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Short Communication

Evaluation of differences in exercise load due to varied lower limb weight during stair ascending and descending: a pilot study

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Abstract

This study aimed to investigate the differences in exercise load due to variations in lower limb weight during stair ascent and descent. The study involved 10 healthy adult men and women without respiratory or circulatory diseases (five men and five women). Using a respiratory gas analysis device, the participants performed stair climbing under three conditions: 1) full weight, 2) half (partial) weight-bearing, and 3) non-weight-bearing. The maximum oxygen uptake during stair climbing was defined as the peak oxygen uptake. Additionally, the time required for ascent and descent was measured using a stopwatch, and heart rate and perceived fatigue at the end were assessed using the Borg scale. Peak oxygen uptake and Borg scale scores significantly increased during ascent and descent under the non-weight-bearing condition compared to those under the full weight-bearing and half-weight-bearing conditions. The required time was significantly extended under the half-weight-bearing and non-weight-bearing conditions compared to that under the full-weight-bearing condition. Therefore, when stair ascent and descent are necessary during a period requiring the use of both crutches, it is considered desirable to perform them only after at least half-weight-bearing condition or more is permitted, as this approach results in a considerable reduction in load.

Keywords: exercise load, lower limb load, oxygen uptake

階段昇降時の下肢重量の違いによる運動負荷の差異についての検討; 予備的研究

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要旨

本研究の目的は、階段昇降時の下肢重量の違いによる運動負荷の差異を調べることである。本研究では、呼吸器および循環器疾患の既往がない健康な成人男女10名（男性5名、女性5名）を対象とした。呼吸ガス分析装置を用いて、参加者は3つの条件下で階段昇降を行った： 1）全荷重負荷、2）部分荷重 (1/2荷重)負荷、3）非荷重負荷。階段昇降中の酸素摂取量の最大値を最高酸素摂取量と定義した。さらに、階段昇降に要した時間をストップウォッチで計測た。また終了時の心拍数を測定し、疲労感はボルグスケールで評価した。

最高酸素摂取量とボルグスケールのスコアは、非荷重負荷において、全荷重負荷

および部分荷重負荷と比較して、昇段降段の両方で有意に増加した。所要時間は、全荷重負荷に比べ、部分荷重負荷および非荷重負荷では有意に延長した。従って、両松葉杖の使用が必要な期間に階段の昇降が必要な場合は、少なくとも部分荷重 (1/2 荷重) が許可された以降に昇降することが、負担軽減になり望ましいと考えられる。

Introduction

When surgery is performed for conditions such as open or complex fractures of the lower limb, weight-bearing restrictions are often imposed, necessitating the use of crutches. Therefore, for a certain period, using crutches is essential as an independent means of mobility and to promote bone healing. Walking with crutches results in an increased load compared to normal walking [*1*]. Adedoyin et al. measured cardiovascular responses during stair ascent and descent using axillary and elbow crutches, reporting significant increases in parameters, including blood pressure and heart rate (HR), with no difference between axillary and elbow crutches [*2*]. Furthermore, Moran et al. measured oxygen consumption during walking on level ground and stair ascent and descent with crutches, identifying a significant increase in oxygen consumption during stair ascent and descent with no differences between sexes [*3*]. Under non-weight-bearing (NWB) conditions of the lower limbs, previous studies have demonstrated that oxygen consumption significantly increases when walking with bilateral crutches without a prosthetic limb compared with walking with a prosthetic limb [4]. Additionally, during stair ascent/descent in the NWB condition, there is a significant increase in the activity of the gluteus medius of the supporting leg [5]. This suggests that bilateral crutch walking under NWB conditions imposes higher muscle and cardiopulmonary loads, with further increases during stair ascent. However, the differences in exercise load due to variations in lower limb weight-bearing during stair ascent remain unknown. Therefore, this study aimed to investigate differences in exercise load during stair ascent with three conditions altering lower limb weight-bearing (full weight-bearing [FWB], half (partial) weight-bearing [1/2 PWB], and NWB) using respiratory gas analysis equipment. The objective was to elucidate differences in exercise load due to changes in lower limb weight-bearing and provide information for lifestyle guidance using crutches.

