Slackline training (balancing on nylon ribbons) has been shown to improve neuromuscular performance in children and adults. Comparable studies in seniors are lacking. Thus, 32 seniors were randomly assigned [strata: age, gender, physical activity (PA)] to an intervention [INT; n = 16, age: 65 ± 4 years, PA: 9 ± 5 h/week] or control [CON, n = 16, age: 63 ± 4 years, PA: 8 ± 4 h/week] group. Slackline training was given for 6 weeks (3 times per week, attendance 97%). Static and slackline standing balance performance, force development, and maximal strength of the ankle muscles were assessed before and after slackline training. Muscle activity (lower limb and trunk) was recorded during balance testing. Moderate to large group \times time interactions (0.02 < P < 0.04, 0.11 < η² < 0.17) in favor of INT were found for slackline standing times (INT: left, +278%, P = 0.02; right, +328%, P = 0.03; tandem, +94%, P = 0.007) and muscle activity during single-limb slackline standing [INT: right: rectus abdominis (RA), P = 0.003, −15%; multifidus (MF), P = 0.01, −15%; left: tibialis anterior (TIB), P = 0.03, −12%; soleus (SOL), P = 0.006, −18%; RA, P = 0.04, −11%; MF, P = 0.01, −16%; gastrocnemius medialis (GM), P = 0.02, −19%]. Static balance performance, ankle strength, and power were not affected. Slackline training induced large task-specific improvements of slackline standing performance accompanied with reductions of lower limb and trunk muscle activity. Transfer effects to static balance and strength measures seem limited.

About 30% of seniors aged ≥65 fall once a year and half of them fall again within the following year (Rubenstein, 2006). Fall-related injuries are considered the leading cause of hospitalizations due to injuries (Jones et al., 2011) and seriously contribute to increasing health care expenditures in the elderly (Stevens et al., 2006). Extrinsic (e.g. twilight, bumps, ice, footwear) and intrinsic fall-risk factors, such as age- and physical inactivity-related declines of maximal and explosive strength of the lower extremities (Skelton et al., 2002) and deteriorated postural control, have been reported to mainly account for fatal and nonfatal falls in seniors (Hytonen et al., 1993; Granacher et al., 2011b).

Regular aerobic, strength, and balance training can attenuate aging-induced declines of cardiorespiratory and neuromuscular capacity (Granacher et al., 2011a). Active seniors with well-developed balance and strength performance have lower overall morbidity and mortality (Bembom et al., 2009) and can reduce their fall risk up to 50% (Gillespie et al., 2003). Older adults should thus be encouraged to regularly include combined strength and balance tasks into their daily lives (Pierre et al., 1998). It has been recommended to employ balance training as appealing training regimes to ensure high attendance rates (Donath et al., 2013) and to induce neuromuscular improvements that beneficially affect individual fall-risk profiles (Gardner et al., 2000). Although measures of balance (e.g. timed-up and go test, functional reach test, perturbed and unperturbed standing) on the one hand and strength performance (maximal strength and force production) measures on the other hand were reported to be not mandatorily interrelated in seniors (Muehlbauer et al., 2012), Gruber and Gollhofer (2004) assumed at least in young adults that balance training (sensorimotor training on unstable surfaces) might modulate reflex activity on spinal level (increase in presynaptic inhibition; Katz et al., 1988), potentially enabling higher rates of force development (Gruber & Gollhofer, 2004). However, a notable body of evidence suggests that traditional balance training leads to reduced H-reflexes (Trimble & Koceja, 2001; Taube et al., 2007a, 2008). Similar adaptations were reported in young adults following several weeks of slackline training (Keller et al., 2012).

Slacklining, i.e., balancing on narrow nylon bands, might serve as an attractive and demanding alternative compared with traditional balance training (Paoletti & Mahadevan, 2012). Medio-lateral sway of a slackline shows high frequent oscillation patterns with notable changes in space (Keller et al., 2012). It was argued that
this reflex inhibition may serve to suppress unwanted joint oscillations (Keller et al., 2012). Available slackline training studies examined training-induced changes of neuromuscular measures in young adults and children only (Granacher et al., 2010; Keller et al., 2012; Donath et al., 2013; Pfusterschmied et al., 2013a). All of these studies revealed improvements of postural control with different emphases. Two groups reported improvements in postural sway velocity (Pfusterschmied et al., 2013b) and medio-lateral path length displacement during upright stance (Keller et al., 2012). Although Granacher et al. (2010) found slight improvements in strength after slackline training, however, the transferability of slackline-specific balance adaptations to static balance and strength/power abilities seems limited (Granacher et al., 2010; Donath et al., 2013). Although Granacher and coworkers also found improvements in ankle muscle force development after slackline training in young adults (Granacher et al., 2010), the transferability of slackline-specific balance adaptations to static balance and strength/power abilities remains questionable.

