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Effects of stair-climbing on balance, gait, strength, resting heart rate, and submaximal endurance in healthy seniors

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Stair-climbing serves as a feasible opportunity to remain physically active within everyday-life. Data on neuromuscular and cardiorespiratory performance after regular stair-climbing in seniors are scarce. Forty-eight seniors were stratified to a one- (taking every step, INT_1) or two-step strategy (every second step, INT_2) or a control group (CON). Thirty-nine seniors [females: $n = 22$, males: $n = 17$; age: 70.5 (SD 5.1) years; BMI: 25.8 (3.1) kg/m^2] completed the 8-week intervention (three weekly sessions). Before and after the intervention, balance, gait, strength, and submaximal endurance (at different intensities) were assessed. Maximal strength and explosive power did not improve significantly ($0.10 < P < 0.78$). Resting heart rate was significantly reduced in INT_2 (−8/min) compared with INT_1 (0/min, $P = 0.02$) and CON (0/min, $P = 0.03$). Compared with CON, perceived exertion for all intensities ($0.007 < P < 0.03$) and submaximal exercise heart rate during moderate uphill walking significantly decreased (−11/min; $P < 0.05$) in INT_2. Step counts for forward beam balancing (4.5 cm width) increased in INT_2 ($P = 0.007$) compared with CON. With more pronounced effects in INT_2, stair-climbing significantly improved resting and exercise heart rates, perceived exertion, and dynamic balance performance in healthy seniors and may contribute to better overall fitness, reduced fall risk, and less perceived strain during daily life activities.

Fall-related injuries in seniors seriously contribute to increasing health care utilizations and expenditures (Stevens et al., 2006). Aging-induced declines of strength, endurance, and balance performance have been reported to mainly account for severe fall events (Lord, 2007). Prospective studies revealed that higher levels of general physical activity may reduce overall morbidity and mortality (Bembom et al., 2009) as well as the risk of falling between 30% and 50% in seniors (Gillespie et al., 2012). Seniors should, thus, be encouraged to maintain or increase habitual physical activity levels (Chodzko-Zajko et al., 2009). In this regard, multimodal training regimens including strength, balance, and endurance tasks are considered important to reduce the risk of fatal and nonfatal falls as well as chronic cardiovascular and metabolic disease (Gardner et al., 2000).

Regular stair-climbing may serve as a feasible opportunity to remain physically active within everyday life and has been shown to beneficially affect maximal oxygen uptake in young women (Boreham et al., 2000, 2005). Inducing a notable health-promoting additional energy expenditure (approx. 8.5 kcal/kg/h; Gottschall et al., 2010), stair-climbing has been shown to increase quadriceps strength, maximal oxygen uptake (Loy et al., 1994), and plantar flexion moments (Riener et al., 2002) in young and middle-aged adults. A two-step strategy (ignoring every second step) can additionally increase the caloric requirements by 15% to 20% as compared with a one-step strategy (taking every step; Gottschall et al., 2010). The intensity of ascending 180 steps of 11 stories has been reported to range between 80% and 90% of maximal heart rate and oxygen uptake (Teh & Aziz, 2002). Therefore, from a strength and cardiorespiratory perspective, stair-climbing seems to induce an appropriate multimodal training stimulus and may serve as a feasible training modality for general fitness improvements in seniors.

The available intervention studies are, however, predominantly limited to younger adults (Boreham et al., 2000, 2005; Aziz & Teh, 2005; Gottschall et al., 2010) or seniors using additional weights during stair-climbing (Bean et al., 2002a). Regarding health promotion and fall prevention in seniors, longitudinal stair-climbing studies that examine training-induced effects on relevant intrinsic fall risk factors and cardiorespiratory fitness are lacking to date.

Thus, the present study aimed at investigating the effects of two 8-week stair-climbing interventions on balance, gait, strength, and endurance parameters in community-dwelling healthy seniors. Thereby, the

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*Both authors contributed equally to the present manuscript.

Table 1. Baseline data of the participants for both interventions (INT_1 and INT_2) and the control group (CON)

	INT_1 ($n = 14$)	INT_2 ($n = 13$)	CON ($n = 12$)	Total ($n = 39$)
Gender (M/F)	4/10	7/6	6/6	17/22
Age (years)	71.4 (5.3)	69.4 (3.6)	70.9 (6.6)	70.6 (5.2)
Height (m)	1.68 (0.12)	1.69 (0.08)	1.70 (0.10)	1.69 (0.10)
Weight (kg)	70.2 (12.8)	74.0 (9.8)	77.9 (17.2)	73.8 (13.5)
BMI (kg/m)	24.9 (3.1)	25.8 (2.1)	26.7 (3.8)	25.8 (3.1)
WHR	0.93 (0.06)	0.94 (0.05)	0.92 (0.06)	0.93 (0.06)
PA (h/week)	7.9 (6.1)	5.9 (3.5)	6.0 (3.9)	6.7 (4.7)*

Data are provided as means with standard deviations (SD). Gender is indicated as F (female) and M (male).

*78% of the reported activities were light intensity (baseline, leisure time) and 22% (~1.2 h/week) were moderate intensity (sports).

BMI, body mass index; WHR, waist-to-hip ratio; PA, baseline physical activity.

one- and two-step strategies were compared with a control condition. We hypothesized that regular stair-climbing with a total training volume applicable to everyday life may relevantly improve balance, gait, strength, and submaximal endurance capacity in healthy community-dwelling seniors as compared with a control group. We additionally assumed that the two-step strategy would enable greater effects compared to the one-step strategy.

