

Effects of Lower Limbs Exercise with Light and Heavy Loads on the Center of Gravity Sway

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Received June 02, 2021; Revised July 05, 2021; Accepted July 15, 2021

Abstract Background: Fatigue to the lower limbs due to exercise load affects the center of gravity sway (COGS) during standing, and the greater the load, the greater the COGS. Research Question: Do different exercise loads to the lower limbs have an effect on the COGS and does sitting/resting promote recovery after exercise. Methods: The subjects were 30 healthy young men. The COGS after light and heavy load exercises was compared after a 3-min sitting/resting period before and after the load exercises. For each test, the COGS was measured for 30 s. Bicycle pedaling for 30 s with loads of 1% (light load) and 7.5% (heavy load) of body weight was selected as the load exercise for the lower limbs. The x-axis and y-axis trajectory lengths, total trajectory length, outer peripheral area, and rectangular area were selected as variables affecting the COGS. Results: Repeated measures analysis of variance clarified that of all variables, COGS after heavy load exercises was significantly greater than that after light load exercises and during standing after sitting/resting. However, there was no significant difference in COGS after light load exercise and during standing. Significance: The COGS after heavy load exercise was greater than that after light load exercise. The light load exercise used in this study had no effect on COGS in young men. Even after heavy load exercise, the COGS recovered after a 3-min sitting/resting period.

Keywords: recovery effect, pedaling exercise, fatigue of the lower limb, trajectory lengths, young men

Cite This Article: Kenji Takahashi, Shin-ichi Demura, and Hiroki Aoki, "Effects of Lower Limbs Exercise with Light and Heavy Loads on the Center of Gravity Sway." *American Journal of Sports Science and Medicine*, vol. 9, no. 1 (2021): 8-12. doi: 10.12691/ajssm-9-1-3.

1. Introduction

The center of gravity sway (COGS) is often used as an index to evaluate the ability of humans to control posture [1,2,3]. The central nervous system integrates information from the visual, somatosensory, and vestibular systems to maintain stable posture and the COGS [4,5]. The COGS fluctuates due to breathing and physical fatigue after work and exercise [6,7,8,9,10]. According to previous studies, fluctuation in the COGS was greater after handling of airport cargo than before [9](Yamamoto et al., 1979) and the center position of foot pressure often significantly fluctuates after physical activity, suggesting that physical activity may affect postural control [11].

In general, high-intensity exercise generates a greater load on the body than low-intensity exercise, resulting in greater respiratory turbulence, muscle fatigue, and fluctuations in COGS. In addition, because recovery of respiratory turbulence and muscle fatigue is slow, it is assumed that recovery of the COGS is also slow. However, Matsuda et al. [12] compared the COGS of the hip abductor muscles before and after fatigue, and found that the trajectory length at the x-axis, but not the y-axis, was

shorter before than after fatigue. Since the degree of fatigue to the lower limb muscles differs between light and heavy loads, the effect of a particular exercise may differ among sway variables. The ability to control balance and leg strength are related to postural maintenance [13] and a decrease in these physical factors is a common cause of falling in the elderly [14]. Especially in the elderly, temporary fatigue of the leg muscles can result in instability while standing, thereby increasing the risk of falling. Up to now, there have been few detailed studies of the effects of temporal fatigue of the leg muscles on the COGS. Therefore, the aim of the present study was to evaluate the effects of temporary fatigue following exercise of the lower limbs on the COGS.

2. Methods

2.1. Participants

The study cohort consisted of 30 healthy young men (mean age, 18.4 ± 2.0 years; mean height, 169.6 ± 5.5 cm; mean weight, 61.7 ± 8.2 kg). All subjects received a full explanation of the aims, procedures, and risks of this study and informed consent was obtained prior to enrollment.

The experimental protocol was approved by the Ethics Committee on Human Experimentation of Japanese Society of Test and Measurement in Health and Physical Education (2018-001) and conducted in accordance with the tenets of the Declaration of Helsinki. The experimental protocol required the subjects to endure heavy physical loads to assess the effects of lower limb exercise on the COGS in adolescents in order to apply this information to prevent the elderly from falling.

2.2. Measurement Plan

The COGS differs day to day due to the effects of body condition and fatigue [11]. Hence, it is difficult to achieve homogeneity among the subjects allocated to the experimental and control groups. Furthermore, a crossover method that alternated allocation of the subjects to the experimental or control group has problems of carry-over and order effects, although it is possible to achieve homogeneity between the groups.

Cernacek et al. [15] reported that physiological responses, such as blood pressure and heart rate, recover to normal states following a 10-min resting period even after high-intensity exercise with incremental loads. Moreover, Konishi et al. [16] found no significant difference in pulse rates at the end of a 30-s sit-to-stand test and 2 min afterward. Based on these reports, we hypothesized that a 3-min sitting/resting period after heavy load exercise will promote recovery from fatigue, at least to some extent.

