Effects of Slackline Training on Balance, Jump Performance & Muscle Activity in Young Children

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Key words
- postural control
- exericse
- intervention
- postural sway
- EMG

Abstract

The study investigated the effects of slackline training (rope balancing) on balance, jump performance and muscle activity in children. Two primary-school classes (intervention, n = 21, INT: age: 10.1 (SD 0.4) y, weight: 33.1 (4.5) kg; control, n = 13, CON: age: 10.0 (SD 0.4) y, weight: 34.7 (7.4) kg) participated. Training was performed within 6 weeks, 5 times per week for 10 min each day. Balance (static and dynamic stance), countermovement jumps, reverse balancing on beams (3, 4.5 and 6 cm width), slackline standing (single- and double-limb) and electromyographic activity (soleus, gastrocnemius, tibialis anterior) were examined. INT significantly improved single- and double-limb slackline standing (double limb: 5.1 (3.4) s–17.2 (14.4) s; right leg: 8.2 (5.8) s–38.3 (36.0) s; left leg: 10.6 (5.8) s–49.0 (56.3) s; $p < 0.001$; $0.17 < \eta_p^2 < 0.22$). Reduced left-leg dynamic sway (−20.8 %, $p = 0.06$, $\eta_p^2 = 0.10$), improved 4.5 cm balancing (+18.5 %, $p = 0.08$, $\eta_p^2 = 0.10$) and decreased muscle activity during slackline standing for the mm. soleus (−23 %, $p = 0.10$, $\eta_p^2 = 0.18$) and tibialis anterior (−26 %, $p = 0.15$, $\eta_p^2 = 0.14$) was observed for INT. Jump performance remained unchanged ($p = 0.28$, $\eta_p^2 = 0.04$). In conclusion, daily slackline training results in large slackline-specific balance improvements. Transfer effects to static and dynamic stance, reverse balancing or jumping performance seemed to be restricted.

Introduction

Balance performance is considered to be an important prerequisite for learning complex motor skills and reducing fall-related injuries during childhood [20,27]. It has been assumed that poor balance and a high fall-risk during childhood are related to neuromuscular immaturity and instability [6]. In order to support maturation and the development of motor skills in children, adequate amounts of balance training should be embedded into comprehensive interventional approaches [22]. The beneficial effects of specific balance training regimens regarding motor development, reduced fall-related injuries and neuromuscular performance, such as static and dynamic postural control are, however, not fully understood in children [11]. Thus, more longitudinal intervention studies addressing balance performance in children are warranted [11,32]. As schools and preschool-settings are considered appropriate for efficient exercise promotion in young children [9,24], static or dynamic balancing tasks on different surfaces under single and multi-task conditions [12] can be applied in playfully arranged settings.

Slackline training is a specific form of balancing over narrow nylon ropes [21] and has been recently examined with regard to the effects on neuromuscular performance and postural control in young adults [10,17,23]. These studies did not reveal consistent findings. Whereas some authors reported an improved postural stability [23] and a reduced excitability of the spinal reflex circuitry [17], Granancher and coworkers did not observe significant improvements in static and dynamic postural control in young adults [10]. To date, no intervention study examined potential benefits of slackline training within a school-based setting on motor skill development, particularly on neuromuscular performance in primary school children.

Therefore, the present study aimed at investigating the effects of slackline training on balance and jumping performance in 4th grade pupils. Muscle activity was measured during slackline as well as static and dynamic upright standing. We hypothesized that 6 weeks of daily school-based

accepted after revision
February 08, 2013

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DOI http://dx.doi.org/10.1055/s-0033-1337949
Published online: May 22, 2013
Int J Sports Med 2013; 34: 1093–1098 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

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Table 1 Anthropometric data of the included children.

	INT (n=21)	CON (n=13)	Total (n=34)
gender [f/m]	7/14	6/7	13/21
age [years]	10.1 (0.4)	10.0 (0.4)	10.1 (0.4)
weight [kg]	33.1 (4.5)	34.7 (7.4)	33.7 (6.0)
height [m]	1.39 (0.05)	1.39 (0.06)	1.39 (0.05)
BMI [$kg \cdot m^{-2}$]	17.0 (2.1)	17.7 (2.9)	17.3 (2.4)
sports club participation [$h \cdot week^{-1}$]	2.4 (1.9)	1.8 (1.2)	2.1 (1.7)

BMI, body mass index; Data are indicated as means with standard deviations (SD)

slackline training beneficially affects neuromuscular performance in primary school children.