Methods

Study design

The present study was conducted as a three-armed randomized controlled trial. Two intervention groups (INT_1 vs INT_2) were compared with one control group (CON). Whereas the participants of INT_1 ascended the stairs by taking each step (one-step strategy), those of INT_2 were instructed to use only every second step (two-step strategy) during stair-climbing training. For both groups, an ascend pattern where both feet alternately reach to the next step was required. One leading leg in ascending was not allowed. To minimize interfering group effects on relevant outcome measures due to social interaction, CON received three supervised social sessions (bowling, playing billiards, and darts). These social gatherings for CON were held in the first, the fourth, and the last week of the intervention period. All participants of CON took part and were instructed not to change their habitual physical activity behavior. No thematic inputs concerning the study or background information were given during these social gatherings of CON. Participants were assigned to one of the three groups using the minimization method (Pocock & Simon, 1975). Age, gender, and physical activity level were applied as stratification criteria. Pre- and posttests were intra-individually performed at the similar time of the day. The order of the tests was inter-individually randomized, but intra-individually kept constant during pre- and posttest. Participants were asked to refrain from any strenuous exercise within the last 72 h prior to the tests. The training period lasted 8 weeks with three sessions per week (total amount: 24 sessions). The duration of the training sessions (the amount of stairs climbed) was progressively increased. All participants were asked to refrain from any changes in habitual physical activity during the intervention period. The study was approved by the local ethics committee (Ethikkommission beider Basel, EKBB, Basel, Switzerland, approval number: 283/11) and complied with the Declaration of Helsinki.

Participants

Initially, 52 community-dwelling seniors responded to the recruitment process. Seniors were recruited by the Prosenectute Seniors' Society (Basel, Switzerland). Subjects with previously examined orthopedic (e.g., endoprosthesis, arthritis, severe arthrosis, osteoporosis), neurologic (stroke, neuropathy according to diabetes), and/or cardiac (chronic heart failure, coronary heart disease) diseases were excluded ($n = 4$). None of the remaining subjects reported any medication intake and relevant orthopedic, neurological, and internal impairments that may affect testing procedure as well as performing the stair-climbing intervention program. To exclude adverse cardiac conditions, resting electrocardiogram at baseline was also recorded and evaluated by an experienced physician. Finally, 48 community-dwelling seniors between 61 and 83 years of age were included in the study. After providing relevant background information on possible risks and harms of participation, all seniors signed an informed written consent prior to the start of the study. Because of illness during the intervention period (dropouts $n = 3$), too low training attendance rate (*a priori* set at a minimum of 67%, i.e., minimum average attendance two times per week, dropouts $n = 2$), and personal reasons (dropouts $n = 4$), 39 subjects remained for statistical analyses (for anthropometric data, see Table 1). Anthropometric baseline data did not significantly differ between the three groups ($P > 0.35$).

Testing procedures

Questionnaire

In order to examine physical activity, the Freiburg Physical Activity Questionnaire was applied (Frey et al., 1995). This questionnaire assesses total weekly activity, which includes a wide range of activitites, for instance, baseline physical activity (e.g., daily walked or biked distance, stair-climbing), leisure time activity (e.g., hiking, dancing, bowling), and sports activity.

Static and dynamic balance testing

Static postural control was tested within 30 s for double-limb stance with closed eyes and left- as well as right-sided single-limb stance with opened eyes. Testing was conducted on a piezoelectric force plate measuring ground reaction forces in three dimensions (Kistler®, 9286BA, Winterthur, Switzerland). According to the manufacturer's recommendations, the force plate was installed on an even floor. Total path length displacement of the center of pressure (COP) was derived from medio-lateral and anterior-posterior sway. The applied sampling rate was 40 Hz and a system-imminent Butterworth filter with a low-pass cutoff frequency of 10 Hz was used (Salavati et al., 2009; Donath et al., 2012). Participants performed three attempts for each testing condition. The best trial was included into further analysis. Subjects were instructed to stand as still as possible while slightly bending their knees (~30°), placing the arms akimbo and focusing a marked spot on the nearby wall. They were not allowed to wear shoes.

To assess dynamic balancing performance, seniors had to separately complete three trials on a 6 and 4.5 cm balance beam (length 3 m). Eight forward steps within each trial should be accomplished without descending from the beam. Thus, a maximal amount of 24 steps for each balance beam was achievable. The sum of the performed steps without touching the ground was recorded for each of the two balance beam width.

The functional reach test is a valid and reliable clinical balance test and highly fall predictive for older (>70 years of age) male subjects (Duncan et al., 1992). The measured outcome is the maximal reaching distance with the dominant outstretched arm. The knees are slightly bent and the feet are closed and placed parallel. Subjects were asked to reach as wide as possible without stepping forward. The arm should be elevated on shoulder height, parallel to the ground. The maximal reaching distance within three trials was included into analysis.

