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Biomechanical Assessment of Rucksack Shoulder Strap Attachment Location: Effect on Load Distribution to the Torso

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Summary

The objective of this study was to conduct biomechanical testing of pack component options to determine the optimal location for the lower attachment of the shoulder strap for the Clothe the Soldier (CTS) Integrated Patrol Pack and Rucksack. A model of a 50th percentile male torso has been split transversely at T12/L1 and instrumented with two six degree of freedom load cells. The shoulder area of the manikin was instrumented with Fscan™ sensors to record the contact pressure distribution in the axilla (armpit) and anterior of the shoulder under the shoulder strap. A 25 kg fixed payload was used for all test configurations. Waist belt, load lifter and shoulder strap tensions were constant during testing. Output variables were reaction forces at T12/L1, waist belt lifting force, average, and peak contact pressures about the shoulder. These were examined as a function of the attachment point location and as a function of the angle the shoulder strap made with respect to the body long axis. Strap angles above 30 degrees resulted in peak axilla contact pressures ranging from 35 to 64 kPa. At strap angles less than 24 degrees, anterior shoulder peak pressures of >32 kPa were recorded. These two effects determined the upper and lower bounds of an optimal range of 24 to 30 degrees with respect to the vertical axis of the body. These results cannot be extrapolated to other attachment locations that were not tested and pertain only to the type of strap tested.

Introduction

This work was undertaken in support of the major Crown Project L2646 "Clothe the Soldier" under which a number of improved personal clothing and equipment items are being acquired or developed in the near term for Canadian Forces soldiers. The objective of this study was to conduct objective biomechanical testing of a shoulder strap to determine the optimal location for the lower attachment point for the CTS Integrated Patrol Pack and Rucksack.

Scope

This study was to determine the magnitude of the horizontal lumbar force (lumbar shear) and the load share borne by the shoulders and hips for a minimum of four vertical and three horizontal locations. A total of six vertical and seven horizontal locations were tested and the results for all locations have been included in this report. Outcome measures included lumbar shear and load distribution between the upper and lower torso, and peak and average pressures experienced about the shoulder. These variables are plotted as a function of shoulder strap angle. Finally, a range of acceptable strap angles is recommended based on these results.

Method for Determining Load Distribution

Load Distribution Manikin. A model of a 50th percentile male torso has been split transversely at T12/L1 and instrumented with a six degree of freedom load cell at this location. A second six degree of freedom load cell (force plate) below the hips permits calculation of the load sharing between the upper and lower parts of the body. Additionally, the shoulder area of the manikin is covered with Bocklite™ and

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instrumented with Fscan™ sensors to record the contact pressure distribution in the axilla (armpit) and anterior of the shoulder. The experimental setup is shown in Figures 1 and 2.

Figure 1. Experimental Setup (41 degree shoulder strap angle).

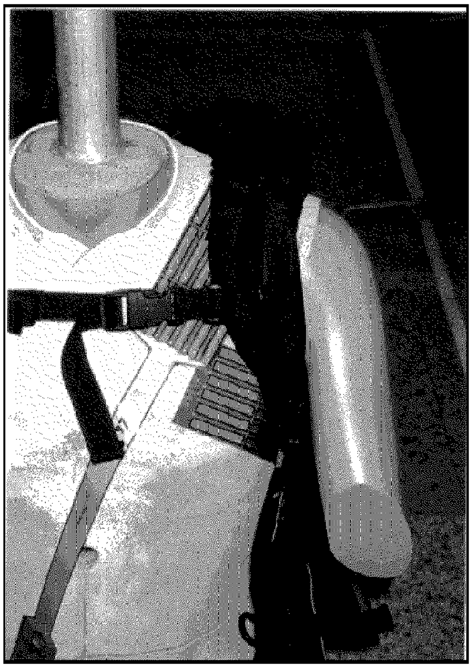

Figure 2. Load Distribution Manikin, Shoulder Detail with F-Scan™ pressure sensors

