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► To cite this version:

Pierre Louis Bernard, Hubert Blain, Guillaume Tallon, Gregory Ninot, Audrey Jaussent, et al.. Influence of repeated effort induced by a 6-min walk test on postural response in older sedentary women. *Aging Clinical and Experimental Research*, 2015, 27 (5), pp.695-701. 10.1007/s40520-015-0338-z . hal-04801578

HAL Id: hal-04801578

<https://hal.science/hal-04801578v1>

Submitted on 7 Jan 2025

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Influence of repeated effort induced by a 6-min walk test on postural response in older sedentary women

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Received: 19 December 2014 / Accepted: 16 February 2015 / Published online: 12 March 2015
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Abstract According to the latest recommendations, adults should exercise regularly at moderate intensity to improve aerobic fitness and body composition. However, it is unknown whether aerobic exercise at submaximal intensity has detrimental effects on balance in older sedentary adults. We explored the effects of two 6-min walk tests (6MWTs) on the postural responses in 49 sedentary women between 60 and 76 years old. We assumed that an increase in the center of pressure (COP) fluctuations or a loss in the complexity of the COP time series would be a sign of a deleterious effect on balance. We used kinematic stabilometric parameters, recurrence quantification analysis (RQA) and the central tendency measure (CTM). We refer to the measures obtained through RQA and CTM methods by dynamical measures. Repeated-measures analysis of variance showed no significant differences between the three sets of postural kinematic measures (before vs. after the first vs. after the second 6MWT). However, we observed significant differences between the three sets for the

CTM measure in the antero-posterior direction ($p < 0.002$), RQA determinism in the medio-lateral (ML) direction ($p < 0.0001$), and RQA entropy in the ML direction ($F = 5.93$; $p < 0.004$). Our results indicate that the effects of moderate-intensity walking exercise on posture are not revealed by classical postural kinematic measures but only by dynamical measures. The loss of complexity in the COP time series observed after both the first and second 6MWTs may indicate presymptomatic deterioration in the postural adaptive capabilities of sedentary older women.

Keywords Aerobic exercise · Elderly · Stabilometric analysis · Dynamic methods

Introduction

According to the latest recommendations from the American College of Sports Medicine, sedentary adults should exercise regularly at moderate intensity for positive effects on aerobic fitness and body composition [1]. Some studies have suggested that local muscle exercise, such as monosegmental exercise of the knee and ankle [2, 3] and/or lumbar spine [4, 5] may disturb postural adaptations. It has also been shown that global muscle exercise, which focuses on cardiorespiratory and energetic components in relation to neuromuscular and musculo-articular solicitations, could alter postural performance [6]. This point is important for sedentary women at risk for falls [7].

The effects of both aerobic and anaerobic exercise may be intensity-dependent, with some disturbance at maximal oxygen output [8–11]. Moreover, it has been reported that the deterioration of postural control may not be significant at submaximal intensity [9, 10]. Independent of intensity, the nature of the exercise may also influence postural

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responses. Balance capabilities are significantly affected by locomotion exercise, which disturbs the sensitivity of utricular and saccular receptors and the integration of vestibular information [12]. In addition, the repetition of mechanical constraints causes proprioceptive and cutaneous dysfunction that may contribute to the disturbance in postural adaptations [13, 14].

The age-related loss or degradation of perception has been shown in many studies. However, the effect of intense exercise on postural control in elderly people has generally been studied using a protocol of monosegmental movements [2, 3, 15]. Some studies using global muscle exercise with repeated effort from the hip, knee and ankle muscles have shown declines in the speed and mean power of sit-to-stand exercise, altered stability or more variable walking patterns [16–18].

Although stabilometric evaluation of kinematic variables is a frequently used method to assess postural control, few studies have used dynamical measures to define postural regulation of old women. We therefore suggest that applying methods derived from nonlinear dynamics and statistical physics to interpret center of pressure (COP) fluctuations may provide insight into these issues. These methods were used in human physiology within the framework of the so-called theory of “loss of complexity with aging and disease” [19]. Recurrence quantification analysis (RQA) provides sensitive measures to detect several factors, such as visual feedback, and to discriminate fallers from non-fallers [20]. A smoothness measure, the central tendency measure (CTM), has also been used to characterize the effect of aging [21]. We selected RQA and CTM because these methods quantify different aspects of the temporal structure of postural fluctuations, namely the predictability of the position time series (RQA) and the smoothness of velocity data (for CTM). In addition, we have shown that these two methods are statistically complementary for the same population [22].

