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TITLE

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Biomechanical assessment of lateral stiffness elements in the suspension system of a rucksack

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Summary

The purpose of this study was to examine the change in load distribution characteristics associated with adding lateral stiffness elements (rods) to a rucksack. A manikin was instrumented to allow determination of the load applied to the shoulders and upper torso independent of the load applied to the hips and lower trunk. Position and mass of the payload (25 kg) was fixed at the centre of the volume of the rucksack and held constant during all testing. Results showed that this active stiffness element shifted 10% of the vertical load from the upper torso to the pelvic region with no adverse affect on other factors known to limit load carriage capacity. Lumbar shear load remained unchanged between the rod and no-rod conditions for all combinations of shoulder strap and waist belt tension. The lateral rods also provided a greater extensor moment about the medio-lateral axis at the L3-L4 level.

Introduction

A primary factor in the success of the human body carrying heavy loads is the ability to transfer the weight of the load onto the body without inducing large ancillary forces. These secondary forces result from the need to balance or stabilize the load and do not directly contribute to the vertical lift required. An optimized Load Carriage System (LCS) should minimize secondary loading on the musculature, specifically on the smaller muscle groups of the upper body. In addition to the muscular effort required to carry a load, Stevenson et al. (1997) found that a horizontal reaction force acting in the lumbar area is a major factor limiting the load carrying capacity of soldiers.

There are many advantages associated with the transfer of rucksack load from the upper torso and shoulders to the hips and lower body during load carriage. When the rucksack load is carried primarily on the pelvis, less subjective discomfort has been found to occur as compared to shoulder load carriage (Holewijn and Lotens, 1992). Sagiv et al. (1994) reported greatly reduced fatigue and discomfort compared to Epstein et al. (1988) and Patton et al. (1991) for 4 hours of treadmill walking with a rucksack under similar speed and load conditions. These differences have been attributed to a well designed waist belt and the resulting load distribution with a greater portion of the weight supported by the larger muscle groups of the hips and legs (Knapik et al., 1996). Load transfer to the pelvis is also an effective means to reduce trapezius muscle activity and high levels of contact pressure occurring at the shoulder straps (Holewijn, 1990). The use of a frame and hip-belt has been shown to decrease the incidence of Rucksack Palsy, a nerve traction injury (Bessen et al, 1987).

Objective of Study

The purpose of this study was to examine the change in load distribution characteristics associated with adding lateral rods to a rucksack. It was hypothesized that lateral rods would; provide a force bridge that transfers part of the vertical load of the pack from the upper back and shoulders to the hip belt (supported by the iliac crest) thereby reducing the vertical load on the torso, and possibly reduce the horizontal reaction force that produces a shear load on the spine.

Methodology

The Load Distribution Manikin (shown in Figure 1) consists of a geometrically correct 50th percentile male split in the transverse plane at the level of the navel and instrumented with a six degree of freedom load cell. This apparatus allowed determination of rucksack load applied to the shoulders and upper torso independent of the load applied to the hips and lower trunk. In each of nine static configurations vertical and anterior-posterior shear force, and moment about the medio-lateral axis were obtained at the L3-4 vertebral level for both rod and no-rod conditions. Testing conditions were as summarized in Table 1. The position and mass of the payload (25 kg) was fixed at the centre of the volume of the rucksack and held constant during all testing. Shoulder strap and waist belt positions on the manikin were marked and also held constant throughout the testing. All testing was performed with ten degrees forward lean of the manikin.

Figure 1. The Load Distribution Manikin is split in the transverse plane at the level of L3-4 vertebra and instrumented with a six degree-of-freedom load cell.

Table 1. Experimental Configurations used for the rod and no-rod testing conditions.

