ACUTE POSITIVE EFFECTS OF EXERCISE ON CENTER-OF-PRESSURE FLUCTUATIONS DURING QUIET STANDING IN MIDDLE-AGED AND ELDERLY WOMEN

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ABSTRACT

Fukusaki, C, Masani, K, Miyasaka, M, and Nakazawa, K. Acute positive effects of exercise on center-of-pressure fluctuations during quiet standing in middle-aged and elderly women. *J Strength Cond Res* 30(1): 208–216, 2016—Acute effects of exercise on postural stability have been studied with a focus on fatigue. This study investigated the acute effects of moderate-intensity exercise on center-of-pressure (COP) fluctuation measures in middle-aged and elderly women. Thirty-five healthy women volunteered: 18 women performed a moderate aquatic exercise session for 80 minutes and 17 remained calm in a sitting position for the same duration. Center-of-pressure fluctuations during quiet standing were recorded for 60 seconds with eyes open and closed before and after the exercise and sitting tasks. The time- and frequency-domain measures of the COP time series were calculated. The frequency-domain measures were also calculated for the COP velocity time series. According to 2-way analysis of variance and paired *t*-tests with a Bonferroni's correction, mean velocity of COP fluctuations, mean velocity of COP fluctuations in the medial-lateral (ML) direction, and total power of the COP velocity time series in the ML direction exhibited significant reductions after 1 session of exercise. These results indicated that a moderate-intensity aquatic exercise decreased COP velocity, counteracting age-related and fatigue-inducing postural deterioration. Therefore, we concluded that a single session of moderate-intensity aquatic exercise has acute positive effects on postural stability in middle-aged and elderly women.

KEY WORDS posture, posturography, static balance, aging, aquatic exercise

INTRODUCTION

Loss of postural stability is one of the most commonly occurring age-related declines in physical functioning (43). Along with muscle strength, postural balance is essential for the high-quality performance of activities of daily living (ADLs) in older age (11,17) and is strongly associated with a risk of falls. Impaired postural balance has been known to cause increased incidences of falls (44). Furthermore, the World Health Organization (51) has reported that falls lead to 20–30% of mild to severe injuries and account for 40% of all injury deaths and that falls are a frequent cause of admission into hospitals and may result in postfall syndrome encompassing dependence, loss of autonomy, confusion, immobilization, and depression, thus leading to further restrictions in ADLs.

One of the major interventions to improve postural balance is regular exercise. For instance, exercising over a period of several weeks, including walking (3), power training (42), aquatic exercise (46), or Tai Chi (49), has been shown to enhance postural stability in elderly adults. Besides the long-term effects of exercise on postural balance, the acute effects of exercise have been investigated with a focus on fatigue. Center-of-pressure (COP) fluctuations during quiet standing increased because of localized muscle fatigue (36,50) and strenuous general fatigue (39,40), which suggested that postural stability deteriorated after a single session of fatiguing exercise and raised concern regarding the increased risks of falls afterwards (23,50).

However, our previous study (15) demonstrated that COP fluctuations slowed down after a single session of moderate-intensity exercise. In that study, middle-aged and elderly women with lower extremity arthritis performed a moderate-intensity aquatic exercise. We observed slowing down of COP fluctuations after the exercise within the power spectrum distributions of the COP and COP velocity time series. Although these changes in COP fluctuations contrasted with those related to age (14,45), they were consistent with results suggesting improvement in postural stability, similar, for

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instance, to the effects observed in treatments of Parkinson disease (33). Thus, the results of our previous study (15) indicated the acute positive effects of exercise on postural balance.

We assumed that the acute positive effects of exercise we observed mainly resulted from the nonsevere exercise intensity and study population involved. The population in our previous study (15) comprised middle-aged and elderly women with lower extremity arthritis who had difficulty with postural control and reduced sensitivity of joint position sense (19,21). This relatively huge inability to control their postural balance might have produced a detectable positive change after a single exercise session. Difficulty with postural control and reduced sensitivity of joint position sense have also been noted in normal aging (29,34). Therefore, we hypothesized that acute positive effects on postural stability after a single session of moderate-intensity exercise would be observed in healthy middle-aged and elderly adults who had better postural stability than the patient population but who had experienced a gradual deterioration of postural control (4,12). This study aimed to test this hypothesis. Fitness consultants and instructors are required to be careful about the deterioration of postural balance and increased risks of falls after exercise as mentioned above. If the study hypothesis is proven to be correct, they will have another option to provide 1 session of exercise for improving postural stability in middle-aged and elderly individuals.

