Effect of Backpack Loads on the Timing of Cardiopulmonary Response in Healthy Men

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Abstract: - The backpack used commonly affects posture and physical performance, resulting in increased oxygen uptake and energy expenditure. The purpose of this study is to confirm the effect of the chest loads on the reaching time of the cardiopulmonary response. Seventeen healthy men participants were monitored for cardiopulmonary function continuously during walking exercise with the Ramp protocol and recorded the time taken to reach THR, VO_2 peak, RR Difference, maximal METs, maximal $FECO_2$, and minimum FEO_2. During the exercise test, subjects were instructed to carry a backpack loaded at no load, 5%, 10%, and 15% body weight in random order. There was a significant difference in the time to reach the THR, the oxygen intake peak time, the maximum metabolic equivalent time, the respiratory rate increase, the minimum oxygen amount, and the maximum carbon dioxide amount at no load and more than 5% load. However, no significant difference was found between the loads. It is thought that even a 5% backpack load of one's body weight can impose on cardiopulmonary energy costs, and this is thought to help improve training programs with a gradual increase in mechanical chest load.

Key-Words: - Load carriage, Cardiopulmonary function, Backpack, Weight, CPX, Ramp protocol.

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1 Introduction

To breathe, oxygen is inhaled and delivered into the bloodstream, and carbon dioxide is expelled through exhalation after the oxygen has been consumed by the body's energy metabolism, [1], [2]. During resistive loaded breathing, an appropriate central nervous respiratory output response and respiratory system mechanical properties like chest wall stability and respiratory muscle strength induce effective tidal volume and minute ventilation, [3].

Backpack-carrying is one of the essential methods of transporting occupational items and is essential in many physically demanding occupations, with first responders and military personnel carrying the heaviest loads, [4], [5], [6]. As the popularity of adventure sports, recreational activities, and mountaineering increases, the use of backpack carrying has expanded, [7], [8]. Thus, various studies have been conducted to investigate the effects of backpack-carrying systems on biomechanics such as posture and gait patterns depending on occupation and type of sports activity.

Backpack load carriage affects physical performance by loading the spine symmetrically and changing the forward tilting trunk inclination and body center of gravity (COG), [9], [10], [11]. According to the previous study, which checked changes in gait patterns, heart rate, and blood pressure by having male students carrying various backpack loads at waist height walk on a treadmill, the anterior tilting angle of trunk increased with loads of 15% and 20% body weight (BW) compared to no load and 10% BW, and a prolonged blood pressure recovery time was observed, [12].

In addition to the shape of the backpack, the thickness of the straps and the wearing style (single or double) have different degrees of restriction on the chest, [13], [14]. Load carriage systems such as jackets or backpacks that cover the entire trunk from front to back reduce pulmonary function greatly, [15]. Restriction of the chest decreases the satisfaction and quality of distinct respiratory sensations, including difficulty inhalation and uncomfortable shallow breathing, [16], [17]. Carrying a load close to the body, such as a backpack, affects lung function by restricting the movement of the chest wall during breathing, due to the structural frame, harness type, and weight of the backpack, [13], [18], [19]. These studies suggested that considering backpack-wearing positioning to optimize the effects on body biomechanics and pulmonary functions, positioning it close to the body promotes anteroposterior and lateral stability by facilitating the body's large muscle groups, [14], [20], [21].

In the preceding paper studies, the effects of unloading and large loads of absolute figures of 15 kg, 30 kg, and 45 kg on cardiopulmonary abilities were presented, [22], [23]. But if you look at most of these prior studies, you can only mention the effects of absolute numerical load on cardiopulmonary functions, and you can't see the effects of proportional load on relative load on cardiopulmonary functions.

There have been previous studies that investigated the effect of backpack chest load on cardiopulmonary function values, but there were no studies that confirmed the timing of the target cardiopulmonary response. Therefore, the purpose of this study is to compare the effect of backpack load by examining the time to reach the cardiopulmonary function response.

2 Methods

2.1 Participants

Seventeen healthy males participated in this study. This study was approved by the Sunmoon University Institutional Bioethics Committee (SM-201904-019-1), and all procedures were performed after subjects provided written consent for participation. All subjects had no history of cardiopulmonary disease and musculoskeletal disorders and had normal pulmonary function.