2.3. Hypotheses

The following three hypotheses were investigated in this study: (1) heavy load exercise affects the COGS more than light load exercise; (2) light/heavy load exercise affects the COGS more than during standing; and (3) a sitting/resting period of 3 min after light/heavy load exercise will promote recovery of the COGS to the same level as when standing.

2.4. Experimental Protocol

The following experimental protocol was devised to investigate the above hypotheses.

In accordance with the experimental protocol outlined in Figure 1, the above hypotheses were verified if fluctuation of the COGS before and after heavy load exercise (COGS difference between measurements 7 and 8) is significantly greater than that before and after light load exercise (COGS difference between measurements 3 and 4), and both values are significantly greater than during the standing/resting period at measurements 1, 2, and 3 (COGS difference between measurements 1 and 2, 5 and 6, and 9 and 10).

2.5. Exercise Load

Exercise loads were applied using a bicycle ergometer (PowerMax V-III; Combi Wellness Corporation, Tokyo

Japan). A load equivalent to 1% of body weight (0.01 kp/kg) was used for the light load exercise and a load of 7.5% of body weight (0.075 kp/kg) was used for the heavy load exercise. The load setting was based on the Wingate test [17], which evaluates the maximum (anaerobic) power by full-power pedaling for a 30-s period with a load of 7.5% of body weight. The light load exercise was defined as fast walking at 4.0 metabolic equivalents (METs) and the heavy load exercise was defined as ascending and descending stairs at 15.0 METs. The subjects were required to maintain pedaling at 80–90 rpm with each load.

2.6. Measurement of the COGS

The COGS is commonly used as an index of the trajectory of the center of gravity (T.K.K.5810; Takei Scientific Instruments Co., Ltd., Niigata Japan). The center of gravity during standing was measured with the subject standing on a plate while assuming a position projected on the plantar surface by four vertical load sensors attached to a rectangular plate on the horizontal plane. Data were recorded with a personal computer at 20 Hz after analog-to-digital conversion.

The subjects were instructed to assume the Romberg posture with both hands aligned to the body [18] on the measuring equipment and to stare at a fixed target placed at eye level. For each of the 10 trials in the series, the COGS was measured for 30 s as follows: 1 trial for 30 s after sitting/resting (3 min), 1 trial after 90 s in the rest/standing posture, 1 trial at 30 s each before and after the light load exercise, 1 trial at 30 s after a 3-min sitting/resting period (3 min), 1 trial after 90 s of the standing/resting posture, 1 trial at 30 s each before and after the heavy load exercise, 1 trial at 30 s after a 3-min sitting/resting period, and 1 trial after 90 s in the standing/resting posture.

2.7. Evaluated Variables

In this study, the following variables were evaluated as described in a previous study [19]: x-axis trajectory length (distance in mm of COG movement along the x-axis); y-axis trajectory length (distance in mm of COG movement along the y-axis); total trajectory length (distance in mm of total distance of COG movement); outer peripheral area (internal area of the outer circumference of the COGS in mm²); and rectangular area (internal area of the maximum width of the COGS along the x- and y-axes in mm²).

2.8. Statistical Analysis

The mean differences of all evaluated variables among the different conditions were assessed using repeated measures analysis of variance (ANOVA). If a significant main effect was identified, Tukey's honestly significant difference (HSD) test was used for multiple comparisons. A probability (p) value of <0.05 was considered statistically significant.

Procedure	Fluctuation of the COGS during standing 1					Fluctuation of the COGS before and after light load exercise						
	Sitting rest	Preparation	Measurement COGS 1	Standing	Measurement COGS 2	Sitting rest	Preparation	Measurement COGS 3	Preparation	Light load exercise	Preparation	Measurement COGS 4
Time (sec)	180	30	30	90	30	180	30	30	30	30	30	30
Total time (sec)	180	210	240	330	360	540	570	600	630	660	690	720

Procedure	Fluctuation of the COGS during standing 2					Fluctuation of the COGS before and after heavy load exercise						
	Sitting rest	Preparation	Measurement COGS 5	Standing	Measurement COGS 6	Sitting rest	Preparation	Measurement COGS 7	Preparation	Heavy load exercise	Preparation	Measurement COGS 8
Time (sec)	180	30	30	90	30	180	30	30	30	30	30	30
Total time (sec)	900	930	960	1050	1080	1260	1290	1320	1350	1380	1410	1440

Procedure	Fluctuation of the COGS during standing 3					COGS: center of gravity sway
	Sitting rest	Preparation	Measurement COGS 9	Standing	Measurement COGS 10	
Time (sec)	180	30	30	90	30	
Total time (sec)	1620	1650	1680	1770	1800	