The importance of adequate trunk muscle performance has been emphasized for preventing falls in the elderly and trunk muscle strength seems to be interrelated with steady-state balance in seniors (Granacher et al., 2013). However, neuromuscular activity of trunk muscles was not yet adequately considered in balance training interventions in general and slackline training studies in particular.

Against the above-mentioned background, we hypothesized that a progressive 6-week (18 training sessions) slackline training intervention improves task-specific balance performance on the slackline. Moreover, we assume changes of lower limb and trunk muscle activity following a slackline training intervention. As balance and force development has been reported to be interrelated, we additionally expect that force development as secondary outcome may benefit from slackline training.

**Methods**

**General study design**

The present study was designed as a two-armed randomized controlled trial (RCT). Participants were stratified (strata: age, gender, and baseline physical activity) using the minimization method to either an intervention (INT) or control (CON) group. To reduce potential influences of unspecific training loads during the training period, all participants were asked to avoid changes in habitual physical activity from pre- to post-testing. This was controlled by means of a training and physical activity diary which had to be completed during the training period in both groups. INT received 18 instructed training sessions (three weekly sessions for 6 weeks). In order to minimize the risk of social or educational confounders, participants of CON were obligated to undergo three educational lessons (90 min each) concerning knowledge on the significance of neuromuscular exercise training for fall prevention.

**Participants**

Thirty-two healthy and active community dwellers were enrolled in the present study (Table 1). One senior of CON dropped out due to illness. This sample size was priorly justified according to findings of Granacher et al. (2009). Thereby, moderate to large balance intervention effects would be detectable with a power of 90% with significant between-group differences in neuromuscular training adaptations (strength and balance) with an alpha significance level of $P < 0.05$. Exclusion criteria were: prior stroke; heart attack; heart failure; bypass; cardiac dysrhythmia; acute flu or cold; spinal, joint, and head pain; diabetes mellitus; hypertension (RR systolic/diastolic $>$ 160/100 mmHg); acute and chronic inflammatory condition; severe arthrosis; recurrent vertigo; knee or hip endoprosthesis; and trauma within the last 6 months. None of the participants reported critical orthopedic, neurological, and internal conditions that would have affected neuromuscular testing and training. All participants signed an informed written consent prior to the start of the study. The present study was approved by the local ethics committee (Ethikkommission beider Basel, Approval No. 257/12) and complied with the Declaration of Helsinki.

**Training intervention**

Each slackline training session was held by an experienced balance training instructor. An additional assistant recorded individual net training volume of each session. In total, 18 training sessions were given. The mean attendance rate was 97% (17.4 ± 0.9 sessions). All participants underwent three progression levels every 2 weeks. Exercises during weeks 1 and 2 included slackline standing and walking forward (vision to the bars should be more and more reduced). Within weeks 3 and 4, standing and walking with reduced holds were conducted. Finally, standing, swinging, turning, and walking with and without holds were allowed in weeks 5 and 6. All participants underwent all progression levels together. More trained subjects were merely able to stand and walk longer in one piece without small breaks between each trial of the respective slackline task. The training sessions (Monday, Wednesday, and Friday) consisted of a quick general warm-up (5–10 min walking, gymnastics, dynamic stretching) and the specific slackline training part (20-min net training for each participant). Exercises of every progression level were carefully introduced. Safety precautions were installed (holding bars and gymnastic mats). Depending on participants’ age and fitness level, four different groups with four participants each were compiled. The intervention was conducted on four Gibbon Slackracks® (ID Sports, Stuttgart, Germany) (length: 5 m; bandwidth: 0.05 m) (Fig. 1). Each senior exercised for 1 min with a follow-up break of 3 min. Participants were allowed to train barefoot or in socks without shoes.