2.2 Procedures

This study was completed with repeated measurement within-subject studies. Subjects underwent basic anthropometric measurements (height, weight). Subjects wore the same training suit (sports pants, T-shirts, and running shoes) and completed four randomly ordered exercise tests with backpack load: unload, 5%, 10%, and 15% of body weight (BW) loads (Figure 1). Since there is a concern about wearing backpacks heavier than 20% of the BW, our study set the lower level up to 15% of BW to avoid injury risk and not to cause musculoskeletal problems, [24], [25].

A conventional double-strap backpack with a capacity of 25L was selected in this study (John Sports Backpack Super Brake, T501008). The backpack was positioned on the spine T12 to ensure consistency while inducing a large postural response to the load, [26]. The exercise test was started at the Resting Heart Rate (RHR) by applying the Ramp protocol until 85% of the Target heart rate (THR). The Ramp protocol in the Electric Running Machines (Standard Industries, Fargo, ND, USA) adjusts belt speeds linearly from approximately 0.5mph up to 3.0mph within the participant's comfortable walking range with low exercise tolerance. The subjects completed a separate exercise while wearing a backpack with unloading, 5%, 10%, and 15% of BW loads randomly. The subjects were conducted with a warm-up (3 minutes), cool-down (3 minutes), and an hour break for recovery.

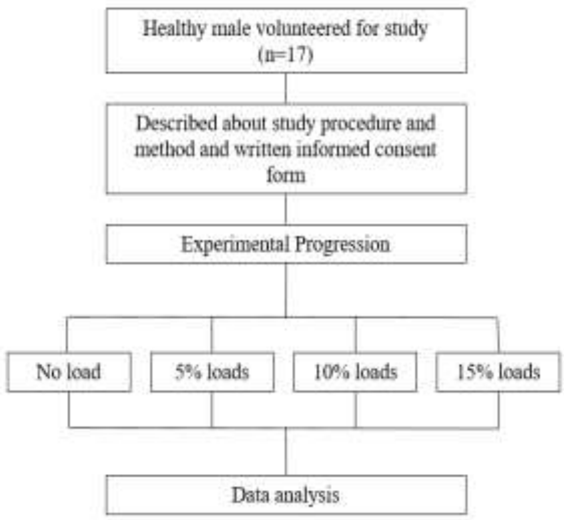

Fig. 1: Experiment protocol flow chart

2.3 Measures

A cardiopulmonary exposure test (CPX) was utilized to measure cardiopulmonary functions, Blood pressure (BP), Heart rate (HR), Oxygen consumption peak (VO_2 peak), Respiratory rate (RR), Metabolic equivalents (METs), Fractional concentration of carbon dioxide in expired gas ($FECO_2$), and Fractional concentration of oxygen in expired gas (FEO_2). Cardiopulmonary functions (HR, VO_2 peak, RR, METs, $FECO_2$, and FEO_2) were analyzed for each breath. The data averaged over 30 seconds were measured and BP was measured every 2 minutes. To analyze the cardiopulmonary function reactions during the exercise tests with four backpack loads conditions, unweighted, 5%, 10%, and 15% of BW, the time to reach THR, VO_2 peak, RR Difference, maximal METs, maximal $FECO_2$, minimum FEO_2 was recorded.

All tests were conducted in a laboratory with similar humidity (40 to 65%) and temperature (21 to 23 ℃). We asked the participants to drink 150ml of cool water during rest. The researchers continuously checked the condition of the subjects (heart rate, blood pressure, motor stress, and ECG) and immediately stopped the experiment if abnormal conditions were observed.

2.4 Statistical Analysis

Statistical analysis was calculated using SPSS version 20.0 for Windows (SPSS INC, Chicago, IL). The repeated measured ANOVA was used to compare the recorded time to reach THR, VO_2 peak, RR Difference, maximal METs, maximal $FECO_2$, and minimum FEO_2 to investigate the effects of backpack load conditions (unload, 5%, 10%, and 15% of BW load). Bonferroni was used to examine relationships between variables of interest. All statistical significance levels were set at $p<.05$ for statistical analysis.