Materials and Methods

Participants

This pilot study involved 10 healthy adult individuals (five men, five women) without cardiovascular or other medical contraindications. Basic information was obtained, and lung function, respiratory muscle strength (Autospiro AS-507; MINATO Co., Osaka, Japan), grip strength (TKK-5401; Takei Scientific Instruments Co., Tokyo, Japan), and quadriceps torque (Isoforce GT-360; OG Wellness Co., Okayama, Japan) were assessed (Table 1). Lower limb weight-bearing conditions were set as FWB, 1/2 PWB, and NWB. To eliminate any order effects, the 10 participants were divided into three groups comprising three, three, and four individuals, and measurements were performed. A washout period of at least 3 days was implemented after each measurement session (Fig. 1). Furthermore, to eliminate the thermal effects of food, all participants were required to fast for 2 h before the examination (water intake was allowed). The crutches were adjusted according to each participant's physique, and the final height was set to the most comfortable level for each participant [*6*]. Prior to the measurements, an educational session of 10–15 min was conducted to practice stair ascent/descent using crutches. In the 1/2 PWB condition, visual feedback was provided during practice using a body scale. These sessions were supervised by two members of the research team. In all three conditions, with the dominant leg as the weight-bearing side, ascent was performed starting from the dominant leg, and descent was performed starting from the non-dominant leg (the NWB condition was for the dominant leg only). Stair ascent and descent were performed in a two-action, one-step pattern for all conditions (Fig. 2).

Study protocol

The oxygen consumption was measured using a respiratory gas analysis device (COSMED K5 wearable metabolic system; COSMED, Rome, Italy). The participants wore the COSMED K5 wearable metabolic system with a harness and performed stair ascent/descent from the first to the third floor (49 steps, each 17 cm) under three conditions: FWB, 1/2 PWB, and NWB. The maximum oxygen consumption value obtained from the data using the breath-by-breath method was defined as the peak oxygen uptake (peak VO_2) and converted to the metabolic equivalent of task (METs). Similarly, minute ventilation (VE) was also measured. Furthermore, previous studies have demonstrated the reproducibility and validity of the COSMED wearable metabolic system [*7,8*]. Before the start of the ascent, all participants were seated for at least 5 min of rest, and the HR was generally maintained at approximately 80 beats/min. It was confirmed that the oxygen intake during rest times was approximately 200 ml/min, corresponding to approximately 1 MET. The speed of stair ascent and descent were optional for the participants. After completing the stair ascent, the HR of the participants was measured, and their breathlessness and fatigue were assessed using the Borg scale. Following stair ascent, participants rested adequately until their pre-ascent state was confirmed (HR approximately 80 beats/min, oxygen intake approximately 200 ml/min), and stair descent was then measured similarly. Additionally, the time required for ascent and descent (task completion time) was measured using a stopwatch (TD-392; TANITA Co., Tokyo, Japan).

Ethical consideration

Ethical considerations were observed, and this study was approved by the Ethics Committee of Seijo University (Approval Number: 2023P0002). Additionally, the research objectives were explained to all participants, and written consent for research participation was obtained.

Statistical analysis

Statistical analysis was performed using EZR software (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria) [*9*]. Results were considered statistically significant if the two-tailed p-value was < 0.05. Data are expressed as mean ± standard deviation, except for non-normally distributed variables, which are presented as medians. Statistical analysis involved testing for normality (Shapiro–Wilk test), followed by repeated measures one-way analysis of variance for the normally distributed variables and Friedman test for the non-normally distributed variables for three conditions: FWB, 1/2 PWB, and NWB. Post-hoc tests were conducted using the Bonferroni method.

Results

The average resting oxygen intake before ascent under the three conditions was 197.6 ± 38.2 ml/min, equivalent to 1.0 ± 0.2 METs. Similarly, the average resting oxygen intake before descent under the three conditions was 218.4 ± 69.1 ml/min, equivalent to 1.0 ± 0.2 METs. The peak VO_2, VE, task completion time, Borg scale scores, and HR during stair ascent are presented in Table 2. In terms of peak VO_2, a significantly higher value was observed under the NWB condition (average of 1844 ml/min [9.5 METs]) than that under the FWB and 1/2 PWB conditions ($p = 0.010$, $p = 0.005$). The rate of increase in workload was approximately 31.6–35.7% higher under the NWB condition than under the FWB and 1/2 PWB conditions (Fig. 3-A). VE significantly increased under the NWB condition compared to that under the FWB and 1/2 PWB conditions (both $p < 0.001$). Regarding task completion time, a significant extension was observed under the 1/2 PWB and NWB conditions compared to that under the FWB condition ($p = 0.001$, $p < 0.001$).