**Table 1. Anthropometric data of the participants**

<table>
<thead>
<tr>
<th></th>
<th>INT ($n = 16$)</th>
<th>CON ($n = 15$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (n, female/male)</td>
<td>7/9</td>
<td>8/8</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64.4 ± 3.7</td>
<td>63.1 ± 4.1</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.66 ± 0.09</td>
<td>1.65 ± 0.11</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>75.1 ± 15.7</td>
<td>75.4 ± 15.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.4 ± 2.9</td>
<td>25.7 ± 3.1</td>
</tr>
<tr>
<td>FES-I</td>
<td>20.3 ± 2.6</td>
<td>22.1 ± 4.6</td>
</tr>
<tr>
<td>Total PA (h/week)</td>
<td>8.6 ± 4.8</td>
<td>8.3 ± 4.2</td>
</tr>
<tr>
<td>Quality of life (sum score)</td>
<td>73 ± 6</td>
<td>71 ± 8</td>
</tr>
</tbody>
</table>

BMI, body mass index; FES-I, sum score of the validated German version of Falls Efficacy Scale Questionnaire; PA, physical activity, derived from WHOQOL-BREF, mean ± SD.
Slackline training in healthy seniors

Testing procedures

Questionnaires

The Physical Activity Readiness Questionnaire was employed to assess whether an elevated risk of exercise-induced adverse events exists. Participants needed to affirm all items in order to be included without additional medical consultation.

To minimize the risk of baseline differences of fear of falling, the Falls Efficacy Scale-International version (FES-I, validated German version) (Helbostad et al., 2010) was used before the training intervention. The FES-I comprises 16 items on a 4-point Likert scale and is regarded as an internally valid (Cronbach’s $\alpha=0.96$) and reliable instrument (Helbostad et al., 2010). The FES-I sum score (max 64) was provided. Higher scores correspond to a higher level of fear of falling.

The Freiburger Physical Activity Questionnaire was used to assess baseline physical activity in hours per week (Frey et al., 1995). The total amount of weekly physical activities is composed of baseline physical activity (e.g., daily walked or biked distance, stair climbing), leisure time activity (e.g., hiking, dancing, bowling), and sportive activity (disciplines). The summarized hours per week were used to describe baseline physical activity of both groups and to stratify participants.

Standing balance testing

Standing balance performance was examined on the slackline and on a force plate in single-leg (left and right) as well as tandem stance. Slackline standing time was recorded while standing on a marked middle position of the slackline. The participants were asked to stand free without any further assistance after an acoustic signal. The completed free standing time without shoes was measured with two handheld stopwatches. The average standing time of both watches was considered for analysis. Three trials for each standing condition were performed. The best trial of the three attempts was analyzed. To adjust for potential baseline differences between both groups, analyses of covariance (ANCOVAs) were calculated. In case of a significant time (pre vs post) × group (INT vs CON) interaction, Tukey’s honestly significant difference (HSD) post-hoc tests for uneven sample sizes were calculated. To adjust for potential baseline differences between both groups, analyses of covariance (ANCOVAs) were additionally calculated for the pre-to-post change scores for each parameter including pretest values as covariates. To estimate effect sizes of the main effects, partial eta squared ($\eta_p^2$) values were computed with $\eta_p^2 \geq 0.1$ indicating small, $\geq 0.059$ medium, and $\geq 0.138$ large effects. 

Muscle activity assessment

Muscle activity of selected lower limb (m. soleus, SOL; m. gastrocnemius, GAS; m. tibialis anterior, TIB) and trunk muscles (m. external oblique, EO; abdominal rectus, RA; m. multifidus, MF; m. glutaeus medius, GM) was captured according to the European recommendations for surface electromyography (SEMG) (Hermens et al., 2000). To guarantee low skin conductance levels (<5 kΩ, monitored before and after testing), the skin of the dominant leg [this was the right leg in all subjects, determined using the lateral preference inventory (Coren, 1993)] was prepared with shavers and fine sandpaper. Bipolar electrodes with a surface area of 1.0 cm (Blue Sensor, Ambu, Balerup, Denmark) were placed on the marked spots in seated position. Interelectrode distance was 2.0 cm. A sampling rate of 1000 Hz and a high-pass filter with a cutoff frequency of 10 Hz were used. Signal processing was performed with a LabVIEW-based program (IMAGO, Pisoft, Germany). Artifacts and noise were visually inspected. EMG data were quantified by integrating the full-wave rectified EMG signals (iEMG). EMG data of the best trial of slackline standing and force plate standing, respectively, were further analyzed. Muscle activity for slackline standing was recorded in $\mu V$ for the total standing time. The recorded total muscle activity was then divided by the achieved standing time and normalized to the maximal voluntary isometric contractions (MVICs). Isolated MVIC tests were performed at pre- and post-testing for SOL (seated isometric plantar flexion), GAS (standing isometric plantar flexion) and TIB (seated isometric dorsal extension), RA (isometric crunches), EO (twisted isometric crunch), MF (isometric back extension in prone position), and GM (isometric abduction in supine position).