Methods

Subjects

34 healthy 4th grade pupils of one urban primary school in Switzerland volunteered. One class (INT, 21 children) underwent the slackline intervention and another class of the same grade served as control group (CON, 13 children, ○ **Table 1**). Children were not randomly assigned to either INT or CON in order to minimize transfer effects through the exchange of slackline experiences between intervention and control children within one class. CON remained normally active (physical education and sports club participation, controlled by a physical activity diary). Physical education (ball games, catching games, track and field sessions, no gymnastics) lessons were maintained and remained similar for both groups. The children were not familiar with slackline or balance training and showed no history of internal, dermatologic, neurological, musculoskeletal and orthopedic disorders that may have affected training or testing. No drop-outs occurred during the training period. Physical activity and sports club participation was assessed using the Freiburg physical activity questionnaire [8]. The dominant leg was determined using the lateral preference inventory [4]. All children reported their right leg as the dominant one. After detailed information was presented, written informed consent was signed by the parents and children. The study protocol was approved by the local ethics committee and complied with the Declaration of Helsinki as well as the international ethical standards according to Harriss and Atkinson [14].

General design and slackline training

Slackline training was provided for 10 min on every school day within 6 weeks. Small groups of 2–3 pupils trained in a separate room during regular school lessons. 28 training sessions were completed during the intervention period. 2 (of 30) intended trainings session had to be cancelled due to school- organisational reasons. Training attendance was 95 %.

The intervention was conducted on Gibbon Slackracks® (ID Sports, Stuttgart, Germany) (length: 5 m, width: 0.05 m). Each child exercised on one slackrack. To provide a safe training environment, several gymnastic mats were placed under the slackracks (height: only 30 cm). Slackline training cards with increasing levels of task difficulty (Basics and Level 1–4) were provided. Each of the 5 exercise levels consisted of five to eight exercises (e.g., Basics: slackline walking with Nordic Walking sticks, climbing on the slackline, single and double limb stance; Level 1: forward walking without help, tandem stance squats, ball catching and throwing, ball circling around body, double limb up and down swinging; Level 2: standing scale, juggling with one ball, bouncing a basketball while standing or walking, football kicking; Level 3: 180° turn around, closed-eye standing, side steps and crossed side steps, knee drop, table tennis bouncing; Level 4: jumping take off, vertical jumps on the slackline, rope skipping). Children were asked to correctly perform as many of the given exercises as possible during the 10 min. Children had to train barefoot, without wearing shoes or socks. The next level was reached when children had completed all exercises of the level before. The training supervisors supported the children and documented all training session. Due to motivational and competitive reasons, the best "slackliners" were ranked and announced.

Testing procedure and devices

Pre- and post-testing took place under similar conditions in a separate classroom with stable temperatures, no distracting noises and bright lighting. Before testing, children completed a standardized 3-min warm-up (trampoline jumping and rope-skipping). Test order was inter-individually randomized but intra-individually constant.

Slackline standing

Slackline standing time was recorded during bipedal and monopedal upright stance. Initially, children stood on a marked middle position of the slackline with assistance of the test supervisor. Following an acoustic signal, the participants had to stand without any help, while time was recorded. To avoid a decline in motivation and attention and due to restricted testing time at school, three trials for each standing condition were performed. The best trial of the 3 attempts was then analyzed. A break of 1 min was provided between trials. Slackline strain was standardized by using a 15 kg calibration weight. The resulting slackline sagging (7.5 cm) was measured and kept stable prior to each training day.

