**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 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 com-
parison of differently designed training loads within a study is nec-
essary to prove reliable statements regarding a lower or higher ef-
effectiveness of balance training on balance performance in youth.
To date, there has been only one study on this topic with adoles-
cent 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 dif-
fferences in the effectiveness of balance training on measures of dy-
namic 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 hy-
pothesized 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 deter-
mine 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 les-
son, 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 con-
tained 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 over-
view of the progress of the study and the group-specific partici-
pants’ 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 disabili-
ies and/or musculoskeletal or neurological disorders that might
have affected their ability to execute the balance training pro-
gams, 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 pro-
cedure 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 submaxi-
mal 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 with-
out shoes to the nearest 0.1 cm. Body mass was determined with-
out 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 kick-
ing 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 an-
terior, 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 stand-
ing with their non-dominant leg on the centralized stance platform.
A total of six trials (three practice trials followed by three data-col-
lection trials) were executed. The maximal absolute reach distance
(cm) per reach direction was used for further analysis. In this re-
gard, 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 com-
puted 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...
Training & Testing

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 post-test values were analyzed for each group separately using paired t-tests. Further, effect size (Cohen’s $d$) was calculated and reported as small ($0 \leq d < .49$), medium ($0.50 \leq d < .79$), and large ($d \geq .80$) [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

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

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Δ% Pretest</th>
<th>Posttest</th>
<th>Δ%</th>
<th>Test</th>
<th>Test x Group</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT [% LL]</td>
<td>73.4 ± 10.9</td>
<td>65.6 ± 6.9</td>
<td>-10.6</td>
<td></td>
<td>80.3 ± 15.0</td>
<td>80.6 ± 11.3</td>
<td>+0.4</td>
<td>87.6 ± 13.8</td>
</tr>
<tr>
<td>PM [% LL]</td>
<td>101.8 ± 9.2</td>
<td>102.6 ± 7.8</td>
<td>+0.8</td>
<td></td>
<td>116.9 ± 19.4</td>
<td>125.7 ± 18.0</td>
<td>+7.5</td>
<td>123.1 ± 14.3</td>
</tr>
<tr>
<td>PL [% LL]</td>
<td>102.7 ± 9.8</td>
<td>103.6 ± 10.7</td>
<td>+0.9</td>
<td></td>
<td>111.7 ± 15.4</td>
<td>122.3 ± 14.5</td>
<td>+9.5</td>
<td>119.9 ± 16.1</td>
</tr>
<tr>
<td>CS [% LL]</td>
<td>92.6 ± 8.3</td>
<td>90.6 ± 7.1</td>
<td>-2.2</td>
<td></td>
<td>103.0 ± 15.5</td>
<td>109.5 ± 12.1</td>
<td>+6.3</td>
<td>110.2 ± 13.9</td>
</tr>
<tr>
<td>TUG [s]</td>
<td>5.1 ± 0.5</td>
<td>5.0 ± 0.9</td>
<td>+2.0</td>
<td></td>
<td>6.0 ± 0.9</td>
<td>5.9 ± 0.8</td>
<td>+1.7</td>
<td>5.6 ± 0.9</td>
</tr>
</tbody>
</table>

Values are mean values ± standard deviations. Figures in brackets are effect sizes (Cohen's d) with 0 ≤ d ≤ 0.49 indicating small, 0.50 ≤ d ≤ 0.79 medium, and ≥ 0.80 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.
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.
References