Gait analyses

Prior to spatiotemporal gait analysis, the comfortable walking velocity was individually measured using two photoelectric timing gates (HL 2–31, Tag Heuer, La Chaux-de-Fonds, Switzerland). A total distance of 12 m was walked each of three times on an even hallway. Ten of the total 12 m (1 to 11 m) were analyzed for average walking velocity. To achieve a daily life-relevant target velocity, subjects were asked to walk without any pacing or rushing (e.g., go for shopping). The first trial was a familiarization trial. Then, the obtained average velocity of the three walking attempts was applied on a one-dimensional ground reaction force measuring treadmill with 5378 pressure sensors (FDM-T system, Zebris Medical GmbH, Isny, Germany; length: 1.5 m; width: 0.5 m). Data were sampled with 120 Hz. After a short testing period of about 1 min 15% below target velocity and 1 min at target velocity, data acquisition period started for 400 consecutive steps (Owings & Grabiner, 2003). We examined and analyzed stride frequency, stride width, time, and length as well as double stance phase (double support as percentage of stride time). Gait variability data were calculated applying the coefficient of variation (CoV = standard deviation of the analyzed 400 steps divided by the mean × 100%) for stride-to-stride length (spatial variability) and time (temporal variability; Faude et al., 2012).

Strength testing

Maximal isometric force or torque and rate of force/torque development (RFD, RTD) were tested for double-limb leg press as well as single-limb (left and right) leg press and plantar flexion on an isokinetic dynamometer (D&R Ferstl, IsoMed 2000, Hemau, Germany). Sampling rate was 200 Hz. A recursive Butterworth filter, with a cutoff frequency of 50 Hz was applied to raw data. For unilateral and bilateral leg press, the seat back was reclined to 45°. Hip and knee angles were individually adjusted at 100° and 120°, respectively. The hip was additionally fixed with a belt. For testing unilateral plantar flexion, the knees were not bent (hip and shinbone were fixed by a belt), the ankle was slightly flexed to 100°, and the respective foot was in 5° external rotation position. Each testing condition consisted of three maximal contractions. Before maximal trials, three series of five submaximal isometric contractions between 2 and 3 s were performed in order to become familiar with the testing. The best maximal trial was analyzed. Maximal force/torque was determined as the maximal value of the force/torque–time relationship. RFD, RTD was described as the slope of the force/torque-time curve between 20% and 80% of the maximal isometric force value. Verbal instructions and encouragement was standardized. Isometric strength testing lasted for 5 s with a post-exercise break of 1 min. In order to minimize the risk of any evasive movements, arms had to be crossed before the chest.

Submaximal endurance testing

Endurance testing was conducted on a treadmill (pulsar, HP cosmos, Nussdorf-Traunstein, Germany). Prior to the treadmill test, resting heart rate was measured while the seniors were sitting on a chair for 5 min. The average heart rate of the last 30 s was taken for further analysis. The applied exercise protocol lasted 15 min, consisting of three submaximal exercise steps (5 min each). The first step was even walking at the previously determined normal walking velocity (moderate even walking). Then, walking velocity was increased by 20% (brisk even walking). The last 5 min had to be walked with the normal velocity but with a treadmill inclination of 8% (moderate uphill walking). At the end of each exercise step, perceived exertion (RPE, CR-10 Borg scale) was requested and a capillary blood sample of 20 µL was taken from the earlobe during a 30-s rest period between steps for determination of blood lactate concentrations (enzymatic-amperometric method, Super GL ambulance, Dr. Müller Gerätebau, Freital, Germany). Heart rate was recorded continuously (Polar M62, Polar Electro, Kempele, Finland). The average heart rate of the last 30 s of each step was included in further analyses.

Stair-climbing training program

The training lasted 8 weeks and was provided three times a week by two experienced research assistants. Training attendance of the included participants was 85 ± 9% for INT_1 and 82 ± 10% for INT_2 ($P = 0.53$). A multilevel (eight levels) parking garage served as training location. The seniors of INT travelled by car or public transport to the training venue. In total, 128 steps lead to the eighth floor (16 steps per level). To avoid eccentric loads, descending the stairs was not allowed. In order to reach the ground floor, subjects had to use the elevator. To minimize fall risk, handrails were available. Subjects who needed the handrail were instructed to avoid any arm-pulling at the handrail. Each training session comprised a general warm-up (5 min: slow and fast skipping, lower limb gymnastics, dynamic stretching) and the main stair-climbing training. The number of stairs climbed within each training session increased stepwise. Because of interindividual differences of physical fitness, the total amount of ascended stairs varied between subjects. Small groups of 3 to 5 seniors with similar fitness levels and ascending velocities performed together. During weeks 1 and 2, the eight levels were on average climbed two times within each training session (total amount of session steps ranging from 128 to 320). During weeks 3 and 4, the eight levels were climbed three times (256 to 448 session steps), weeks 5 and 6, four times (384 to 896 session steps), and weeks 7 and 8, on average five times (448 to 1280 session steps). The overall vertical distance [INT_1: 1659 (349) m vs INT_2: 1556 (235) m, $P = 0.38$] as well as the totally achieved vertical work [INT_1: 1144 (290) kJ vs INT_2: 1126 (201) kJ, $P = 0.85$] during the 8-week intervention did not significantly differ between groups. At the end of each ascend, perceived exertion level using the Borg CR-10 scale was requested. In addition, heart rate (Polar M62, Polar Electro) was measured during 3 to 4 training sessions in each participant. The total individual climbing time was also recorded. Whereas heart rate [INT_1: 121 (9)/min vs INT_2: 128 (7)/min, $P = 0.05$] and perceived exertion [INT_1: 3.3 (0.5) vs INT_2: 4.1 (0.4), $P < 0.001$] were significantly higher with the two-step strategy, total climbing time [INT_1: 135 (20) min vs INT_2: 107 (27) min, $P = 0.005$] was lower in this group.