Test Protocol. Physical layout of the test apparatus and the identifiers for the attachment locations are shown schematically in Figure 3. A test pack was provided by Ostrom Outdoors that was similar to the CTS Rucksack M1 (Modular) prototype. This rucksack was equipped with a series of D-rings sewn along the vertical edge of the framesheet which allowed the shoulder strap to be moved through six vertical locations at approximately 5 cm intervals. The lowest of these corresponded to the bottom corner of the framesheet. This resulted in a vertical range of approximately 25 cm. An aluminum bar (25 x 3 mm, T6062) was placed horizontally on the pack side of the frame sheet with its lower edge aligned with the top of the waist belt. This bar was bolted directly to the two vertical aluminum stays. The outer ends of the bar were brought forward to follow the curvature of the waist belt around the hips. This bar projected forward horizontally, just above the height of the waist belt and corresponded to the third vertical position (V3). It was marked at 2.5 cm intervals and allowed a horizontal variation in the attachment point of approximately 18 cm. Horizontal location was referenced to the framesheet such that H0 was at the frame sheet and H7 was at the approximate midline of the body.

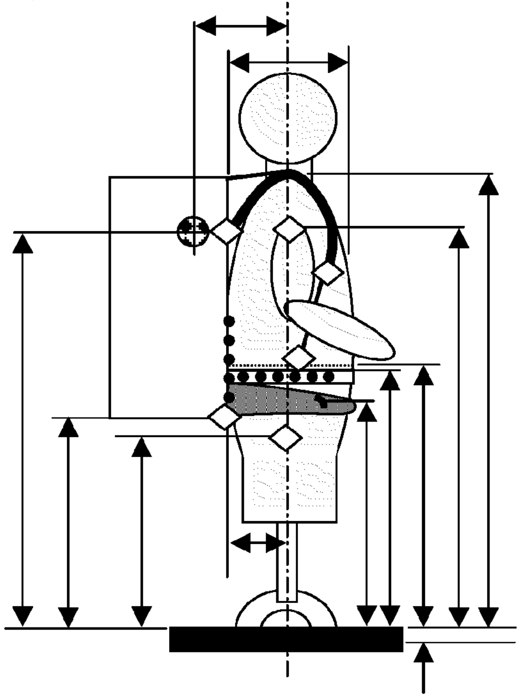

Figure 3. Schematic of Load Distribution Test Apparatus (Shoulder Strap attachment points indicated by black circles – 12 positions of varied vertical heights and horizontal positions. Optotrak position markers indicated by white diamonds).

The position and mass of the payload (25 kg) was placed at the height of the shoulder blades, as close as possible to the body for all testing. Strap tensions were set to 51 N (+/- 2) at the shoulders and 45 N (+/- 2) at the waist and recorded for all configurations. An Optotrak 3-D motion tracking system, accuracy +/- 0.1 mm, was used to measure torso lean, strap angle and pack angle. To determine these variables, position markers were placed in the locations shown as white diamonds in Figure 3.

For each test configuration, data was recorded capturing forces and moments (Fx, Fy, Fz, Mx, My, Mz) at both load cell locations, shoulder strap tension, waist belt tension and the X, Y, Z position of the 6 location markers. With the pack in place, the load distribution (LD) manikin was inclined forward using a rotational vice on the force plate until the moment about the medial/lateral axis was zero. This was achieved at 4.6 degrees forward lean. Forward lean angle remained constant for all testing as the position of the payload remained fixed for all configurations. Calibration of the load cells was done by capturing baseline data for the LD manikin with no pack at this forward lean. This baseline was then subtracted from all data. Data from the force plate was transformed using the direction cosine of the forward lean angle to rotate the force plate data into alignment with the load cell at T12/L1. Forces and moments are then reported with reference to the axis of the human spine.

The position of the centre of gravity of the pack and the manikin was determined using a force balance analysis and the load cell data for the conditions listed in Table 1.

Table 1. Calculation of Centre of Gravity

Backpack	Lean Angle
on	0
on	4.6 *
off	0
off	4.6 *

*Lean angle required for 0 anterior / posterior moment.

