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ORIGINAL ARTICLE

Balance and gait performance after maximal and submaximal endurance exercise in seniors: is there a higher fall-risk?

Lars Donath · Lukas Zahner · Ralf Roth ·
Livia Fricker · Mareike Cordes · Henner Hanssen ·
Arno Schmidt-Trucksäss · Oliver Faude

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Abstract Impaired balance and gait performance increase fall-risk in seniors. Acute effects of different exercise bouts on gait and balance were not yet addressed. Therefore, 19 healthy seniors (10 women, 9 men, age: 64.6 ± 3.2 years) were examined on 3 days. After exhaustive treadmill testing, participants randomly completed a 2-km treadmill walking test (76 ± 8 % $VO_{2\max}$) and a resting control condition. Standing balance performance (SBALP) was assessed by single limb-eyes opened (SLEO) and double limb-eyes closed (DLEC) stance. Gait parameters were collected at comfortable walking velocity. A condition × time interaction of center of pressure path length (COP_{path}) was observed for both balance tasks ($p < 0.001$). Small (Cohen's $d = 0.42$, $p = 0.05$) and large ($d = 1.04$, $p < 0.001$) COP_{path} increases were found after 2-km and maximal exercise during DLEC. Regarding SLEO, slightly increased COP_{path} occurred after 2-km walking ($d = 0.29$, $p = 0.65$) and large increases after exhaustive exercise ($d = 1.24$, $p < 0.001$). No significant differences were found for gait parameters. Alterations of SBALP after exhaustive exercise might lead to higher fall-risk in seniors. Balance changes upon 2-km testing might be of minor relevance. Gait is not affected during single task walking at given velocities.

Keywords Upright stance · Gait variability · Elderly · Older · Physical activity · Exercise training

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L. Donath (✉) · L. Zahner · R. Roth · L. Fricker · M. Cordes · H. Hanssen · A. Schmidt-Trucksäss · O. Faude
Institute of Exercise and Health Sciences, University of Basel, Birsstrasse 320B, 4052 Basel, Switzerland
e-mail: lars.donath@unibas.ch

Introduction

Increasing life expectancy seriously affects worldwide population aging and proportions. Despite regional disparities, the global percentage of the population aged ≥ 60 years was expected to increase from 10 to 32 % until the end of the present century (Lutz et al. 2008). With 46 % in the year 2100, the highest percentage of this age-group was estimated for Western Europe (Lutz et al. 2008). This apparent societal over-aging is even more critical against the background of health-care utilization and expenditures. In this regard, unintentional falls and its related injuries are considered to be major economic and public health burdens in the elderly. Depending on morbidity status, the annual fall rates of seniors aged ≥ 65 years range between 0.3 and 1.6 falls (weighted mean 0.6) per person (Rubenstein 2006) and the associated direct medical care costs amounts to $0.2 billion for fatal and $19 billion for non-fatal fall-related injuries (Stevens et al. 2006). Studies addressing circumstances and mechanisms that lead to a higher fall-risk within the process of aging are therefore mandatorily required.

Beside a variety of reported extrinsic fall-risk factors (e.g. lack of handrail, uneven terrain, twilight, obstacles), a body of evidence emphasized that aging-associated personal factors (intrinsic risk factors), such as (a) visual impairment, (b) medication intake, (c) strength deficits of the lower limb, (d) gait variability and (e) impaired balance performance should be obligatorily taken into account in terms of reducing the risk of falling in older people (de Menezes and Bachion 2008; Granacher et al. 2010a, 2011a; Kressig et al. 2008).

Several studies investigated the long-term influence of physical exercise interventions on intrinsic fall-risk factors, such as e.g. strength, balance and gait performance training in older people (Hauer et al. 2001, 2006). It has been shown, for example, that music-based multitask training (Trombetti et al. 2011) and balance as well as strength training can significantly improve both fall-risk predicting parameters (Granacher et al. 2011b). However, acute effects of exercise bouts on these fall-risk factors are rarely examined (Parijat and Lockhart 2008; Helbostad et al. 2007, 2010a). These studies predominantly reported fatigue-induced alterations of balance and gait performance due to repeated sit-to-stand tasks or various resistance exercises. Data on acute influences of maximal and submaximal aerobic exercise on balance and gait performance are not available to date. This is particularly interesting since such exercises are often prescribed for cardiovascular endurance training in the elderly or they are exposed to similar demands in everyday life.