Statistics

All outcome measures are given as means with standard deviations (SD). Prior to analyses, normal distribution and homogeneity of variances were tested using the Kolmogorov–Smirnov test and the Levene test, respectively. Potential baseline differences between groups were tested by one-factorial analyses of variance (ANOVAs) for each parameter. 3 (group: INT$_1$, INT$_2$, CON) × 2 (time: pre, post) repeated measures ANOVA (rANOVA) were calculated for all static and dynamic balance as well as strength parameters. For endurance parameters (heart rate, RPE, and lactate), an additional repeating factor (intensity: moderate even walking, brisk even walking, moderate uphill walking) was included into the rANOVA. Within-group changes from pre- to posttest (with 95% confidence intervals, 95% CI) were calculated and an analysis of covariance (ANCOVA) was computed (Vickers & Altman, 2001). Thereby, pretest values were included as covariates in order to adjust for initial baseline differences between groups. In case of statistically significant between-groups differences, Tukey honestly significant difference post-hoc tests were conducted. To estimate practical relevance, effect sizes (partial eta squared, η_p^2) were calculated and given only for the between-groups effects (ANCOVA). According to Cohen (Cohen, 1988), an $\eta_p^2 \geq 0.01$ indicates a small, ≥0.06 a medium, and ≥0.14 a large effect.

Results

Balance performance

Following rANOVA analyses, we observed neither statistically significant time effects ($0.32 < P < 0.42$) nor time × group interactions ($0.10 < P < 0.63$) in COP path length displacements for all stance conditions. Moreover, the observed effect sizes were negligible. These findings did not change after ANCOVA analyses, adjusting for baseline differences (Table 2). However, we found a significant between-groups effect (ANCOVA) for balancing on the 4.5 cm wide beam ($P = 0.04$, $\eta_p^2 = 0.17$; Fig. 1) with significantly increased steps at posttest for INT$_2$ as compared with CON ($P = 0.03$) and INT$_1$ ($P = 0.07$, Fig. 1). In contrast, 6 cm balancing did not reveal a between-groups effect (ANCOVA: $P = 0.10$; Fig. 1). A significant time effect with higher values at posttest for all groups was present for the functional reach test (ANOVA: $P = 0.01$; Fig. 1), but no significant between-groups effect (Fig. 1).

Spatiotemporal gait parameters

In almost all spatiotemporal parameters, ANOVA analyses revealed neither significant time effects ($0.33 < P < 0.72$) nor time × group interactions ($0.054 < P < 0.82$) in spatiotemporal gait characteristics. ANOVA analyses revealed significant time effects for the double support period ($P = 0.02$) and spatial gait variability ($P = 0.001$). Additionally, an ANOVA time effect ($P = 0.001$) with a significant increase [+0.2 (95% CI 0.0 to 0.4) km/h] was found for habitual gait speed in all groups. After adjusting for baseline differences, ANCOVA analyses did not reveal between-group effects for all spatiotemporal gait characteristics (Table 3).

Strength

Although significant time × group interactions (ANOVA) were observed for maximal strength during bilateral ($P = 0.045$) and unilateral ($P = 0.040$) leg press, these effects disappeared after adjusting for baseline differences (ANCOVA: $0.10 < P < 0.20$, Table 3). However, the effect sizes remained at least moderate (ANCOVA: $0.09 < \eta_p^2 < 0.13$). The other maximal strength and explosive power parameters did not reveal any interaction effects (ANOVA: $0.06 < P < 0.61$). Time effects were found only for force development of right-sided plantar flexion (ANCOVA: $P = 0.008$; $\eta_p^2 = 0.18$) and maximal left-sided unilateral leg press ($P = 0.02$; $\eta_p^2 = 0.14$). Between-groups comparison (ANCOVA) adjusting for baseline differences did not affect the results (Table 4).

Resting heart rate and submaximal endurance

After adjusting for baseline differences (ANCOVA), there was a significant between-groups effect for resting heart rate ($P = 0.005$, $\eta_p^2 = 0.26$) with significantly reduced values after the training period in INT$_2$ [−8 (95% CI −14 to −2)/min] as compared with INT$_1$ [±0 (−4 to

Table 2. Changes in center of pressure (COP) path length displacement for double-limb stance, eyes closed (DLEC), and left- and right-sided single-limb stance, eyes open (SLEO) of INT-1, INT-2, and CON between pre- and posttesting

		Pre	Post	Between-group comparison (ANCOVA)	
		Mean (SD)	Mean (SD)	P	η_p^2
Spatiotemporal gait parameters					
DLEC	CON	3543 (1442)	3164 (939)	$P = 0.15$	0.10
	INT-1	2854 (831)	2537 (789)		
	INT-2	2781 (687)	2901 (825)		
SLEO_R	CON	4422 (1371)	4461 (1169)	$P = 0.16$	0.10
	INT-1	4562 (1190)	3946 (1169)		
	INT-2	4257 (1262)	4018 (959)		
SLEO_L	CON	5079 (1598)	4627 (1222)	$P = 0.90$	0.002
	INT-1	4196 (1076)	4167 (1251)		
	INT-2	4079 (1412)	3987 (1095)		

Data are provided as means with standard deviations (SD). ANCOVA results for the between-group comparison are presented together with partial eta squared effect sizes (η_p^2). Pretesting values were included as covariate. Significance level was set at $P < 0.05$