We explored the effects of two successive 6-min walk tests (6MWTs) on the postural responses of sedentary postmenopausal women. We hypothesized that the repeated efforts would result in degraded postural responses associated with an increase in COP fluctuations, as measured with classical stabilometric parameters, and a loss in the complexity of the COP time series, as assessed by RQA and the central tendency measures (CTM) extracted from the COP signals.

Method

Population

49 Sedentary community-dwelling women aged from 60 to 76 years were recruited from public meetings to promote physical activity in postmenopausal sedentary women

(Table 1). The women were eligible to participate if they had no medical condition or were taking no medications known to alter physical performance. All participants provided a medical certificate of no contraindication to exercise and written informed consent. To be considered as sedentary, the women had to have a score above 9.4 on the Physical Activity Scale for the Elderly (PASE) and a 6MWT score not greater than the theoretical distance determined by the equation of Troosters et al. [23] based on age, gender, body weight and height.

Women who were diagnosed with rheumatoid arthritis, osteoarthritis, ischemic heart disease, previous joint replacement surgery or cerebrovascular disease affecting lower limb function, with malignant tumors, who experienced pain or used medication known to alter physical performance or balance (e.g., corticosteroids, estrogens, statins, or antiestrogen drugs, psychotropic drugs) or who experienced a fall in the previous year were excluded from the study. The fall events were reported and did not characterize the participants.

The study was approved by the Committee for the Protection of Human Subjects (CPP Sud-Méditerranée III, Number: 2008.07.04).

Protocol

6-min walk test (6MWT)

The 6MWT is a rectangular, continuous and submaximal field test to evaluate exercise tolerance [24, 25]. Participants were equipped with a heart rate monitor to assess the physiological adaptations to exercise and prevent potential complications. After a 3-min warm-up of walking and leg stretching (quadriceps, hamstring, iliopsoas and triceps surae), they then performed the 6MWT over 30 m with markers every 10 m. During the test, the distance walked was recorded every minute and the heart rate was continuously recorded. No verbal encouragement was given. The participants rested for 20 min between the two tests, which was assumed to be adequate physiological recovery. The stabilometric evaluations associated to 6MWT were systematically performed during the morning and for all the participants.

Stabilometric evaluation

The environment satisfied the norms for postural evaluation regarding dimensions, brightness and environmental

Table 1 Characteristics of the population

	Age (year)	Weight (kg)	Height (cm)	BMI
M	64.98	65.54	160.6	25.4
SD	3.87	11.37	5.35	4.43

noise. The experimental situation respected the norms for static postural evaluation on hard floor [26].

Participants had to maintain quiet stance conditions while standing on a $530 \times 460 \times 35$ -mm force platform (Médicapteurs “40 Hz/16b”) equipped with three pressure sensors (hysteresis $<0.2\%$). Signal processing was accomplished with a 16-bit A/D converter at 40 Hz. Participants, with arms alongside the body, were asked to focus on a fixed visual reference 1 m away. The recordings started 5 s after the beginning of each test, and lasted for 51.2 s. The sampling frequency was 40 Hz, each test therefore forming a 2048-point time series.

At baseline, participants were assessed in eyes opened (EO) and eyes closed (EC) conditions with a 30-s rest between these two configurations. After each 6MWT, the trials were performed only in EC condition. This was done to avoid the learning effect and to select the more constraining task. After each 6MWT, women had a 3-min recovery interval without movement before a new postural test. Twenty minutes separated the end of the first from the beginning of the second 6MWT.

The main dependent variables were: the length (Lg) and surface (Surf) of the stabilogram, the mean along the x -axis (Xm) and the mean along the y -axis (Ym). L represented the total length of the COP path, defined as the sum of the distances between all consecutive points on the COP path. S was taken to represent the area of the ellipse that best fitted the COP displacement at the 95 % confidence interval.

