THE EFFECTS OF FATIGUE AND BACKPACK DESIGN ON POSTURE

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The purpose of this study was to determine the effects of fatigue and backpack design on head and trunk position. Twenty four young female volunteers were filmed while walking 3200m around a track with a suspension and student backpack, as well as in an unloaded control condition. Head and trunk absolute angles were recorded after 400m and again at 2800m for all three conditions. A repeated measures ANOVA indicated that significant differences did occur between the two backpacks in head flexion, maximal trunk extension, and total range of motion of the trunk. Fatigue differences were seen in head flexion and maximal trunk flexion. It was concluded that even with relatively light loads a supported backpack was superior to a student backpack.

KEY **WORDS:** backpack design, fatigue, angular kinematics.

INTRODUCTION: While physiological demands of load carriage have been well documented, there have not been many studies that have focused on the mechanical consequences of fatigue and backpack design (Martin and Nelson, 1986). Although backpack design has been studied in relationship to military manoeuvres (Martin and Nelson, 1986; Holewijn, 1990; Holewijn and Lotens, 1992), there is little data as it applies to trekking or mountaineering, especially with women subjects. Jorgensen and Nicolaisen (1987) stated that frequency of low back trouble is higher in groups with low static endurance of the trunk extensors, which would include hikers and many college students.
Studies focusing on lifting fatigue have established that there is up to a 40% decrease in strength after a two hour period and that fatigue is significant as early as 20 minutes into low load lifting (Potvin and Norman, 1993). Legg, Perko, and Campbell (1997) had ten healthy male students compare two backpacks for thirty minutes on a treadmill. Subjective data on comfort specific to site was collected. While they found one backpack superior in fit, size, and balance; kinematic data were not collected. The purpose of this study was to determine the effects of fatigue and backpack design on trunk and head position.

METHODS: Subjects signed a consent form approved by the internal review board at the University of Puget Sound prior to participating in this study. Twenty four healthy women, with no history of back pain, mean (SD) age of 21.4 (1.3) years and weight of 63.6 (3.2) kg volunteered for this study.
Data were collected for three trials: with an internal suspension (IS) and student (ST) backpack each uniformly loaded with 11.4 kgs, and in an unloaded control condition. The IS backpack was used with both a hip belt and sternum strap, as well as a patented cross system that suspends the weight off the back. The ST pack was a typical college backpack without sternum strap or hip belt. Each trial consisted of walking 3200m in approximately 30 minutes around a 400 m track. Two cameras were set up to collect data in the sagittal plane of motion on the front and back straight away of the track. Only one camera (Panasonic AG 450, 60 Hz) actually recorded data, as the other camera was used to help ensure that subjects did not alter their gait while in front of the camera. Two complete strides were recorded after each 400m lap. One complete stride, from left heel contact to the subsequent left heel down, was analysed at approximately 400m and again at 2800m to represent a relatively rested state and a mildly fatigued state. During data collection rate of perceived exertion (RPE) was recorded every 800m to gauge fatigue level.
The Peak Performance © (v5.3) system was used to analyse and smooth data. For this study mean head and trunk angles, maximal trunk flexion and extension, the range of motion (ROM) of the trunk, velocity, and rate of perceived exertion were recorded. A repeated measures ANOVA was used to determine significance at $\alpha < .05$.

RESULTS AND DISCUSSION: Mean head flexion was calculated as the angle between the ear, base of the neck and the y-axis. Mean head flexion was significantly greater for the ST backpack than both the IS pack and the control condition. The IS system was not significantly different from the control trials. There was a significant increase in mean head flexion between the rested and fatigued conditions, but the interaction between fatigue and backpack was not significant (see Table 1 and Figure 1). Mean trunk flexion was measured as the absolute angle between the left shoulder, hip and y-axis. The backpacks exhibited significantly more mean trunk flexion than the unloaded condition. There was no significant difference between the backpacks, lap, and interaction effect in trunk flexion (see Table 1 and Figure 2).