METHODS

Experimental Approach to the Problem

To investigate the acute effects of exercise on postural stability, a nonexercise group (i.e., the control group) of similar age and physique to the exercise group (i.e., the experimental group) was asked to perform seated rest for the same duration as the exercise intervention. Postural stability was evaluated by measuring COP fluctuations during quiet standing, which was expected to be sensitive to changes in postural stability (12) and had previously been used to demonstrate fatigue effects of exercise on postural stability (36,39,40,50). The change in COP measures induced by exercise was compared with that induced by seated rest through a 2-way analysis of variance (ANOVA) in addition to the comparison between preintervention and postintervention values. We adopted a single session of aquatic exercise as the experimental intervention because it demonstrated the potential to positively affect postural stability in our previous study (15).

Subjects

Thirty-five middle-aged and elderly women volunteered to participate in this study. As in our previous study (15), only women were enrolled in the study. Individuals who had joint and circulatory diseases and who were taking medications were excluded from the study. Eighteen women participated in an aquatic exercise session, and 17 performed a seated rest session. The average age, height, and weight of the aquatic exercise group were 60.1 ± 5.2 years (range, 51–70 years), 155.6 ± 6.4 cm, and 53.8 ± 8.6 kg, respectively, and those of the seated rest group were 62.4 ± 7.0 years (range, 50–73 years), 156.6 ± 5.0 cm, and 50.1 ± 5.3 kg, respectively. This study was designed and conducted in accordance with the Helsinki Declaration and was approved by the Research Ethics Committee of The University of Tokyo. Before participation in the study, subjects' written informed consent was obtained pursuant to the law.

Procedures

In the aquatic exercise group, COP was measured before and after the exercise session, which lasted for 80 minutes. The seated rest group remained in a calm sitting position for 80 minutes and COP was measured before and after the session. All postmeasurements were completed within 30 minutes after the aquatic exercise and seated rest sessions.

An 80-minute aquatic exercise session consisted of a 10-minute warm-up, a 20-minute session of whole body stretching and strength exercises, 20 minutes of fast walking, a 5-minute break, 20 minutes of walking with arm movements using kickboard and water noodle, and a 5-minute cool down. The strength exercise was conducted using drag forces of water and consisted of upper body exercise, such as biceps curl, triceps curl, shoulder flexion and extension, and shoulder abduction and adduction, and lower-body exercise, such as knee flexion and extension, hip flexion and extension, and hip abduction and adduction. A 100-cm-deep pool was used, and water temperature was around 31° C. During the exercise session, heart rate (HR) was measured at 5-second intervals using an HR monitor (Polar Vantage NV; Polar Electro Oy, Kempele, Finland) to calculate mean HR during exercise. Exercise intensity was calculated using the percent age-predicted maximal HR (%HR_{max}), where the maximal HR was estimated on the basis of the formula published by Gellish et al. (16): $HR_{max} = 206.9 - (0.67 \times \text{age})$.

For COP measurements, subjects stood barefoot in an upright position on a force platform (Gravicorder GS3000; ANIMA Corp., Tokyo, Japan) for 60 seconds. The measurements were conducted twice: first with eyes open and subsequently with eyes closed. During the measurements, subjects were asked to stand as still as possible with their arms at their sides and their feet together and to look straight ahead at a point on a wall 3 m away for the eyes open measurement. Subjects practiced this procedure at least 3 times in preliminary trials to get accustomed to it. Center-of-pressure sway area (in square millimeters per second) and mean velocity (in millimeters per second) on the 2 consecutive occasions of measurement were compared. Additional measurements were performed when the percentage difference between the 2 consecutive values was greater than 5%.

Time-domain measures such as sway area, mean velocity, and root mean square (RMS, in millimeters) were calculated for the COP displacement sampled at a rate of 20 Hz. Root mean square was calculated as RMS of resultant distance, which is the vector distance from the mean COP to each pair of points in the anterior-posterior (AP) and medial-lateral (ML) directions. In addition, mean velocity and RMS were calculated for each COP time series in the AP and ML directions.

Frequency-domain measures calculated for each COP time series in the AP and ML directions included total power (in square millimeters), mean power frequency (in hertz), 50% power frequency (in hertz), and 95% power frequency (in hertz). Fifty percent and ninety-five percent power frequencies were defined as the frequencies below which 50 and 95% of the total power was observed, respectively. All of these time- and frequency-domain measures were calculated according to the definition by Prieto et al. (45).

The COP AP and ML time series were further differentiated to derive the COP velocity time series for the AP and ML directions, respectively. Similar to our previous study (15), the same frequency-domain measures as the COP time series were calculated for these COP velocity time series.

