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Research article

The beneficial effects of acute strength training on sway activity and sway regularity in healthy older men: Evidence from a posturography study

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ABSTRACT

The effects of acute strength training on balance control were studied in healthy older human men (age-range 60–77y). Participants performed the Tandem Romberg Stance while completing an attention demanding cognitive task (Mathematical Counting) before and after a single acute strength training session applied to the lower limb musculature (experimental group; n = 19) or no intervention (control group; n = 18). Balance stability and the automaticity of balance control were estimated through the calculation of the center-of-pressure (CoP) velocity (Vcop) and the statistical regularity (wavelet entropy) of the CoP trajectory (WEcop), respectively. Training included 3 sets of 3 repetitions of barbell squats using Smith Machine, ranging from 90 % of one repetition maximum (1RM) to 100 % 1RM with 3 min rest between repetitions and 5 min rest between sets. Vcop and WEcop decreased after training (all time main effects, $p \leq 0.028$) but group time interactions were not significant (all, $p \geq 0.056$). Exploratory analyses revealed that participants in the experimental group showed a significant decrease of Vcop and WEcop in the mediolateral (ML) directions from pre to post [ML Vcop: 15.4 %; Bonferroni-corrected $p = 0.048$); ML WEcop: 10.5 %; Bonferroni-corrected $p = 0.016$]. A trend towards a decrease in Vcop and WEcop was also observed in controls, with more prominent gains in the anteroposterior than in the ML direction (Bonferroni-corrected $p > 0.2$). Overall, findings suggest that acute strength training may improve attentional control of balance along the narrow dimension of the support. Further studies are warranted to examine the specific mechanisms underlying these findings.

1. Introduction

Balance and postural control impairments are major contributors to falls and loss of functional mobility in older adults over 65 years of age [1]. The negative effect of age on balance and postural control can be attributed to sensorimotor dysfunctions [2], muscle weakness [3], and structural changes in brain grey and white matter [4]. Balance control may be improved, nonetheless, through recruitment of attention to reach sufficient level of balance control [5]; possibly as a compensatory strategy to reinforce postural control in challenging dual- and multi-task conditions [6]. However, the availability of attentional resources and the ability to allocate attention toward a postural task is expected to become more demanding in challenging balance conditions, especially for old adults since resource limitations are expected to trigger a resource prioritization process in this population [7]. Increasing ability to allocate attentional resources to the balance task in older adults is, therefore, of great relevance as it can have implications for improving balance control and preventing fall incidents among the aging population.

Balance instability and attentional control of movements can be quantified from the center of pressure (CoP) measurements by examining the amount of sway and the statistical regularity (entropy) of the CoP trajectory, respectively [8]. In healthy individuals with no neurological disorders, decrease in the statistical regularity scores (as manifested by an increase in CoP entropy) is expected to be associated with a decreased deployment of attention to the postural task [8–10]. For example, Drozdova-Statkevičienė et al. [10] showed that sway entropy and sway activity in healthy older adults become positively correlated under dual task but not under single task conditions, suggesting that older adults can reduce dual-task interference effects by allocating more

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attentional resources to the postural task and reducing automatized control of balance.

The overall evidence suggests that exercise interventions involving physical activity have beneficial effects on cognitive and motor functioning, could effectively preserve brain structural and functional integrity, and lower the risk of developing cognitive and motor impairments [11–14]; see review [15]. Importantly, muscular strength development induced by strength training is underpinned by combination of multiple morphological and neural factors [16], which could foster potential (beneficial) training outcomes across different levels of the neuromuscular system. These beneficial effects can effectively improve functional mobility, cognitive control, and induce neuropathic changes in the aging brain [12]. Besides gains on muscle strength and physical functioning (e.g. static/dynamic balance and mobility) [14,15], strength training was also found to be an effective means to improve cognitive functioning and attentional control either after a chronic intervention [17] or a single bout of exercise [18,19]; although other studies reported no beneficial effects [20,21]. In addition, much of the previous research into the impact of strength training on balance control and attention (as well as on the interplay between postural stability and attentional control) lacks evidence for the mechanisms underlying balance improvements. In this exploratory study, we aim to examine the effect of a single bout of strength training on both CoP entropy and CoP sway activity as well as on the effect of this intervention on the associations between the two aforementioned measures. The research question addressed in this study revolves around the effect of acute strength training on attentional control of balance. Specifically, we examined whether single acute strength training positively influences allocation of attentional resources to the postural task (i.e., increasing regularity of the CoP trajectory) and improve balance stability (i.e., reducing sway activity) immediately after the intervention.

