# COMPARISON OF TWO BACKPACK DESIGNS USING BIOMECHANICAL AND METABOLIC ASPECTS OF LOAD CARRIAGE

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The purpose of this study was to compare the compartmentalized backpack to a control backpack using metabolic and biomechanical parameters. Thirteen apparently healthy female subjects were asked to carry a load while walking on a treadmill at 1.3 m/s for 27 minutes with both the compartmentalized backpack and a control backpack. Parameters for comparison were oxygen consumption ($VO_2$), respiratory exchange ratio (RER), mean head and trunk angles, stride length, and stride rate. There were no significant differences in parameters between the compartmentalized pack and the control pack, but differences were found in $VO_2$ and RER with fatigue. These results suggest that the load distribution of the compartmentalized pack was comparable to the control pack.

**KEY WORDS**: backpack design, posture, center of mass.

## INTRODUCTION:

Extensive research has been performed on variations of load carriage. Studies have shown that changes in load distribution give rise to alterations in metabolic and biomechanical parameters. Increasing the mass of the load, thus increasing overall workload, consistently results in an increased energy expenditure (Hong et al., 2000; Kirk and Schneider, 1992), forward lean in posture with increased spinal curvature (Knapik et al., 2004; Orloff and Rapp, 2004), forward head lean (Pascoe et al., 1997), and decreased stride length (Chow et al., 2005; Quesada et al., 2000).

Variations in load position have also been associated with changes in metabolic cost (Abe et al., 2004; Legg et al., 1992; Stuempfle et al., 2004). In general, energy expenditure is reduced when the load's center of mass is placed closer to the body's center of mass (Legg et al., 1985; Obusek et al., 1997). Studies have shown that high load distributions are closer to the body's center of mass than lower loads, suggesting that higher loads are generally more metabolically efficient than lower loads (Stuempfle et al., 2004).

Many backpacks have been designed specifically to improve load distribution, balance, stability, and organization. One such design is the compartmentalized backpack, created specifically to carry and organize textbooks. The compartmentalized backpack has three major compartments made of elastic materials. The structure and elasticity of the compartments are designed to help to keep the textbooks close to the body's center of mass and to keep the mass from settling at the bottom of the backpack. The purpose of this study was to compare a compartmentalized backpack and a standard backpack in relation to metabolic and biomechanical factors.

## METHODS:

Thirteen apparently healthy female subjects (ages 18 to 22 years,1.69$\pm$.05m, 62.7$\pm$8.1kg) were asked to carry a load while walking on a treadmill for two trials; one trial with a compartmentalized backpack and the other trial with a control backpack. Each trail was performed at least a day apart to eliminate potential fatigue factors. In each trial, subjects walked at a rate of 1.3 m/s for 30 minutes, carrying a load of 15% of their body mass. The load consisted of three to four textbooks, each book bounded by tape and weighed prior to testing. Lead pellets were added for any extra weight needed to reach 15% body mass and to standardize the local the center of mass in the backpack.

During each trial, a Parvo Medics Metabolic Cart (TrueMax 2400) was used measure oxygen consumption and respiratory exchange ratio (RER). Kinematic data were collected from the sagittal plane for two strides using a 60 Hz JVC camera streaming video clips to a Simi

Motion Analysis system, which was used for digitizing video data. The video analysis system was used to determine stride length, stride frequency, and trunk and head angles throughout the gait cycle. Mean values for all parameters were calculated for minutes 3 (rest), 15 (intermediate stage), and 27 (fatigue) for both the compartmentalized backpack and the control backpack. All values were compared using Multiple Analysis of Variance (α<0.05).

**RESULTS:**

Table 1 presents mean values of metabolic and biomechanical data while carrying each type of backpack. Results indicated that trunk and head angles, stride length, stride rate, oxygen consumption, and RER were not significantly different (α<0.05) when comparing backpack types. With fatigue, oxygen consumption significantly decreased and RER significantly increased from rest to the intermediate stage (Figure 1).

**Table 1 Mean values (SD) for poster, gait, and energy expenditure while carrying control and compartmentalized backpacks**

| | **Control *(SD)*** | | | **Compartmentalized *(SD)*** | | |
|---|---|---|---|---|---|---|
| **Time** | **3 min.** | **15 min.** | **27 min** | **3 min.** | **15 min.** | **27 min.** |
| Trunk Angle (deg.) | 10 (2.4) | 10 (2.8) | 10 (2.8) | 10 (3.1) | 10 (2.6) | 11 (2.8) |
| Head Angle (deg.) | 19 (6.5) | 20 (6.1) | 20 (4.8) | 19 (4.9) | 19 (5.5) | 21 (5.6) |
| Stride Length (m) | 1.40 (.06) | 1.41 (.06) | 1.41 (.06) | 1.39 (.06) | 1.40 (.06) | 1.40 (.05) |
| Stride Rate (Stride/sec) | 1.07 (.05) | 1.07 (.05) | 1.08 (.05) | 1.06 (.04) | 1.07 (.05) | 1.07 (.04) |
| $VO_2$ (ml/kg/min) | 13.2 (1.1) | 13.0 (0.9) | 13.2 (1.0) | 13.5 (1.4) | 13.0 (1.2) | 13.2 (1.2) |
| RER | 0.86 (.06) | 0.88 (.04) | 0.86 (.04) | 0.87 (.05) | 0.90 (.04) | 0.89 (.05) |

