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CTS Load Carriage System Phase III D
-Stage 2: Effect of Rucksack Lateral Rods
on the Load Distribution to the Torso

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March 15, 1999

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Sy CTS Load Carriage System Phase III D
-Stage 2: Effect of Rucksack Lateral Rods
St on the Load Distribution to the Torso

by

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Abstract

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 the horizontal reaction force acting in the lumbar area is a major factor limiting the load carrying capacity of soldiers Load transfer to the waist is an effective means to reduce high levels of contact pressure occurring at the shoulder straps (Holewijn, 1990) and has been shown to reduce Rucksack palsy incidence (Bessen et al, 1987) An anthropometrically correct 50^{th} percentile male manikin was split in the transverse plane at the level of the navel and instrumented with a six degree of freedom load cell to allow determination of the rucksack load applied to the shoulders and upper torso independent of the load applied to the hips and lower trunk Rod and no-rod conditions were tested in a fully factorial design with three levels of shoulder strap tension (60, 70, and 80 N) and three levels of waist belt tension (70, 90, and 110 N) Vertical force along the compressive axis of the spine, and lumbar shear in the postero-anterior direction were obtained at the L3-4 vertebral level and used to determine the load transfer characteristics associated with adding lateral stiffness rods to a rucksack. A three-way, general linear model ANOVA in SPSS statistics software was used to analyse the results. 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% without any corresponding increase in shear load at the lumbar spine ($F=2.04$, $p>.05$, $df=1$). 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 load on the shoulders and upper torso during load carriage Shear load in the lumbar area was not affected by the use of lateral rods, it was unchanged between the rod and no-rod conditions

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1. 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).

1.1 Rationale

Currently the CTS Prototype does not have lateral stiffening rods. Adding these may improve the load transfer to the body by providing a direct force bridge between the top of the hip (iliac crest) and the top of the pack frame. This may allow a user to reduce the horizontal shear in the spine by allowing a portion of the weight to be lifted by a pure vertical force supplied by the top front of the pelvis. If this is successful, lumbar shear may be reduced.

1.2 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: 1) 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 2) reduce the horizontal reaction force that produces a shear load on the spine.

2. METHODOLOGY

The Load Distribution Manikin (shown in Figure 1) consists is 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.

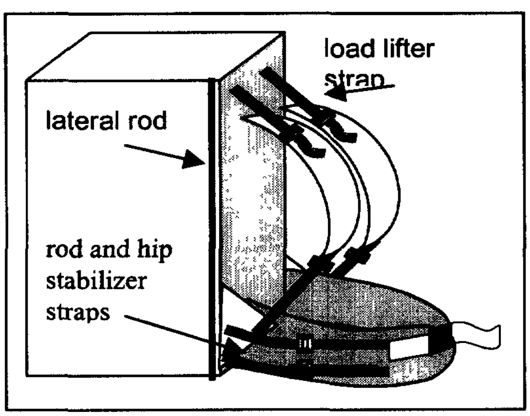
The no-rod condition is shown in Figure 2a). The upper and lower hip stabilizer straps on each side of the rucksack were tensioned to 100 N and the lateral rod attached passively on each side of the pack. The setup for the rod condition is shown in figure 2b). Only the upper hip stabilizer strap was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

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

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.

a)



b)

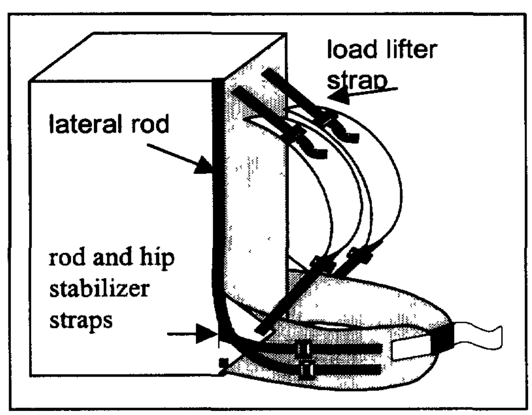


Figure 2. a) Compression and Shear Force, and Moments acting at L3-L4 vertebra. b) The upper portion of the lateral rod is encapsulated within a sleeve leaving the lower portion free to flex anteriorly when attached to the tensioned lower hip stabilizer strap

3. 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 3) without no 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 4). 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.