Figure 1. Timing of the experimental protocol

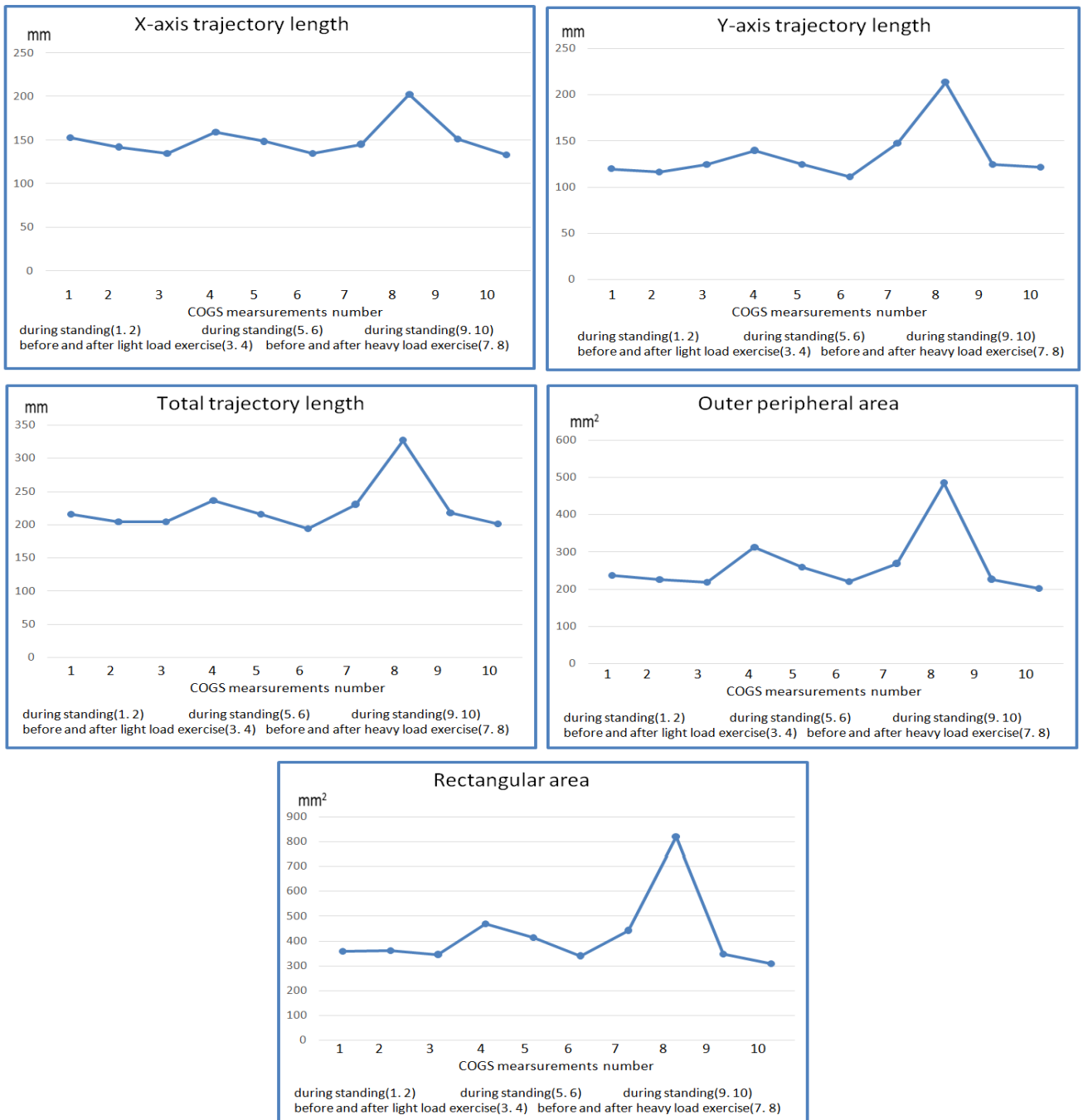


Figure 2. Time-series plots of the mean values of all evaluated variables

Table 1. Basic statistics of the COGS and results of repeated measures ANOVA and multiple comparison tests (Tukey's HSD) after light/heavy load exercise and the resting/standing posture

Evaluation variable	1: Standing 1		2: Light load exercise		3: Standing 2		4: Heavy load exercise		5: Standing 3		F-value	Post-hoc
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
X-axis trajectory length (mm)	26.2	21.7	39.6	26.9	25.9	19.5	60.5	35.1	24.8	16.6	11.408*	4>1,2,3,5
Y-axis trajectory length (mm)	19.9	22.9	24.5	19.7	22.0	18.7	71.6	64.2	21.8	15.3	12.610*	4>1,2,3,5
Total trajectory length (mm)	32.8	32.1	49.2	27.9	29.7	26.6	103.0	72.9	30.9	19.8	16.866*	4>1,2,3,5
Outer peripheral area (mm ²)	98.3	60.9	145.1	121.9	106.4	87.7	262.2	245.5	58.8	46.4	10.922*	4>1,2,3,5
Rectangular area (mm ²)	160.9	122.0	237.4	193.1	160.2	145.9	488.2	562.5	91.2	66.0	9.858*	4>1,2,3,5

*p < 0.05.