Statistical Analyses

The data are expressed as mean ± *SD*. For each eye condition, a 2-way mixed factorial ANOVA (group × time; group = between subjects, aquatic exercise and seated rest groups; time = within subjects, preintervention and postintervention) was performed to compare the effects of interventions (the aquatic exercise and seated rest sessions). In addition, a paired *t*-test with a Bonferroni's correction was performed to compare preintervention and postintervention

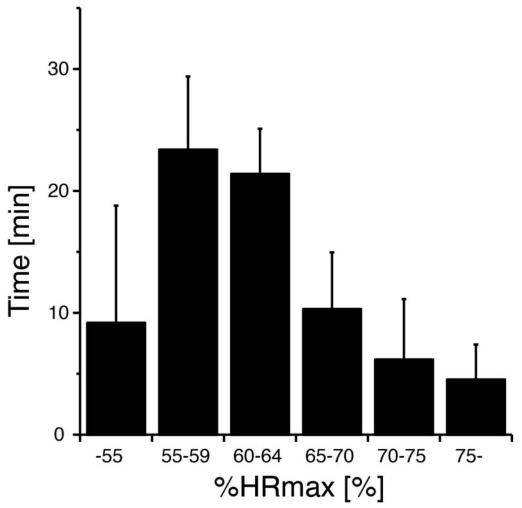

Figure 1. Exercise intensity and duration of the aquatic exercise session (mean ± *SD*). A 5-minute break was excluded from the total exercise duration.

Table 1. Time-domain measures of COP fluctuations.*

	Eyes open				Eyes closed			
	Aquatic exercise		Seated rest		Aquatic exercise		Seated rest	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Sway area ($mm^2 \cdot s^{-1}$)	4.35 ± 2.24	4.20 ± 2.27	3.95 ± 2.03	3.77 ± 1.71	6.99 ± 4.56	6.69 ± 4.29	6.29 ± 3.50	6.52 ± 3.07
Mean velocity ($mm \cdot s^{-1}$)	11.2 ± 2.7	10.5 ± 2.2†	11.2 ± 2.9	11.4 ± 3.2‡	16.9 ± 4.4	15.5 ± 3.3†	16.3 ± 4.0	17.1 ± 0.5‡
Mean velocity–AP ($mm \cdot s^{-1}$)	7.30 ± 1.67	7.18 ± 1.75	6.28 ± 1.29	6.38 ± 1.55	11.0 ± 3.1	10.3 ± 2.4	9.63 ± 2.86	9.89 ± 3.28
Mean velocity–ML ($mm \cdot s^{-1}$)	6.94 ± 2.18	6.16 ± 1.46†	7.83 ± 2.91	7.97 ± 3.26‡	10.6 ± 3.1	9.30 ± 2.55†	11.1 ± 3.2	11.7 ± 4.8‡
RMS (mm)	6.69 ± 2.14	6.08 ± 1.80	6.09 ± 1.43	5.95 ± 1.63	7.32 ± 2.04	7.36 ± 2.22	7.35 ± 1.96	7.33 ± 1.62
RMS–AP (mm)	5.49 ± 2.13	4.75 ± 1.50	4.58 ± 1.02	4.36 ± 1.26	5.49 ± 1.85	5.74 ± 1.99	5.38 ± 1.66	5.32 ± 1.41
RMS–ML (mm)	3.72 ± 0.95	3.74 ± 1.23	3.94 ± 1.26	3.94 ± 1.44	4.74 ± 1.34	4.56 ± 1.18	4.90 ± 1.55	4.94 ± 1.29

*COP = center-of-pressure; RMS = root mean square; AP = in the anterior-posterior direction; ML = in the medial-lateral direction.
†Significant difference between the preintervention and postintervention values by *t*-test with a Bonferroni's correction, $p \leq 0.05$.
‡Significant interaction effect analyzed for eye condition by analysis of variance, $p \leq 0.05$.

Table 2. Frequency-domain measures of the COP time series.*

	Eyes open				Eyes closed			
	Aquatic exercise		Seated rest		Aquatic exercise		Seated rest	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Total power–AP (mm^2)	13.1 ± 12.1	10.7 ± 8.2	8.06 ± 3.07	7.10 ± 2.76	14.0 ± 9.6	16.5 ± 13.7	12.8 ± 7.6	11.3 ± 6.1
Total power–ML (mm^2)	6.77 ± 4.12	7.14 ± 5.09	7.81 ± 6.24	8.37 ± 7.09	11.3 ± 8.3	9.95 ± 6.54	12.2 ± 8.1	11.0 ± 6.4†
Mean power frequency–AP (Hz)	0.195 ± 0.076	0.207 ± 0.058	0.180 ± 0.047	0.220 ± 0.104	0.299 ± 0.085	0.269 ± 0.076	0.251 ± 0.063	0.265 ± 0.073
Mean power frequency–ML (Hz)	0.265 ± 0.095	0.240 ± 0.107	0.259 ± 0.070	0.272 ± 0.098	0.325 ± 0.111	0.294 ± 0.112	0.308 ± 0.103	0.335 ± 0.069
50% power frequency–AP (Hz)	0.088 ± 0.045	0.103 ± 0.054	0.081 ± 0.042	0.114 ± 0.085	0.194 ± 0.095	0.158 ± 0.069	0.128 ± 0.082	0.131 ± 0.069‡
50% power frequency–ML (Hz)	0.134 ± 0.078	0.132 ± 0.084	0.115 ± 0.071	0.136 ± 0.081	0.183 ± 0.102	0.168 ± 0.088	0.175 ± 0.103	0.179 ± 0.064
95% power frequency–AP (Hz)	0.712 ± 0.253	0.756 ± 0.189	0.681 ± 0.170	0.746 ± 0.256	0.915 ± 0.224	0.853 ± 0.204	0.842 ± 0.174	0.907 ± 0.259
95% power frequency–ML (Hz)	0.976 ± 0.265	0.830 ± 0.322§	0.954 ± 0.160	0.950 ± 0.222	1.15 ± 0.21	1.06 ± 0.32	1.10 ± 0.24	1.22 ± 0.23‖