Configuration	Shoulder Strap		Waist Belt		Sternum Strap	Load Lifter	Rod &Hip Stabilizer Straps
1	**L**	60 N	**L**	70 N	60 N	60 N	100 N
2	**L**	60 N	**M**	90 N	60 N	60 N	100 N
3	**L**	60 N	**H**	110 N	60 N	60 N	100 N
4	**M**	70 N	**L**	70 N	60 N	60 N	100 N
5	**M**	70 N	**M**	90 N	60 N	60 N	100 N
6	**M**	70 N	**H**	110 N	60 N	60 N	100 N
7	**H**	80 N	**L**	70 N	60 N	60 N	100 N
8	**H**	80 N	**M**	90 N	60 N	60 N	100 N
9	**H**	80 N	**H**	110 N	60 N	60 N	100 N

The no-rod condition is shown in Figure 2a). Upper and lower hip stabilizer straps on each side of the rucksack were tensioned to 100 N and the lateral rod attached passively on each side of the pack. The setup for the rod condition is shown in Figure 2b). The upper hip stabilizer strap was again tensioned to 100 N. The lower stabilizer strap was attached to the lower end of the lateral stiffness rod and tensioned, causing the lateral stiffness rods to become an active component of the pack suspension system.

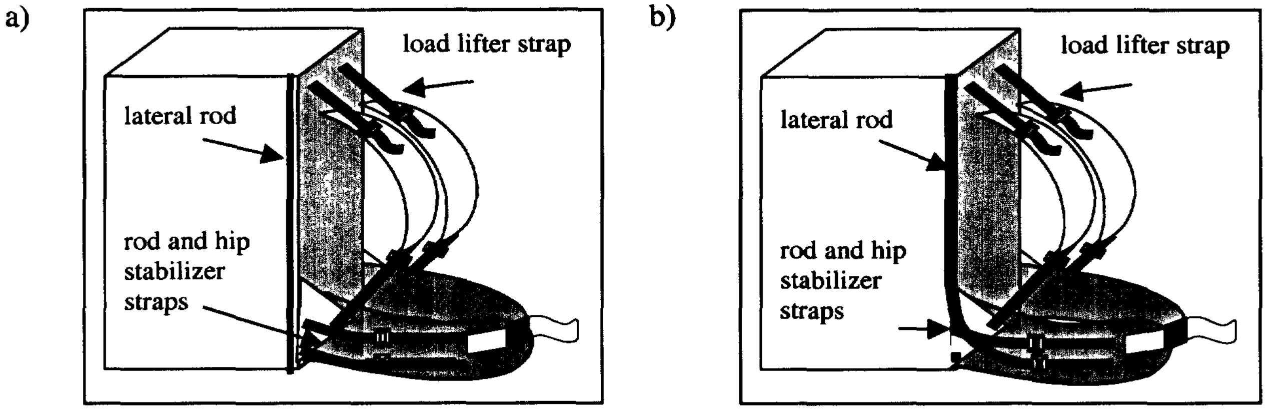

Figure 2.

a) Compression and Shear Force, and Moments acting at L3-L4 vertebra.
b) The upper portion of the lateral rod is encapsulated within a sleeve leaving the lower portion free to flex anteriorly when attached to the tensioned lower hip stabilizer strap

Results

Refer to Figure 3 for compression, shear, and moment orientations. Addition of lateral rods to the rucksack reduced the vertical load applied to the upper back and shoulders (F=77.00, p<. 05, df=1) by approximately 10% (Figure 4) without any increase in shear load at the lumbar spine (F=2.04, p>.05, df=1). An interaction effect between shoulder strap tension and 'rod vs. no-rod' conditions (F=15.00, p<.05, df=2) revealed a direct relationship between extensor moment and shoulder strap tension for the no-rod condition and an inverse relationship between extensor moment and shoulder strap tension for the rod condition (Figure 5). The main effect for the rod vs. no-rod condition (F=254.53, p<.05, df=1) revealed a greater extensor moment with the addition of the lateral rods.