Static and dynamic postural sway

Static and dynamic balance performances during single- and double-limb upright stance were assessed on a portable force-plate (GK-1000, IMM, Mittweida, Germany). The force-plate was placed on an even and rigid floor for the static condition. To assess dynamic balance performance, the force-plate was mounted into a cage (GK-1000, Schwingrahmen, IMM, Mittweida, Germany) which allows swinging in the transversal plane. Center-of-pressure (COP) path length displacement (postural sway) was obtained from 4 vertically measuring strain-gauge sensors, placed in the 4 corners. The sampling rate was 40 Hz and a system-immanent Butterworth filter with a low pass cut-off frequency of 10 Hz was applied [7]. 3 attempts for each condition were allowed. Trials that were not maintained for 30 s were not repeated. A break of 1 min was warranted between each trial. The best trial was included into further analysis. During static and dynamic testing, children were instructed to stand as still as possible without wearing shoes in neutral foot position (not turned-out) while slightly bending their knees, placing the arms akimbo and gazing at a marked spot on the wall. Test-retest reliability was indicated as high (static condition, intra-class-correlation (ICC) = 0.91, dynamic condition, ICC = 0.81) [10]. The best of the 3 attempts was included into analyses.

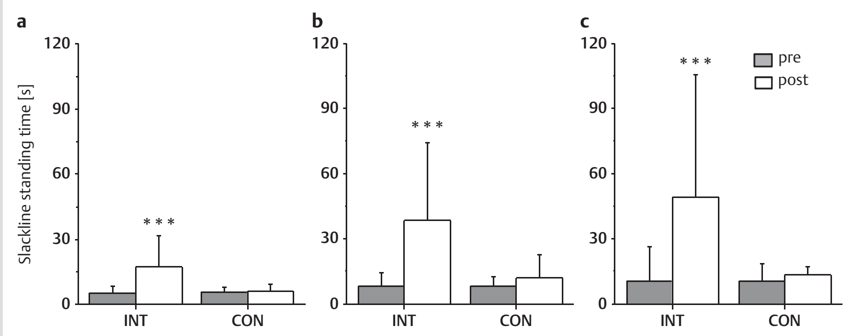

Fig. 1 Slackline standing times during double limb stance **a** single limb stance right **b** and single limb stance left **c** for the intervention (INT) and control (CON) group. Pre- (dark box) and post- (white box) test data are given as means and standard deviation (SD). $p<0.001$ ***.

Balance beams

In order to assess functional balance performance, the children were asked to separately perform 8 barefoot backward steps on 6, 4.5 and 3 cm wide balance beams. 3 trials with an intermediate break of 1 min for each beam were allowed. One practice trial for each beam was allowed. In order to become progressively familiar, however, all children started with the 6 cm bar. Thus, the maximum amount of steps per balance beam was 24. Total steps performed without touching the ground were recorded. Test-retest reliability was reported to be $r=0.84$ (Pearson's correlation) [24].

Jump testing

Following instruction and a few practice trials, children performed 3 consecutive countermovement jumps (CMJ). Maximal height was assessed using a vertically measuring force-plate (Kistler, Quattro Jump, 9290 AD, Wintherthur, Switzerland). Children started in an upright position with arms placed akimbo. The applied sampling frequency was 500 Hz. Jumping height was computed using the flight time method. The best of the three attempts was analyzed. For CMJ without arm swing, high intra-class correlation coefficients were reported (0.80 (95 CI: 0.53–0.92) [29]. Between jumps, a break of one minute was provided.

Muscle activity

Due to restricted testing time at school, we measured muscle activity of lower limb muscles (mm. soleus, SOL; gastrocnemius, GAS; tibialis anterior, TIB) in 9 randomly selected children of each group according to the European recommendations for surface electromyography (SEMG) [15]. To provide low skin conductance levels (<5 kΩ, monitored before and after testing), the skin of the dominant (right) leg was prepared using shavers and fine sandpaper. Bipolar electrodes with a surface area of 1.0 cm (Blue Sensor, Ambu, Balerup, Denmark) were placed on the required spot marks while the children were seated. Distance between electrode centers was 2.5 cm. A sampling rate of 1000 Hz and a high-pass filter with a cut-of frequency of 10 Hz was used. Signal processing was conducted employing a labview based program (IMAGO, Pfisoft, Germany). Additionally, artifacts and noise were visually inspected. EMG data was quantified by integrating the full-wave rectified EMG-signals (iEMG). EMG data of the best trial for each task was included into analyses. Muscle activity was analyzed for 30 s of static and dynamic upright standing as well as the individually achieved total standing time on the slackline. EMG analysis was started when the hands were released from the holding position. The iEMG-signals were normalized by the performance time of the respective standing task. Muscle activity patterns were given relative to maximum voluntary isometric contractions (%MVC) measured over 5 s. Isolated MVC-tests were performed for SOL (seated isometric plantar flexion), GAS (standing isometric plantar flexion) and TIB (seated isometric dorsal extension).