*COP = center-of-pressure; AP = in the anterior-posterior direction; ML = in the medial-lateral direction; ANOVA = analysis of variance.
†Significant time effect analyzed for eye condition by ANOVA, $p \leq 0.05$.
‡Significant group effect analyzed for eye condition by ANOVA, $p \leq 0.05$.
§Significant difference between the preintervention and postintervention values by *t*-test with a Bonferroni's correction, $p \leq 0.05$.
‖Significant interaction effect analyzed for eye condition by ANOVA, $p \leq 0.05$.

TABLE 3. Frequency-domain measures of the COP velocity time series.*

	Eyes open				Eyes closed			
	Aquatic exercise		Seated rest		Aquatic exercise		Seated rest	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Total power–AP (mm^2)	47.9 ± 21.9	47.7 ± 24.8	35.1 ± 17.0	37.4 ± 20.5	109 ± 63	95.0 ± 44.8	87.4 ± 52.9	88.7 ± 59.4
Total power–ML (mm^2)	47.7 ± 33.8	35.3 ± 17.0†	58.5 ± 52.8	62.9 ± 53.7‡	108 ± 70	79.0 ± 43.4†	112 ± 73	137 ± 126‡
Mean power frequency–AP (Hz)	1.34 ± 0.26	1.30 ± 0.22	1.39 ± 0.38	1.33 ± 0.34	1.40 ± 0.23	1.34 ± 0.31	1.42 ± 0.35	1.43 ± 0.40
Mean power frequency–ML (Hz)	1.31 ± 0.21	1.29 ± 0.20	1.36 ± 0.25	1.34 ± 0.23	1.38 ± 0.15	1.33 ± 0.16	1.47 ± 0.22	1.47 ± 0.23
50% power frequency–AP (Hz)	1.00 ± 0.21	0.98 ± 0.18	1.04 ± 0.36	0.96 ± 0.33	1.04 ± 0.17	1.05 ± 0.26	1.05 ± 0.37	1.10 ± 0.41
50% power frequency–ML (Hz)	1.10 ± 0.18	1.11 ± 0.23	1.13 ± 0.24	1.09 ± 0.20	1.22 ± 0.15	1.20 ± 0.21	1.25 ± 0.18	1.28 ± 0.20
95% power frequency–AP (Hz)	3.62 ± 0.72	3.53 ± 0.67	3.73 ± 0.62	3.58 ± 0.73	3.70 ± 0.68	3.51 ± 0.77	3.89 ± 0.79	3.74 ± 0.85§
95% power frequency–ML (Hz)	3.10 ± 0.60	3.04 ± 0.41	3.35 ± 0.79	3.30 ± 0.67	3.06 ± 0.48	2.94 ± 0.41	3.51 ± 0.75	3.45 ± 0.77‖

*COP = center-of-pressure; AP = in the anterior-posterior direction; ML = in the medial-lateral direction; ANOVA = analysis of variance.
†Significant difference between the preintervention and postintervention values by *t*-test with a Bonferroni's correction, $p \leq 0.05$.
‡Significant interaction effect analyzed for eye condition by ANOVA, $p \leq 0.05$.
§Significant time effect analyzed for eye condition by ANOVA, $p \leq 0.05$.
‖Significant group effect analyzed for eye condition by ANOVA, $p \leq 0.05$.

values for each COP fluctuation measure. The data were considered statistically significant if $p \leq 0.05$. All statistical analyses were performed using IBM SPSS Statistics 19 (SPSS Japan Inc., an IBM Company, Tokyo, Japan).

RESULTS

Exercise Intensity in Aquatic Exercise Session

Figure 1 shows the exercise intensity (%HR_{max}) and duration of the exercise session. Mean HR was 102.6 ± 5.7 $b \cdot min^{-1}$, which corresponds to an exercise intensity of 61.4 ± 2.9% HR_{max}.