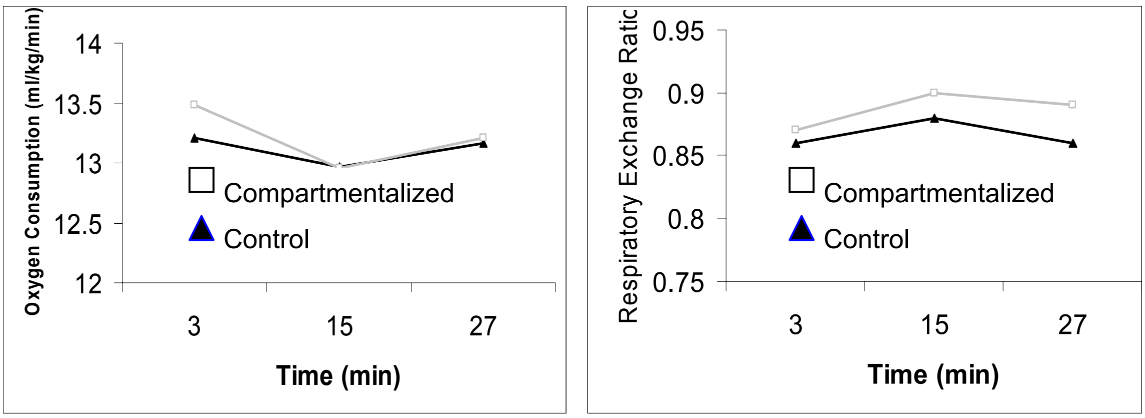


Figure 1: Mean values of oxygen consumption and RER for the control and compartmentalized backpacks

**DISCUSSION**:

When comparing fatigue factors, significant differences were observed for oxygen consumption and RER between minute three and minute fifteen. There appeared to be an inverse relationship between RER and oxygen consumption: as RER increased, oxygen consumption decreased. This relationship implies that the energy expenditure was relatively constant throughout the exercise (Wilmore and Costill, 1994). Metabolic parameters were not affected by the backpack carried in this study. These findings are comparable to those found by Kirk and Schneider (1992), who found no significant differences in metabolic parameters when comparing internal and external backpacks for females. Conversely, the double backpack, which distributes parts of the load to the front of the body, has been shown to be more physiologically efficient than the standard rucksack (Lloyd and Cooke, 2000).

Mean posture and gait parameters showed no significant differences between backpack designs. In current literature, variations in backpack designs often result in changes in posture and other parameters. Bloom and Woodhull-McNeal (1987) found that when making static measurements of posture for carriers of the internal and external backpacks, the internal-frame pack caused more deviations because of the lower center of mass; the lower load forces the carrier to lean forward in order to balance (Bloom and Woodhull-McNeal, 1987). Similarly, the double pack has been shown to have significant differences in gait in comparison to the standard backpack, and there is less trunk inclination in double packs compared to regular backpacks (Harman et al., 1994; Knapik et al., 2004). These differences can be attributed to improved load distribution, as the load of the backpack is much closer to the center of mass (Knapik et al., 2004).

The results from the current study suggest that the differences between the backpack designs are too marginal to detect through metabolic and biomechanical parameters. If the load distributions were considerably different (i.e, one load higher than the other) then the results in the current study most likely would have been comparable to those of Bloom and Woodhull-McNeal (1987). Since no significant differences were observed in any of the parameters recorded between the compartmentalized and standard backpacks, it may be assumed that the load distributions of the two backpacks were quite similar. In contrast to studies that found significant differences in responses to backpack designs, carriers in this study were using essentially the same muscle groups with more comparable load distributions, resulting in comparable metabolic and biomechanical responses to load carriage.

The lack of significant difference between backpack designs in this study may be attributed to poor fitting of the compartmentalized backpack, due to its considerably longer length. Since the compartmentalized backpack was designed to keep the load from sagging to the bottom of the backpack, it seems that the length of the backpack was counterproductive to the distribution of the load. The bottom of the compartmentalized backpack often rested below the waist, resulting in lessened support from the back. In addition, the longer pack length forced the load away from the body's center of mass by the buttocks. Proper fitting of the compartmentalized backpack in this study would have likely yielded in a higher-carried, more proximal load. The compartmentalized backpack, therefore, may have been more efficient for a taller population.

## CONCLUSION:

Significant differences were observed for oxygen consumption and RER rest and the intermediate stage. There were no significant differences in oxygen consumption, RER, head and trunk angles, stride length, and stride rate between the compartmentalized pack and the standard pack in this study.

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*Acknowledgement*
This study was funded by a University of Puget Sound Research Grant. The authors wish to thank Bryce Sumida and Gary McCall for their contributions to this study.