Statistical analysis

All parameters, despite slackline standing time at post-testing, were normally distributed (Kolmogorov-Smirnov test) and variances were homogeneous (Levene test). A multivariate analysis of variance (MANOVA) was conducted in order to assess baseline group differences. Then, separate 2 (group: INT, CON)×2 (time: pre, post) repeated measures analyses of variances (rANOVA) were calculated. To account for possible baseline differences between groups, an analysis of covariance (ANCOVA) was calculated for the pre-to-post change scores including pre-test values as covariates. In case of a significant time x group interaction, Tukey HSD post-hoc tests for uneven sample sizes were calculated. To estimate effect sizes, partial eta squared (η_p^2) was computed with $\eta_p^2 \geq 0.01$ indicating small, ≥ 0.059 medium and ≥ 0.138 large effects [3]. As non-parametric testing revealed nearly identical results for slackline standing time as compared to the rANOVA procedure, we decided to show the parametrical tests in this case to present the results in a uniform manner. The level of statistical significance was set at $p<0.05$.

Results

▼

We observed no significant baseline differences in anthropometric characteristics ($0.34<p<0.87$) and all performance parameters ($0.21<p<0.76$) between groups.

Slackline standing

We found significant group × time interactions with large effect sizes for double- ($F=8.9$, $p=0.006$, $\eta_p^2=0.22$) and single-limb standing time (right leg: $F=6.7$, $p=0.01$, $\eta_p^2=0.17$; left leg: $F=7.4$, $p=0.009$, $\eta_p^2=0.19$). Post-hoc testing revealed significantly prolonged standing times at post- compared to pre-testing for INT ($p<0.001$) for all conditions, whereas the control group remained unchanged ($0.45<p<0.87$, ▶ **Fig. 1**). ANCOVA analyses did not relevantly change outcomes for double- ($p=0.007$, $\eta_p^2=0.22$) and single-limb stance (right: $p=0.007$, $\eta_p^2=0.21$ left: $p=0.039$, $\eta_p^2=0.13$).

Postural sway

No significant group × time interactions for total COP path length displacements were observed during static and dynamic single

Table 2 Means and standard deviations (SD) and rANOVA results for static and dynamic center of pressure (COP) path length displacement as well as muscle activity data (m. soleus (SOL), m, gastrocnemius (GAS) and m. tibialis anterior (TIB)) given as percentages of maximum voluntary contraction (%MVC) for the intervention (INT) and control (CON) group.

		INT		CON		rANOVA			
COP [mm]		**pre**	**post**	**pre**	**post**	**time-effect**	η_p^2	**group × time interaction**	η_p^2
static	left	1453 (378)	1425 (356)	1455 (372)	1287 (275)	**p = 0.049**	0.12	p = 0.15	0.06
	right	1316 (281)	1292 (349)	1337 (302)	1275 (265)	p = 0.17	0.06	p = 0.54	0.01
dynamic	left	2023 (598)	1604 (405)	1673 (381)	1465 (279)	**p = 0.009**	0.51	p = 0.06	0.10
	right	1665 (409)	1563 (505)	1327 (350)	1379 (247)	p = 0.74	0.003	p = 0.31	0.03
muscle activity [%MVC]									
static	SOL	57 (16)	46 (11)	51 (16)	45 (10)	**p = 0.02**	0.30	p = 0.48	0.03
	GAS	41 (17)	36 (8)	44 (24)	39 (20)	p = 0.17	0.12	p = 0.89	0.001
	TIB	21 (8)	22 (8)	25 (10)	22 (10)	p = 0.76	0.007	p = 0.31	0.07
dynamic	SOL	56 (14)	47 (12)	55 (18)	47 (11)	**p = 0.03**	0.29	p = 0.87	0.002
	GAS	42 (16)	47 (9)	49 (24)	46 (18)	p = 0.81	0.004	p = 0.19	0.11
	TIB	25 (5)	27 (12)	24 (10)	25 (10)	p = 0.41	0.05	p = 0.64	0.02