2. Methodology

2.1. Subjects

Participants were 38 older men (age range: 60–77 years) who were divided into two groups: experimental (n = 20) and control (n = 18) in a pseudo random order based on day of birth (odd days – control group; even days – experimental group) and participant entry to the research (the latter was used to compensate for unequal sample size). Participants were not aware about the actual purpose of the study but were informed about the acute intervention and were told that testing will involve examination of their postural stability with and without a mathematical counting task. In few occasions, participants were less keen to undergo the strength training exercise (or control intervention). These participants were reallocated to the opposite group whenever possible or otherwise were excluded from the study. The participants were free of any physical and/or neurological disorders, and were screened for cognitive impairment with the Mini–Mental State Examination (MMSE) test using the cut-off score of 24. MMSE scores were equal to or greater than 26. Participants did not report using any medications or drugs that could act on the nervous system and/or affect motor/cognitive functions, were free of chronic pain, did not have strength training for the last 6 months and did not experience any pain during data collection. All participants signed an informed consent form before their inclusion in the study. The study was approved by the Kaunas Regional Biomedical Research Ethics Committee (License No. BE-2-46). All participants were asked to complete a questionnaire about their demographic data, physical activity habits, and health status prior to their inclusion in the study. One participant in the experimental group did not complete the full testing protocol and was not included in the study. Mean (SD) of age, anthropometric characteristics, and scores on the MMSE test of the included participants (n = 37) are shown in Table 1.

Table 1
(a) Group means (± SD) of participants age, anthropometric characteristics, scores on the MMSE test. **(b)** Baseline values of AP and ML Vcop and EWcop in the TRS-S (baseline) postural paradigm.

Variable	Experimental group (n = 19)	Control group (n = 18)	p-value (*t* -test)
(a)			
Age (years)	67.4 ± 4.4	68.1 ± 5.2	> 0.9
Weight (kg)	78.3 ± 9.0	75.6 ± 7.8	> 0.6
Height (cm)	177.4 ± 4.9	175.7 ± 4.2	> 0.6
BMI (kg/m^2)	24.8 ± 2.2	24.5 ± 2.1	> 0.7
MMSE (points)	29.4 ± 0.7	29.2 ± 0.9	> 0.4
(b)			
AP Vcop (mm/s)	18.6 ± 4.7	19.1 ± 5.3	> 0.8
ML Vcop (mm/s)	17.8 ± 5.6	17.9 ± 6.1	> 0.9
AP WEcop (au)	0.48 ± 0.12	0.47 ± 0.06	> 0.8
ML WEcop (au)	0.42 ± 0.10	0.41 ± 0.06	> 0.7

au = arbitrary units; TRS-S = Tandem Romberg stance as a single task; BMI = Body Mass Index; MMSE = Mini–Mental State Examination. 1RM measures were collected only for participants in the Experimental group and as such were not included in the Table.