Time series analysis

Recurrence quantification analysis (RQA)

RQA is derived from a graphical approach providing a so-called recurrence plot (RP), which is a specific representation of the distances between all time-delayed vectors $X_i(m) = (x_i, x_{i+\tau}, x_{i+2\tau}, \dots, x_{i+(m-1)\tau})$, where (x_i) are the samples of COP time series. RQA was first applied to COP data by Riley et al. [27]. RPs are graphical representations of symmetric binary matrices in which each point (i, j) corresponds to the distance between two vectors $X_i(m)$ and $X_j(m)$. The recurrence points forming diagonals and the complexity of the structure of these diagonals are used to extract quantifications of predictability and complexity. RQA is applied to nonstationary, stochastic and nonlinear data. In this study, we directly applied RQA to COP position time series (x_i) . RQA requires several input parameters including m , τ and threshold distance r , which were selected according to the procedure described by Ramdani et al. [20]. We have selected $m = 8$, $\tau = 6$ and $r = 25\%$ of mean of all the distances. We computed two

RQA measures: the percentage of determinism (Det) and the entropy (Ent). Det is a measure of the predictability of the analyzed signal. It increases with the predictability of the signal. Ent quantifies the complexity of the RP regarding its diagonal lines. It generally decreases with the level of noise of COP signal (see [20] and references therein). We used the Cross Recurrence Plot Toolbox 5.13 (R25) to perform the RQA.

Central tendency measure (CTM)

The CTM is a measure of smoothness computed after obtaining the tangent vectors in the reconstructed phase space given by time delay embedding. The CTM is a measure of the irregularity of the cosine values of the angles between the successive tangent vectors in the reconstructed phase space given by time delay embedding [21]. It decreases for smoother trajectories. Conversely to RQA, the CTM was computed for the differenced COP time series. This is mainly motivated by the fact the CTM cannot be estimated for nonstationary and correlated data (see [21] for more details).

Statistical analysis

The normality of the distribution was tested by the Kolmogorov–Smirnov test. A t test for matched series was used to compare the values of the two 6MWTs and the stabilometric data collected during the EO and EC conditions. A repeated-measures ANOVA compared the stabilometric data obtained in the EC condition during the three sets of measures, i.e., at rest and after the first and second 6MWT. The analysis was performed using traditional kinematic and dynamical measures. The level of statistical significance was set at $p < 0.05$. The analyses were performed with Statview 5.0.

Results

Table 1 displays the characteristics of participants. The mean score on the PASE was $5.3 (\pm 1.7)$ and the distance walked during the 6MWTs was on average 82 % of the theoretical distance (476 m for an expected theoretical distance of 579.7 m), which confirmed the sedentary profile of the women. The mean distances walked during test 1 (473.1 m) and test 2 (478.2 m) were not significantly different ($t = -0.81$; $p < 0.42$). We have measured the heart rate during the 6MWT. The maximal heart rate during the first test was $109.10 (\pm 17.23)$ and during the second test was $107.87 (\pm 15.67)$. These observations confirmed the submaximal level of this exercise.

Kinematic postural measures with EO and EC

At baseline, i.e., before the first 6MWT, the EC condition was associated with a degradation in the postural kinematics compared with EO, with an increase in surface ($t = -2.95$; $p < 0.005$) and length ($t = -4.59$; $p < 0.0003$) and a significant difference in the medio-lateral (ML) direction ($t = -2.18$; $p < 0.04$). No significant difference was observed in the antero-posterior (AP) direction ($t = -1.38$). For the dynamical measures, we observed a significant difference for CTM in the AP direction ($t = -3.40$; $p < 0.001$), RQADet in the ML direction ($t = 3.75$; $p < 0.001$), RQADet in the AP direction ($t = 2.96$; $p < 0.01$), RQAEnt in the ML direction ($t = 3.40$; $p < 0.001$) and RQAEnt in the AP direction ($t = 3.83$; $p < 0.001$). No significant difference was observed for CTM in the ML direction ($t = 1.31$).

Influence of repeated 6MWTs on postural responses tested with EC

The repeated-measures analysis showed no significant differences between the three sets of postural kinematic measures (before, and after the first and second 6MWT) for the parameters of surface ($F = 1.20$), length ($F = 1.91$), ML direction ($F = 2.62$) and AP direction ($F = 0.31$) (Table 2).

Influence of repeated 6MWTs on dynamical measures obtained with EC

The results showed significant differences between the three sets for the measures of CTM in the AP direction ($F = 6.56$; $p < 0.002$), RQADet in the ML direction ($F = 9.54$; $p < 0.0001$) and RQAEnt in the ML direction ($F = 5.93$; $p < 0.004$) (Table 3). The analysis showed no significant differences for the three sets of measures of CTM in the ML direction ($F = 0.45$), RQADet in the AP direction ($F = 2.49$) and RQAEnt in the AP direction ($F = 2.16$) (Table 3).