Therefore, the present study was conducted to investigate the acute effects of a single bout of (1) exhaustive maximal endurance exercise and (2) submaximal exercise that is common during everyday life on single and double limb standing balance performance (SBALP) as well as temporal and spatial gait parameters. It was hypothesized that exercise-induced alteration of standing balance and gait performance might lead to a higher susceptibility to sustain falls in the elderly. These results might contribute to a better understanding of higher fall risks during everyday life and following certain regimes of aerobic exercise in the older and aging population.

Methods

Participants

Based on the physical activity readiness questionnaire (PAR-Q), medical history was taken and physical examination was performed in 19 active seniors (Table 1), who took part in the present study. All participants did not report any medication intake and relevant health impairments, such as orthopedic, neurological and internal diseases that may affect standing balance and gait performance. Moreover, all participants had to successfully complete a 12-lead electrocardiogram (ECG) during rest and maximal exercise. The participants were additionally asked to refrain from any severe exercise within the last 72 h prior to the examination days. The study was approved by the local ethics committee (Ethikkommission beider Basel, EKBB, Basel, Switzerland) and complied with the Declaration of Helsinki. All participants signed an informed written consent prior to the start of the study.

Study design

The present study was conducted as semi-randomized controlled cross-over trial. All participants were examined on 3 days in weekly intervals. On each day, measurements were intra-individually performed at the same time of day. Due to the required exercise-ECG (Custo cardio 100, Custo med GmbH, Ottobrunn, Germany), the first day was obligatorily set as maximal exercise test. Before starting maximal exercise testing, the “Freiburg physical activity questionnaire” (Frey et al. 1999) and the “Fall efficacy scale” (FES-I, validated German version) (Helbostad et al. 2010b) were applied in order to obtain secondary physical activity and fear of falling data. On the second and third day, either the submaximal 2-km walking test or the resting control condition was randomly conducted. Balance and gait testings were conducted before and after each interventional condition.

Interventions

Maximal exercise test

On the first day, a maximal exhaustive ramp-like exercise test on a treadmill (h/p Cosmos, Pulsar 4.0, HP-Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany) was performed. A well-established age-adapted exercise protocol was applied. This walking-based “Pepper-protocol” combines the increase of inclination (%) and velocity (miles per hour) and is described in detail elsewhere (Peterson et al. 2003). Briefly, this exercise protocol started with an inclination of 0 % and a velocity of 1.5 m per hour. Exercise intensity was increased every minute by elevating either treadmill inclination or velocity until subjective maximal exhaustion level was reported. After reaching objective spiroergometric exhaustion levels in order to obtain maximal oxygen uptake (heart rate above age-predicted maximum, respiratory exchange ratio (RER): > 1.15) (Midgley et al. 2007), subjects immediately underwent standing balance and gait testing.

Submaximal 2-km exercise test

In accordance to Oja et al. (1991), a submaximal 2-km walking test was conducted on the same treadmill of the maximal exercise test. The corresponding velocity and inclination of the CR-10 Borg-value of “four” during maximal exercise testing was used to determine a moderate exercise intensity for the 2-km exercise test. The subjects were requested to perform a total distance of 2 km at this exercise intensity.