Statistics

Data are provided as means with standard deviations (SDs). Numerous 2 (group: INT, CON) × 2 (time: pre, post) repeated measures analyses of variance (rANOVAs) were calculated for each outcome measure separately. In case of a significant time (pre vs post) × group (INT vs CON) interaction, Tukey’s honestly significant difference (HSD) post-hoc tests for uneven sample sizes were calculated. To adjust for potential baseline differences between both groups, analyses of covariance (ANCOVAs) were additionally calculated for the pre-to-post change scores for each parameter including pretest values as covariates. To estimate effect sizes of the main effects, partial eta squared ($\eta_p^2$) values were computed with $\eta_p^2 \geq 0.1$ indicating small, $\geq 0.059$ medium, and $\geq 0.138$ large effects.
The differences of group means from pre- to post-testing of the relative muscle activity were provided for each muscle and slackline stance condition together with 90% confidence intervals. Thereby, pretest values were included into the inference about magnitude analyses (Batterham & Hopkins, 2006) to adjust for possible baseline differences. A practically meaningful change from pre- to post-testing was assumed when the difference score was at least 0.2 of the between-subject SD (Hopkins et al., 2009). The likelihood for practically meaningful changes was calculated according to the magnitude-based inference approach using the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely (Batterham & Hopkins, 2006). The default probabilities for practically beneficial effects were <0.5% (most unlikely) for harm and >25% (possibly) for benefit (Hopkins et al., 2009). These calculations were conducted using a published spreadsheet in Microsoft® excel (Hopkins, 2014).

Results
Standing balance performance
Moderate to large group × time interaction effects were found following separately computed rANOVA for left-sided ($P = 0.03; \eta_p^2 = 0.16$) and right-sided ($P = 0.04; \eta_p^2 = 0.11$) single-limb as well as tandem ($P = 0.05; \eta_p^2 = 0.17$) slackline standing time (Fig. 2). Follow-up post-hoc testing revealed significant differences between pre- and posttests for INT during all slackline stance conditions (Fig. 2). A large time effect was found for tandem stance ($P = 0.002; \eta_p^2 = 0.39$). These results did not relevantly change after adjusting for baseline differences (ANCOVA, between-group effect, left: $P = 0.04; \eta_p^2 = 0.14$, right: $P = 0.05; \eta_p^2 = 0.09$, tandem, $P = 0.01; \eta_p^2 = 0.30$).

Neither relevant time nor interaction effects were found for total and medio-lateral COP$_{path}$ length displacement during static tandem stance and left-/right-sided single-limb stance on the force plate (Table 2). These results were not affected after adjusting for baseline differences.

Ankle power and strength
We found only moderate to large time effects with increases of RTD and maximal strength at the right side for both dorsal and plantar flexion (Table 3). We did not observe interaction effects for maximal strength and

Table 2. Total and medio-lateral center of pressure (COP) path length displacement for the intervention (INT) and control (CON) groups during tandem stance and left-/right-sided single-limb stance. Data are presented as means with standard deviations (SD). Partial eta squared ($\eta_p^2$) values are provided to estimate the effect sizes of the repeated measures analyses of variance (rANOVAs)

<table>
<thead>
<tr>
<th>Postural sway COP (mm)</th>
<th>INT</th>
<th>CON</th>
<th>rANOVA</th>
<th>Postural sway COP (mm)</th>
<th>INT</th>
<th>CON</th>
<th>rANOVA</th>
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<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Time</td>
<td>Group × time interaction</td>
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<td>Total</td>
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<td>Tandem</td>
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<td>Single limb, left</td>
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<td>Medio-lateral</td>
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<td>Tandem</td>
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<td>Single limb, left</td>
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<tr>
<td>Single limb, right</td>
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</tbody>
</table>
provided to estimate the effect sizes of the repeated measures analyses of variance (rANOVAs). Significant differences were set at \( p < 0.05 \).