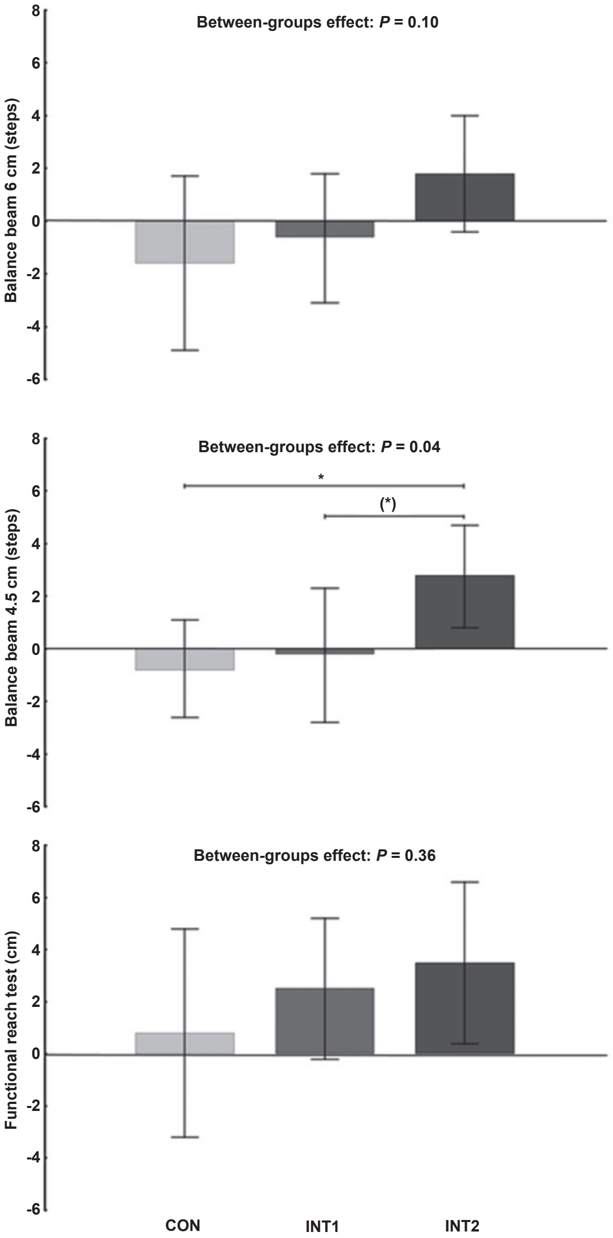

Fig. 1. Pre-post change scores [means (SD)] with ANCOVA between-group effects between groups for beam balancing (6 cm, upper panel; 4.5 cm mid-panel) and functional reach testing (lower panel). $0.05 < P < 0.10$ (*), $P < 0.05$*.

5)/min, $P = 0.02$] and CON [±0 (−3 to 3)/min, $P = 0.03$]. Within-group changes in submaximal endurance parameters from pre- to posttest for all groups are presented in Fig. 2. We observed a significant between-groups effect (ANCOVA) in all walking conditions for RPE as well as for moderate even and uphill walking for heart rate and blood lactate. Post-hoc testing revealed greater decreases in INT_2 as compared with CON for all parameters during uphill walking (heart rate: $P = 0.02$; RPE: $P = 0.001$; bLa: $P = 0.03$). In addition, RPE decrease was greater during brisk even walking in INT_2 as compared with CON ($P = 0.02$).

Discussion

The overall main result of the present study was that regular stair-climbing training did not significantly affect static balance, spatiotemporal gait characteristics, and strength performance in healthy seniors. Beneficial improvements were observed concerning dynamic balance, resting heart rate, and submaximal endurance, particularly during uphill walking, in this population. Although both ascending strategies particularly revealed notable cardiorespiratory effects, the two-step strategy revealed slightly greater improvements in most parameters.

The most pronounced training effects in the present study were the decreases in heart rate and perceived exertion during submaximal treadmill walking. After the 8-week intervention period, submaximal exercise heart rates decreased on average by 11/min during moderate uphill walking for INT_2. Similar effects were previously reported after 3 months of traditional endurance training programs in healthy, untrained middle-aged adults (Scharhag-Rosenberger et al., 2009), after 20 weeks of aerobic training in older adults (50 to 65 years; Wilmore et al., 2001), and after 26 weeks of endurance training in 70- to 79-year-old men (Hagberg et al., 1989). Such notable adaptations may contribute to decreased efforts during activities of daily life. The resulting reduction of cardiorespiratory strain was accompanied by clearly lower ratings of perceived exertion during both moderate and brisk even as well as uphill walking. Perceived exertion was decreased particularly in the intervention group which used the two-step strategy. Similar reductions in perceived exertion were reported after endurance training (Hagberg et al., 1989) as well as after 12 weeks of weighted stair-climbing (Bean et al., 2002a). Together, these findings point toward lower cardiorespiratory strain and less perceived exertion during submaximal endurance tasks in everyday life. These adaptations may contribute to a delayed onset of fatigue during exhausting real-life situations (e.g., rushing to the bus). As exhaustive exercise can acutely deteriorate balance performance (Donath et al., 2013b), these adaptations may also contribute to more safety in everyday life from a balance and fall risk perspective.

