.057
BMI (kg/m²)	19.9 ± 3.2	18.7 ± 4.2	17.6 ± 2.1	.078
Leg length (cm)	91.3 ± 5.3	92.1 ± 6.0	88.7 ± 4.7	.166
Leg dominance (l, r)	17/2	16/0	18/2	–

Data are group mean values ± standard deviations. [1]The maturity offset was calculated by using the formula provided by Moore et al. [13]. Post-hoc comparisons for age and maturity offset indicate significant differences between the control group and the two intervention groups only. BMI = Body-Mass-Index; BT-HV = high volume balance training; BT-LV = low volume balance training; CON = active control group (i. e., regular physical education); f = female; l = left; m = male; r = right; PHV = peak height velocity.

▶ **Table 2** Group-specific description of the exercise programs

Load dimension	CON (*n* = 19)	BT-LV (*n* = 16)	BT-HV (*n* = 20)
Training period	8 weeks	8 weeks	8 weeks
Training frequency	2 sessions/week	2 sessions/week	2 sessions/week
Balance training volume (incl. rest)	–	4 min (16 min)	18–24 min (54–60 min)
Exercise number	–	4	6
Exercise duration	–	30 s	45–60 s
Exercise sets	–	2	4
Rest between sets	–	90 s	90 s
Training exercises	P.E. lessons including gymnastics and swimming (each once per week)	static (e. g., standing exercises), dynamic (e. g., walking exercises), proactive (e. g., weight shifting while standing), and reactive (e. g., perturbed standing) balance tasks	
Training progression	none	– reduction in the base of support – manipulation of the sensory input – inclusion of unstable devices (e. g., wobble board)	

BT-HV = high volume balance training; BT-LV = low volume balance training; CON = active control group (i. e., regular physical education); P.E. = physical education

allocated. None of the participants reported any test- or training-related injury. Overall, the data of 55 participants were included in the analysis (▶ **Fig. 1**). ▶ **Table 3** displays descriptive and inference statistics for all analyzed variables. For the Y-balance test, the analyses revealed significant main effects of Test and Group as well as significant Test × Group interaction effects for all reach directions and the composite score. Post-hoc analyses yielded significant enhancements from pre- to post-training in the BT-LV group (posteromedial reach: $p = .003$, $d = .46$; posterolateral reach: $p = .003$, $d = .70$; composite score: $p = .012$, $d = .46$) and in the BT-HV group (anterior reach: $p < .001$, $d = .94$; posteromedial reach: $p = .015$, $d = .41$; posterolateral reach: $p = .007$, $d = .51$; composite score: $p < .001$, $d = .63$) but not in the CON group (▶ **Fig. 2a**). Concerning the Timed-Up-and-Go test, the analysis showed a significant main effect of Test and Group and a significant Test × Group interaction. Post-hoc analyses detected significant improvements from pre- to post-training in the BT-HV group ($p = .003$, $d = .81$) but not in the BT-LV group and the CON group (▶ **Fig. 2b**).

Discussion

We investigated the effects of balance training using a low or a high training volume on dynamic balance performance in healthy children. The main findings of the study were that (1) balance performance significantly improved in both balance training groups compared to the control group; and (2) performance enhancements in some parameters (i. e., anterior reach distance and Timed-Up-and-Go test duration) were larger for the high-volume than for the low-volume group.

Effects of balance training on measures of balance performance

In accordance with our hypothesis of balance training-related performance improvements, we found that both balance training conditions resulted in enhanced dynamic balance performance when compared with the control condition (i. e., physical education lessons). This finding corresponds with those from earlier studies [8, 18, 19] investigating the impact of balance training on meas-

▶ **Table 3** Effects of balance training using a low versus high training volume on measures of balance performance in healthy children