2.2. Intervention and experiment protocol

Data collection and training of the subjects were conducted at the Lithuanian Sports University between January 2017 and December 2018. All participants were tested on the same time of the day between 9–11 a.m. The intervention consisted of an acute resistance exercise which included barbell squats using Smith Machine. The participants arrived at the laboratory two times on separate days, with 2–3 days between visits. On the first day (day 1) participants in both the experimental group (EG) and the control group (EC) were familiarized with the postural task. Participants in the experimental group underwent in addition a familiarization session with the intervention and were instructed how to perform the squats correctly. The training protocol followed the recommendations of Fragala et al. [22] for resistance training in older adults related. Following the familiarization training session, one repetition maximum (1RM) was calculated for each participant in the EG that was used for training (in the second visit). For the assessment of the 1RM, a standard 1RM testing protocol was used as outlined by the National Strength and Conditioning Association [23,24] and the predicted 1RM was calculated using an online 1RM calculator https://exrx.net/Calculators/OneRepMax [25]. In the second visit (day 2), participants underwent the full testing protocol. Prior to the onset of the testing protocol participants were instructed to rest in a sitting position for 15 min during which their heart rate (HR) was measured using a pulse meter (SIGMA PC 25.10) and then were asked to complete the pre-test (PRE) measurements of the postural task. Participants of the EG underwent a warming up session that included **10** min cycling on a veloergometer (Monark 834E) at a power output of 60−80 W and a cadence of 50–60 rpm, which resulted in a heart rate of 120–140 beats/min. The resistance exercise included 3 repetitions of 90 % 1RM (with 3 min rest between repetitions); 5 min rest; 3 repetitions of 95 % 1RM (3 min rest between repetitions); 5 min rest; and 3 repetitions of 100 % 1RM (3 min rest between repetitions). Heart rate (HR) was measured during the whole period of the acute strength training. Participants of the CG were instructed to stay in a waiting room for 45 min while seated and were allowed to read magazines or interact with the experimenters. Following the end of the intervention (or waiting time), post-test measurements (POST) were conducted.

2.3. Experimental measurements

A posturography method with a single piezoelectric force plate (KISTLER, Switzerland, Slimline System 9286) was used to measure postural sway activity. The signals collected from the force plate were digitized at 100 Hz and were stored on PC for an off-line analysis. The application point (center of pressure - CoP) of the measured foot-ground reaction forces in the anteroposterior (AP) and mediolateral (ML) directions was calculated based on the known geometric locations of the piezoelectric transducers. Participants were instructed to step, barefoot, on the force plate, to place their feet in a heel-to-toe position along the midline of the platform and to stand still in this Tandem Romberg stance position with eyes open. The positioning of the feet were determined in the familiarization trial to allow maximum conformability of the subject. The selected foot positions remained the same for all the testing trials. CoP recordings were made under two experimental conditions: *(i)* Tandem Romberg stance as a single task (TRS-S) which was performed once before intervention and was used as baseline, *(ii)* Tandem Romberg stance while performing a Mathematical Counting task (TRS-MC) that was repeated before and after the intervention. Each condition was repeated 3 times (with approximately 1 min between two consecutive trials), resulting in a total of 9 trials per participant: three baseline TRS-S trials, three pre-test TRS-MC trials, and three TRS-MC post-tests trials. Data collection lasted 25 s of which the last 20 s were taken for data analysis. The first 5 s prior to data collection were used to allow participants to accommodate to the required standing position. The Mathematical Counting task was similar to that used by Drozdova-Statkevičienė et al. [10]. Negative or positive one-digit integer-numbers (10 in total) were presented vocally in each trial at 2 s intervals and participants were instructed to calculate and remember the sum. At the end of each trial participants were asked to verbally report the correct answer. For example, the correct answer "10″ was expected for the numbers [+6, +8, −3, +9, −5, −1, +6, −8, −4, +2]. Participants were instructed to concentrate on the calculation and to memorize the calculated sum in their mind at each step throughout the trial. All participants were familiarized with the Tandem Romberg stance and the Mathematical Counting task on day 1 and again before the start of the experiment on day 2.