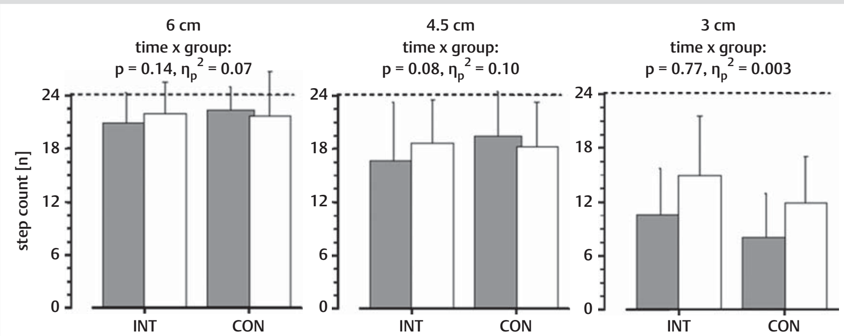

Fig. 2 Pre- (dark box) and post- (white box) test data for INT and CON during reverse balancing on a 6, 4.5 and 3 cm balance beam. Data are provided as means and standard deviations. The horizontal dashed line indicates the maximal step count that could have been achieved (ceiling). η_p^2 = partial eta squared.

limb stance (▸ **Table 2**). We observed a moderately reduced left-leg dynamic sway for INT as compared to CON. Significant time-effects, indicating postural sway improvement for both groups between pre- and post-testing were found for left-sided static and dynamic stance (▸ **Table 2**). ANCOVA analyses ($0.19 < p < 0.74$) did not affect outcomes.

Balance beam

We observed no significant group × time interactions for backward balancing on the beams ($0.08 < p < 0.77$, ▸ **Fig. 2**). Step count was moderately increased for INT and nearly constant for CON on the 4.5 cm beam ($\eta_p^2 = 0.10$, $p = 0.08$). Whereas the results for the 6 cm ($p = 0.23$, $\eta_p^2 = 0.05$) and 3 cm ($p = 0.59$, $\eta_p^2 = 0.009$) were not affected, the effect size for the 4.5 cm beam was no more moderate after adjusting for baseline differences ($p = 0.27$, $\eta_p^2 = 0.009$).

Countermovement jump

Neither a significant time-effect ($p = 0.16$) nor a group × time interaction ($p = 0.28$) was found for jumping height (INT, pre: 29.6 (3.7) cm vs. post: 29.8 (3.7) cm and CON, pre: 29.8 cm (4.3) vs. post: 30.9 (3.3) cm). ANCOVA analyses did not affect the results.

Muscle activity

Although no significant group × time interactions were present, slackline standing revealed notable decreases in muscle activity, indicated by medium to large effect sizes for SOL ($F = 3.7$, $p = 0.10$, $\eta_p^2 = 0.18$), GAS ($F = 1.8$, $p = 0.35$, $\eta_p^2 = 0.06$) and TIB ($F = 4.3$, $p = 0.15$, $\eta_p^2 = 0.14$) (▸ **Fig. 3**). For slackline standing, ANCOVA analyses revealed increased effect sizes for GAS ($p = 0.14$, $\eta_p^2 = 0.15$) and TIB ($p = 0.11$, $\eta_p^2 = 0.17$). The large effect for SOL, however, disappeared ($p = 0.70$, $\eta_p^2 = 0.01$). Muscle activity during static and dynamic balance testing on the force-plate revealed no significant group × time interaction for either muscle. SOL activity was significantly reduced in both groups at post-testing (▸ **Table 2**). These results were not relevantly changed by ANCOVA analyses ($0.31 < p < 0.96$).