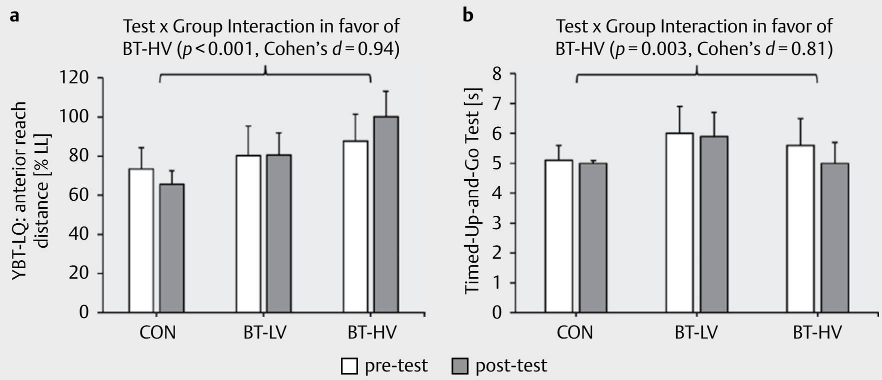
Outcome	CON (*n* = 19)			BT-LV (*n* = 16)			BT-HV (*n* = 20)			*p*-value (*Cohen's d*)		
	Pretest	Posttest	Δ%	Pretest	Posttest	Δ%	Pretest	Posttest	Δ%	Test	Test x Group	Group
AT [% LL]	73.4 ± 10.9	65.6 ± 6.9	− 10.6	80.3 ± 15.0	80.6 ± 11.3	+ 0.4	87.6 ± 13.8	100.1 ± 13.0	+ 14.3	< .001 (1.67)	< .001 (2.50)	< .001 (2.50)
PM [% LL]	101.8 ± 9.2	102.6 ± 7.8	+ 0.8	116.9 ± 19.4	125.7 ± 18.0	+ 7.5	123.1 ± 14.3	128.6 ± 10.9	+ 4.5	< .001 (1.34)	< .001 (1.34)	< .001 (1.34)
PL [% LL]	102.7 ± 9.8	103.6 ± 10.7	+ 0.9	111.7 ± 15.4	122.3 ± 14.5	+ 9.5	119.9 ± 16.1	127.6 ± 11.5	+ 6.4	< .001 (1.40)	< .001 (1.37)	< .001 (1.37)
CS [% LL]	92.6 ± 8.3	90.6 ± 7.1	−2.2	103.0 ± 15.5	109.5 ± 12.1	+ 6.3	110.2 ± 13.9	118.8 ± 10.9	+ 7.8	< .001 (1.74)	< .001 (2.21)	< .001 (2.21)
TUG [s]	5.1 ± 0.5	5.0 ± 0.9	+ 2.0	6.0 ± 0.9	5.9 ± 0.8	+ 1.7	5.6 ± 0.9	5.0 ± 0.7	+ 10.7	< .001 (1.67)	< .001 (2.50)	< .001 (2.50)

Values are mean values ± standard deviations. Figures in brackets are effect sizes (Cohen's *d*) with 0 ≤ *d* ≤ .49 indicating small, .50 ≤ *d* ≤ .79 medium, and *d* ≥ .80 large effects. AT, anterior; BT-HV, high-volume balance training; BT-LV, low-volume balance training; CON, active control group (i. e., regular physical education); CS, composite score; LL, leg length; PL, posterolateral; PM, posteromedial; TUG, Timed-Up-and-Go Test

ures of balance performance in healthy children. For instance, Kayapnar [19] studied the influence of a 12 weeks (3 times per week) movement education program including basic movements, different children games, and posture exercises on static balance (i. e., unipedal stance time within one minute) in preschool children (age range: 5–7 years). When compared with the control group (i. e., received the regular curriculum), the training group showed a significantly increased stance time. Further, Altinkök [18] assigned 6-year-old primary school children to a group that performed an "Activity Education with Coordination" program or received their regular activity education without coordination exercises. Following 8 weeks (2 sessions per week) of intervention, the group with the specific program achieved significant improvements in static (i. e., unipedal stance time within one minute) and dynamic (i. e., time in balance on a stabilometer within 30 s) balance but not the group with the regular program. Finally, Dobrijevic et al. [8] examined young rhythmic gymnasts (age range: 7–8 years) that conducted 12 weeks (biweekly) of balance training in addition to gymnastic training or gymnastic training only. The authors detected significantly enhanced static balance performance (i. e., unipedal stance time within one minute) in favor of the group with additional balance exercises. In sum, the aforementioned findings and the observed results of the present study indicate that balance training is an effective means to improve balance performance in healthy children, although there is a relatively large heterogeneity in the methodological approaches used. More importantly, the effectiveness of balance training does not seem to be limited to certain types of balance as adaptations to training have been shown for less (i. e., static) as well as more (i. e., dynamic) demanding postural control tasks.