Discussion

This study showed that, in older sedentary women, two consecutive bouts of 6 min of aerobic exercise separated by a 20-min rest period did not significantly alter linear postural kinematic measures but only measures of complexity.

Studies have shown that a submaximal intensity of about 60 % of maximal heart rate (HRmax) [9] or 70 % of the pulmonary ventilation threshold [10] does not increase postural oscillations, contrary to exercise performed at maximal oxygen uptake [10, 11], at an intensity between

Table 2 Mean and standard error values obtained with EC for the surface and length parameters, in the medio-lateral direction (X) and the anterior–posterior direction (Y) of the center of pressure (COP) at rest before the first 6MWT, after the first 6MWT and after the second 6MWT

	Surf (mm ²)	Lg (mm)	X (mm)	Y (mm)
At rest				
M	263	841	-4.6	-9.7
SD	203	645	15.2	14.3
	Surf (mm ²)	Lg (mm)	X (mm)	Y (mm)
	Surf 1	Lg 1	Y 1	X 1
After 6MWT 1				
M	268	814	-2.7	-10.0
SD	209	458	11.9	11.1
	Surf (mm ²)	Lg (mm)	X (mm)	Y (mm)
	Surf 2	Lg 2	Y 2	X 2
After 6MWT 2				
M	304	759	-3.5	-12.8
SD	308	325	14.8	11.8
F	1.20	1.91	2.62	0.31
P<	0.30	0.15	0.08	0.73

90 and 100 % of HRmax [28], and at exercise beyond the second lactate threshold [9]. Our results support this finding, showing that one or two 6MWTs (a walking distance of about 500 m in 6 min, with a speed close to 5 km/h), corresponding to an effort intensity somewhere between the maximal aerobic intensity and the intensity at the ventilatory threshold—i.e., at an intensity above the widely accepted recommendations for aerobic retraining programs for older sedentary subjects—do not significantly alter COP kinematic parameters (surface and length in both ML and AP directions). These results are similar to findings for other types of lower limb movements. Moore et al. [18] had subjects perform three sets of 10–12 repetitions of six lower limb exercises and showed a significant alteration in balance quantified by stabilogram diffusion analysis. Helbostadt et al. [17] analyzed the effects of muscle fatigue induced by repetitions of sit-to-stand on the walking patterns of elderly people. No significant difference was observed in the preferential walking speed or the step length. In contrast, these authors showed a significant increase in step width and trunk acceleration in the ML direction for the group performing the fatiguing exercise. Egerton et al. [16] analyzed the dynamical balance of subjects at high risk of falling and concluded that a single bout of moderate-intensity physical activity did not negatively affect postural stability. The 6MWT requires that people walk, but not run, as fast as possible. Walking leads to a majority

Table 3 Mean and standard error values and significant values obtained with EC for the dynamical parameters of the central tendency measure (CTM), the percentage of determinism (RQADet) and the entropy (RQAEnt) from recurrence quantification analysis in the medio-lateral (ML) and in the anterior–posterior (AP) directions at rest, after the first 6MWT (1) and after the second 6MWT (2)

	CTM		RQA Det		RQA Ent	
	ML EC	AP EC	ML EC	AP EC	ML EC	AP EC
At rest						
M	0.27941	0.27204	0.91753	0.85792	3.65181	3.3794
SD	0.00832	0.01374	0.092531	0.1813	0.5752	0.70926
	CTM		RQA Det		RQA Ent	
	ML EC	AP EC	ML EC	AP EC	ML EC	AP EC
After 6MWT 1						
M	0.28068	0.27644	0.9346	0.85942	3.72326	3.38161
SD	0.00822	0.01185	0.08132	0.18648	0.53256	0.71121
	CTM		RQA Det		RQA Ent	
	ML EC	AP EC	ML EC	AP EC	ML EC	AP EC
After 6MWT 2						
M	0.28048	0.27767	0.95437	0.8894	3.86237	3.49185
SD	0.0094	0.01237	0.04506	0.12406	0.44148	0.58497
F	0.45	6.56	9.54	2.49	5.93	2.16
P<	NS	0.002	0.0001	NS	0.004	NS

of horizontal accelerations mobilizing the utricular and kinesthetic receptors [29], thereby causing less balance disturbance and/or musculotendinous damages than running [12]. The finding that walking at submaximal intensity stimulates both vestibular and kinesthetic receptors without adversely affecting balance, together with these other findings, supports the recommendation of brisk walking for sedentary women, who are known to have a higher risk of falling than fit women [1, 7].