Results

Strap angle refers to the angle between the vertical body axis and the lower portion of the shoulder strap. The relationship between the strap angle and anatomical landmarks is shown in Figure 4.

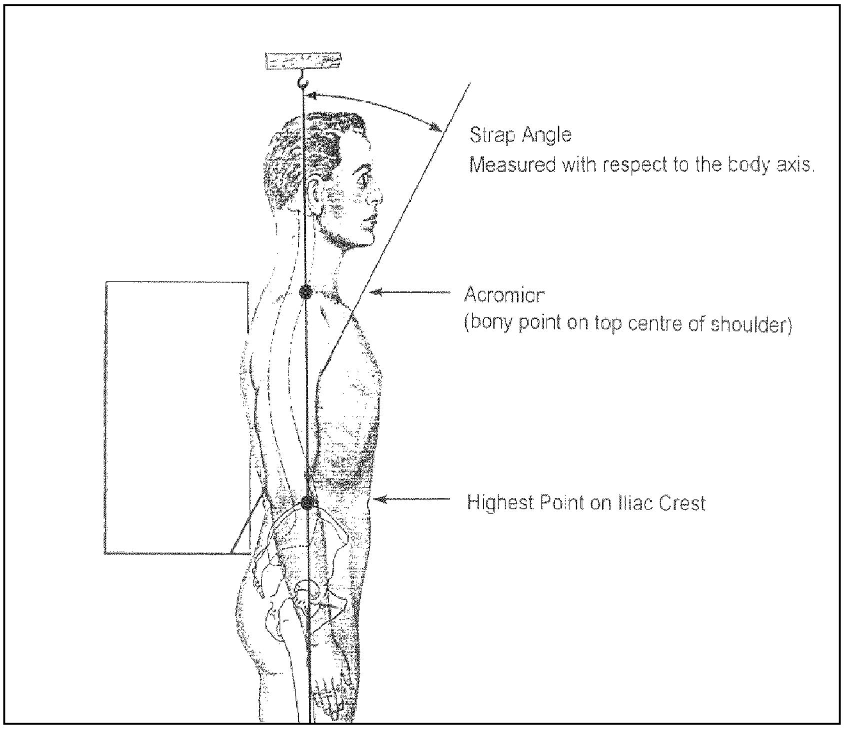

Figure 4. Relationship of Strap Angle to Anatomical Landmarks

Table 2 contains a summary of force and pressure results from the study. It includes calculated lumbar shear and compression forces over all attachment locations, the vertical lift contribution of the waist belt as well as calculated values of peak pressure, average pressure, and force experienced by the body for all the strap configurations tested. A selection of results is shown graphically in Figures 5 through 7.

Table 2. Forces and Pressure Results Summary

					Peak Pressure (kPa)		Average Pressure (kPa)		Average Body Force (N)*		
Location (horizon-tal & vertical)	Strap Angle (deg)	Lumbar Shear (N)	Compres-sive Force (N)	Waist Belt Lift (N)	Peak Anterior Shoulder	Peak Armpit	Avg. Anterior Shoulder	Avg. Armpit	Anterior Shoulder	Armpit	Total
H0V1	35.84	86.1	216.8	662.3	28.8	32	18.2	21.6	910	591.8	1501.8
H0V2	38.19	110.4	181.9	697.3	26.2	38.9	15.7	21.8	632.8	606	1238.8
H0V3	40.53	109.2	209.0	675.5	26.2	38.9	15.8	22.7	611.5	585.7	1197.2
H0V4	50.22	89.8	178.6	702.3	23.6	43.5	15.6	26	730.1	754	1484.1
H0V5	56.65	85.7	162.3	721.9	23.6	48	14.9	26.8	721.2	691.4	1412.6
H0V6	63.93	73.5	185.1	699.5	23.6	52.6	15.1	26.4	730.8	554.4	1285.2
H0V3	42.21	109.2	209.0	675.5	26.2	38.9	15.8	22.7	910	591.8	1501.8
H1V3	36.59	94.7	211.1	673.5	26.2	34.3	16.2	25.8	732.2	665.6	1397.8
H2V3	32.31	99.5	232.8	651.4	28.8	25.2	18.5	19.3	865.8	405.3	1271.1
H3V3	27.46	95.7	203.0	680.4	31.4	25.2	17.4	17.8	842.1	315.1	1157.2
H4V3	21.59	88.4	219.7	665.4	34	25.2	17.8	19.2	890	247.7	1137.7
H5V3	15.82	88.4	219.7	668.3	36.7	22.9	18.5	17.8	895.4	144.1	1039.5
H6V3	13.03	80.3	206.8	677.9	39.3	27.4	19.9	18.8	899.5	152.3	1051.8
H7V3	11.12	73.7	214.6	669.5	34	27.4	19.3	20	872.4	129	1001.4