2.4. Data processing and statistics

Prior to all analyses, mean and linear trends of the AP and ML components of the CoP trajectory were subtracted and spectral analysis was performed to determine the frequency characteristics of the raw signals. Since 99 % of the overall power of the signals was below 15 Hz and contribution of higher frequencies was nearly zero, a fourth-order low pass Butterworth bi-directional filter with a cutoff frequency of 15 Hz was applied. CoP velocity vector (Vcop) and wavelet entropy (WEcop) [10,26] were calculated from the displacement vector of the CoP, using a custom-written MATLAB script (MathWorks, Natick, MA). Wavelet entropy is a metric that combines wavelet decomposition and entropy to estimate the degree of order/disorder of the displacement vector of the CoP with a high time-frequency resolution [26] and can be used to measure the automaticity and regularity of postural control [8–10]. The posturographic dependent variables Vcop and WEcop were averaged over the three repeated trials at baseline (i.e., TRS-S condition) and in the TRS-MC task conditions before (TRS-MC-pre) and after (TRS-MC-post) the intervention with acute strength training (for participants in the experimental group) or after a 45 min waiting time (for participants in the control group). A repeated measure analysis of covariance (ANCOVA) with the baseline value (respectively, the sway activity or sway regularity measures at the TRS-S condition; see Table 1) as a covariant was performed on the data acquired in the TRS-MC-pre and TRS-MC-post conditions to examine the effects of intervention on sway activity (as assessed by Vcop) and sway regularity (as assessed by WEcop). Upon visual inspection of the postural data, exploratory paired t-tests were performed to test PRE to POST differences (gains) within each group and for Vcops and WEcop AP and ML components separately and a Bonferroni correction was applied (corrected p-value = raw p-value × 8; see Table 2 for details). Finally, the relationship between sway activity gains (as assessed by pre-to-post decrease of Vcop) and sway regularity gains (as assessed by pre-to-post decrease of WEcop) was examined with the Pearson's correlation test for each of the two groups. Gains were expressed as percentage of the pre-to-post differences in the two measures relative to their pre-measures: i.e., Gain = 100 × |Post-Pre|/Pre. Positive values indicate improvement of balance (i.e., a decrease of Vcop and WEcop from PRE to POST) whereas negative values indicate deterioration of balance (i.e., an increase of Vcop and WEcop from PRE to POST). Gains were calculated for each individual, separately, and were averaged within each group. All statistical analyses were performed with SPSS for Windows software (version 20.0). The level of significance was set at $p < 0.05$.

Table 2
Group means (± SD) pre to post differences (gains) of posturographic outcome measures in the dual-task postural paradigm (TRS-MC).

	Variable	TRS-MC Pre	TRS-MC Post	Pre-to-Post gain (% change from Pre)[1]	Exploratory pairwise *t* -test (corrected p-value)[2]
Experimental group (n = 19)	AP Vcop (mm/s)	21.2 ± 6.6	18.1 ± 6.1	12.2 ± 21.8	0.088
	ML Vcop (mm/s)	19.6 ± 6.8	16.6 ± 7.7	15.4 ± 20.8	**0.048**
	AP WEcop (au)	0.51 ± 0.08	0.46 ± 0.10	9.1 ± 15.3	0.088
	ML WEcop (au)	0.47 ± 0.07	0.42 ± 0.09	10.5 ± 14.6	**0.016**
Control group (n = 18)	AP Vcop (mm/s)	20.9 ± 6.4	18.8 ± 5.2	5.1 ± 28.6	0.264
	ML Vcop (mm/s)	20.2 ± 7.0	18.6 ± 6.2	2.1 ± 35.1	0.608
	AP WEcop (au)	0.45 ± 0.08	0.41 ± 0.06	6.6 ± 17.4	0.272
	ML WEcop (au)	0.43 ± 0.07	0.42 ± 0.05	2.6 ± 13.4	1.000

au = arbitrary unit; TRS-MC = Tandem Romberg stance + Mathematical Counting.

[1] Gains were calculated for each individual, separately, and were averaged within each group.