3 Results

General characteristics and measures according to the weight loads for the subjects are listed in Table 1 and Table 2, respectively.

2

Table 1. General characteristicsof the subject

General Characteristics	
Sex(Male/Female)	17/0
Age(year)	20.47±1.53
Height(cm)	175.17±6.83
Weight(kg)	70.70±15.30
Systolic blood pressure	126.82±16.18
Diastolic blood pressure	73.12±22.88
Heart rate	90.76±26.35

3.1 The Time to Reach the Target Heart Rate

The time to reach the THR showed a significant difference between unloading and 5%, 10%, and 15% loads ($p<.05$), although there was also a significant difference between unloading and 10%, unloading and 15% ($p<.05$) There was no significant difference between 10% and 15% ($p>.05$). In other words, as the load increases, the time to reach the target heart rate between the loads decreased, no significant difference between the 10% and 15% loads was found ($p>.05$). As a result of the post-test, the time to reach THR between unload and 5% load decreased the most (Figure 2).

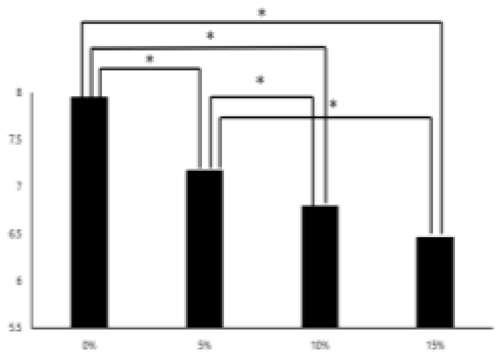

Fig. 2: THR[†] according to load

Table 2. Means and standard deviation values by backpack loads

	0%	5%	10%	15%	*F*
THR[b] reaching time	7.95 a (0.99)	7.17 (0.85)	6.79 (0.73)	6.4 (0.84)	77.294*
VO_2[c] peak reaching time	7.83 (1.09)	7.00 (0.89)	6.67 (0.70)	6.45 (0.85)	21.417*
RR[d] increasing	6.88 (3.44)	7.71 (2.52)	5.56 (2.3)	6.82 (3.84)	1.772
Maximal METs[e] reaching time	7.71 (1.04)	7.05 (0.81)	6.78 (0.61)	6.44 (0.81)	28.776*
Maximal $FECO_2$[f], Minimal FEO_2[g] reaching time	7.68 (1.08)	6.88 (0.8)	6.69 (0.62)	6.40 (0.67)	31.579*

*$p<.05$, [a]: All values are mean value ± Standard deviation, [b]: Target heart rate, [c]: Oxygen consumption peak, [d]: Respiratory Rate, [e]: Metabolic equivalents, [f]: Fractional concentration of carbon dioxide in expired gas, [g]: Fractional concentration of oxygen in expired gas

3.2 The Time to Reach VO_2 Peak

The analysis of the time to reach VO_2 peak showed a significant difference between unload and 5%, unload and 10%, unload and 15% load, 5% and 15% load each (*p*<.05). There was no between 5% and 10% load, 10% and 15% load each (*p*>.05). As a result of the post-test, the time to reach VO_2 peak between unload and 5% load decreased the most (Figure 3).

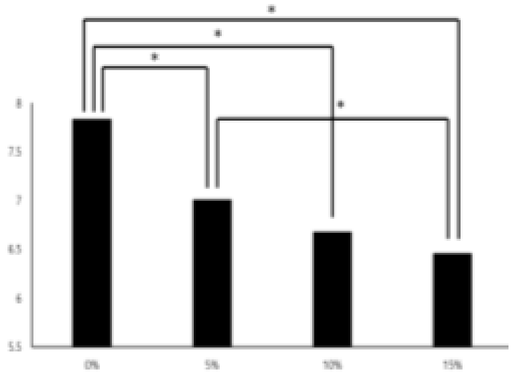

Fig. 3: $VO_2^{\dagger}$ peak according to load

3.3 Respiratory Rate Difference

The analysis of the increase in the RR for each load showed no significant difference between unload, 5%, 10%, and 15% loads (p>.05) (Figure 4).