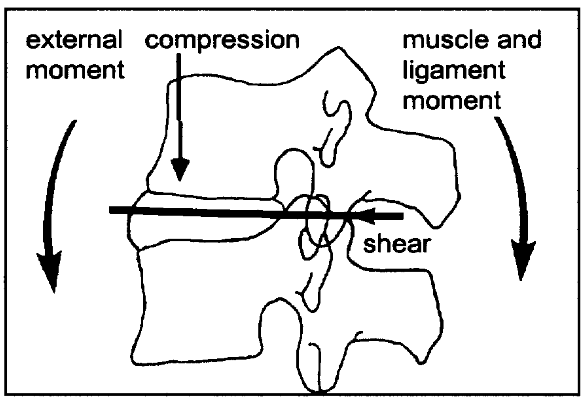


Figure 3. Compression, shear and moments acting on the L3-L4 vertebra.

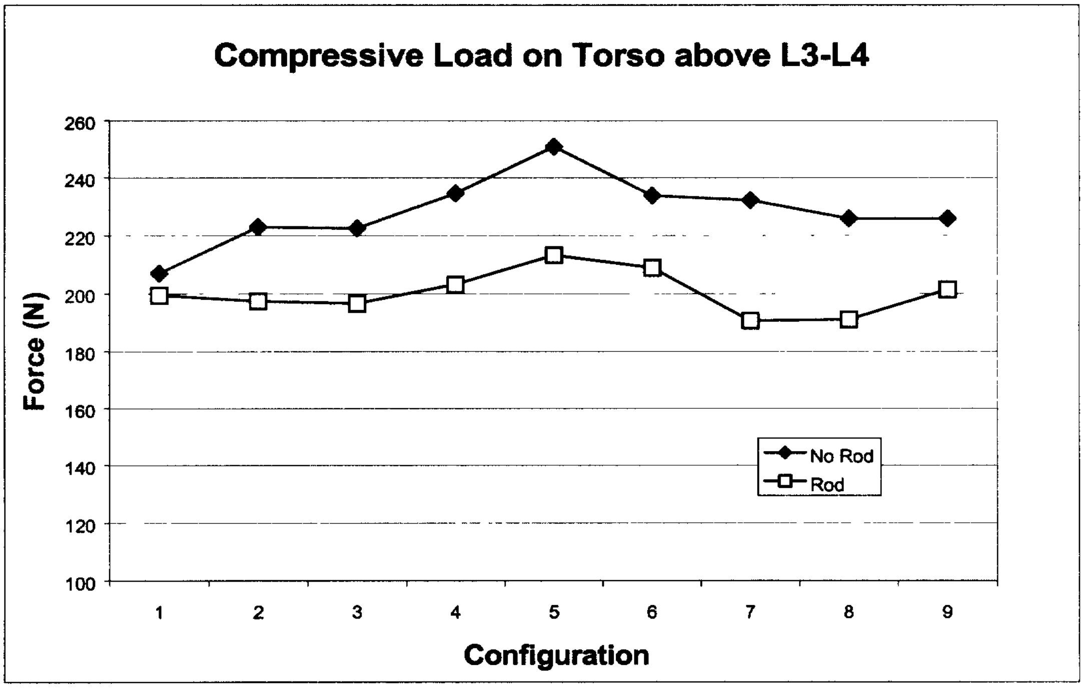


Figure 4. Vertical load force on the shoulders and upper torso for the rod and no-rod conditions.