Kinoshita (1985) found significant increases in trunk inclination between all backpack conditions and normal walking. This study replicates these results, as the subjects leaned further forward at the trunk than in the control condition. Martin and Nelson (1986) also observed increased forward lean in rucksack conditions, while they found that females seemed to be more sensitive to load changes as it affected trunk position. Although the mean trunk position did not significantly change with fatigue, the mean head flexion did increase from 400m to 2800m. The subjects seemed to use their heads to help counter balance the weight as they fatigued. Head flexion increased with style of carrying loads in a study published by Pascoe et al. (1997). They found that head flexion increased when carrying a backpack and an athletic bag on a short runway. The IS system had similar mean head flexion as the control condition, while the ST saw dramatic head flexion. The relationship of mean head and trunk flexion can be viewed in Figure 3. The scatter plot shows groupings of head versus trunk flexion for the three trials. The IS backpack relied more on trunk flexion and less on head flexion in order to counter balance the weight of the backpack. The increased stability gained with trunk flexion may lower the moment of inertia and help in dynamic situations (Bloom and Woodhull-McNeal, 1987). The ability to use a hip belt, attached in this case to the IS pack, relieved pressure from the shoulders to tolerable levels (Holewijn, 1990; Poumarat et al., 1998). The additional head flexion may have been needed with the ST backpack to relieve pressure from the shoulder straps that could not be counterbalanced with the trunk.

Table **1** Means and Standard Deviations of Parameters

	Internal Backpack		Student Backpack		Control Condition	
Variable	**Rested**	**Fatigued**	**Rested**	**Fatigued**	**Rested**	**Fatigued**
Mean Head	**11.98 ^ !**	**14.22 ^ !**	**26.29 ^ !**	**30.20 ^ !**	**9.01 !**	**11.03 !**
Flexion in ° #	± 5.62	± 6.18	± 8.01	± 8.47	± 5.74	± 6.39
Mean Trunk	10.25 *	12.62 *	9.31 •	9.98 •	3.96 * •	4.39 * •
Flexion in °	± 3.88	± 3.74	± 4.17	± 4.39	± 4.28	± 4.14
Max. Trunk	-4.03 ◊ !	-6.16 ◊ !	-.97 ◊ !	-2.45 ◊ !	6.29 ◊ !	5.93 ◊ !
Extension in °	± 4.01	± 4.01	± 4.52	± 4.23	± 5.22	± 5.18
Max. Trunk	16.71 *	19.08 *	17.05 •	17.36 •	11.65 * •	13.13 * •
Flexion in ° #	± 4.18	± 4.07	± 4.80	± 4.21	± 5.17	± 4.84
Trunk Range	12.71 ◊	13.22 ◊	17.12 ◊	15.12 ◊	18.08 ◊	19.04 ◊
of Motion in °	± 3.37	± 2.82	± 4.88	± 3.15	± 3.11	± 3.85
Velocity	1.66 ι	1.68 ι	1.64 ι	1.65 ι	1.78 ι	1.77 ι
in m/s	± .11	± .09	± .13	± .09	± .14	± .11
RPE #	2.7 (±1.4) ι	4.4 (±1.4) ι	3.0 (±1.5) ι	5.3 (±1.3) ι	2.0 (±1.3) ι	2.8 (±1.4) ι

^ - Internal Frame Backpack is significantly different at a < .05 from Student Backpack.

* - Internal Frame Backpack is significantly different at a < .05 from the Control.

◊ - Internal Frame Backpack is significantly different at a < .05 from the Control and Student Backpack

! - Student Backpack is significantly different at a < .05 from the Control and Internal Frame Backpack

• - Student Backpack is significantly different at a < .05 from the Control.

ι - Student and Internal Backpacks significantly different at a < .05 from the Control.

- 400m significantly different at a < .05 from 2800m.

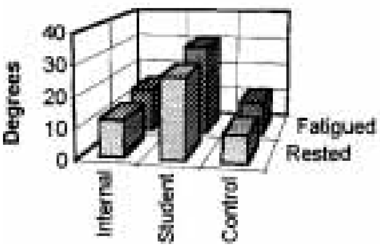

Figure 1. Mean Head Flexion.

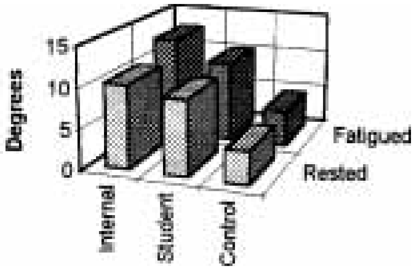

Figure 2. Mean Trunk Flexion.