Left

Right

\( \eta^2 \) values are provided to estimate the effect sizes of the repeated measures analyses of variance (rANOVAs). Significant differences were set at \( p < 0.05 \) and \( p < 0.01 \). Furthermore, the probability of a practically worthwhile effect is presented.

Muscle activity during slackline and static stance

Moderate to large group \( \times \) time interaction effects were found for trunk and limb muscle activity during single-limb slackline standing with reductions after the intervention period in INT (Table 4). Muscle activity during tandem slackline stance remained unchanged. These results were not affected after adjusting for baseline differences. The percentage change between both groups (Fig. 3) indicated likely beneficial reductions of muscle activity for nearly all limb and trunk muscles during single-limb standing according to the inference about magnitude approach (Table 4, right column).

Muscle activity during static balance on the force plate

Slackline training in healthy seniors

RTD during dorsal and plantar flexion at both sides (Table 3). These results did not change after adjusting for baseline differences.

Table 3. Left- and right-sided rate of torque development (RTD) and maximal (MAX) strength for INT and CON at pre- and post-testing during dorsal flexion (DF) and plantar flexion (PF). Data are presented as means with standard deviations (SDs). Partial eta squared (\( \eta^2 \)) values are provided to estimate the effect sizes of the repeated measures analyses of variance (rANOVAs)

<table>
<thead>
<tr>
<th></th>
<th>INT</th>
<th>CON</th>
<th>rANOVA</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Pre (%)MVIC</td>
<td>Post (%)MVIC</td>
<td>Pre (%)MVIC</td>
</tr>
<tr>
<td><strong>Left</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD_DF (Nm/ms)</td>
<td>0.91 (0.53)</td>
<td>1.00 (0.55)</td>
<td>0.79 (0.34)</td>
</tr>
<tr>
<td>RTD_PF (Nm/ms)</td>
<td>2.1 (0.9)</td>
<td>2.5 (0.7)</td>
<td>2.5 (1.3)</td>
</tr>
<tr>
<td>MAX_DF (Nm)</td>
<td>256 (114)</td>
<td>240 (108)</td>
<td>266 (116)</td>
</tr>
<tr>
<td>MAX_PF (Nm)</td>
<td>861 (250)</td>
<td>900 (361)</td>
<td>974 (197)</td>
</tr>
<tr>
<td><strong>Right</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD_DF (Nm/ms)</td>
<td>0.81 (0.46)</td>
<td>0.98 (0.59)</td>
<td>0.82 (0.30)</td>
</tr>
<tr>
<td>RTD_PF (Nm/ms)</td>
<td>2.2 (0.9)</td>
<td>2.8 (0.8)</td>
<td>2.6 (1.4)</td>
</tr>
<tr>
<td>MAX_DF (Nm)</td>
<td>250 (99)</td>
<td>227 (80)</td>
<td>257 (103)</td>
</tr>
<tr>
<td>MAX_PF (Nm)</td>
<td>934 (261)</td>
<td>895 (283)</td>
<td>1047 (206)</td>
</tr>
</tbody>
</table>

Table 4. Muscle activity in percent of MVIC of the tibialis anterior (TIB), gastrocnemius medialis (GAS), soleus (SOL), external oblique (EO), rectus abdominis (RA), multifidus (MF), and gluteus maximus (GM) for the intervention (INT) and control (CON) groups at pre- and post-testing during tandem as well as left- and right-sided single-limb stances. Data are presented as means with standard deviations (SDs). Partial eta squared (\( \eta^2 \)) values are provided to estimate the effect sizes of the repeated measures analyses of variance (rANOVAs). Significant differences were set at \( p < 0.05 \) and \( p < 0.01 \). Furthermore, the probability of a practically worthwhile effect is presented.
(0.34 < P < 0.88; 0.001 < ηp² < 0.04; 0 < Δ%<1), GAS (0.22 < P < 0.63; 0.01 < ηp² < 0.08; -6 < Δ%<2), SOL (0.55 < P < 0.69; 0.01 < ηp² < 0.02; -1 < Δ%<1), EO (0.57 < P < 0.82; 0.003 < ηp² < 0.02; -1 < Δ%<1), RA (0.13 < P < 0.52; 0.007 < ηp² < 0.10; 0 < Δ%<8), MF (0.24 < P < 0.97; 0.001 < ηp² < 0.07; 1 < Δ%<2), and GM (0.09 < P < 0.99; 0.001 < ηp² < 0.07; -2 < Δ%<5). These results did not change after adjusting for baseline differences.