* Body force is calculated from the F-scan data by integrating the pressure over the recorded contact area. It reflects the total load felt by the body

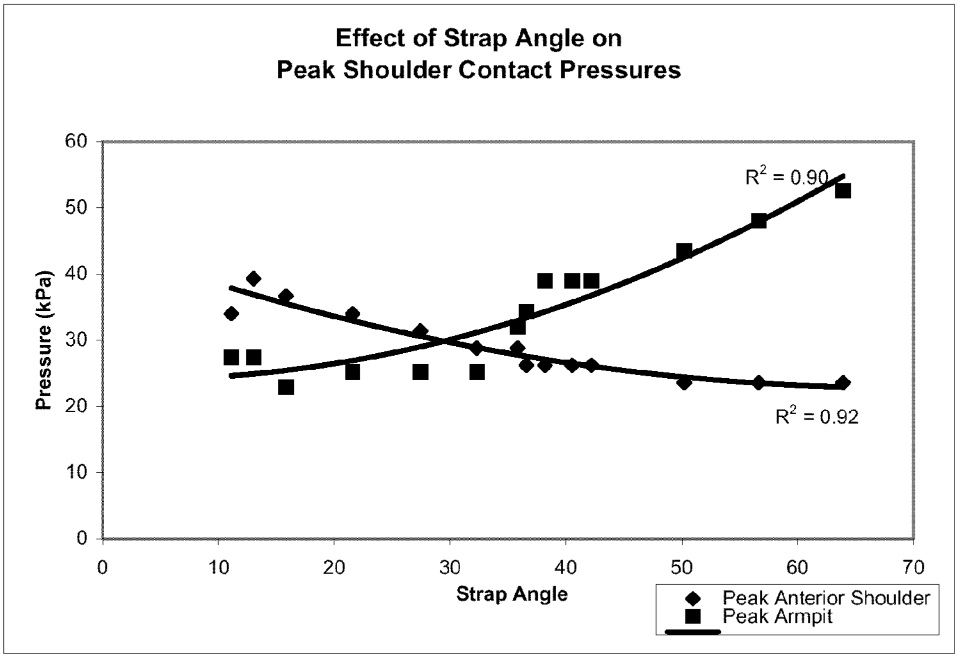

Figure 5. The effect of shoulder strap angle on peak contact pressures in the axilla and on the anterior shoulder.