Time-Domain Measures of Center-of-Pressure Fluctuations

According to 2-way ANOVA, there were significant interaction effects in mean velocity with eyes open ($p = 0.025$) and closed ($p = 0.003$) and mean velocity of the COP ML time series (mean velocity in the ML direction) with eyes open ($p = 0.019$) and closed ($p = 0.004$) (Table 1). Bonferroni-corrected paired t-tests revealed significant differences between pre- and post-exercise values in mean velocity with eyes open ($p = 0.049$) and closed ($p = 0.018$) and mean velocity in the ML direction with eyes open ($p = 0.043$) and closed ($p = 0.009$). There were no significant differences between preseated and postseated rest values in any parameter.

Frequency-Domain Measures of Center-of-Pressure Time Series

There was a significant interaction effect in 95% power frequency in the ML direction with eyes closed ($p = 0.005$) (Table 2). A significant group effect was found in 50% power frequency in the AP direction with eyes closed ($p = 0.025$), and a significant time effect was found in total power in the ML direction with eyes closed ($p = 0.039$). There was a significant difference between pre- and post-exercise values in 95% power frequency in the ML direction with eyes open ($p = 0.024$). No significant differences were found between preseated and postseated rest values in any parameter.

Frequency-Domain Measures of Center-of-Pressure Velocity Time Series

There were significant interaction effects in total power in the ML direction with eyes open ($p = 0.015$) and closed ($p = 0.004$). A significant group effect was found in 95% power frequency in the ML direction with eyes closed ($p = 0.021$), and a significant time effect was found in 95% power frequency in the AP direction with eyes closed ($p = 0.014$) (Table 3). There were significant differences between pre- and post-exercise values in total power in the ML direction with eyes open ($p = 0.046$) and closed ($p = 0.012$). No significant differences were found between preseated and postseated rest values in any parameter.

DISCUSSION

We hypothesized that a single session of moderate-intensity exercise would positively affect postural stability in middle-aged and elderly adults. There were significant interaction effects and significant changes/decreases after exercise in the mean velocity of COP fluctuations with eyes open and closed, mean velocity of COP fluctuations in the ML direction with eyes open and closed, and total power of the COP velocity time series in the ML direction with eyes open and closed. The total power of the COP velocity time series reflects the mean velocity of COP fluctuations because the total power of a time series is related to its variance; a larger variance in a velocity time series indicates high-frequency occurrence of faster velocity. Thus, the results of this study suggest that a single session of moderate-intensity exercise slowed down spontaneous COP fluctuations during quiet standing, which is similar to our previous study with lower extremity arthritis.

The mean velocity of the COP is a reliable (27) and sensitive (32,45) measure of COP fluctuations. Many studies have demonstrated an increase in the mean velocity of the COP in normal aging (14,27,32,45) and after fatiguing exercise (36,39,40,50). Thus, the change/slowing down observed in this study is opposite to COP changes that are age related and fatigue induced. Because aging and fatigue are known generally to cause impaired balance, the present results likely indicate that a single moderate-intensity aquatic exercise session positively affects postural stability, thereby validating our study hypothesis.

The slowing down of COP fluctuations after the aquatic exercise session occurred predominantly in the ML direction. Prior research suggests that increased postural sway in the ML direction is more strongly associated with balance deficits accompanying aging (25) and falls (30) than is postural sway in the AP direction. Thus, the current results provide further support for the notion that a single exercise session has positive effects on postural stability.

Postural stability during quiet standing depends on effective regulation of the sensorimotor system while integrating sensory information from the visual, vestibular, and somatosensory systems (22). Among these processes, lower-limb proprioception is suggested to be a major contributor to balance control during quiet standing (13,31). Previous research has found that even just 1 exercise session can positively affect lower-limb proprioception; for example, warm-up exercises improve an individual's ability to sense his or her knee joint position (1,2). Furthermore, a single exercise session can increase nerve conduction velocity (18,48), which is a component of the sensorimotor system. Lower-limb proprioception sensitivity deteriorates with normal aging (24,47), and this deterioration has been implicated in increased postural sway (29,34) and a history of falls (28). Nerve conduction velocity also decreases with normal aging (9,41), and this decrease contributes to a slowing of muscle responses to postural perturbation, thereby increasing postural sway (20,38). Thus, a single exercise session can potentially compensate–at least temporarily–for the age-related deterioration of postural control mechanisms, consequently improving postural stability.

One of the factors contributing to the increase in proprioceptive sensitivity (10,37) and nerve conduction velocity (5,7) through a single exercise session is the increase in body temperature. This suggests that the positive effects of a single exercise session found in this study may not persist for long. Future studies should investigate the duration of these effects and the physiological mechanisms underlying the acute positive effects of exercise.