[2] P-values were corrected for multiple comparison with the Bonferroni correction (corrected p-value = raw p-value × 8). Significant Pre-to-Post gains (corrected ps ≤ 0.048) are indicated in **bold**.

3. Results

3.1. Sway activity

Group means (± SD) of AP and ML of Vcop and pre-to-post gains are summarized in Table 2. Results of the time × group ANCOVA for AP and ML Vcop measures revealed a significant main effect for time [AP Vcop: $F(1,35) = 9.81$, $p = 0.004$; ML Vcop: $F(1,35) = 10.8$, $p = 0.003$] but not for group [both AP and ML Vcop: $F(1,34) \leq 1.10$, $p > 0.3$]. The time × group interactions were not significant [both AP and ML: $F(1,35) < 1$]. Exploratory pairwise comparisons revealed a statistically significant pre-to post decline of ML Vcop (Bonferroni-corrected $p = 0.048$) and a trend towards a significant decline of AP Vcop (Bonferroni-corrected $p = 0.088$) in the experimental group (Table 2). No significant pre-to-post changes in Vcop measures were found in the control group [both AP and ML Vcop: Bonferroni-corrected $p \geq 0.264$], albeit a slight trend towards lower AP Vcop was observed at post-test over pre-test.

3.2. Sway regularity

Group means (± SD) of AP and ML of WEcop and pre-to-post gains are summarized in Table 2. Results of the time × group ANCOVA for AP and ML WEcop measures revealed a significant main effect for time [AP WEcop: $F(1,35) = 13.2$, $p = 0.001$; ML WEcop: $F(1,35) = 5.35$, $p = 0.028$] but not for group [both AP and ML WEcop: $F(1,34) \leq 2.16$, $p > 0.1$]. A marginally significant time × group interaction effect was found for the ML WEcop [$F(1,35) = 3.96$, $p = 0.056$] whereas the time × group interaction effect for AP WEcop was not significant [$F(1,35) < 1$]. Exploratory pairwise comparisons revealed a statistically significant pre-to post decline of ML WEcop (Bonferroni-corrected $p = 0.016$) and a trend towards a significant decline of AP WEcop (Bonferroni-corrected $p = 0.088$) in the experimental group (Table 2). No significant pre-to-post changes in WEcop measures were found in the control group [both AP and ML WEcop: Bonferroni-corrected $p \geq 0.272$]. Again, a slight trend towards a declining AP WEcop can be observed at post-test.

3.3. Association between sway activity and sway regularity gains

The results of the Pearson's correlation test revealed a significant positive correlation between pre-to-post gains on Vcop and pre-to-post gains on WEcop in the experimental group ($r = 0.471$, $p = 0.042$), but not in the control group ($r = 0.094$, $p > 0.7$); see Fig. 1. In line with this observation, we suggest that improvement in balance stability (i.e., decreased sway activity) following the acute strength training was associated with increased sway regularity.

4. Discussion

The aim of the present study was to examine the beneficial effects of acute strength training on postural stability and balance control in a group of older healthy adults. Overall, our observations indicated that a single bout of high-intensive strength training led to a decrease of sway activity and an increase in sway regularity in both the mediolateral (ML) and anterior-posterior (AP) directions, thus improving balance control. Yet, results of the ANCOVA showed no significant group or time × group interaction effects, suggesting that pre-to post-test improvements on the balance tasks occurred in both groups. For participants in the control group, trends towards improvements in the abovementioned measures of postural stability and regularity were observed mainly in the AP directions. Given that gains were also found in the control group, one should not exclude the possibility that a decrease in sway activity and an increase in sway regularity were partly influenced by test-retest learning effect effects, albeit these testing effects were more pronounced for balance control in the AP than in the ML direction. Importantly, pre-to-post improvements in postural regularity following the intervention were observed specifically in the ML direction. This observation could hint at the possibility that pre-to-post gains in attentional (conscious) control of balance were more prominent for sway along the narrow dimension of the support.