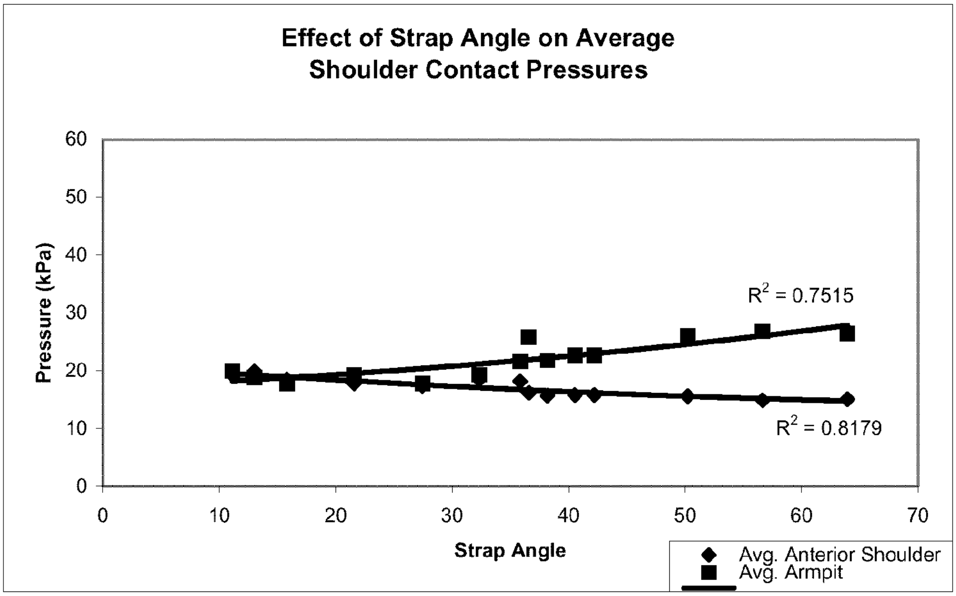

Figure 6. Effect of Shoulder Strap Angle Contact Pressures in the Axilla and Anterior Shoulder. Values greater than 20 kPa are correlated to long term user discomfort.

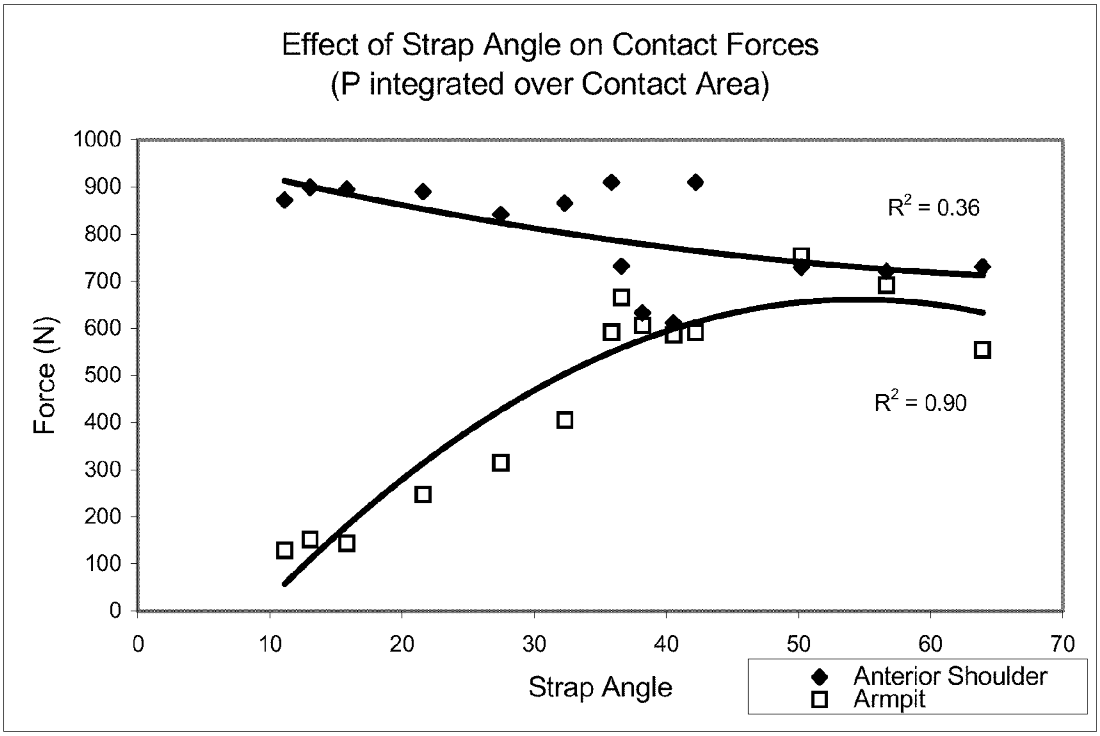

Figure 7. Effect of Shoulder Strap Angle on the force experienced by the body. These values are calculated by integrating the recorded pressure over the contact area.