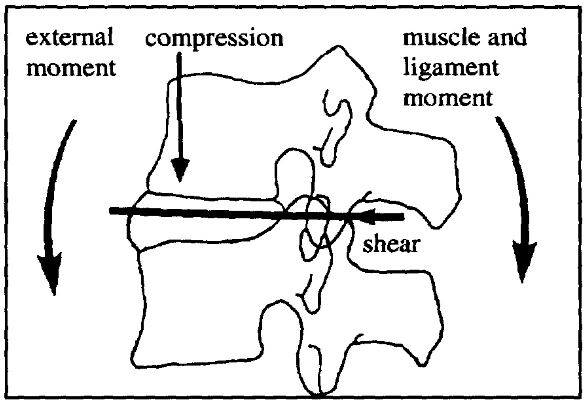

Figure 3. Compression, shear and moments acting in the L3-L4 vertebra.

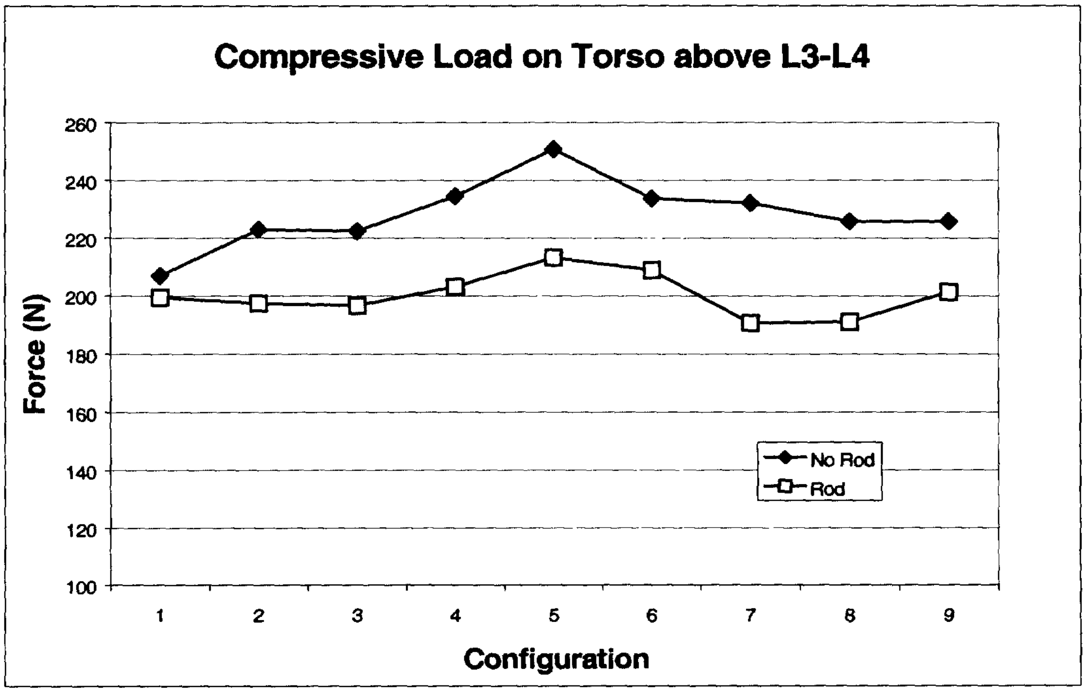

Figure 4. Vertical load force on the shoulders and upper torso for the rod and no-rod conditions.

