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Effects of Intensive Up-to-Exhaustion Walking Exercise on the Center of Gravity Sway

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Abstract

Because an intensive exercise of walking up-to-exhaustion (walking exercise) results in considerable whole-body fatigue, it might affect the center of gravity sway (COGS) while standing and delay its recovery. This study aimed to examine the effects of a walking exercise on the COGS and its recovery by comparing exercising and non-exercising conditions. Fifteen healthy adult men walked on a treadmill, with a multi-stage incremental load, until exhaustion. The exercising group took the COGS test for 60 s before and immediately after exercising and after a 3-min-long sitting rest. The control group underwent the same test simultaneously. The X-axis and Y-axis trajectory lengths, total trajectory length, outer peripheral area, and rectangular area were selected as COGS variables. Repeated measures two-way (exercise x time) analysis of variance and multiple comparisons revealed that all mean COGS variables, measured after exercising, were greater than all means obtained for the control group, and than those measured in the exercising group before performing the exercise. The means of COGS variables measured in the exercising group remained greater even after a 3-min sitting rest period. In conclusion, intensive walking exercise affected the COGS in adult men. This effect was not reverted by a 3-min sitting rest.

Keywords

Fatigue, Standing, Recovery, Treadmill, Sitting Rest

1. Introduction

In humans, the center of gravity sway (COGS) while standing is determined by the posture and skeletal muscle alignment [1, 2]. The COGS depends on a reflex control based on afferent inputs from the visual, vestibular (semicircular duct), and somatosensory systems [3, 4]. Humans maintain a stable posture by holding the COGS within their base of support [3, 4]. The visual sense is important for the postural control [5, 6]. The balance function and leg strength are also involved in maintaining a stable posture [7]. During aging, the COGS is affected by the decline of nervous functions [8] and decreased leg strength [9].

The foot center of pressure fluctuates considerably after physical activity [10]. Moreover, the COGS varies after cargo handling work and exercise [11, 12]. Because physical activity results in whole body and leg fatigue, the COGS is believed to increase after physical activity.

According to Takahashi et al. [13], a light-load pedaling exercise on an ergometer did not affect the COGS, whereas the COGS was modified by a heavy-load exercise. Additionally, Nardone et al. [14] reported that walking on a treadmill impacted the COGS, whereas a pedaling exercise did not. Moreover, Selthafner et al. [15] evidenced that walking on a treadmill (2 km/h) resulted in fluctuations of the center of pressure measured before and after the exercise in the anteroposterior (COP displacement in anterior-posterior; COP-AP) and left-right (mediolateral; COP-ML) directions. Matsuda et al. [9] compared the COGS measured before and after fatigue of the hip abductor muscles and showed that the left-right fluctuation (the X-axis trajectory length) was greater after muscular fatigue, whereas the before/after fluctuation (the Y-axis trajectory length) was not different. Pedaling is a leg-based exercise which the body weight is not carried by the legs, whereas walking is a whole body exercise, which imposes the body weight on the legs and uses arm movements. Because the body load is greater during walking, the impact of walking on the COGS is probably greater than that of pedaling.

According to Takahashi et al. [13], a 3-min sitting rest period after a heavy-load pedaling exercise allows to recover a normal COGS in adult men. However, Hill et al. [16] reported that the COGS was not restored in the female elderly within 10 min after an intensive walking or pedaling exercise. In contrast, Nardone et al. [14] showed that intensive walking exercise affected the COGS in adults, but this effect disappeared within a few minutes. As stated above, the body bears a greater load while walking than pedaling. Consequently, the recovery from fatigue and restoration of the COGS are likely delayed after walking exercises. Thus, the extent to which the fatigue after a walking exercise influences the COGS recovery might differ from that observed after a pedaling exercise. However, only a few detailed studies investigated the effects of walking exercises on the COGS recovery. Because walking is the most basic exercise for maintaining and promoting health and is frequently practiced by the elderly, it is necessary to examine its effects on the COGS and COGS recovery.