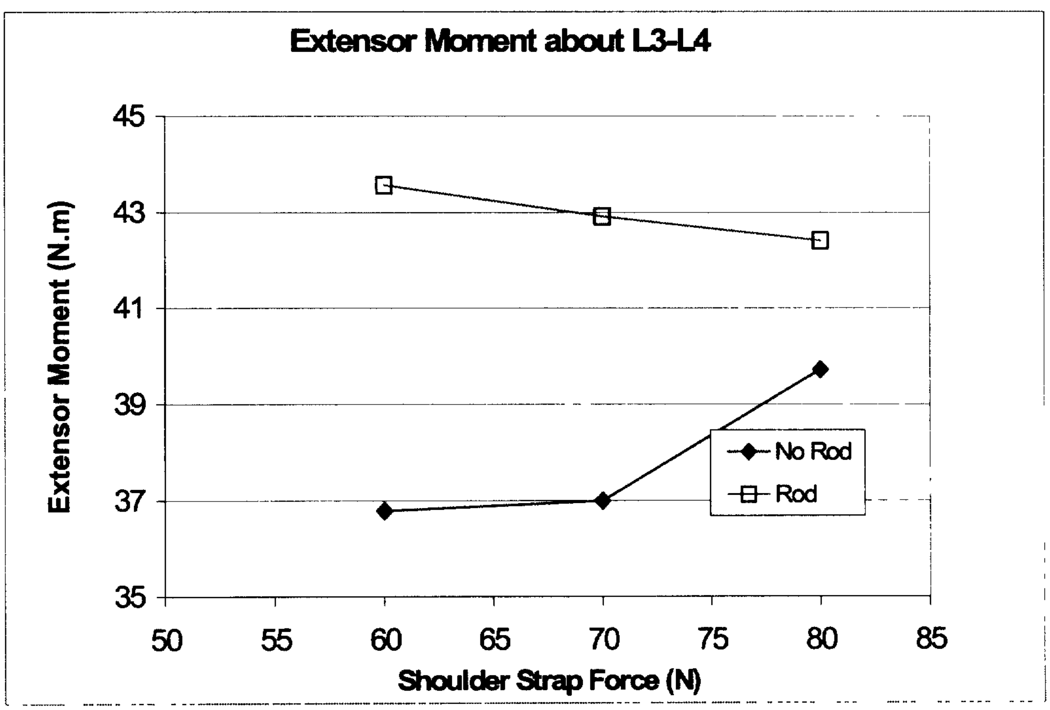


Figure 5. Anterior-posterior extensor moment for rod and no rod conditions.

4. 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 was not reduced with the use of the lateral rods as was hypothesized in this study; shear load remained unchanged between the rod and no-rod conditions for all combinations of shoulder strap and waist belt tension. Since no interaction was found between the use of the rods and lumbar shear, 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 needs to be conducted on the active element suspension system 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 factor 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 lateral rods on load distribution of a rucksack highlights the importance of investigating different 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. Different designs to be examined could include a range of rod materials and cross sections, torsion or gas springs and a range of element pretensions

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14. ABSTRACT

(U) 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 the horizontal reaction force acting in the lumbar area is a major factor limiting the load carrying capacity of soldiers. Load transfer to the waist is an effective means to reduce high levels of contact pressure occurring at the shoulder straps (Holewijn, 1997) and has been shown to reduce Rucksack palsy incidence (Bessen et al, 1987). An anthropometrically correct 50th percentile male manikin was split in the transverse plane at the level of the navel and instrumented with a six degree of freedom load cell to allow determination of the rucksack load applied to the shoulders and upper torso independent of the load applied to the hips and lower trunk. Rod and no-rod conditions were tested in a fully factorial design with three levels of shoulder strap tension (60, 70, and 80 N) and three levels of waist belt tension (70, 90, and 110 N). Vertical force along the compressive axis of the spine, and lumbar shear in the postero-anterior direction were obtained at the L3-4 vertebral level and used to determine the load transfer characteristics associated with adding lateral stiffness rods to a rucksack. A three-way, general linear model ANOVA in SPSS statistics software was used to analyse the results. 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% without any corresponding increase in shear load at the lumbar spine ($F=2.04, p>.05, df=1$). 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 load on the shoulders and upper torso during load carriage. Shear load in the lumbar area was not affected by the use of lateral rods, it was unchanged between the rod and no-rod conditions.

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