

2006

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Recommended Citation

Watts, PB, Jensen, RL. The effects of backpack loading styles on energy expenditure and movement in the sagittal plane during treadmill walking. In Proceedings of the XXIV International Symposium of Biomechanics in Sports (Schwameder, H, Strutzenberger, G, Fastenbauer, V, Lindinger, S, Müller, E, editors) 2006; 633-666

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THE EFFECTS OF BACKPACK LOADING STYLES ON ENERGY EXPENDITURE AND MOVEMENT IN THE SAGITTAL PLANE DURING TREADMILL WALKING

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Backpacking is physically demanding on the body. Although much of the load is carried securely inside the pack, non-secure attachment of provisions is commonly practiced. The purpose of this study was to analyze the effects of a non-secure loading style as compared to a secure loading style of a backpack. Fifteen male subjects walked on a treadmill for 10 minutes in four conditions: 2% grade secure and non-secure and 15% grade secure and non-secure. Expired air analysis and movement in the sagittal plane were analyzed. A two-way (pack by grade) ANOVA for energy expenditure yielded significant differences for grade: one minute averages ($p < .001$), over the each condition ($p < .001$), and over an estimated 60 minute interval ($p = .675$). No other energy expenditure differences and no sagittal plane movement differences were found.

KEY WORDS: load carriage, physiology, kinematics

INTRODUCTION: Major backpacking research goals have been to determine the physical costs backpacking places on the body (Charteris, 1998; Huang et al., 2005; Chow et al., 2005; Harman et al., 1997; Pierrynowsky et al., 1981; Obusek et al., 1997; Stuempfle et al., 2004; Soule et al., 1978; LaFiandra et al. 2003) and how these costs can be minimized to reduce the risk of injury and to improve the physiological efficiency of the activity (Harman et al., 1992; Jacobson et al., 1997; Knight and Caldwell, 2000; Schwameder et al., 1999). Anecdotal backpackers' knowledge suggests securely and evenly distributing backpack weight, however, little is known of the physiological and kinematic effects of non-secure backpack weight distribution. Current backpack designs often contain external belts and loops from which to hang various items for quick access. Many backpackers take advantage of these designs by attaching a water bottle, a pair of shoes, and other equipment to the outside of their backpack. It is not known what consequences this practice may have on the physiology and biomechanics of backpacking.

The purpose of this study was to analyze the effects of a non-secure loading style as compared to a secure loading style of a backpack. For the current study, the secure loading style consists of three components: 1) the heaviest weight rests closest to the back, 2) the heaviest weight is positioned at mid-back for males, and 3) the weight is evenly distributed so that there is equal distribution on the left and right sides of the center of mass of the backpack. A non-secure loading style is the same as a secure style except 3.1 kg of the weight has been transferred and attached to the outside of the backpack. This purpose of this study was to specifically analyze experienced backpackers and attempt to answer the following questions:

1. Does an external weight loading style change the energy expenditure of a task when compared with an evenly distributed classic loading style in backpacking?
2. Does an external weight loading style change movement on the sagittal plane when compared with an evenly distributed loading style.
3. Is there a relationship between energy expenditure and sagittal plane movement?

METHODS: *Subjects* Fifteen male students from Northern Michigan University with prior backpacking experience were asked to participate in the study after giving informed consent. Subjects walked on Stairmaster Clubtrack 612 treadmill (Nautilus Inc., Vancouver, WA) at $0.66 \text{ m} \cdot \text{s}^{-1}$ under four different counterbalanced conditions completed the same day. The four walks were 10 minutes in duration and consisted of: 1) 2% grade secure backpack loading, 2) 2% grade non-secure loading style, 3) 15% grade secure backpack loading, and 4) 15% grade non-secure loading style.

Equipment: Backpack weight for the secure loading style was 22.4 kg of internally distributed weight in a Lowe Alpine Contour IV 90 + 15 internal frame backpack (190 Hanover St. Lebanon, NH). Backpack weight for the non-secure loading style was 19.3 kg of evenly distributed weight with 3.1 kg of weight attached to the outside of an identical internal frame backpack.

Energy Expenditure: During each of the four conditions, expired air was continuously analyzed using a SenorMedics 29c metabolic analysis system (SensorMedics Corp., Yorba Linda, CA). Data from the first two minutes and last two minutes of each 10-minute analysis period were discarded. This analysis provided an assessment of oxygen consumption and energy expenditure.

Movement in the Sagittal Plane: Reflective markers were attached to the subjects' right acromion and greater trochanter. Reflective markers were digitized using Motus 8.2 (PEAK Performance Technologies, Englewood, CO). All trials contained at least two complete steps on the right side. The lowest location of the reflective marker cites during each step were subtracted from the highest location during each step to determine the sum of movement for each step.

Statistical Analysis: The caloric expenditures for one minute averages; total caloric expenditure; and estimated caloric expenditure when total caloric expenditures were expanded out to 60 minutes were compared by separate two-way (pack by grade) ANOVAs with repeated measures for percent grade in each condition. Two separate two-way (pack by grade) repeated measures ANOVAs were used to determine differences in the movement of the acromion and the greater trochanter in the sagittal plane for trial 1 of each condition. Two separate two-way (pack by grade) repeated measures ANCOVAs (covarying out the effect of height) were used to determine differences in the movement of the acromion and greater trochanter in the sagittal plane for trial 1 of each condition.