Discussion

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The present school-based balance training study revealed that 10 min of daily slackline training within a 6-week period led to slackline- specific improvements of balance performance in primary school children. These improvements were accompanied by large effects of muscle activity reductions during slackline standing for selected lower limb muscles. Transfer effects to static and dynamic standing balance as well as jumping performance seemed to be restricted.

Balance and neuromuscular performance are considered to be important components in children's motor skill development [20,27]. Balance training studies in healthy children, however, are scarce. The majority of training studies in children investigated balance training in disabled populations [13,28,32]. Balance exercises were recently included in a large longitudinal lifestyle intervention approach in preschoolers [24]. These authors did not report relevant improvements in balancing ability after the 1-year intervention. Moreover, as they used a multifactorial approach including a variety of physical exercises, specific neuromuscular

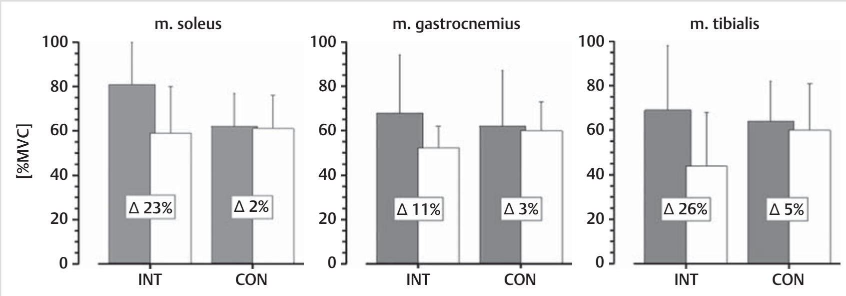

Fig. 3 Electromyographical activity of the m. soleus, m. gastrocnemius and m. tibialis anterior relative to maximal voluntary contraction (%MVC). Pre- (dark box) and post- (white box) test data are provided as means and standard deviations.

adaptations in children cannot be assessed within such a setting. To our knowledge, only one study specifically examined the effects of balance training in healthy pre-pubertal children thus far [11]. 15 first graders completed a traditional balance training program 3 times per week (45 min each session) for a total of 4 weeks. No relevant changes in COP displacement, jump performance, maximum torque and rate of torque development (RTD) during plantar flexion were reported. The authors hypothesized that incomplete and inhomogeneous neuromuscular maturation of the children's postural control system likely account for this finding.

In contrast to the latter study [11], we observed significant balance improvements in 4th grade pupils in those tasks which were specifically taught. These adaptations were achieved after 6 weeks with only 10 min of daily training. The children in our study were about 3.5 years older. Thus, it may be speculated that their neuromuscular system was likely more developed. This may have enabled at least task-specific adaptations. Indeed there is evidence that children of about 7 years of age can adopt postural strategies similar to those of adults [26]. Otherwise, it has been reported that the visual and vestibular afferent systems do not achieve adult levels until adolescence [30].

We did not observe transfer effects to other balance tasks or explosive leg power, although such effects have been previously reported in adults and seniors after traditional balance training [12]. The lack of transfer effects in the present study might be attributed to the specific training modality. Moreover, motor development matures in different rates. Whereas, the neuronal system achieved about 90% of the adult level around the age of 7, the muscular system is comparatively less developed at this age [30, 33]. Thus, improvements of neural performance cannot be simply transferred to increases of jumping performance, where a high amount of explosive leg power is needed.

From a biomechanical viewpoint, the slackline may be considered as a double swinging pendulum [21]. COP swings above a small supporting base which additionally swings with high-frequency oscillations below the COP. To date, 2 studies have analyzed slackline training in young adults with contradictory results. Keller et al. reported considerable adaptations in different balance tasks [17], while Granacher et al. merely observed a 15% increase in RTD during plantar flexion but no improvements in static and dynamic balancing as well as jump height [10]. More research seems warranted to disentangle whether slackline training adaptations can be transferred to other balance tasks. Otherwise, it seems plausible that a matured neuromuscular system and a variety of previous coordinative experiences are necessary to enable the transfer of specific adaptations to different neuromuscular demands. Taube and colleagues found a training-induced shift from cortical to sub-cortical structures in adults [31]. Supra-spinal motor centers may not be sufficiently developed in young children [2] and, thus, such an adaptive shift may be exacerbated in children. It seems possible that relevant neuronal pathways must be first initiated in children, whereas variable neuronal constellations already exist in adults facilitating the transfer between coordinative tasks [16]. However, to explain these mechanisms with certainty, more research on neurophysiological adaptations in children compared to adults is needed. Finally, it may be speculated that a lack of attention may increase baseline variability during balance testing in young children and, thus, possible training effects might be not detected.