The current study is, to the best of our knowledge, the first one to test the beneficial effect of acute strength training on sway activity and sway regularity in healthy older adults. Our findings can be discussed, nonetheless, in light of evidence obtained from previous studies that showed improved cognitive functions and attention following acute exercise intervention [17–19]. In line with these findings, it is tempting to suggest that the improvement in balance control following the intervention with acute strength training group may occur, partly, due to improving attentional control of posture [27], as signified in our study by the increased sway regularity. In addition to possible beneficial effects on attention, balance control can also be affected by increased corticomotor excitability which have been reported to occur immediately after the end of the intervention and often sustain more than an hour post-intervention [28,29]. Endocrine factors such as increased levels of testosterone and cortisol [30] may also be considered as mediating factors for improving attentional control of balance. However, at the absence of additional neurophysiological measures, the underlying mechanisms explaining the positive effects of acute strength training on balance control could not be assessed directly from the current findings.

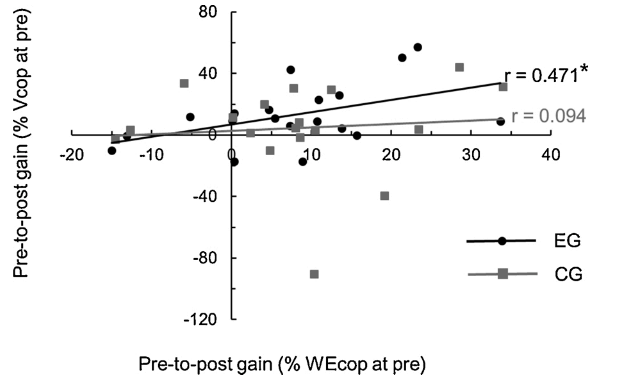

Fig. 1. Associations between pre-to-post gains on the two posturographic outcome measures. Positive values indicate an improvement of balance and negative values indicate a deterioration of balance from pre-to-post. * $p < 0.05$. EG = experimental group (n = 19). CG = control group (n = 18).

Increased allocation of attentional resources to the postural task have been previously shown to be a contributing factor for improving balance stability [8–10,27]. Evidence also suggests that attention control (and executive functions in general) can be temporarily enhanced by a single bout of exercise involving strength and/or endurance training [17–21]; however, note that literature has emerged that offers contradictory findings [31–33]. In line with these observations, it was expected that participants in the intervention group, who showed substantial decrease in sway activity will also show a high degree of sway regularity. The aforementioned supposition is supported by the findings of a significant positive association between pre-to-post gains in sway activity and sway regularity (Fig. 1). The fact that improvements in sway activity and/or sway regulatory occurred in some but not in all participants in the experimental group points at inconsistent responding to the intervention. This inconsistency may be explained by differences in baseline physical conditions of the participants [31] or genetic factors [34].

Finally, study limitations should be announced, specifically but not exclusively: (1) the lack of follow-up tests to determine the extent by which the immediate beneficial effects observed here sustained beyond the first 15 min following the end of the intervention, and (2) the inability to determine possible underlying mechanisms that might mediate the observed effects. Nonetheless, findings from the current study showing improvements in automatic control of balance in some of the participants should encourage further research into the effects of strength training on central processes. Testing the same participants under control and training conditions on separate days should be considered in order to increase statistical power, eliminate possible confounding effects of inter-individual variations, and prevent pre-to-post learning effects.

CRediT authorship contribution statement

Margarita Drozdova-Statkevičienė: Data curation, Investigation, Project administration, Writing - original draft. **Vida Janina Česnaitienė:** Data curation, Investigation, Project administration, Writing - original draft. **Oron Levin:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Visualization, Writing - review & editing. **Lisa Pauwels:** Validation. **Kazimieras Pukėnas:** Formal analysis. **Werner F. Helsen:** Validation, Writing - review & editing. **Filip Staes:** Validation, Writing - review & editing. **Nerijus Masiulis:** Conceptualization, Methodology, Supervision, Writing - review & editing.

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