Table 1 Anthropometric, physical activity and exercise data of the participants

	Women ($n = 10$)	Men ($n = 9$)	Total ($n = 19$)
Personal data			
Age (years)	64.6 ± 3.7	64.6 ± 2.7	64.6 ± 3.2
Weight (kg)	63.2 ± 10.1	76.6 ± 7.8	69.6 ± 11.2
Height (m)	1.62 ± 0.05	1.79 ± 0.05	1.70 ± 0.10
BMI (kg m^{-2})	24.1 ± 3.5	23.9 ± 2.6	24.0 ± 3.0
Physical activity (h $Woche^{-1}$)	12.5 ± 6.0	9.2 ± 5.0	11.0 ± 5.5
FES-I	16.4 ± 0.7	16.3 ± 0.5	16.4 ± 0.6
Maximal ramp-test			
t (min)	22.7 ± 2.1	22.9 ± 3.7	22.8 ± 2.9
VO_{2max} (L min^{-1} kg^{-1})	32.4 ± 4.1	30.1 ± 5.8	31.3 ± 4.5
HR_{max} (min^{-1})	168 ± 8	163 ± 11	165 ± 10
RER	1.19 ± 0.10	1.29 ± 0.08	1.24 ± 0.10
RPE	9.4 ± 1.0	9.7 ± 0.5	9.5 ± 0.8
Submaximal 2-km walking test			
t (min)	28.5 ± 4.0	26.8 ± 3.1	27.7 ± 3.6
VO_2 (L min^{-1} kg^{-1})	23.5 ± 4.9	24.9 ± 4.4	24.2 ± 4.6
VO_{2max} (%)	72 ± 7	77 ± 5	75 ± 6
HR (min^{-1})	131 ± 8	124 ± 9	127 ± 10
RER	0.90 ± 0.08	0.97 ± 0.09	0.94 ± 0.09
RPE	3.7 ± 0.8	4.3 ± 0.9	4.0 ± 0.9
BR(min^{-1})	30 ± 5	28 ± 7	29 ± 6

BMI body mass index, *physical activity* derived from the Freiburger physical activity questionnaire, *FES-I* sum score of the validated German version of fall efficacy scale questionnaire, *t* exercise time during the maximal ramp-like exercise test, VO_{2max} oxygen uptake, *HR* heart rate, *RER* respiratory exchange ratio, *RPE* subjectively perceived exertion level at the Borg CR-10 scale, *Borg* averaged perceived exertion level during the 2-km walking test, *BR* breathing rate; data are provided as mean ± SD

Resting control condition

To provide an individual control measure, patients underwent a resting control condition in standardized supine posture without any postural demands or other distraction. They wore comfortable clothes, but no sport wear. The examination room was kept silent, with comfortable temperature between 21 and 24 °C. In order to provide a feasible and inter-individually objective and standardized real resting condition with reduced potential influences of any interfering external and internal effects during sitting or standing, we have chosen the supine position. Thus, subjects remain in a supine position within the similar timeframe (~ 30 min) of the performed or estimated 2-km exercise time, respectively.

Testing procedure

Standing balance parameters

Following a 5-min familiarization period before pre-measurements by trying all relevant standing balance positions (two times, 10 s for each condition), the testing procedure was started immediately after a short post-familiarization break of 3 min. The piezoelectric Kistler® force platform (KIS) was used to assess SBALP and installed on a flat and rigid laboratory floor according to the manufacturer's installation requirements. Compared to strain gauge-basing systems, piezoelectric measures produce a very small signal drift. Despite a drifting signal, piezoelectric force plates are, however, regarded as suitable in terms of force-plate basing standing balance measures (Middleton et al. 1999). In addition, such a potential but negligible bias would occur during all conditions and tasks and, thus, it seems unlikely that the present results would be affected. Laboratory light (~500 luces), temperature (21 °C) and air humidity (60 %) were kept stable. The order of measured standing balance tasks was double limb stance with closed eyes (DLEC) first and second, single limb stance with open eyes (SLEO). The dominant leg for SLEO was determined via the lateral preference inventory (Coren 1993). Three attempts for each standing balance task were performed. Both standing balance tasks were tested for 30 s, followed by a post-exercise break of 1 min.

The participants were instructed in a standardized manner to (a) perform without shoes, (b) place their feet comfortably, nearly parallel at approximately shoulder-width on the platform, (c) place the hands on the hips, (d) bend the knees slightly and (e) stand as still as possible while focusing a marked circle at the nearby wall (distance: 1.5 m; height: 1.75 m).