The present study aimed to investigate whether the standing COGS increased after intensive walking exercise on a treadmill (hypothesis 1) and was restored to its original state after a 3-min sitting rest (hypothesis 2).

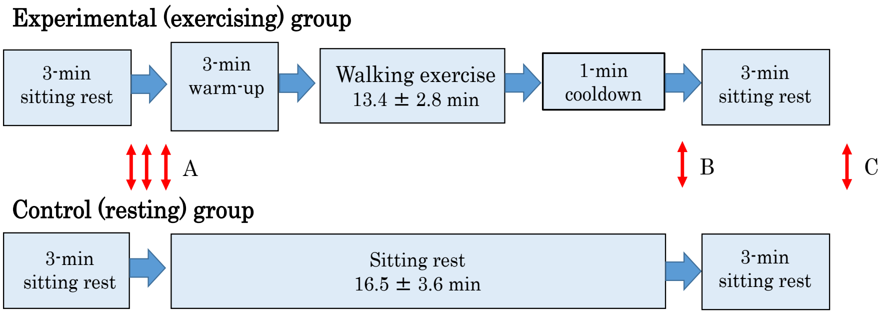
2. Methods

2.1 Participants

Participants were 15 healthy adult men (aged 21-34 years; mean age = 23.1 years, standard deviation [SD] = 3.4 years; mean height = 171.6 cm, SD = 6.3 cm; mean weight = 62.7 kg, SD = 10.8 kg). The mean values for height and body weight corresponded to age-matched Japanese normative values [17]. No participant reported previous wrist injuries or upper limb nerve damage, and all were in good health. The purpose and procedure of this study were explained in detail to all participants before starting. All participants signed informed consent form. The experimental protocol was approved by the Ethics Committee on Human Experimentation of Test and Measurement in Health and Physical Education (2018-001) and Division of Human Science, Kanazawa University (2018-001). None of the participants had undergone a COGS test previously.

2.2 Experimental plan

Because the center of gravity sway (COGS) varies daily according to the body condition and fatigue [10], it was difficult to allocate the participants homogeneously into the experimental and control groups. Hence, participants were randomly distributed into both groups. A crossover method, by which the experimental or control groups were exchanged in the second half of the study, was used. Fig.1 shows the experimental protocol. Cernacek et al. [18] reported that normal physiological responses, such as blood pressure and heart rate, are regained following a 10-min resting period even after high-intensity exercises with incremental loads. Konishi et al. [19] found no significant difference in the pulse rate measured directly after a 30-s sit-to-stand test or after a 2-min resting period. Additionally, Nardone et al. [14] showed that an intensive walking exercise affects the COGS in young adults, but this effect disappears within a few minutes. Considering these data, we compared the COGS recovery from fatigue after an intensive hard walking exercise followed by a 3-min sitting rest.



Note: ↕ (arrow): COGS measurement before (A), immediately (B), and 4-min after (C) exercising.

Figure 1. Experimental protocol.

2.3 Exercise load and measurement of the COGS

Walking exercises were performed on a treadmill (Wellroad 200E; Takei Scientific Instruments Co. Ltd. Niigata Japan) following the Bruce method with a multi-stage incremental load [20]. Every 3 min, the walking velocity was increased to 2.7, 4.0, 5.5, 6.9, 8.0, and 9.6 km/h and the slope of the treadmill belt was enhanced by 2% from a 10% initial incline [21]. The exercise burden was estimated using a heart rate monitor (Polar heart rate monitor) and Borg's scale. The exercise was terminated when two or more of the following criteria were reached: 1) estimated maximum heart rate = (220 − age) ± 15 beats, 2) heart rate did not increase with heavier exercise loads, and 3) Borg's scale value = 17 (quite hard).

The walking exercise started after a 3-min sitting rest and 3-min warm-up (Fig.1). Individual differences were found in the duration of the exercise which was on average 13.4 ± 2.8 min. The exercise was immediately followed by a 1-min cooldown. Therefore, the mean time between the warm-up and cooldown was 16.5 ± 3.6 min in the exercise group. The control group rested in a sitting position for about 20 min.