Few studies have analyzed cardiorespiratory adaptations after specific stair-climbing interventions. One study observed a decrease in submaximal exercise heart rate (7/min) during a standardized stair-climbing field test in young and sedentary women (Boreham et al., 2000). This was achieved by small amounts of daily stair-climbing (on average less than 10 min/day) over a period of 7 weeks. Another study of this workgroup with a similar population and training approach revealed an increase of 17% in maximal oxygen uptake (Boreham et al., 2005). Bean et al. (2002b) observed a significant reduction in the rate-pressure-product as well as in perceived exertion during submaximal treadmill testing in mobility-limited seniors. These authors used a weighted stair-climbing intervention lasting 12 weeks with three

Table 3. Habitual gait speed and spatiotemporal gait parameters of INT-1, INT-2, and CON for pre- and posttesting

		Pre	Post	Between-group comparison (ANCOVA)	
		Mean (SD)	Mean (SD)	*P*	η_p^2
Spatiotemporal gait parameters					
Habitual gait speed (km/h)	CON	4.6 (0.4)	4.8 (0.5)	*P* = 0.84	0.001
	INT-1	4.5 (0.4)	4.7 (0.4)		
	INT-2	4.5 (0.4)	4.7 (0.4)		
Cadence (steps/min)	CON	61.7 (4.5)	61.4 (4.8)	*P* = 0.28	0.07
	INT-1	61.2 (4.5)	62.2 (3.8)		
	INT-2	62.6 (3.8)	61.5 (2.9)		
Stride width (cm)	CON	8.8 (2.2)	8.5 (2.3)	*P* = 0.60	0.03
	INT-1	7.3 (2.8)	8.1 (3.1)		
	INT-2	8.7 (2.7)	8.9 (2.3)		
Double stride time (s)	CON	0.97 (0.07)	0.98 (0.07)	*P* = 0.11	0.12
	INT-1	0.99 (0.07)	0.96 (0.05)		
	INT-2	0.96 (0.05)	0.97 (0.04)		
Double stride length (cm)	CON	122.2 (10.05)	123.9 (10.05)	*P* = 0.17	0.10
	INT-1	120.4 (9.94)	118.7 (9.50)		
	INT-2	116.4 (12.75)	118.1 (11.26)		
Double support (%)	CON	25.7 (2.38)	25.2 (2.69)	*P* = 0.88	0.07
	INT-1	24.9 (2.39)	24.5 (2.81)		
	INT-2	26.4 (2.66)	25.7 (2.70)		
Temporal gait variability (%)	CON	1.9 (0.56)	1.9 (0.69)	*P* = 0.24	0.08
	INT-1	2.3 (1.83)	1.82 (0.50)		
	INT-2	1.6 (0.88)	1.6 (0.33)		
Spatial gait variability (%)	CON	2.6 (0.77)	2.3 (0.75)	*P* = 0.29	0.07
	INT-1	3.0 (1.46)	2.5 (0.68)		
	INT-2	2.4 (0.89)	2.0 (0.45)		

Between-group effects were calculated by ANCOVA analyses. Thereby, pre-exercise baseline values were included as covariates. Data are indicated as means with standard deviations (SD). Significance level was set at $P < 0.05$.

Table 4. Maximal force/torque and rate of force/torque development (RFD/RTD) during uni- and bilateral leg press and plantar flexion for both intervention (INT_1 and INT_2) and the control group (CON) between pre- and posttesting

		CON		INT_1		INT_2		Between-groups comparison (ANOVA)	
		Pre	Post	Pre	Post	Pre	Post	*P*	η_p^2
Maximal force leg press (N)	Bilateral	2629 (1225)	2279 (1081)	1868 (963)	1994 (880)	2142 (717)	2140 (588)	0.20	0.09
	Right leg	1717 (672)	1486 (641)	1358 (558)	1340 (464)	1408 (422)	1361 (403)	0.30	0.07
	Left leg	1746 (640)	1398 (567)	1433 (690)	1368 (637)	1440 (477)	1417 (477)	0.10	0.13
RFD leg press (N/s)	Bilateral	4337 (2167)	3777 (1997)	3446 (2027)	3702 (2317)	3301 (1220)	3836 (1530)	0.35	0.06
	Right leg	2866 (1473)	2603 (1170)	2445 (1463)	2363 (1064)	2294 (770)	2430 (657)	0.78	0.01
	Left leg	3096 (1560)	2784 (1292)	2316 (1051)	2444 (1253)	2246 (829)	2336 (727)	0.55	0.03
Maximal torque plantar flexion (Nm)	Right leg	88.5 (34.8)	88.2 (28.7)	67.1 (26.4)	74.1 (23.4)	72.5 (28.0)	75.9 (23.1)	0.70	0.02
	Left leg	83.9 (37.4)	78.2 (32.1)	63.0 (27.0)	67.6 (27.7)	64.1 (27.6)	67.0 (21.2)	0.30	0.07
RTD plantar flexion (Nm/s)	Right leg	190 (88)	185 (80)	155 (74)	178 (79)	138 (60)	179 (70)	0.15	0.10
	Left leg	187 (82)	187 (81)	140 (82)	165 (99)	149 (70)	154 (50)	0.39	0.05

Data are provided as means with standard deviations (SD). *P*-values and effect sizes (partial eta squared, η_p^2) for the between-groups comparison were calculated including pre-exercise baseline values as covariates.

sessions per week. Sessions did not last longer than 10 min. These results are very similar to our findings. Exercise intensity during stair-climbing in the present study was between 75% (INT_1) and 80% (INT_2) of estimated maximal heart rate (207–0.67 × age). Perceived exertion was between 3 and 4 on the CR-10 scale. This is lower as recommended by the American College of Sports Medicine (ACSM) for moderate physical activity (Chodzko-Zajko et al., 2009). However, a recent study showed that perceived exertion levels between 3 and 5 revealed exercise intensities of about 75% of maximal oxygen uptake or 80% of maximal heart rate in healthy, community-dwelling seniors (Donath et al., 2013a). This is very similar to the exercise intensity induced by stair-climbing in the present study. Although the total amount of work was similar between groups, training intensity was slightly greater in INT_2. This may have contributed to the greater training effects in this group.