3. Results

The mean values of all evaluated variables are shown as time-series plots in Figure 2. The COGS value was greatest after heavy load exercise, while the other COGS values were within certain ranges.

The basic statistics of the degree of fluctuation of the COGS before and after light/heavy load exercise, during standing/resting posture, and the results of repeated measures ANOVA and multiple comparison tests (Tukey's HSD) are shown in Table 1. For all variables, fluctuation of the COGS before and after heavy load exercises was significantly greater than after light load exercises and during the standing/resting posture, but not between the light load exercise and during the standing/resting posture.

4. Discussion

In general, the greater the exercise intensity, the greater the burden on the body, and the greater the COGS after exercise. However, the COGS is recovered by sitting/resting for a certain period of time even after heavy load exercises [15]. The following three hypotheses were investigated in this study: (1) heavy load exercise affects the COGS more than light load exercise; (2) light/heavy load exercise affects the COGS more than during standing; and (3) a sitting/resting period of 3 min after light/heavy load exercise will promote recovery of the COGS to the same level as when standing. Bicycle pedaling with a load of 1% of body weight was selected with fast walking (4.0 METs) as the light load exercise, and a load of 7.5% of body weight equivalent to ascending and descending stairs (15.0 METs) as the heavy load exercise.

The results showed that the fluctuation in the COGS values of all evaluated variables were significantly greater after heavy load exercises than light load exercises and during standing. However, there was no significant difference between the values after the light load exercises and during standing. In general, light load exercise resulted in little muscle fatigue to the lower limbs and had no effect on the COGS. On the other hand, as the heavy load exercise selected in this study, a 30-s period of full-power (anaerobic) pedaling with a load of 7.5% body weight [19] resulted in a large burden and temporary muscle fatigue to the lower limbs and notable effect on the COGS. Bedo et al. [10] reported that combined exercises, such as sprinting, sidestep cutting, jumping, landing, and lateral and back shifting, caused muscle fatigue to the lower limbs and increased the COGS. Degache et al. [8]

reported that the COGS had increased after maintaining the plantar flexion posture for 30 s. Based on these previous reports, it is considered that lower limb exercise over a certain level causes muscle fatigue to the lower limbs and has notable effects on the COGS. On the other hand, Matsuda et al. [12] compared the COGS before and after hip abduction exercises, and reported that the x-axis trajectory length became greater after exercise than before, while the y-axis trajectory length remained unchanged. In the present study, all COGS variables were affected by heavy load exercise regardless of the trajectory direction. The influence on the COGS can differ depending on the degree of exercise load on the lower limb muscles or different muscle groups directly impacted by the exercise load. Generally, sitting/resting (a passive recovery method) promotes rapid recovery from fatigue even after strenuous exercise [9]. In the present study, there was no significant difference in the COGS after light load exercise vs. during standing, and a 3-min sitting/resting period promoted recovery from fatigue after a heavy load exercise. Konishi et al. [16] reported no significant difference in pulse rate after a 30-s sit-to-stand test and 2 min afterward. Collectively, these findings suggest that the COGS during standing recovers by sitting/resting for about 3 min even after heavy exercise, which imposes the largest burden on the lower limbs. Based on the above results, hypotheses 1 and 3 were verified, while hypothesis 2 was partially verified for only the heavy load exercise.

This study examined the effect of different exercise loads to the lower limbs on the COGS and the recovery effect of sitting/resting after exercise using adolescents in consideration of the subject's physical burden. The results of the present study clarified that the COGS is affected by heavy load exercise, but not light load exercise, such as walking, and that the COGS had recovered after a 3-min sitting/resting period even after heavy load exercise. The elderly may have impaired balance, which poses a greater risk of falling in response to fatigue of the lower limb muscles after light load exercise. Nonetheless, further studies are warranted to examine the effect of the light load exercise used in this study on the COGS and the relationship between the sitting/resting period and recovery of the COGS in elderly subjects.

5. Conclusion

Heavy load pedaling (7.5% of body weight) had a notable effect on the COGS during standing, but not light load pedaling exercise (1.0% body weight), and the COGS

recovered after a 3-min sitting/resting period even after heavy exercise.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP18K11097.

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