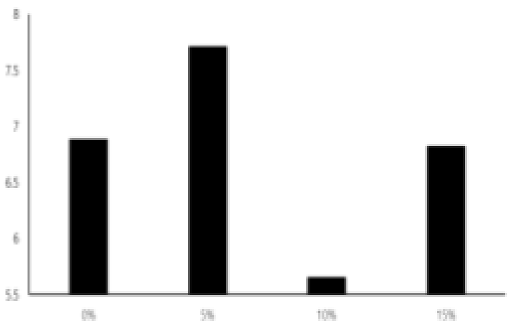

Fig. 4: $RR^{\dagger}$ according to load

3.4 The Time to Reach Maximal METs

The time to reach the maximal METs showed a significant difference between unload and 5%, unload and 10%, unload and 15% load, 5% and 15% load each (*p*<.05). No significant difference between 5% and 10% load, 10% and 15% load each was shown (*p*>.05). As a result of the post-test, the time to reach maximal METs between the unload and the 5% load decreased the most (Figure 5).

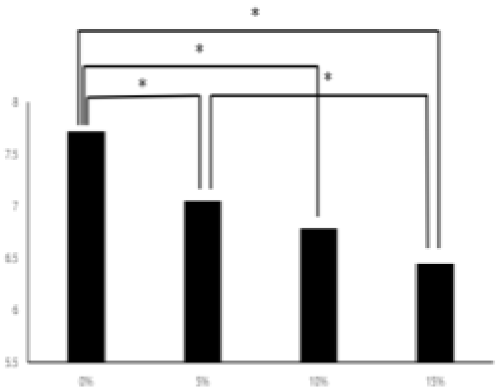

Fig. 5: $METs^{\dagger}$ according to load

3.5 The Time to Reach Maximal $FECO_2$ and Minimum FEO_2

The time to reach the maximal FECO2, and minimum FEO2 showed a significant difference between unload and 5%, unload and 10%, unload and 15% load, and 5% and 15% load each (*p*<.05). There was no significant difference between 5% and 10% load, 10% and 15% load each (*p*>.05). As a result of the post-test, the time to reach the maximal $FECO_2$ (minimal FEO_2) between unload and 5% load decreased the most (Figure 6).

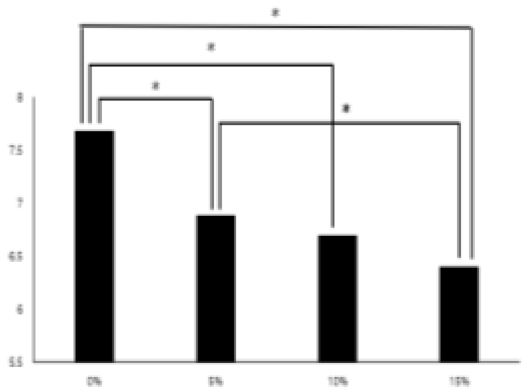

Fig. 6: $FECO_2^{\dagger}$, $FEO_2^{\dagger}$ according to load

4 Discussion

This study compared the time of reaching THR, VO_2 peak, RR Difference, maximal METs, maximal $FECO_2$, and minimum FEO_2 under four backpack load conditions in 17 healthy men.

As a result, there was a significant difference in the THR reaching time, VO_2 peak reaching time, maximal METs reaching time, minimum FEO_2, and maximum $FECO_2$ reaching time between unload and load conditions.

Chest load carriage via vest or backpack has been shown to place mechanical restrictions on respiratory muscles, reducing respiratory efficiency

[27], [28]. Chest load increases energy expenditure along with oxygen consumption as load increases during activity [29]. In this study, it was observed that as the load weight increased, the reaching time, which indicates a change in cardiopulmonary physiological response, became faster. Previous studies have shown that the torque-generating capacity of ankle plantar flexors and knee extensors is reduced by dynamometers before and after load carriage transporting [30].

Reduced knee extensor strength during load carrying leads to a less economical gait pattern, but increased muscle fiber recruitment required to maintain movement leads to increased VO_2, [31], [32], [33].