Moreover, the NWB conditions were significantly extended compared to the 1/2 PWB condition ($p < 0.05$). The Borg scale results mirrored those of peak VO_2, showing a significant increase in breathlessness and fatigue under the NWB condition compared to that under the FWB and 1/2 PWB conditions (both $p < 0.001$). HR significantly increased under the NWB condition compared to that under the FWB condition ($p < 0.05$).

The peak VO_2, VE, task completion time, Borg scale scores, and HR during stair descent are presented in Table 3. Similar to stair ascent, peak VO_2 under the NWB condition was significantly higher than that under the FWB and 1/2 PWB conditions ($p = 0.001$ and $p = 0.017$, respectively). Although the workload was not as high as that during ascent, an average of 1341 ml/min (7.2 METs) indicated a substantial load during descent. The rate of increase in workload was 37.5–44.4% higher under the NWB condition than under the FWB and 1/2 PWB conditions (Fig. 3-B). VE significantly increased under the NWB condition compared to that under the FWB and 1/2 PWB conditions ($p < 0.001$ and $p = 0.010$, respectively). Regarding task completion time, a significant extension was observed under the 1/2 PWB and NWB conditions compared to that under the FWB condition (both $p < 0.001$). Moreover, the NWB conditions were significantly extended compared to the 1/2 PWB conditions ($p < 0.05$). At the end of the Borg scale, results reflected those of peak VO_2. The findings showed a significant increase in breathlessness and fatigue under the NWB condition compared to that under the FWB and 1/2 PWB conditions ($p < 0.001$ and $p = 0.001$, respectively). HR significantly increased under the NWB condition compared to that under the FWB condition ($p < 0.05$).

Discussion

Walking with bilateral crutches in the NWB condition is speculated to impose higher muscular and cardiorespiratory loads [*4,5*], with further increases during stair ascent/descent. However, there have been no studies on workload at different load levels on the lower extremities. Generally, 1/2 PWB and NWB conditions require the use of both crutches, since the use of both crutches is necessary. Therefore, in our study, we examined differences in exercise load during stair ascent/descent using bilateral crutches under FWB, 1/2 PWB, and NWB conditions.

The results revealed a significant increase in workload during ascent and descent under the NWB condition compared with that under the FWB and 1/2 PWB conditions. Similarly, a significant increase in VE was also observed. Furthermore, HR was significantly elevated under the NWB condition compared to that under the FWB condition. Key findings of our study are the significant increases in workload, by 32–36% during NWB ascent and 38–44% during NWB descent, compared with those under the

FWB and 1/2 PWB conditions.

Even on level ground, walking with crutches under NWB conditions increases cardiopulmonary load; however, during stair ascent under NWB conditions, the supporting leg bears high loads and must also lift and lower body weight. Additionally, as the load on the lower limbs decreases, the load on the upper limbs increases accordingly [*10,11*], suggesting that under NWB conditions, both upper limbs are subjected to high loads. The significant increase in VE and HR under NWB conditions provides evidence of high load. These factors likely contribute to the high workload observed under the NWB condition.

On the Borg scale, significant increases in breathlessness and fatigue were observed under the NWB condition compared to those under the FWB and 1/2 PWB conditions. These results, consistent with those of peak VO_2, suggest that as the exercise load increases, breathlessness and fatigue also increase.

Regarding task completion time, a significant extension was observed under 1/2 PWB and NWB conditions compared with that under the FWB condition. The prolonged task completion time in the NWB and 1/2 PWB conditions suggests that an increase in workload and the addition of tasks involving crutch use influenced the extension of time.

This study has some limitations. First, while a decrease in lower limb load would likely result in an increased load on the upper limbs [*10,11*], we did not investigate its impact on the upper limb load. Additionally, we did not account for sex differences in muscle strength. Secondly, fractures are also common in older adults [*12*], necessitating the use of crutches; however, our study focused only on young adults, leading to a potential selection bias. Additionally, not specifying the speed during stair ascent and descent and leaving it to individual discretion should be considered as it may have influenced the results.