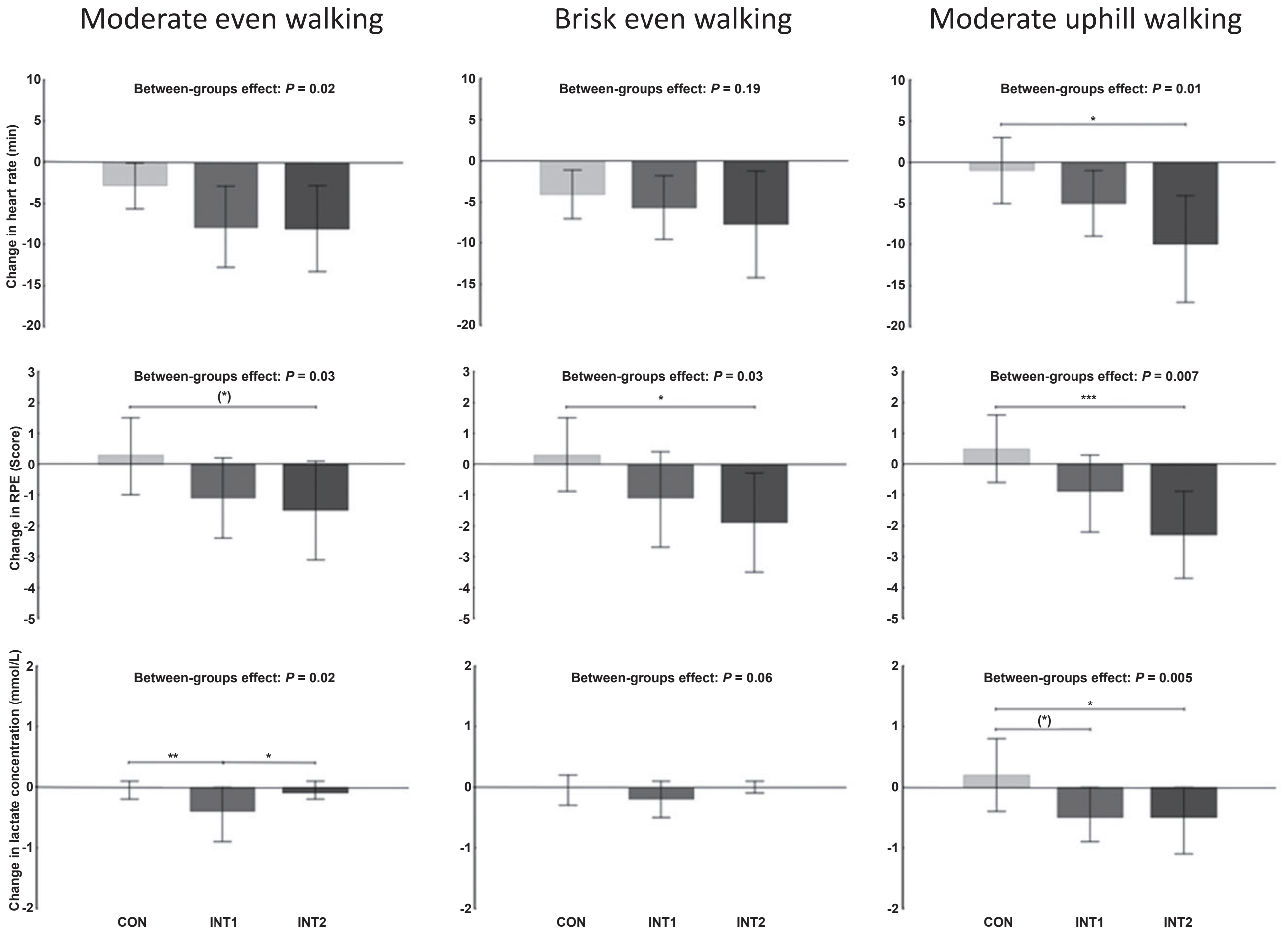

Fig. 2. Pre-post change scores [means (SD)] with ANCOVA between-group effects for heart rate (HR, upper panel), perceived exertion (RPE, mid-panel), and blood lactate concentration (bLa, lower panel) during moderate even (left side), brisk even (middle), and moderate uphill walking (right side). $0.05 < P < 0.10$ (*), $P < 0.05$*, and $P < 0.001$***.

As decreased resting heart rates have been reported to be associated with a larger vagal tone and decreased mortality (Shi et al., 1995), the reductions of resting heart rates in the present study are significant. With a reduction between 1.2 and 9.8 beats per minute (95% CI) following traditional endurance training, comparable reductions of resting heart rates have been reported in a meta-analysis (Huang et al., 2005). Thus, relatively short bouts of intense stair-climbing on a regular basis might induce similar health-related reductions of resting heart rates compared with traditional endurance training.