The COGS has been commonly used as an index of the trajectory of the COG and was assessed using an apparatus (T.K.K.5810; Takei Scientific Instruments Co. Ltd. Niigata Japan) with four vertical load sensors attached to a rectangular horizontal plate. The position of the COG was determined in participants standing on the plate by measuring the distribution of the plantar pressure. Data were recorded with a personal computer at 20 Hz after analog-to-digital conversion.

The participants were instructed to take the Romberg posture with both hands aligned along the body axis [22] on the measuring equipment while staring at a fixed target placed at eye level. For each trial, the COGS was measured for 60 s.

In the exercising group, the COGS was measured 3 times (60 s rest time between each measurement) after an initial 3-min sitting period, once immediately after exercising, and once after a 3-min sitting rest following the exercise. In the control group, the COGS was measured at times corresponding to the COGS measurement times in the exercise group.

2.4 Estimation variables

Variables were selected according to a previous study [23] as follows: X-axis trajectory length (distance in mm traveled by the COG along the X-axis [left/right]); Y-axis trajectory length (distance in mm traveled by the COG along the Y-axis [forward/backward]); total trajectory length (total distance in mm traveled by the COG); outer peripheral area (area encircled by the outer perimeter of the COGS in mm^2); and rectangular area (internal area defined by the maximum width of the COGS along the X- and Y-axis in mm^2).

Table 1 shows the means, SDs, intraclass correlation coefficient (ICC), and test results of the differences between the means obtained from the three measurements after the initial 3-min sitting rest (the first rest measurement) in the control (resting condition) group. There were no significant differences among trials for all variables. A favorable ICC greater than 0.79 was obtained for all variables. Thus, the mean values obtained from the last two measurements after the initial 3-min sitting rest were used as the represented values for both groups [24].

2.5 Statistical analysis

Data were analyzed using SPSS software version 23.0 for Windows (SPSS Inc., Tokyo, Japan). Descriptive statistics were reported as means ± SDs. For each estimated variable, the trial-to-trial mean differences were assessed using repeated measures one-way analysis of variance (ANOVA). The reliability was determined using ICCs. A repeated measures two-way ANOVA was used to examine the significance of differences among each variable measured with or without exercising at different time points. If a significant interaction or main effect was identified, the Bonferroni method was used for multiple comparisons. A probability (p) value < 0.05 was considered to be statistically significant.

3. Results

Table 2 shows the means, SDs, and results of the two-way ANOVA (factor 1: with or without exercise x factor 2: time course) for each COGS variable. The ANOVA revealed significant interactions for all COGS variables (X-axis, Y-axis, and total trajectory lengths, outer peripheral and rectangular areas). Multiple comparison tests of factor 1 showed that the X-axis, Y-axis, and total trajectory lengths measured immediately and 4 min after exercising (4 min later) were greater in the exercising group than those obtained in the resting group. Moreover, the outer peripheral and rectangular areas measured immediately after exercising were greater in the exercising group. Factor 2 had a significant effect only in the exercising group. Indeed, the X-axis, Y-axis, and total trajectory lengths decreased over time, with the greater value obtained immediately after the exercise, a lower value measured 4 min later, and the lowest lengths were obtained before exercising. The outer peripheral and rectangular areas measured immediately after exercising were greater than those obtained before and 4 min after (4 min later) exercising.

4. Discussion

Generally, increasing exercise intensity results in a greater burden on the body and greater COGS [13]. In addition, normal ranges of physiological parameters are recovered, even following an intensive treadmill walking exercise (walking exercise), after a sitting rest [18]. Here, an exercise requiring walking on a treadmill up-to-exhaustion (13.4 ± 2.8 min) [21] with incremental load defined using the multi-stage method (Bruce method) was performed. The following two hypotheses were investigated: the COGS while standing increases after intensive walking exercise (hypothesis 1), and a normal COGS is recovered after a 3-min sitting rest (hypothesis 2).