This supports the results of this study, which showed that the time to reach THR, VO_2 peak, maximum MET, RR, maximum $FECO_2$, and minimum FEO_2 became shorter as the load increased.

A recent 25kg chest load carriage showed increased ventilation during continuous movement (45 minutes at 68% VO_2 peak), [34]. In a previous study examining peak performance and cardiometabolic responses to vest-wearing load carrying among U.S. Army soldiers, peak walking speed gradually and significantly decreased as vest load increased, increasing the physiological cost of carrying, [35]. The metabolic and motivational effects of a load of 30-70% of body weight were determined while walking at a constant speed on a treadmill, [36], with an increase in load systematically increasing transport energy costs (VO_2, RPE, and HR), [6]. On the other hand, in some studies, the increase in metabolic rate during exercise with progressive loads (15 to 45 kg) did not show a systematic linear proportion to the change in backpack weight, [23]. These results indicate the concept that the physiological response to a load depending on the characteristics of the load is not uniform. The results of this study showed that as the load increased from no load, the time to reach THR, VO_2 peak, maximal METs, and maximal $FECO_2$, minimal FEO_2 gradually became shorter. Particularly, there was a significant difference between no load and 5% and 15% load conditions, which supports the results that the above-mentioned load affects physiological responses.

For the Respiratory Rate, there was no significant difference in the increase in the Respiratory Rate between the load and the unload, and there was no significant difference between the loads. Exercise induces increased ventilation through increases in respiratory rate and tidal volume. An increase in tidal volume is achieved through a gradual increase in end-inspiratory lung volume while the end-expiratory lung volume decreases, [37], [38]. However, a study comparing backpack load conditions during exercise with matched oxygen demand found no difference in lung volume and minute ventilation between load conditions during the first 10 minutes after starting exercise, [39]. During the exercise test in this study, to see rapid changes in response, a ramp protocol was used to change the incline and speed, resulting in a shorter exercise time than regular treadmill walking. In addition, when the ventilatory threshold is reached during exercise under no load and various load conditions, the rate of increase in oxygen intake slowly decreases, which is thought to have affected the respiratory rate.

Our research team suggested that as little as 5% backpack load showed significant difference in the THR reached, VO_2 peak reached, maximal METs reached, Respiratory Rate, maximal FECO2, and minimal FEO_2. Therefore, to reduce the burden of cardiopulmonary ability, even if 5% of the body weight was not applied, the backpack load could be less than the load.

This study has some limitations. First, although random loading was selected, and sufficient rest was given between measurements, the measured values may be changed due to the subject's compliance and fatigue due to repeated measurements. Second, we set up a target for stopping the exercise of RHR + (MHR-RHR) * 0.85, which is the THR. Third, all subjects were normal males in their 20s and cannot be generalized to patients or all age groups.

5 Conclusion

The purpose of this study was to compare differences in cardiopulmonary responses in healthy men under backpack loading conditions and showed that there were significant differences in THR reach time, VO_2 peak reach time, maximum METs reach time, minimum FEO_2, maximum $FECO_2$ according to load. That is, an increase in backpack load of even 5% of body weight triggers a cardiopulmonary response, and these findings suggest that gradually increasing mechanical loading on anatomical structures may help improve injury rehabilitation and monitor training programs.

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Abbreviations:
THR: Target Heart Rate (time)
VO2 peak: Oxygen consumption peak (time)
RR: Respiratory Rate
METs: Metabolic equivalents (time)
FECO2: Fractional concentration of carbon dioxide in expired gas (maximal time)
FEO2: Fractional concentration of oxygen in expired gas (minimal time)

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Lee Chungil, Choi Jiho, and Jo Hojoon organized the study design and carried out the experiments.
- Lee Jieyon, and Lee Dongyeop were responsible for interpreting the study results and organizing references.
- Hong Jiheon, Yu Jaeho, and Kim Seonggil oversaw interpreting the results of the study and scheduling the overall progress.
- Kim Jinseop fine-tuned the research design and searched for prior research.

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Conflict of Interest

The authors have no conflicts of interest to declare.