Gait parameters

Before starting the gait analysis, the individual comfortable walking velocity was measured using two photoelectric timing gates (Tag Heuer, HL 2-31, la Chaux-de-Fonds, Switzerland). Therefore, all participants were instructed to walk a total distance of 12 m in an even hallway for three times. 10 of the total 12 m (1–11 m) were measured in order to calculate the average walking velocity. To mirror everyday walking conditions, subjects were requested to walk normally (like going for a walk), without rushing, acceleration or deceleration. Each subject had one free trial. Then, the average velocity of the three consecutive walking attempts was applied on a one-dimensional ground reaction force measuring treadmill (Zebris Medical GmbH, FDM-T system, Isny, Germany) for gait analysis. This treadmill was different from the one used during maximal and submaximal exercise testing. After a short familiarization period of 1 min, 10 % below the target velocity and one additional minute at the target velocity, data acquisition started. Subjects had to walk 400 steps on the treadmill at their a priori evaluated comfortable walking velocity.

Secondary outcome variables

Heart rates (Accurex Plus, Polar Electro-Oy, Kempele, Finland) and gas exchange data were collected during maximal and submaximal exercise testing in order to achieve (a) objective maximal exhaustion level and (b) a controlled submaximal ventilatory and cardiac exercise response during the 2-km walking test.

Data acquisition and analysis

Standing balance measurements

Standing balance data were collected within a time frame of 30 s using a frequently applied sampling rate in postural control measures of 40 Hz (Granacher et al. 2010b). As single limb balance tasks—in contrast to the bipedal stance—are usually performed for 10 s (Clark et al. 2010), we calculated center of pressure (COP) path lengths for a 10-s interval between the 5th and 15th second of the total 30 s data acquisition time. To avoid high frequency noise contamination, a system-immanent and commonly employed Butterworth filter with a low pass cut-off frequency of 10 Hz was applied to the time-related signals (Salavati et al. 2009) of the KIS ground reaction forces. Total center of pressure (COP) path length serves as outcome measure, which has been frequently applied to determine SBALP (Clark et al. 2010; Salavati et al. 2009). Out of the three consecutive repetitions for both standing balance tasks, the mean of the two shortest COP path lengths of the three attempts were included into statistical analyses.

Gait analysis

Temporal and spatial gait parameters, such as mean stride frequency (steps/min), stride width (cm), double stride time (seconds) and length (cm) as well as double stance length were obtained during 400 steps of comfortable walking velocity. The relevant gait parameters were averaged over the required 400 walking steps (Owings and Grabiner 2003). Gait variability data were calculated using the coefficient of variances (CoV) for temporal and spatial stride-to-stride length and time. Both parameters were indicated as percentage values.

Maximal and submaximal ventilatory and heart rate data

Spiroergometric data were collected using a breath-by breath spirometric system (Metamax 3B, Cortex, Leipzig, Germany). These data were averaged to provide data points for each 10 s time-interval. The mean of the highest three consecutive VO_2 values within a 30-s time frame of the final exercise step was regarded as maximal oxygen uptake ($VO_{2\text{max}}$). Additionally, the highest recorded heart rate, RER, and perceived exertion level (Borg-scale, CR-10) were considered as maximal exercise values. These data were recorded to provide a standardized and objective maximal physical exhaustion level during maximal exercise testing. Percentages of $VO_{2\text{max}}$ and HR_{max} were given to indicate the ventilatory and heart rate response during the submaximal 2-km Borg-paced walking test.

Statistical analysis

First, data were tested for normal distribution (Kolmogorov–Smirnov Test) as well as homogeneity of variances (Levene Test) and were provided as mean and standard deviations (SD). All dependent parameters were analyzed by two (SLEO, DLEC) separately conducted 2 (time: pre, post) × 3 (repeating factors, condition: maximal exercise, submaximal exercise, control condition) repeated measure analysis of variances (rANOVA). Follow-up Tukey HSD post hoc tests were separately conducted in case of a significant main condition effect or condition × time interaction.

Effect sizes (Cohen's d, trivial: $d < 0.2$, small: $0.2 \leq d < 0.5$, moderate: $0.5 \leq d < 0.8$, large $d \geq 0.8$; Cohen 1992) and the percentage changes of the COP path length displacements between pre- and post-measures for maximal exercise, submaximal exercise and the control condition during SLEO and DLEC were additionally calculated. Statistical significance level was set at $p < 0.05$.