There was no significant mean difference between the exercise and control groups for all COGS variables (X-axis, Y-axis, and total trajectory lengths, outer peripheral area, and rectangular area) measured after the initial sitting rest before the exercise. In contrast, the means of X-axis, Y-axis, and total trajectory lengths were greater immediately and 4 min after exercising in the exercise group than those obtained in the control group. The outer peripheral and rectangular areas measured in the exercising group were also increased immediately after the exercise. Additionally, all means of COGS variables measured immediately after exercising were greater than those obtained during the initial rest in the exercising group, whereas no significant differences were found among the means in the control group. The COGS of the control group might remain unaffected because the body burden experienced while sitting was low.

Table 1. Trial-to-trial reliability and mean differences among each trial (n = 15)

	1st time		2nd times		3rd times					Analysis of variance				
	M	SD	M	SD	M	SD	ICC	F	P	Factor	df	F	P	Partial η^2
										Trial	2	0.65	0.53	0.04
X-axis trajectory length (mm)	345.8	110.66	333.6	88.58	337.2	90.68	0.79	1.89	0.171	Subject	14	29.15	0.00	
										error	28	(908.88)		
	266.9	94.73	272.1	86.05	263.7	79.58	0.86	1.16	0.327	Trial	2	0.16	0.85	0.01
Y-axis trajectory length (mm)										Subject	14	1935.40	0.00	
										error	28	(1664.64)		
	483.9	159.91	477.6	135.31	473.2	127.54	0.90	1.19	0.320	Trial	2	0.19	0.83	0.01
Total trajectory length (mm)										Subject	14	3669.60	0.00	
										error	28	(2804.62)		
	494.2	358.16	574.7	466.16	585.6	557.50	0.80	0.85	0.437	Trial	2	0.85	0.43	0.06
Outer peripheral area (mm^2)										Subject	14	13.00	0.00	
										error	28	(43758.31)		
	622.0	344.85	890.1	783.63	681.5	437.02	0.86	0.75	0.480	Trial	2	3.40	0.05	0.19
Rectangular area (mm^2)										Subject	14	275.41	0.00	
										error	28	(87363.99)		

Note: M: mean, SD: standard deviation, ICC: intraclass correlation coefficient, F: F-value, df: degree of freedom

Table 2. Results of two-way analysis of variance for each COGS variable (n = 15)

		Time course						Analysis of variance					Multiple comparisons
		A. before exercising		B. immediately after exercising		C. 4 min after exercising							
		M	SD	M	SD	M	SD	Factor	df	F	P	Partial η^2	
X-axis trajectory length (mm)	With or without exercise							With or without exercise	1	8.95	0.01	0.39	
	Control (rest) group	351.2	80.88	316.2	55.82	338.4	76.82	error	14	(17281.17)			
	Experimental (exercise) group	335.4	88.11	504.2	197.91	414.9	135.99	Time course	2	8.80	0.00	0.39	Rest: non
								error	28	(3813.91)			Exercise: A < C < B
								Interaction	2	17.35	0.00	0.55	
								error	28	(4501.54)			B, C: rest < exercise
Y-axis trajectory length (mm)	With or without exercise							With or without exercise	1	10.95	0.01	0.44	
	Control (rest) group	278.5	77.43	268.9	79.00	282.9	95.82	error	14	(27110.96)			
	Experimental (exercise) group	267.9	79.92	526.7	292.54	380.3	172.81	Time course	2	11.95	0.00	0.46	Rest: non
								error	28	(9756.98)			Exercise: A < C < B
								Interaction	2	16.36	0.00	0.54	
								error	28	(8365.26)			B, C: rest < exercise
Total trajectory length (mm)	With or without exercise							With or without exercise	1	10.94	0.01	0.44	
	Control (rest) group	496.9	118.24	460.6	100.06	489.4	128.87	error	14	(50084.67)			
	Experimental (exercise) group	475.4	129.35	815.1	364.40	624.6	233.68	Time course	2	14.64	0.00	0.51	Rest: non
								error	28	(11805.83)			Exercise: A < C < B
								Interaction	2	21.58	0.00	0.61	
								error	28	(12392.59)			B, C: rest < exercise
Outer peripheral area (mm^2)	With or without exercise							With or without exercise	1	11.89	0.00	0.46	
	Control (rest) group	580.2	489.24	458.3	285.08	589.2	466.23	error	14	(291706.10)			
	Experimental (exercise) group	515.6	387.60	1459.7	1185.36	830.4	639.29	Time course	2	9.98	0.00	0.42	Rest: non
								error	28	(128970.31)			Exercise: A, C < B
								Interaction	2	12.29	0.00	0.47	
								error	28	(183941.36)			B: rest < exercise
Rectangular area (mm^2)	With or without exercise							With or without exercise	1	13.40	0.00	0.49	
	Control (rest) group	844.7	668.79	714.2	455.14	849.1	666.89	error	14	(710923.17)			
	Experimental (exercise) group	785.9	583.11	2274.1	1901.78	1300.0	1061.46	Time course	2	10.20	0.00	0.42	Rest: non
								error	28	(345272.46)			Exercise: A, C < B
								Interaction	2	10.79	0.00	0.44	
								error	28	(476246.55)			B: rest < exercise