Leg strength and particularly leg power, i.e., the ability to produce strength quickly, have been shown to be important determinants of physical performance in mobility-limited seniors (Bean et al., 2002b). Although maximal strength during leg press decreased from pre-to posttesting in the control group and maximal strength during these tasks maintained in both intervention groups, the statistical significance of these interaction effects disappeared after adjusting for baseline differences. Similar findings were found for plantar flexion. As plantar flexion strength, particularly the rate of torque development, has been reported to be an important predictor of falls in elderly (Pijnappels et al., 2008), ankle power was increased in both intervention groups, whereas it remained nearly constant in CON. After adjusting for baseline differences, also, this finding did not remain significant. Since Bean et al. (2002a) used stair-climbing with weighted vests lasting 12 weeks and reported improvements in leg press power of 16%, it seems reasonable to assume that the present strength training stimulus (without additional weights) may have been too small in order to induce significant and relevant strength effects.

In contrast to cardiorespiratory adaptations, few changes in balance parameters occurred. There was only a significant improvement in balancing on a 4.5-cm-wide beam in the two-step strategy group. Stair-climbing requires repetitive lifting and balancing the body upwards, mainly using closed-chain movements of leg extension and plantar flexion. Such movements are usually included in balance and strength-training programs. As plantar flexion strength has been associated with balance performance in older adults (Orr et al., 2008), we initially assumed that stair-climbing can also serve as a balance and strength-training modality. With the present approach, we did not reveal relevant strength improvements. Effects to balance tasks were observed. With improvements during the functional reach test and tandem walk, one study also found adaptations during comparable balance tasks following traditional resistance training (Granacher et al., 2009). In addition, dynamic balance improvements after resistance training in older women were also reported by other authors (Holviala et al., 2006). Considering our findings, it might be plausible that also small strength stimuli within stair-climbing lead to selected dynamic balance improvements. However, it can be speculated that testing standing balance performance is not appropriate to assess specific balance adaptations resulting from stair-climbing.

Some limitations need to be addressed. Although we carefully stratified the participants prior to the start of the study due to dropouts, randomization was not perfect with regard to gender distribution, body mass, and baseline physical activity. Whereas both genders were equally distributed in CON and INT_2, INT_1 included nearly twice as many women. This may have contributed to lower baseline values in all strength parameters in INT_1 as compared with INT_2 and, particularly, to CON. However, there were no significant baseline differences in all parameters and training adaptations did not significantly differ between women and men in the main outcome parameters ($0.23 < P < 0.89$). A second limitation might be seen in the fact that we studied healthy and active seniors. We likely would have observed even greater effects in more frail, disabled, or fall-prone populations for whom physical activity interventions might be regarded as even more important as compared with already active elderly. Particular when using the two-step strategy, stair-climbing requires a stable gait and a minimum of physical fitness, which should have been fulfilled by all participants. In seniors with more pronounced mobility limitations, stair-climbing might also be a promising means to increase physical fitness during daily life. However, in such a population, safety concerns, particularly regarding fall risk, need to be considered. In order to avoid social confounders and to improve compliance, the control group received a total of three sessions of group activities within the 8-week study, which included exercise of light to moderate intensity. This was likely insufficient to result in significant improvements in physical performance in active and healthy seniors. It seems possible that a part of the training effects of both intervention groups might be due to transportation from and to the training venue. However, as the participants travelled by car or public transport (because of distance and weather conditions) to the training venue, it seems unlikely that such confounding may have occurred. Moreover, the present study did not examine the effects of both ascend and descend stair-climbing. This might be a limitation in terms of transferability and external validity, respectively. However, walking downstairs was not employed in order to (a) minimize the risk of severe falls while descending (Zietz et al., 2011; restricted space in the staircase, and therefore, danger of collisions) and (b) to determine whether benefits could be elicited using concentric exercise alone.

Perspectives

The latest ACSM position stand (Chodzko-Zajko et al., 2009) on exercise and physical activity in older adults emphasized that regular exercise can minimize the detrimental effects of a sedentary lifestyle and increase active life expectancy. In addition, psychological and cognitive benefits are likely as a result of an increased activity level. A combination of aerobic and resistance training is recommended as being more effective than either form alone. In this respect, the results of the present study provide evidence that small amounts of regular stair-climbing can result in relevant adaptations in submaximal endurance, resting heart rate, and dynamic balance in active and healthy community-dwelling elderly. No significant effects were present in static balance, strength, and gait. The observed adaptations may contribute to better overall fitness, reduced fall risk, and less exertion during daily life activities. Regular stair-climbing, thus, can contribute to a healthy lifestyle and limit the aging-induced physical decline in seniors. The observed benefits seem to be more pronounced when taking only every second step. This strategy might be suitable and effective for healthy and active seniors. More frail seniors might also benefit from using the one-step strategy. However, this remains an interesting perspective for future research. The widespread implementation of stair-climbing activities into everyday life, for instance by multicomponent campaigns (Lewis & Eves, 2012) including motivational and volitional measures such as point-of-decision prompts (Soler et al., 2010) with particular regard to relevant target groups and more frail elderly seems promising from a public health perspective.

Key words: training, neuromuscular performance, postural control, aerobic exercise, elderly, leg power.

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