Results

Anthropometric and exercise performance data

All data are presented in detail in Table 1. Both groups consist of homogeneous distributed male and female subjects. No gender differences were found regarding anthropometric and physiological variables. Included subjects did not report fear of falling, were physically active and not overweighted. Maximal exercise parameters indicated good physical fitness (relative oxygen uptake) and objective exhaustion occurred during maximal exercise testing. Submaximal exercise was performed at moderate perceived exertion and around 75 % of maximal oxygen uptake.

Static SBALP

Significant condition × time interactions were observed both for SLEO ($F = 29.7$, $p < 0.001$) and DLEC ($F = 23.2$, $p < 0.001$). However, post hoc testing solely revealed significant differences of COP path length between pre and post testing following maximal endurance exercise for SLEO and DLEC (Fig. 1). Submaximal exercise did not affect both standing tasks. Merely the supine control condition leads to decreased path length during SLEO. Moreover, a significant time-effect for SLEO ($F = 31.8$, $p < 0.001$) and DLEC ($F = 51.1$, $p < 0.001$) was found. Detailed means and SDs with its significance levels are presented in Table 2.

Regarding percentage changes and effect size calculation of postural sway alterations between pre and post testing, small decreases of COP_{path} were found at the control day (DLEC: -8 %, effect size (d) $= 0.21$, $p = 0.60$; SLEO: -22 %, $d = 0.47$, $p = 0.04$). In turn, small (sub: +18 %, Cohen's $d = 0.42$, $p = 0.05$) as well as large (max: +52 %, $d = 1.04$, $p < 0.001$) increases of COP_{path} were found following submaximal 2 km and maximal walking during DLEC. Similarly during SLEO, slightly increased COP_{path} were found after the 2-km walking test ($\sim$+15 %, $d = 0.29$, $p = 0.65$) and large increases after exhaustive exercise ($\sim$+88 %, $d = 1.24$, $p < 0.001$).

Temporal and spatial gait analysis data

A significant time × condition interaction was merely found for double stance phase ($p = 0.004$). However, post hoc testing did not reveal significant differences between pre and post testing. The detailed rANOVA results including means and differences are provided in Table 3.

Discussion

To our knowledge for the first time, the present study revealed evidence that maximal and submaximal endurance exercise bouts affect SBALP during single and double limb stance in population of healthy and active seniors. Compared to the relatively small alterations of postural sway following submaximal 2-km exercise testing, large effect sizes and percentage changes of COP path length displacements were observed after maximal exhaustive walking exercise. In contrast, no relevant changes of temporal and spatial gait parameters were observed within the 400 steps of treadmill gait analysis at individually given walking velocities and under single task condition for all three testing conditions.

The observed elevations of COP path length displacements, especially pronounced during single limb stance, suggest that at least healthy and active seniors showed elevated fall-risk parameters following exhaustive physical exercise. Beside exercise-induced alterations of respiration and otolith function that may influence postural control (Schmid et al. 2004; Charles et al. 2002), also central and peripheral fatigue processes might contribute to this finding (Helbostad et al. 2010a). However, we did not objectively measure neuromuscular fatigue, by e.g. EMG activity patterns, in order to address this issue with certainty. With respect to comparatively alterations of postural sway, previous findings in adults revealed similar percentage changes and effect sizes upon maximal exercise in adults (Gauchard et al. 2002) and younger subjects (Nardone et al. 1997). Nevertheless, baseline COP path length data have been shown to be more elevated in seniors (Abrahamova and Hlavacka 2008). It can be additionally assumed that prolonged walking with repetitive eccentric components may lead to alterations of proprioception, potentially by alterations of mechanoreceptors function (Riskowski et al. 2005) and an overstimulation of the otolith function (Lepers et al. 1997; Charles et al. 2002).