Discussion

The present study aimed at investigating whether a structured and progressive slackline training intervention over 6 weeks (18 sessions) serves as an appropriate neuromuscular training approach in order to improve standing balance performance, maximal and explosive strength, as well as lower limb and trunk muscle activity. We assumed mainly task-specific improvements of slackline standing balance performance and explosive power of the ankle muscles accompanied with reductions of limb and trunk muscle activity during upright slackline standing. We merely observed large slackline-specific balance improvements during single- and double-limb standing going along with practically worthwhile reductions of trunk and lower limb muscle activity. In contrast, total and medio-lateral postural sway of upright force plate standing and strength performance did not relevantly change.

More than two-thirds of the seniors of INT were able to accomplish a minimum of 10 s single-limb slackline standing after the training period. As standing balance testing under single-limb condition does not commonly exceed 10 s (Granacher et al., 2011b) due to aging-induced declines of postural control, these slackline-specific balance improvements can be interpreted as remarkable. In contrast to single-limb stance on a slackline, standing on ropes or nylon bands in a closed kinetic chain (e.g., tandem stance) has been considered very demanding (Paoletti & Mahadevan, 2012). Thus, only tendencies of training-induced improvements of tandem stance on the slackline were observed due to its potential over-challenging character. With comparable training volumes in net slackline standing time, absolute and relative (nearly double fold mean percentage increases in children) training-induced slackline standing times are notably lower in seniors compared with children and young adults as well (Keller et al., 2012; Donath et al., 2013). A decline of motor learning and adaptive capacity during the process of aging may account for this finding (King et al., 2013). We therefore assume that isolated and intense slackline training provokes substantial slackline-specific neuromuscular adaptations in both groups with more pronounced increases for children. However, a large neuromuscular adaptive training potential needs to be stated for the elderly, particularly regarding task-specific balance adaptations.

Improvements of slackline standing balance performance were accompanied with likely meaningful reductions of relative muscle activity during single-limb slackline stance of the lower leg and trunk muscles. In line with the less distinct improvements of tandem slackline standing performance, also lower reductions of limb and trunk muscle activity were found during tandem slackline stance. To the best of our knowledge,
no high-quality training studies (meeting the majority of the Consort criteria for RCTs) that analyzed lower leg and trunk muscle activity are available yet. Although slackline standing remains challenging when achieving prolonged standing times (Pfusterschmied et al., 2013a), trunk and lower limb muscle activity contributions notably decreased after the training period by improving both the hip- and ankle-based balance strategies. Two major mechanisms might lead to decreased muscle activity during slackline standing. On the one hand, reductions of slackline sway might require less muscle activation to sustain balance and, on the other hand, seniors improved their ability to align the center of mass within the “slackline” resulting in reduced required muscle activations. However, we did not measure slackline sway directly. Thus, we can only speculate on this. The pronounced reduction of trunk muscle activity was present during both left- and right-sided single-limb slackline stances. These findings, however, merely emphasize that trunk muscles play an important role for postural control and, in turn, improved trunk muscle control may also beneficially affect hip function that could lead to a better trunk control during step initiating when tripping (Carty et al., 2015). In line with Granacher et al. (2013), the importance of training and testing trunk muscle performance within neuromuscular exercise studies regarding fall prevention should not be underestimated. Corroboratively, these functional aspects should be further considered in future studies when conducting exercise-based fall prevention studies (Grabiner et al., 2014).