Maximal trunk extension indicated that most subjects did extend in the control condition, while they remained in flexion with loads. The maximal trunk extension was significantly different between the two packs and the control. There was also significant difference between the IS and the ST backpack. With the IS backpack the subjects remained flexed, with the ST backpack the subjects neared a neutral position, while the unloaded subjects extended (See Table 1 and Figure 4). Maximal trunk flexion was significantly more for the two loaded conditions versus the control. There was also considerably more trunk flexion in the rested state than in the fatigued state (See Table 1 and Figure 5). Surprisingly the IS backpack showed significantly less trunk ROM than the ST backpack and the control. It was expected that trunk flexion would increase and trunk extension would decrease with the added load (Ghori and Luckwill, 1985; Kinoshita, 1985). The need for the subjects to keep forward momentum controlled would logically leave one to believe that forward lean would be tempered with limited extension (Neumann and Cook, 1985). That was the case with the IS backpack: the maximal flexion increased with fatigue, while the maximal extension decreased. The same pattern was seen with maximal extension with the ST backpack, but the maximal flexion remained constant instead of increasing with fatigue. This factor may have also led to the increased head flexion with the ST backpack.

The last two parameters investigated, velocity and RPE, were used as a check system. RPE indicated that the subjects were more fatigued at 2800m than at 400m. Unfortunately the subjects velocity was significantly greater in the unloaded walk. The subjects' velocities did not differ between the two loaded conditions (See Table 1). Although the investigators reminded the subjects of their velocity after the first 400m, it was thought that constant reminders would alter gait and possibly posture. It was certainly the intent to have the subjects perform at the same velocity, but it was believed that the results were not tainted by this factor. All studies reviewed indicated significant differences between the control and loaded conditions (Martin and Nelson, 1986; Pascoe et al., 1997; Ghori and Luckwill, 1985), even when velocity was tightly controlled in the laboratory.

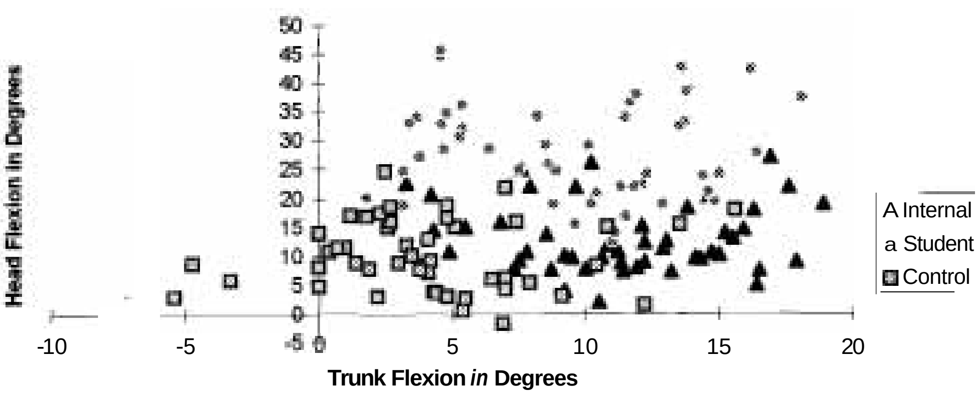

Figure 3. Trunk versus Head Flexion.

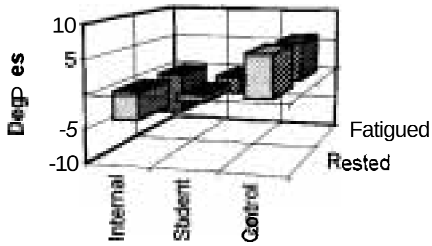

Figure 4. Mean Maximum Trunk Extension.

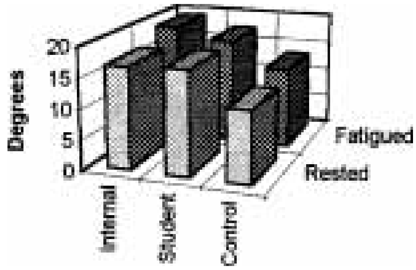

Figure 5. Mean Maximum Trunk Flexion.

CONCLUSION: This study indicated that head flexion may be excessive with backpacks lacking proper support and with fatigue. Maximal trunk flexion was limited by the ST backpack design and possibly by the inability of the shoulders to bear all of the load. Although maximal trunk extension did not differ between the two loaded conditions, total trunk ROM did differ significantly. In order to reduce stresses placed on the lower back and cervical spine it is recommended that backpackers invest in fully supported packs with frames, hip belts and sternum straps.

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