Based on the above results, ascending and descending approximately 50 stairs with bilateral crutches under NWB conditions impose a high load (7.1–9.5 METs or more), even in healthy adults. This results in approximately a 30–45% increase in cardiac load compared to that under FWB and 1/2 PWB conditions. Therefore, stair ascent and descent under NWB conditions are not recommended for older individuals with low exercise tolerance or those with heart or respiratory conditions. Conversely, when half of the body weight is supported, the load is significantly reduced. Therefore, when stair ascent and descent are necessary during a period requiring the use of both crutches, they should ideally be performed only after at least 1/2 PWB or more is permitted.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

Contributions

SS, TM and KI conceptualized the study design and protocol. SS, TM, SH, KY and KI collected and assembled the data. SS and TM carried out the analysis and interpretation of data. SS, TM and KI drafted the manuscript. All authors have critically reviewed, revised and approved the final.

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Legends

Table 1. Baseline characteristics of the participants.

Table 2. Results of stair ascent under three conditions.

Table 3. Results of stair descent under three conditions.

Fig. 1. Order of measurement.

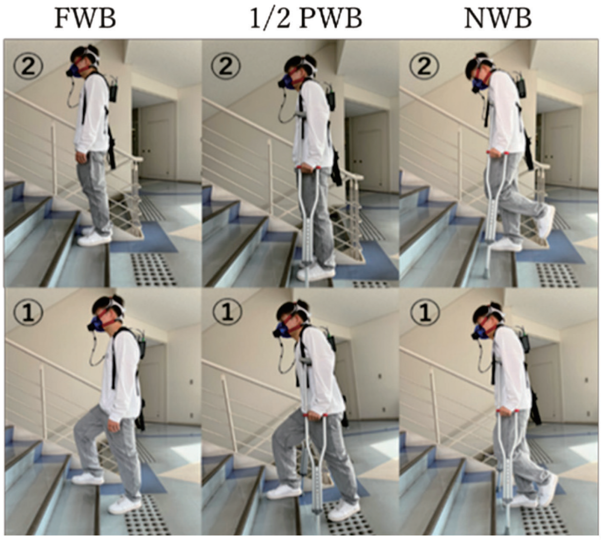
Fig. 2. Stair ascent in three conditions. Stair ascent was performed starting from the dominant leg, and stair descent was performed starting from the non-dominant leg.

Fig. 3. Rate of load increase stair ascension/descent in three conditions. (A) Stair ascent, (B) stair descent.

	First		Second		Third
A group (3 cases)	NWB	washout period	1/2 PWB	washout period	FWB
B group (3 cases)	1/2 PWB		FWB		NWB
C group (4 cases)	FWB		NWB		1/2 PWB

FWB; full weight-bearing, 1/2 PWB; half (partial) weight-bearing, NWB; non-weight-bearing

Figure 1. Order of measurement.

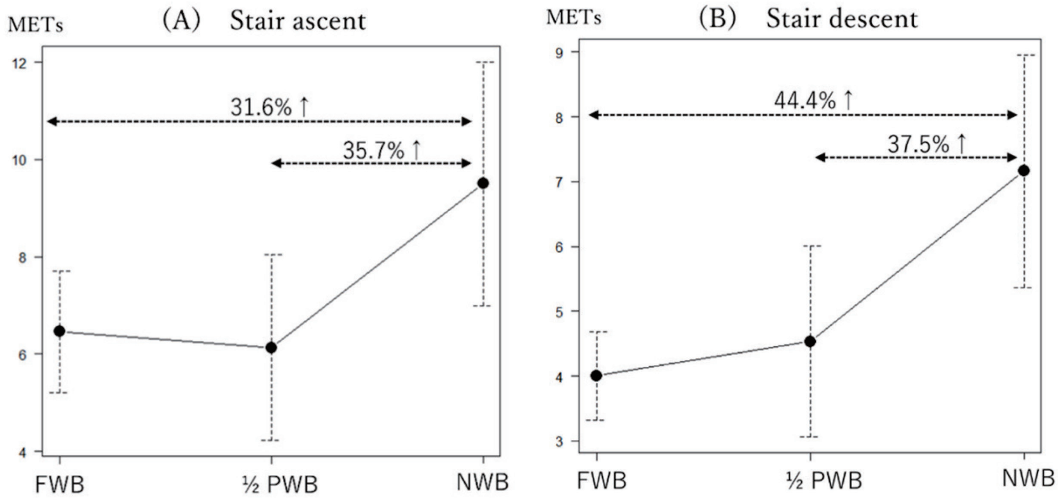


Order ① → ②

FWB; full weight-bearing, 1/2 PWB; half (partial) weight-bearing, NWB; non-weight-bearing

Figure 2. Stair ascent in three conditions.