Discussion

Comparison to Threshold Limit Values. As seen in Figure 5, attachment points with strap angles higher than 30 degrees resulted in increases to peak skin contact pressures in the axilla. Anatomically, this corresponds to having an attachment point above the height of the iliac crest. This result is consistent with the direction and relative magnitude of the body's shoulder force predicted in the biomechanical model developed by Stevenson et. al. (1995). The peak contact pressures values measured in the axilla at strap angles greater than 30 degrees ranged from 35 to 64 kPa. These values are expected to result in significant discomfort for users. This was used to select an upper bound of 30 degrees to the recommended strap angle.

A study by Holloway et al. (1976) suggests that a safe physiological contact pressure limit for continuous pressure over 8 hours is 14 kPa, while the average contact pressure threshold limit for the perception of pain was determined to be approximately 20 kPa in work by Stevenson et al. (1997). Average contact pressure on the axilla (Figure 6) began to exceed 20 kPa at strap angles greater than 30 degrees. This was consistent with the results for the peak pressure distribution.

As shown in Table 2, the magnitude of lumbar shear force decreased as strap angle decreased but this was tied to an increase in the load experienced by the anterior shoulder. Figure 5 shows that at strap angles less than 24 degrees, peak anterior shoulder pressures approached 32 kPa.

A previous study (Stevenson et al., 1995) also determined a maximum allowable value of 135 N for transverse loads on the spine based on achieving optimal human load carriage performance. Although no attachment location resulted in a lumbar shear force greater than 135 N (see Table 2), there was a twofold change in the magnitude of the lumbar shear over the range of strap angles tested.

Figure 7 illustrates how the change in shoulder strap angle affected the total load experienced by the shoulder region. Although the top front of the shoulder unloaded, the load on the axilla increased at a greater rate, causing an increase in the total load experienced by the body at higher strap angles.

These factors were used to determine a recommended lower bound on the optimal strap angle range of 24 degrees. Strap angles of 24-30 degrees can be achieved in two configurations: with the attachment point at the lowest point possible on the pack; and when the attachment point was moved forward towards the body midline. In the test rucksack provided, the strap angle was 35 degrees at the lowest point possible on the pack and would have to move an additional 5 cm lower to reach the optimal range.

Conclusions and Reservations

The study concluded that:

- The optimal configurations for load distribution to the body resulted when the lower part of the shoulder strap achieved an angle of between 24-30 degrees with respect to the vertical axis of the body; and

- Strap angles in this range can be achieved by locating the attachment point at locations V3H2 and V3H3, just posterior to the body midline at the height of the iliac crest. A strap angle of 35 degrees was achieved at the lowest point on the pack frame sheet as tested. If this location were an additional 5 cm lower, the resulting strap angle would be within the optimal range.

Note that only single measures were recorded at each configuration. This limits the strength of conclusions based on these data. Additionally, these results cannot be directly applied to other possible attachment locations that were not tested.

Acknowledgement

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References

Stevenson, J.M., Bryant, J.T., dePencier, R.D., Pelot, R.P., & Reid, J.G. (1995). Research and Development of an Advanced Personal Load Carriage Syste (Phase I). *DCIEM Contractor Report* (unpublished), submitted in partial fulfillment of PWGSC Contract No. W7711-4-7225/01-XSE.

Stevenson, J.M., Bryant, JT., Pelot, R.P., Morin, E.M., Deakin, J.M., Reid, S.A., & .Doan, JB. (1997) Research and Development of an Advanced Personal Load Carriage System, Phases II and III. *DCIEM Contractor Reports* (unpublished), submitted in partial fulfillment of PWGSC Contract No. W7711-5-7273/001/TOS.

Holloway, J.A., Daly, C.H., Kennedy, D., & Chimoskey, J. (1976). Effects of External Pressure Loading on Human Skin Blood Flow. *Journal of Applied Physiology*, 40: 596-600.