The absence of influence on the postural kinematic measures can be explained by two factors. The first was the high inter-variability observed for the kinematic parameter of surface and the parameter of length. The variability is known for the elderly people and specifically characterized our population. This variability can explain the statistical absence of difference for the kinematic parameters.

The second was in relation with the stabilometric method and the limits of the kinematic parameters. The analysis of postural control based on stabilometric parameters delivered some information. Nevertheless, for other authors, it appears difficult to define some discriminative tasks or parameters which permit to

discriminate elderly from young, fallers from non-fallers as well as different levels of autonomy. Teasdale et al. [30] have shown that postural oscillations were weakly influenced by one perturbation such as the lack of vision and have shown that the addition of two perturbations was necessary. Prieto et al. [31] have shown the interest of the surface, the mean speed and the standard deviations measured during eyes opened and eyes closed conditions in antero-posterior direction. Kang et al. [32] and Du Pasquier et al. [33] confirmed this analysis for the length and specifically in the antero-posterior direction.

Some studies raised the limits of kinematic stabilometric parameters to discriminate the capabilities of postural control [34–36] and to discriminate the autonomy profile of elderly people [37–39]. Norris et al. [40] criticize the sensibility of surface, mean speed and standard deviation to demonstrate the influence of age. Besides, Piirtola et Era [41] confirmed the difficulties to recognize failing risk elderly persons with stabilometric evaluations.

This study showed the effects of walking exercise on balance parameters using the following dynamical measures: CTM in the AP direction ($p < 0.002$), RQADet in the ML direction ($p < 0.0001$) and RQAEnt in the ML direction ($p < 0.004$). The significant increase in the percentage of RQADet in the ML direction represents an increase in the predictability of the time series, a marker of reduced postural complexity and less adaptive postural capabilities in the ML direction, according to the loss of complexity of aging and disease theory [19]. A possible interpretation of this finding is a less adaptive behavior related to a hip muscle strategy adversely affected by the exercise of walking.

We found that the CTM measure was increased after exercise only in the AP direction. CTM is a measure of the smoothness of COP velocity trajectories and it may be related to the abruptness and/or frequency of the corrections in these trajectories. Thus, an increased CTM may be associated with more abrupt and/or more frequent corrections in COP velocity. Since CTM was modified only in the AP direction, a potential interpretation might be that the exercise had an effect on the delay before the activation of closed-loop mechanisms through a modification in ankle muscle response and reflex times (see [21] and references therein).

Thus, our results support the fact that, conversely to kinematic measures, some dynamical measures are able to detect significant influence of exercise on the complexity and predictability of the stabilometric signal. These findings were specific to the parameters, however, which limit the scope of our analysis.

This study could suffer from some limitations. For example, the fatigue of hip and ankle muscles could be quantified by isokinetic testing of strength output. In

addition, the analysis of muscle excitability before and after a maximal voluntary contraction using the twitch interpolation technique could be a future direction. Proportional decreases in the amplitude of the M-wave and of peak twitch amplitude would indicate an alteration in muscular excitability after submaximal aerobic exercise.

Taken together, these results suggest that dynamical analyses of postural response may detect presymptomatic deterioration in the postural adaptive capabilities of sedentary older women. Moreover, they lend further support to the hypothesis that a sedentary profile is a risk factor of balance deterioration. The evolution in postural complexity indicators suggests presymptomatic deterioration in the postural adaptive capabilities of older sedentary women, justifying recommendations to exercise regularly.

To conclude, our findings suggest that moderate-intensity walking exercise did not significantly alter linear postural kinematic measures but only measures of complexity in sedentary women 60 years old. Moreover, the study showed the effects of walking exercise on balance parameters using dynamical analyses, which appear to be promising methods to detect slight deteriorations in postural adaptive capabilities. It remains to be determined whether slight decreases in postural complexity at rest or after exercise are the first signs of deterioration in postural and functional reserves.

Acknowledgments The authors would like to thank Dr. Olivier Hue from the University of Trois Rivieres, Quebec, and Dr. Francis Degache from the University of Lausanne, Switzerland, for their valuable suggestions. Moreover, we thank the Federation Française de l'Éducation Physique et de la Gymnastique Volontaire (FFEPGV) for collaboration on this research (CPP Sud-Méditerranée III, Number: 2008.07.04).

Conflict of interest None.

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