Effects of balance training volume on measures of balance performance

Partly in line with our hypothesis, we detected greater enhancements in dynamic balance performance for the high- compared to the low-volume group. More precisely, only Timed-Up-and-Go Test time and Y-balance test anterior reach distance but neither the other reach distances nor the composite score showed superior improvements for the high- compared to the low-volume group. There is one study available that previously investigated the effect of low versus high balance training volume on balance performance. More precisely, Bal [12] assigned adolescent girls (mean age: 15.5 ± 1.7 years) to a low-volume group (i. e., 3 exercises with 2–4 sets of 9–13 repetitions or 18–30 s duration) or a high-volume group (i. e., 3 exercises with 2–4 sets of 8–15 repetitions or 18–35 s duration). Before and after 6 weeks of balance training (3 sessions per week), both groups were tested on static (i. e., unipedal stance time on stable ground) and dynamic (i. e., unipedal stance time on unstable [wobble board] ground within 15 s) balance performance. For both measures, they found a tendency toward significant improvements for the high-volume but not for the low-volume group. The fact that significant improvements were found in the present study, however, may be due to methodological differences. Although the total number of training sessions was almost the same with 18 sessions in the study of Bal [12] and with 16 sessions in the present study, there are differences in the sample studied. For instance, Bal [12] investigated female adolescents (mean age:



▶ **Figure 2** Group-specific performance changes (mean ± standard deviation) during the intervention period in a) anterior reach distance in the Lower Quarter Y-balance test, and b) Timed-Up-and-Go test. BT-HV, high-volume balance training; BT-LV, low-volume balance training; CON, active control group (i. e., regular physical education); LL, leg length

15.5 ± 1.7 years) but we studied female and male children (mean age: 11.0 ± 0.7 years). There is evidence that adolescents and especially girls have significantly better balance skills than children or boys of the same age [20, 21], indicating a smaller adaptive reserve in adolescents compared to children [3]. Therefore, the sample used in the Bal study might have had a lower reserve to adapt on balance training-induced stimuli than the individuals in the present study, which would explain its report of non-significant changes. Further, the difference in balance training volume between groups was smaller in the Bal study (i. e., low-volume group: 3 exercises with 2–4 sets of 9–13 repetitions or 18–30 s duration; high-volume group: 3 exercises with 2–4 sets of 8–15 repetitions or 18–35 s duration) than those in the present study (low-volume group: 4 exercises with 2 sets of 30 s duration; high-volume group: 6 exercises with 4 sets of 45–60 s duration), with the latter leaving more room for volume-specific adaptations.

The partly larger improvements in the high- compared to the low-volume group can most likely explained by the fact that a higher training volume results in a longer exposure to balance-demanding training stimuli that affect postural control (i. e., vestibular, proprioceptive, and visual system). Specifically, a total exercise duration of 64 min (i. e., 8 weeks × 2 times/week × 4 min/session) occurred in the low-volume group and a duration of 288–384 min (i. e., 8 weeks × 2 times/week × 18–24 min/session) in the high-volume group. A longer versus a shorter exposure to the balance training stimuli, in turn, offers the potential for greater adaptation processes in the postural control system. Consequently, future studies should investigate whether the expected greater adaptations are reflected in the underlying neural mechanisms (i. e., cortical and spinal plasticity) [22].

The strengths of this study were that a relatively large number of $N = 60$ healthy children were studied. In addition, the Lower Quarter Y-Balance Test and the Timed-Up-and-Go Test are valid and reliable tests to assess children's balance performance. A limitation of the present study is that it was restricted to children. In fact, previous research suggests that adaptations to balance training in youth may be age-dependent [3, 23]. Further, there is evidence that in children the effectiveness of balance training may differ between males and females [24]. However, in the present study it was not distinguished between girls and boys. Future studies should therefore scrutinize the role of age and sex in relation to the effects of different balance training volumes.

Conclusions

We investigated differences in the effectiveness of balance training using a low versus a high training volume on balance performance in healthy children. For both training regimens as compared to the control condition, we found significant improvements in measures of dynamic balance performance. Further, the performance enhancements in some parameters (i. e., anterior reach distance and Timed-Up-and-Go duration) were larger for the group that used a high training volume. These findings indicate that balance training is an effective means to improve dynamic balance in healthy children and that a high (i. e., 288–384 min in 8 weeks, 36–48 min/week) compared to a low (64 min in 8 weeks, 8 min/week) training volume is partially more effective.

Acknowledgements

The authors declare that the research was conducted in the absence of any conflict of interest.

Conflict of Interest

The authors declare that they have no conflict of interest.

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