Stair ascent was performed staring from the dominant leg, and descent was performed staring from the non-dominant leg.



FWB; full weight-bearing, 1/2 PWB; half (partial) weight-bearing, NWB; non-weight-bearing

Figure 3. Rate of load increase during stair ascent / descent in three conditions. (A) Stair ascent, (B) stair descent.

Table 1. Baseline characteristics of the participants

	All participants (n=10)
Age (years)	21 (21-22)
Gender (Men, %)	5 (50)
Height (cm)	162.6 ± 8.6
Weight (kg)	58.6 ± 13.3
Grip strength (kg)	37.4 ± 10.2
Quadriceps torque (Nm)	131.3 ± 38.3
VC (L)	4.1 ± 0.8
%VC (%)	96.8 ± 5.5
FEV1 (L)	3.5 ± 0.6
FEV1 /FVC (%)	87.3 ± 4.6
Inspiratory muscle strength (cmH_2O)	74.2 ± 15.5
Expiratory muscle strength (cmH_2O)	83.6 ± 28.0

VC; vital capacity, FEV1; forced expiratory volume in one second, FVC; forced vital capacity

Table 2. Results of stair ascent under three conditions

	FWB	1/2 PWB	NWB	effect size (η^2)
Peak VO_2 (ml/min) (METs)	1305.0 ± 311.2 (6.5 ± 1.3)	1246.6 ± 479.7 (6.1 ± 1.9)	1843.7 ± 361.7**♭♭ (9.5 ± 2.5)	0.16
Minute ventilation (L/min)	29.2 ± 5.6	31.6 ± 7.2	43.2 ± 9.0**♭♭	0.29
Task completion time (s)	63.6 ± 5.1	89.0 ± 11.5**	98.1 ± 13.3**♭	0.46
Borg scale	1.0 (1.0-1.8)	2.0 (1.0-2.0)	5.0 (3.3-5.0)**♭♭	0.41
Heart rate (beat/min)	103.4 ± 16.3	117.7 ± 19.6	127.0 ± 14.6*	0.07

** p<0.01vs FWB, * p<0.05 vs FWB, ♭♭ p<0.01 vs 1/2 PWB, ♭ p<0.05 vs 1/2 PWB

FWB; full weight-bearing, 1/2 PWB; half (partial) weight-bearing, NWB; non-weight-bearing, Peak VO_2; peak oxygen uptake, min; minute, s; second

Table 3 Results of stair descent under three conditions

	FWB	1/2 PWB	NWB	effect size (η^2)
Peak VO_2 (ml/min) (METs)	822.6 ± 235.0 (4.0 ± 0.7)	887.4 ± 321.1 (4.5 ± 1.5)	1341.2 ± 250.4$^{**\flat}$ (7.2 ± 1.8)	0.27
Minute ventilation (L/min)	23.7 ± 4.2	27.2 ± 6.9	34.4 ± 6.9$^{**\flat}$	0.25
Task completion time (s)	53.9 ± 2.5	85.7 ± 13.8**	102.5 ± 23.4$^{**\flat}$	0.42
Borg scale	1.0 (0.3-1.0)	1.0 (1.0-1.8)	3.0 (3.0-3.8)$^{**\flat\flat}$	0.35
Heart rate (beat/min)	94.7 ± 12.7	102.8 ± 14.1	111.3 ± 8.6*	0.07

$^{**}p<0.01$vs FWB, $^{*}p<0.05$ vs FWB, $^{\flat\flat}p<0.01$ vs 1/2 PWB, $^{\flat}p<0.05$ vs 1/2 PWB

FWB; full weight-bearing, 1/2 PWB; half (partial) weight-bearing, NWB; non-weight-bearing, Peak VO_2; peak oxygen uptake, min; minute, s; second