Note: M: mean, SD: standard deviation, df: degree of freedom, F: F-value

It is believed that, because an intensive, up-to-exhaustion walking exercise put considerable strain on the legs and whole body, it affected the COGS [13]. Bedo et al. [12] reported that the COGS increases in young adults after exercises causing muscle fatigue in the whole body and legs such as sprinting, jumping, landing, sidestep cutting, and lateral and back shifting on the court. Takahashi et al. [13] showed that the COGS increases in young adults after 30 s of pedaling at 80-90 rpm with a load of 7.5% of the body weight [25]. These studies suggest that intensive walking exercises cause muscle fatigue in the whole body and legs and affect the COGS. On the other hand, Matsuda et al. [9] reported that, although the X-axis trajectory length was affected by the hip abduction muscle fatigue, the Y-axis trajectory length remained unchanged. Here, both before/after (COP displacement in anterior-posterior; COP-AP) and left/right (medial-lateral; COP-ML) directions were affected, similarly to the data obtained during a walking exercise on a treadmill by Selthafner et al. [15]. Thus, the COGS is likely affected by walking exercises, regardless of the before/after and left/right directions.

Generally, a sitting/resting period (passive recovery method) allows to recuperate rapidly from fatigue even after strenuous exercise [11]. Konishi et al. [19] measured a pulse rate immediately and 2 min after a 30-s sit-to-stand test, reporting that it recovered a normal state. Takahashi et al. [13] reported that the COGS stabilized in young adults after a 3-min sitting rest period following a pedaling exercise (7.5% body weight load) corresponding to climbing and descending stairs at 15.0 METs. However, here, the COGS was not recovered even after a 3-min sitting rest period (X-axis trajectory length: increase ratio of 23.7%, ES = 0.7 and Y-axis trajectory length: increase ratio of 70.4%, ES = 0.8). This discrepancy is likely because the body load is greater in an intensive, up-to-exhaustion walking exercise than that in a pedaling exercise. Thus, a 3-min sitting rest might not allow to recover from the fatigue and restore a normal COGS. Therefore, we verified hypothesis 1 but not hypothesis 2.

This study examined the effects of an intensive, up-to-exhaustion walking exercise on the COGS by comparing COGS measured at rest and before and after exercise in young adults while considering the participant's physical burden. The walking exercise affected the COGS, which was not recovered after a 3-min sitting rest. The elderly frequently uses walking for maintaining and promoting their health. Although they cannot walk quickly, their balance is disrupted while walking due to leg fatigue [26]. The present data suggest that a walking exercise induces a greater physical burden than pedaling and a greater COGS change. Thus, further studies in the elderly, with careful safety considerations, on the effects of different intensity walking exercises on the COGS and the relationship between the sitting rest duration and COGS recovery are needed.

5. Conclusions

In conclusion, an intensive, up-to-exhaustion walking exercise affected the COGS. This effect was not reverted by a 3-min sitting rest even in young adults.

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