In this study, the mean intensity of the aquatic exercise session was approximately 60%HR_{max} (i.e., moderate exercise intensity). Therefore, the aquatic exercise session did not cause fatigue that could lead to deterioration of postural stability. Previous studies investigating the acute effects of submaximal aerobic exercise on postural balance found that COP fluctuations increased slightly after a 2-km walk on the treadmill at an intensity equivalent to "4" on the Borg's Category Ratio 10 scale (8) and remained unchanged after 60 minutes on the ergocycle at 70% of the ventilatory threshold (35), 30 minutes of treadmill walking and treadmill running of equal energy expenditure (at speeds of 1.9–2.2 $m \cdot s^{-1}$) (6), and 25 minutes on the treadmill (walking) and ergocycle at approximately 55%HR_{max} (40). Our present findings, slowing down of COP fluctuations after exercise, were inconsistent with the results of these studies. A possible explanation may be the difference in participants' ages. Participants of this study were healthy middle-aged and elderly adults, whereas participants of the studies by Mello et al. (35), Derave et al. (6), and Nardone et al. (40) were healthy young adults. Thus, submaximal aerobic exercise neither positively nor negatively affected postural stability in the young adults studied. As we mentioned earlier, the physiological mechanisms controlling postural stability during quiet standing deteriorates with aging (9,24,41,47), which a single session of moderate-intensity exercise may affect positively. Therefore, middle-aged and elderly participants may be able to benefit more from a single session of exercise than might younger participants. The subjects of the study by Donath et al. (8) were the same generation as those in this study, but their study showed a slight increase in COP fluctuations after exercise. Exercise intensity in the study by Donath et al. (8) was designed to be equivalent to a "4" on the Borg's Category Ratio 10 scale, which was measured to be about 75% of maximal oxygen uptake. It is thought to be higher than that in this study and may be one of the reasons for the different outcomes observed in both studies.

The type of exercise can affect the acute effects of exercise on postural stability. Although no significant differences were found between pre- and post-exercise values in the research by Derave et al. (6), they found a larger increase in the mean velocity of COP fluctuations after submaximal treadmill running than after treadmill walking of equal energy expenditure and duration, as ascertained by a significant interaction effect in the ANOVA. They also found more excessive head movement during running than while walking, which suggested that the larger increase in COP fluctuations observed after running was possibly due to larger disturbances to the vestibular and visual systems while running. Investigating the effects of strenuous aerobic exercise, Lepers et al. (26) noted that young participants displayed a larger postural sway during platform oscillations after a strenuous 25-km run than after exercising on the ergocycle at equivalent intensity for a similar duration, suggesting less effective use of vestibular inputs after running. The aquatic exercise used in this study is performed in a unique environment of water with a low-gravity load and turbulence. These conditions could induce smaller vertical oscillations of the head and subjects' greater challenge to postural instability during exercise compared with those on land, which may be advantageous for improvement of postural control. Thus, in addition to variations in exercise intensity, differences in the type of exercise performed possibly contributed to the different outcomes obtained between this study and the submaximal treadmill walking study conducted by Donath et al. (8) in which participants were healthy seniors.

In conclusion, the results of this study demonstrate that a single session of moderate-intensity aquatic exercise has acute positive effects on postural stability in middle-aged and elderly women, especially indicated by the slowing down of COP fluctuations during quiet standing.

PRACTICAL APPLICATIONS

Loss of postural stability with normal aging is related to impairments in ADLs (11,17) and is a well-known risk factor for falls (43). Although they may be transient and not persist for long, the acute positive effects of exercise on postural stability attained in this study will contribute toward preventing falls and consequent injuries, as well as further impairments in ADLs. Thus, fitness consultants and instructors have a new option when providing a single exercise session. They will need to carefully select exercises of appropriate intensity and type to obtain benefits from the acute exercise. Fatigue caused by strenuous muscular or aerobic exercise impairs postural stability (36,39,40,50). Research has shown that exercises involving large head movement may also do so (6,26). At this point, we recommend moderate-intensity aquatic exercise, used in our present and previous studies (15), as a viable option that fitness consultants/instructors working with middle-aged and elderly adults consider when designing exercise programs leveraging the acute positive effects of exercise in enhancing postural stability.