Although maximal exhaustive exercise bouts with similar high exercise intensities are less common during daily life in much older, co-morbid or even frail seniors, higher

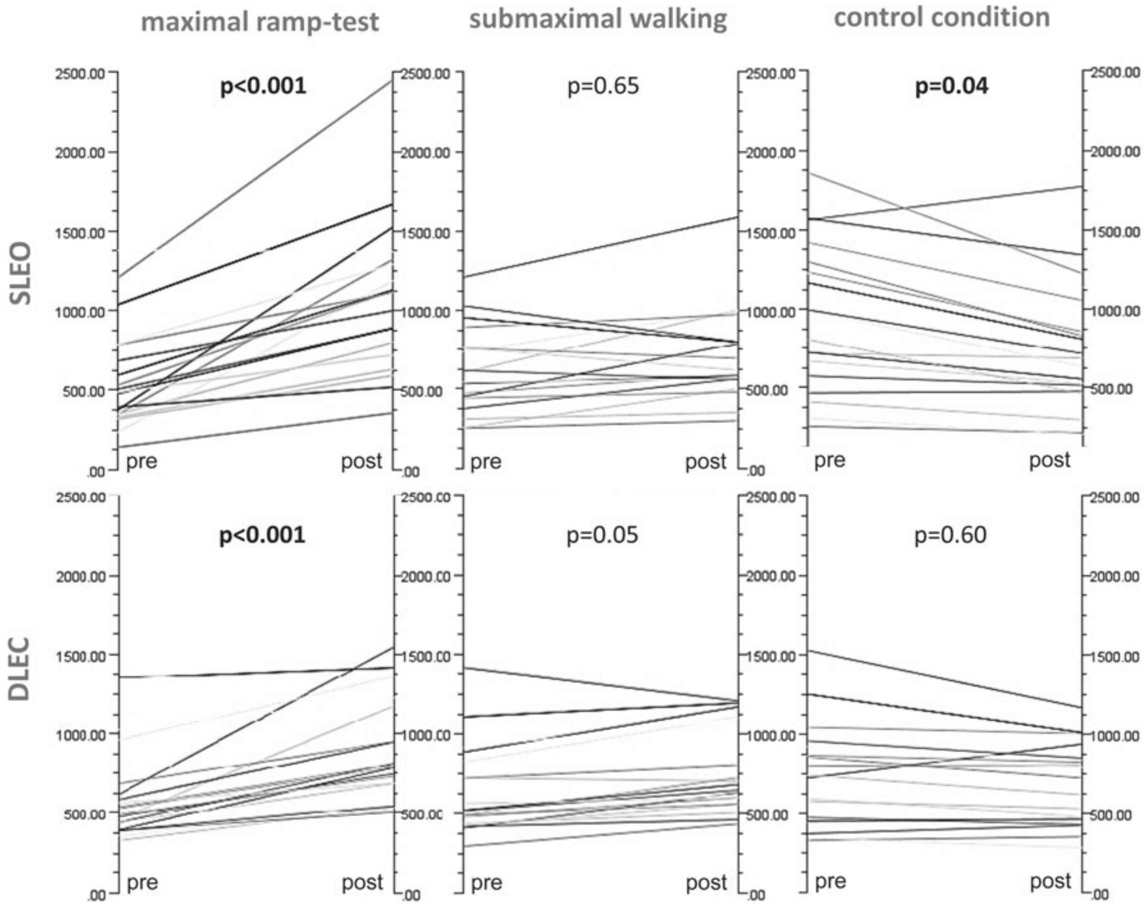

Fig. 1 Single data line-plots between pre and post testing during single limb stance-opened eyes (SLEO, upper three charts) and double limb stance-eyes closed (DLEC, lower three charts) for the maximal ramp-like exercise test (**a**), submaximal 2-km walking test (**b**) and control condition (**c**). *P* values of the Tukey HSD post hoc tests are provided for each chart. Significant level was set at $p < 0.001$***; $p < 0.01$*** and $p < 0.05$*

Table 2 Pre and post center of pressure (COP) path length displacements (mm) after maximal exercise, submaximal 2-km testing and control condition during single limb-eyes open (SLEO) and double limb-eyes closed (DLEC) upright stance