The task-specific balance adaptations were accompanied by reduced neuromuscular activity, particularly of GAS and TIB. Keller and colleagues observed significant improvements in postural control which were associated with reduced H-reflexes of SOL after 4 weeks of slackline training in young adults [17]. The authors speculated that a diminished stretch reflex activity inhibits reflex-mediated joint oscillations which may be responsible for uncontrollable sway. A reduced reflex activity may be explained by an altered excitability of the motoneuronpool of the agonistic muscles and, thus, result in an overall reduced muscular activity. Keller et al. observed no significant changes ($p=0.18$, data not presented) in normalized EMG of selected lower limb muscles and, therefore, excluded changes in neuronal excitability as a potential mechanism for their findings [17]. Indicating a familiarization effect in both groups, the time-effect of reduced soleus muscle activity during static and dynamic upright stance might be attributed to reduced anticipatory actions needed by the ankle muscles to counteract reduced body position changes during upright stance [19]. Despite large slackline-specific effects of EMG-changes for GAS and TIB in our study, the results were not statistically significant and we did not assess reflex activity. Thus, our findings should be regarded as preliminary and further more detailed analyses are needed to understand the underlying neuromuscular mechanisms of slackline-specific balance adaptations, particularly with regard to possible differences between young children and adults.

Some limitations need to be addressed. We did not randomly assign the children to INT and CON. Since the pupils of both classes were from the same catchment area, we did not expect relevant differences in potential confounders. We were more concerned about mixing classes with both INT and CON pupils as they may have shared their slackline experiences with their control classmates, and those in turn may have desired to try the same or similar balance tasks during their leisure time. This approach though led to differences in sample sizes. Unbalanced groups can be problematic as possible confounders might be not equally distributed and the assumption of homogeneous variances might be violated. In the present study, however, most variances were homogeneous, and there is no obvious indication that possible confounders may have influenced study outcomes. In addition, the applied post-hoc test is robust in case of unequal sample sizes [25]. As balance training studies in young children are rare, we designed the study as a "proof of principle"-comparison and did not apply comparative tasks for the control group.

We conclude that slackline training can improve slackline balance performance in primary school children. Daily training of only 10 min resulted in task-specific neuromuscular adaptations. As traditional balance training has not yet been proven beneficial in children and might be unattractive, innovative approaches seem more appealing and can be implemented into multimodal physical activity approaches. In this regard, slackline training may serve as an effective and feasible tool which can be incorporated into a supervised school-based training setting, e.g. within physical education lessons, during activity breaks within academic lessons [5,18], as physical activity homework [5,18] or within after-school physical activity programs [1]. Future research seems necessary with particular regard to neuromuscular adaptations as a result of different training modalities and their transferability to other coordinative tasks. Furthermore, potential differences in neuromuscular adaptations between young children, adults and seniors seem to be an interesting topic.

Acknowledgements

First, we would like to thank all pupils who enthusiastically took part in the present study. Special thank is dedicated to Mrs. Herz and Mrs. Scholer (intervention class teachers) and Mrs. Braun (control class teacher) for supporting the study. Furthermore, the head of the elementary school Mrs. Ruetz (Dayschool "Erlensträsschen", Riehen, Switzerland) who agreed to conduct the study during school-time and to provide the infrastructural requirements to successfully complete the present study should be mentioned. We also appreciate the confidence of the parents who allowed to train and test their children. ID Sports (Stuttgart, Germany) should be appreciately mentioned for providing the Gibbon Slackracks®. No external funding was received for the present study.

Conflict of interest: None declared.

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