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References

1. Bartlett, MJ and Warren, PJ. Effect of warming up on knee proprioception before sporting activity. *Br J Sports Med* 36: 132–134, 2002.
2. Bouët, V and Gahéry, Y. Muscular exercise improves knee position sense in humans. *Neurosci Lett* 289: 143–146, 2000.
3. Brooke-Wavell, K, Athersmith, LE, Jones, PRM, and Masud, T. Brisk walking and postural stability: A cross-sectional study in postmenopausal women. *Gerontology* 44: 288–292, 1998.
4. Colledge, NR, Cantley, P, Peaston, I, Brash, H, Lewis, S, and Wilson, JA. Aging and balance: The measurement of spontaneous sway by posturography. *Gerontology* 40: 273–278, 1994.
5. de Jesus, PV, Hausmanowa-Petrusewicz, I, and Barchi, RL. Effect of cold on nerve-conduction of human slow and fast nerve fibers. *Neurology* 23: 1182–1189, 1973.
6. Derave, W, Tombeux, N, Cottyn, J, Pannier, JL, and De Clercq, D. Treadmill exercise negatively affects visual contribution to static postural stability. *Int J Sports Med* 23: 44–49, 2002.
7. Dioszeghy, P and Stålberg, E. Changes in motor and sensory nerve-conduction parameters with temperature in normal and diseased nerve. *Electroencephalogr Clin Neurophysiol* 85: 229–235, 1992.
8. Donath, L, Zahner, L, Roth, R, Fricker, L, Cordes, M, Hanssen, H, Schmidt-Trucksäess, A, and Faude, O. Balance and gait performance after maximal and submaximal endurance exercise in seniors: Is there a higher fall-risk? *Eur J Appl Physiol* 113: 661–669, 2012.
9. Dorfman, LJ and Bosley, TM. Age-related changes in peripheral and central nerve conduction in man. *Neurology* 29: 38–44, 1979.
10. Eldred, E, Lindsley, DF, and Buchwald, JS. The effect of cooling on mammalian muscle spindles. *Exp Neurol* 2: 144–157, 1960.
11. Ensrud, KE, Nevitt, MC, Yunis, C, Cauley, JA, Seeley, DG, Fox, KM, and Cummings, SR. Correlates of impaired function in older women. *J Am Geriatr Soc* 42: 481–489, 1994.
12. Era, P, Sainio, P, Koskinen, S, Haavisto, P, Vaara, M, and Aromaa, A. Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology* 52: 204–213, 2006.
13. Fitzpatrick, R and McCloskey, DI. Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. *J Physiol* 478: 173–186, 1994.
14. Freitas, SMSF, Wieczorek, SA, Marchetti, PH, and Duarte, M. Age-related changes in human postural control of prolonged standing. *Gait Posture* 22: 322–330, 2005.
15. Fukusaki, C, Masani, K, and Nakazawa, K. Acute effects of exercise on posture in arthritic patients. *Int J Sports Med* 32: 653–658, 2011.
16. Gellish, RL, Goslin, BR, Olson, RE, McDonald, A, Russi, GD, and Moudgil, VK. Longitudinal modeling of the relationship between age and maximal heart rate. *Med Sci Sports Exerc* 39: 822–829, 2007.
17. Guralnik, JM, Simonsick, EM, Ferrucci, L, Glynn, RJ, Berkman, LF, Blazer, DG, Scherr, PA, and Wallace, RB. A short physical performance battery assessing lower-extremity function: Association with self-reported disability and prediction of mortality and nursing-home admission. *J Gerontol* 49: M85–M94, 1994.
18. Halar, EM, Hammond, MC, and Dirks, S. Physical activity: Its influence on nerve conduction velocity. *Arch Phys Med Rehabil* 66: 605–609, 1985.
19. Hassan, BS, Mockett, S, and Doherty, M. Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. *Ann Rheum Dis* 60: 612–618, 2001.
20. Huisinga, JM, St George, RJ, Spain, R, Overs, S, and Horak, FB. Postural response latencies are related to balance control during standing and walking in patients with multiple sclerosis. *Arch Phys Med Rehabil* 95: 1390–1397, 2014.
21. Hurley, MV, Scott, DL, Rees, J, and Newham, DJ. Sensorimotor changes and functional performance in patients with knee osteoarthritis. *Ann Rheum Dis* 56: 641–648, 1997.
22. Johansson, R and Magnusson, M. Human postural dynamics. *Crit Rev Biomed Eng* 18: 413–437, 1991.
23. Johnston, RB III, Howard, ME, Cawley, PW, and Losse, GM. Effect of lower extremity muscular fatigue on motor control performance. *Med Sci Sports Exerc* 30: 1703–1707, 1998.
24. Kaplan, FS, Nixon, JE, Reitz, M, Rindfleish, L, and Tucker, J. Age-related changes in proprioception and sensation of joint position. *Acta Orthop Scand* 56: 72–74, 1985.
25. Laughton, CA, Slavin, M, Katdare, K, Nolan, L, Bean, JF, Kerrigan, DC, Phillips, E, Lipsitz, LA, and Collins, JJ. Aging, muscle activity, and balance control: Physiologic changes associated with balance impairment. *Gait Posture* 18: 101–108, 2003.
26. Lepers, R, Bigard, AX, Diard, JP, Gouteyron, JF, and Guezennec, CY. Posture control after prolonged exercise. *Eur J Appl Physiol* 76: 55–61, 1997.
27. Lin, D, Seol, H, Nussbaum, MA, and Madigan, ML. Reliability of COP-based postural sway measures and age-related differences. *Gait Posture* 28: 337–342, 2008.
28. Lord, SR, Clark, RD, and Webster, IW. Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc* 39: 1194–1200, 1991.
29. Lord, SR, Clark, RD, and Webster, IW. Postural stability and associated physiological factors in a population of aged persons. *J Gerontol* 46: M69–M76, 1991.
30. Lord, SR, Rogers, MW, Howland, A, and Fitzpatrick, R. Lateral stability, sensorimotor function and falls in older people. *J Am Geriatr Soc* 47: 1077–1081, 1999.
31. Lord, SR and Ward, JA. Age-associated differences in sensorimotor function and balance in community-dwelling women. *Age Ageing* 23: 452–460, 1994.
32. Maki, BE, Holliday, PJ, and Fernie, GR. Aging and postural control. A comparison of spontaneous- and induced-sway balance tests. *J Am Geriatr Soc* 38: 1–9, 1990.
33. Maurer, C, Mergner, T, Xie, J, Faist, M, Pollak, P, and Lücking, CH. Effect of chronic bilateral subthalamic nucleus (STN) stimulation on postural control in Parkinson's disease. *Brain* 126: 1146–1163, 2003.
34. McChesney, JW and Woollacott, MH. The effect of age-related declines in proprioception and total knee replacement on postural control. *J Gerontol* 55: M658–M666, 2000.
35. Mello, RGT, de Oliveira, LF, and Nadal, J. Effects of maximal oxygen uptake test and prolonged cycle ergometer exercise on the quiet standing control. *Gait Posture* 32: 220–225, 2010.
36. Mello, RGT, Oliveira, LF, and Nadal, J. Anticipation mechanism in body sway control and effect of muscle fatigue. *J Electromyogr Kinesiol* 17: 739–746, 2007.
37. Mense, S. Effects of temperature on discharges of muscle-spindles and tendon organs. *Pflugers Arch* 374: 159–166, 1978.
38. Nardone, A, Siliotto, R, Grasso, M, and Schieppati, M. Influence of aging on leg muscle reflex responses to stance perturbation. *Arch Phys Med Rehabil* 76: 158–165, 1995.
39. Nardone, A, Tarantola, J, Galante, N, and Schieppati, M. Time course of stabilometric changes after a strenuous treadmill exercise. *Arch Phys Med Rehabil* 79: 920–924, 1998.
40. Nardone, A, Tarantola, J, Giordano, A, and Schieppati, M. Fatigue effects on body balance. *Electroencephalogr Clin Neurophysiol* 105: 309–320, 1997.
41. Norris, AH, Shock, NW, and Wagman, IH. Age changes in the maximum conduction velocity of motor fibers of human ulnar nerves. *J Appl Physiol* 5: 589–593, 1953.
42. Orr, R, de Vos, NJ, Singh, NA, Ross, DA, Stavrinos, TM, and Fiatarone-Singh, MA. Power training improves balance in healthy older adults. *J Gerontol Biol Sci Med Sci* 61A: 78–85, 2006.
43. Overstall, PW, Exton-Smith, AN, Imms, FJ, and Johnson, AL. Falls in elderly related to postural imbalance. *Br Med J* 1: 261–264, 1977.