RESULTS AND DISCUSSION: *Caloric Energy Expenditure:* Separate two-way (pack by grade) repeated measures ANOVAs were calculated comparing caloric energy expenditure in the four conditions (Table 1). A significant treadmill grade effect was found for the 1 minute average caloric expenditure ($p < .001$), the total condition caloric expenditure ($p < .001$), and the estimated 60 minute caloric expenditure ($p < .001$). The difference in caloric expenditure should be expected since it has been previously documented that energy expenditure increases with increasing workloads (Pierrynowski, 1981). No other significant effects or interactions were found.

One concern was that over an extended period of time small differences in energy expenditure would accumulate. This would pose a problem for individuals backpacking for extended periods of time. Using the secure backpack, subjects would expend 262.12 kcals (± 32.87) over an estimated 60-minute interval at a 2% grade, 4.96 less calories per hour than with the non-secure pack (Table 1). Though this difference is not significant, it appears caloric needs would be higher for individuals who used a non-secure pack style, indicating that loads should be tucked inside the pack at low (or no) grades over long distances when energy conservation may be crucial. The lack of difference between pack styles at a 15% grade showed that subjects would expend essentially the same amount of calories. Thus, it may not be as important to tuck all provisions inside the backpack when backpacking at higher grades.

Table 1. Energy expenditure means \pm SD for: 1) kcals \cdot min⁻¹ 2) kcals \cdot 6 min⁻¹ and 3) kcals \cdot 60 min⁻¹.

	kcals \cdot min ⁻¹	kcals \cdot 6 min ⁻¹	Estimated kcals \cdot 60 min ⁻¹
2% Secure	4.37 \pm 0.55	26.21 \pm 3.29	262.12 \pm 32.87
2% Non-secure	4.45 \pm 0.44	26.71 \pm 2.62	267.08 \pm 26.15
15% Secure	7.93 \pm 0.76	47.62 \pm 4.57	476.17 \pm 45.74
15%Non-secure	7.94 \pm 0.77	47.62 \pm 4.64	476.15 \pm 46.36

Movement in the sagittal plane: Separate two-way (pack by grade) repeated measures ANOVAs were calculated to compare the movement of the right acromion and greater trochanter in the sagittal plane in the first trial of each of the four conditions. No significant differences were found for the pack, grade, or interaction. Separate ANCOVAs were used to co-vary out the possible effect of height on movement of the right acromion and right greater trochanter in the sagittal plane. No significant differences were found for the pack, grade, or interaction. This indicates that height does not affect the movement of the acromion or greater trochanter in the sagittal plane.

Previous research (LaFiandra et al., 2003), suggested that ipsilateral arm and leg swings during load carriage may assist in counterbalancing the lower body. The current study indicates that the movement of the acromion may be different at different grades. Differences in movement of the acromion, and other measures of upper body, between different grades should be included in future studies. It's also possible that increased grades coupled with load carriage may not result in the same effect on the greater trochanter, or lower body. Leroux et al. (2002) determined that the lateral drop of the pelvis decreased during inclined walking without external loads. Chow et al. (2005) and LaFiandra et al (2003) determined that pelvic rotation decreased with increasing load carriage.

In the current study, there was an insignificant increase in movement from the lower grades to the higher grades. The non-secure pack style was associated with slightly more movement than the secure style. The subjects may have decreased lateral movement to account for the shifting external weight without compensating much in energy expenditure. This may also be one reason why there was almost no difference in energy expenditure estimated over 60 minutes for the 15% grade. Less lateral drop of the pelvis may have helped to keep the external pack items from moving excessively and causing additional energy expenditure.

Table 2. Acromion and greater trochanter means \pm SD for movement in the sagittal plane (meters).

	Acromion	Greater Trochanter
2% Secure	0.046 \pm 0.012	0.048 \pm 0.020
2% Non-secure	0.057 \pm 0.020	0.053 \pm 0.025
15% Secure	0.053 \pm 0.021	0.046 \pm 0.015
15% Non-secure	0.065 \pm 0.038	0.050 \pm 0.020

CONCLUSIONS: It may not be as critical to carry all provisions securely on the inside of a backpack when backpacking for short periods of time, but for long periods of time it may be important for energy conservation. Findings from the current study may be limited to walking on a treadmill at low to moderate inclines. Additional studies comparing these findings to over-ground hiking with variable terrain and surfaces are recommended. Furthermore, this study indicates that attaching light weight to the outside of the pack may not cause additional movement in the sagittal plane that may result in loss of balance or injury to lower extremities and back. There is less of a risk during inclined hiking than at level hiking, possibly due to the reduction in the lateral drop of the hip during increased grades (Leroux et al., 2002). The current study is limited to treadmill and even terrain situations and does not pertain to situations of rough terrain, where balance may already be compromised. It is unknown to what extent the effect of external items may have on the movement in the sagittal plane during rough terrain situations.

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Acknowledgement

This paper was partially supported by a Northern Michigan University College of Professional Studies Grant and the Excellence in Education Grant