	Pre	Post	Cohen's *d* effect size
SLEO			
Maximal	577 ± 332***	1,083 ± 482	+1.24
Submaximal	661 ± 314	761 ± 368	+0.29
Control	961 ± 466*	754 ± 408	−0.47
DLEC			
Maximal	582 ± 263***	884 ± 317	+1.04
Submaximal	640 ± 282*	754 ± 263	+0.42
Control	746 ± 320	685 ± 254	−0.21

exercise intensities might occur at least in active and sportive seniors, e.g. when hiking, rushing to the bus or train, or during specific high-intensity exercise programs. High intensity exercise training applying several short bouts of nearly maximal individual intensity (e.g. 4 times, 4 min at 95 % of maximal heart rate) has been increasingly considered to be beneficial in various clinical and non-clinical populations (Kemi and Wisloff 2010). Considering these contexts, also higher exercise intensities seem reasonable in this certain group of fit and healthy seniors. Independent of seniors' fitness and health state, an appropriate time of post-exercise recovery should then be warranted in order to avoid immediate exercise- or fatigue-associated falls. This recommendation is of greater importance since younger athletes need 15 post-exercise minutes to sufficiently recover to baseline performance of

Table 3 Temporal and spatial gait parameters for the three conditions (maximal, submaximal, control) during pre and post testing

Gait parameter	Maximal exercise test		Submaximal 2-km test		Control condition		rANOVA		
	Pre	Post	Pre	Post	Pre	Post	Time (*p*)	Condition (*p*)	Condition × time (*p*)
Stride frequency (steps min^{-1})	62.1 ± 4.3	61.8 ± 4.4	61.3 ± 5.3	60.1 ± 4.6	60.1 ± 5.5	60.1 ± 5.0	0.237	0.104	0.484
Stride width (cm)	8.7 ± 2.6	8.3 ± 2.8	8.9 ± 2.5	8.6 ± 2.5	8.8 ± 2.4	8.7 ± 2.5	**0.031**	0.162	0.394
Double stride time (s)	0.97 ± 0.07	0.98 ± 0.07	0.99 ± 0.09	1.00 ± 0.09	0.99 ± 0.09	0.99 ± 0.08	0.421	0.058	0.418
Double stride length (cm)	132.1 ± 12.5	131.4 ± 12.7	134.5 ± 12.1	135.1 ± 11.4	134.8 ± 12.1	134.5 ± 11.0	0.793	**0.001**[a]	0.663
Temporal gait variability (%)	1.9 ± 0.010	1.8 ± 0.8	1.5 ± 0.7	1.4 ± 0.4	1.4 ± 0.4	1.4 ± 0.4	0.301	**0.001**[a]	0.782
Spatial gait variability (%)	2.4 ± 1.1	2.4 ± 1.0	2.2 ± 1.0	2.0 ± 1.0	2.0 ± 1.0	2.0 ± 1.0	0.804	**0.009**[a]	0.223
Double stance phase (%)	25.0 ± 2.2	24.7 ± 2.3	24.4 ± 2.9	24.5 ± 2.5	24.2 ± 2.5	24.5 ± 2.5	0.906	0.329	**0.004**[b]

Data are provided as mean ± standard deviation. Temporal and spatial gait variability data were presented as percentage values of coefficient of variance (CoV) data of double stride time (temporal) and double stride length (spatial)

[a] Post hoc testing revealed differences between maximal and submaximal as well as maximal and control

[b] Post hoc testing did not reveal significance differences for any condition and time

postural control (Fox et al. 2008). Unfortunately, it is not clear in which time-frame older adults are able recover from exercise-induced alterations of SBALP to baseline COP path length displacements. Further studies are needed to address this issue with repeated measure time-series analyses of standing balance parameters after exercise in the elderly.

Alterations of SBALP following submaximal endurance exercise bouts have been found to be less pronounced in seniors. Differences concerning single limb stance between pre and post testing were not within statistical significance. Percentage changes between pre and post testings were less than 20 % and the calculated effect sizes were merely moderate. Thus, these changes seem to be of minor practical relevance.