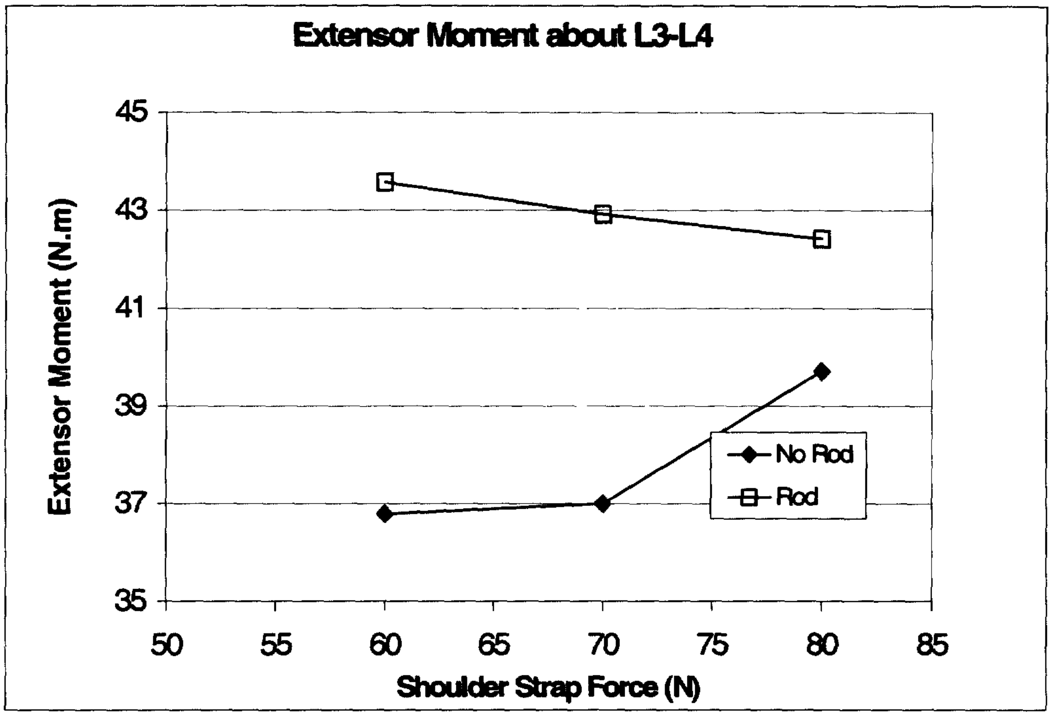

Figure 5. Anterior-posterior extensor moment for rod and no rod conditions.

Discussion

The addition of lateral rods provided a force bridge to transfer part of the vertical load of the pack from the upper back and shoulders to the hip belt (supported by the iliac crest) thereby reducing vertical load on the shoulders and upper torso during load carriage.

Lumbar shear load remained unchanged between the rod and no-rod conditions for all combinations of shoulder strap and waist belt tension. No interaction was found between the use of the rods and lumbar shear, therefore, it is likely that stiffening the rods will provide a similar benefit to a wide range of users.

The lateral rods provided a greater extensor moment about the medio-lateral axis at the L3-L4 level. Since erector spinae muscle activity has been found to increase with heavy rucksack loads in the order of 30-40 kg (Bobet and Norman, 1984), the extensor moment created by the lateral rods may provide potential to reduce low back muscular fatigue and spinal compression as load mass increases.

Continued research should be conducted on active element suspension systems to achieve a better understanding of their full potential for load carriage systems. It is possible that a much greater load distribution shift from the shoulders to the hips may be achieved through the determination of optimal stiffness characteristics for a given set of load parameters.

This study has demonstrated that an active stiffness element which bridged the shoulder and hip regions can shift 10% of the vertical load from the upper torso to the pelvic region with no adverse affect on other factors known to limit load carriage capacity. Further, the effects of the rod suspension system were limited to static characterization in this study. It is important to determine the dynamic characteristics of the rod suspension system: there may be potential to use the elastic nature of the rod suspension to conserve energy of the system, by absorbing energy in one phase of the load carriage cycle and returning stored energy in a subsequent phase.

The positive effect of rods on rucksack load distribution highlights the importance of investigating active suspension strategies to achieve improved load carriage systems. Research into a range of stiffness elements is needed to determine the optimal design, placement and characteristics to maximize the benefit of this advance. Designs could include different rod materials and cross sections, torsion or gas springs and a range of element pretensions.

Acknowledgement

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