44. Piirtola, M and Era, P. Force platform measurements as predictors of falls among older people–A review. *Gerontology* 52: 1–16, 2006.
45. Prieto, TE, Myklebust, JB, Hoffmann, RG, Lovett, EG, and Myklebust, BM. Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Trans Biomed Eng* 43: 956–966, 1996.
46. Simmons, V and Hansen, PD. Effectiveness of water exercise on postural mobility in the well elderly: An experimental study on balance enhancement. *J Gerontol A Biol Sci Med Sci* 51: M233–M238, 1996.
47. Skinner, HB, Barrack, RL, and Cook, SD. Age-related decline in proprioception. *Clin Orthop Relat Res* 184: 208–211, 1984.
48. Tesfaye, S, Harris, ND, Wilson, RM, and Ward, JD. Exercise-induced conduction velocity increment: A marker of impaired peripheral nerve blood flow in diabetic neuropathy. *Diabetologia* 35: 155–159, 1992.
49. Tsang, WWN and Hui-Chan, CWY. Effect of 4- and 8-wk intensive Tai Chi training on balance control in the elderly. *Med Sci Sports Exerc* 36: 648–657, 2004.
50. Vuillerme, N, Forestier, N, and Nougier, V. Attentional demands and postural sway: The effect of the calf muscles fatigue. *Med Sci Sports Exerc* 34: 1907–1912, 2002.
51. World Health Organization. *WHO Global Report on Falls Prevention in Older Age*. Geneva, Switzerland: World Health Organization, 2007.