Regarding potential standing balance training approaches, it appears reasonable to assume that visual impairment might additionally increase exercise-induced alterations of postural control since the process of aging results in a more vision-based sensory feedback during upright standing balance tasks (Colledge et al. 1994). In accordance to findings of Chapman and Hollands, it might be paid attention on applying open-eyed dynamic balance tasks pre-dominantly to improve the role of vision during feed forward mechanisms, for example, random goal-orientated stepping tasks (Chapman and Hollands 2006a). This more obstacle-orientated approach might also be beneficial since older adults particularly need to look earlier ahead to future stepping targets and fix them for a longer period of time to place their feet accurately (Chapman and Hollands 2006b).

With respect to the gait analysis, we did not find relevant alterations of temporal and spatial gait parameters after a submaximal and maximal bout of endurance exercise. Despite an condition × time interaction of the double stance phase and condition effects of double stride length and temporal as well as spatial gait variability, we did not find post hoc differences between pre and post testing following both exercise regimes. Interestingly, the observed condition effects might be addressed to a familiarization effect since the maximal exercise test was always conducted first. Generally, walking at given velocities and under single task condition appears as a relative stable and rigid pattern. However, further studies should address fatigue-induced gait alterations (a) under dual- and multi-task condition, (b) during gait analysis without given velocities on a treadmill and (c) in older, less active and frailer seniors with notably higher fall efficacy scores.

Some limitations need to be addressed concerning the present study. We solely investigated healthy, active and less frail seniors without any health impairments. Further cross-sectional and prospective studies are required in more fall-prone and fragile older seniors with additional health impairments. Compared to the included subjects, it seems plausible that seniors with more cardiovascular or cardiocirculatory comorbidities will not achieve such maximal exercise intensities during everyday life. It seems merely likely that larger alteration of postural sway and temporal and spatial gait parameters may occur even following submaximal exercise regimes in this population. Moreover, the present results show merely general response of static and dynamic postural control following exercise in an active and physically fit population of seniors and, thus, should not interpreted interchangeably with comorbid subject suffering from any age-related diseases. Healthy and fit elderly are still able to achieve exhaustive exercise intensities and participate in sport programs. From a health-care perspective, also these subjects are relevant. The present data also does not allow comparative age-related conclusions of deteriorations of postural sway following both exercise regimes. We cannot address with certainty whether the amount of these particular endurance exercise-induced alterations of balance performance will be similarly occur in young adults or seniors suffering from any cardiac, metabolic or neurological disease that frequently occur in seniors. Concerning gait analysis, we did not examine gait parameters during normal gait at different velocities. Treadmill walking is known to represent a kind of artificial walking. Also investigations addressing the recovery time frame to baseline COP path length displacements are needed in order to estimate the "open-window" of an exercise-induced higher risk of falling. Such recovery time-frame data are, however, available at least in young adults (Nardone et al. 1997). Moreover, the study was merely semi-randomized since the first day has to be set as an exhaustive exercise-ECG in order to exclude any adverse exercise-induced cardiac events. The control condition was performed without shoes and at the same intra-individual time of day, but with normal street clothes. This fact might explain the systematically elevated baseline path length at the control day. This assumption underpins the finding of Heller and colleagues, who reported elevated path length when wearing a bag pack (~15–20 % of bodyweight). Slightly heavier clothes (jeans, sweater) may also lead to prolonged COP path lengths. Despite decreasing COP path lengths during the control day might suggest a learning effect, we would assume that the more sedative and recovering supine position during the control day might lead to a higher parasympathical drive, which in turn may induced an even stiller and quieter upright stance. However, further research would be needed to address this issue with certainty.

In conclusion, SBALP is notably affected following maximal aerobic endurance exercise of a total duration between 20 and 30 min in active and healthy seniors. Following a submaximal everyday-life endurance exercise, for example, walking or shopping, or an aerobic exercise training session seniors showed slightly impaired static SBALP. Dynamic balance during gait is not relevantly affected in this age-group. To more thoroughly address changes in fall-risk factors as a consequence of submaximal endurance exercise, further studies with asymmetric loads, different walking distances and intensities seem to be warranted in young adults, seniors with and without common comorbidities and risk factors, respectively, such as smoking (including COPD), obesity, diabetes, high blood pressure or cardiac disease (CHD, CHF).

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Conflict of interest None declared.

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