The transferability of slackline-related balance improvements to other neuromuscular tasks seems to be restricted. Keller et al. (2012) as well as Pfusterschmied et al. (2013b) found improvements of postural sway. Interestingly, the most pronounced reduction in platform movements of the Posturomed (swinging platform enabling various perturbations) was found in the medio-lateral direction (Keller et al., 2012). This seems reasonable as walking and standing on a slackline mainly results in medio-lateral oscillations. Therefore, postural adaptations in the present study are more pronounced in balance tasks closely related to the training task. In contrast, we did not observe meaningful transfer effects to other balance tasks. In this regard, static balance tests (e.g., on a force plate) have been reported to have less predictive power to indicate future falls compared with dynamic measures of postural control (e.g., reactive stepping behavior upon a forward loss of balance) (Carty et al., 2015). We observed neither improvements of total and medio-lateral postural sway nor strength or power adaptations in seniors. Our findings regarding transfer effects to strength tasks are mainly in line with Granacher et al. (2010) for adults and Donath et al. (2013) for children. Both research groups did not observe relevant transfer effect of slackline improvements to maximal strength or jump performance. Donath et al. (2013) merely noticed medium effect sizes of left-sided postural sway on a swinging force plate. These findings might support the assumption that transfer effects mainly occur in tasks closely related to the training contents. In contrast, traditional balance training seems to have much broader abilities for such transfer effects indicated by enhanced (explosive) strength (Gruber & Gollhofer, 2004; Gruber et al., 2007; etc.) and improved jump performance (Taube et al., 2007b). Available evidence also suggests that slackline training changes Ia-afferent reflex transmission during a medio-lateral balance task (Keller et al., 2012). These reflex reductions on spinal level have been interpreted to contribute to less uncontrolled reflex-mediated oscillations of the joints (Keller et al., 2012). In line with Granacher and coworkers, one can speculate that such alterations of the excitability of the spinal reflex circuitry may also contribute to improvements of plantar flexor strength and torque production rate, respectively (Granacher et al., 2010). Along with these speculations, Gruber and Gollhofer (2004) presumed alterations of spinal reflex activity after sensorimotor training that might account for increased force production rates. However, as both studies did not examine spinal reflex activity, the link between changes in spinal reflexes and changes in the rate of force development is not clear yet. After strength training, Ia-afferent transmission is enhanced and the H-reflex is facilitated, and this, in turn, has been considered to positively contribute to a more rapid force production (Aagaard et al., 2002; Taube et al., 2007a). Despite available speculations that balance training might beneficially affect spinal reflex activity that could improve rapid force development, we neither found improvements of maximal ankle muscle strength and torque production. The present methodological approach does not allow to state about underlying neuromuscular processes with certainty and remain speculative. Future research should focus on adaptations of reflex activity after balance training and potential interference with measure of muscle strength in a population of seniors. As strength and power improvements merely served as a secondary purpose in this study, the strength-related outcomes were not sufficiently statistically powered prior to the start of the study. Nevertheless, the calculated effect sizes we found for strength and power did not exceed small effect sizes.

Some limitations need to be addressed. For a proof of principle, we initially included only healthy and active elderly people. The applicability of our results to frail, inactive, and older subjects seems restricted. Although no transfer effects occurred in our study, we would assume more pronounced transfer effects of slackline training to force measures in detrained older or clinical populations. However, seniors’ risk of falling or misstepping while balancing on a slackline should be justified in relation to available safety precautions and the size of the intervention effects. Compared with
traditional balance training and from an ethical viewpoint, the higher risk on a slackline should be counteracted by large intervention effect sizes. Despite its likely appealing character mirrored by very high training attendance rates (97%) compared with other balance training studies in seniors, however, the adaptive potential of slackline training to general neuromuscular measures should be handled with caution. It seems to be more reasonable to embed such an approach into multimodal balance training regimes. In this case, a wider range of neuromuscular adaptations could be expected. These assumptions need to be verified by future longitudinal training studies comparing neuromuscular adaptations of mono- and multimodal training regimes in different age groups.

**Perspectives**

Slackline training seems to be an appealing balance training approach eliciting specific dynamic balance and muscle activity adaptations. To the best of our knowledge, our study was the first that includes surface EMG analyses of the trunk muscles. Although findings of trunk muscle activity reductions in the present study did not allow to clearly state on how the trunk contributes to postural control, we would like to emphasize that trunk strategies to reduce postural sway on the slackline should be further investigated. For example, this could be realized with kinematic approaches. The transferability of these training-induced changes to other standing balance tasks and maximal and explosive strength performance seems to be restricted. Adaptations to slackline training predominantly occur in balance performance and muscle activity closely linked to the trained task. Future studies should investigate slackline training embedded in multimodal training regimes. Balance performance should be examined employing more dynamic and unexpected or perturbed testing conditions including also electrophysiological methods. Therewith, the interrelation between spinal reflex modulation and balance and strength performance could be further disentangled.

**Key words:** Postural sway, trunk, SEMG, balance, strength, gait, exercise, elderly.

**Acknowledgements**

We are grateful for the compliance and confidence of the seniors. Martina Michel and Nadine Girod should be kindly acknowledged for their assistance during exercise training and testing.

**References**


Slackline training in healthy seniors


