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Ergonomics

Scott Schneider Column Editor

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Evaluation of Muscular Stress in Construction Machine Operators An EMG Study

Scott Schneider, Column Editor

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In their work, operators of wheeled construction machines run the risk of being afflicted with ailments localized in the musculoskeletal system, which are often caused by poor working postures in the cab as well as repeated, uncomfortable, and physically stressing operating maneuvers.

Poor visibility is one of the risk factors. The visual demands determine the working posture and, as a consequence, the driver may not be able to utilize the ergonomic properties of the cab. Visibility improvements are very important measures that ought to be prioritized, partly to meet comfort and safety requirements, but also to increase the productivity of the machines.

The aim of this study was to arrive at an objective evaluation of the muscular stress on the shoulders and lumbar region of wheeled loader operators in the performance of 10 representative maneuvers. The measurements were recorded during the operation of an older cab model and Volvo BM's new Care Cab which has been designed to achieve even better driver comfort. Among other things, the window surface area has been increased by about 50 percent, and a new steering system confers ergonomic advantages.

The study has shown that the stress on the muscles of the lumbar region decreased on both the right and left side in the new cab as a consequence of ergonomic improvements. Similarly, there was a decrease in the so-called stress dose in the shoulders in the new cab, whereas the level of stress in the left shoulder increased due to an unfavorable positioning of the driver's wheel.

The most important individual factor in the improved ergonomics of the new cab is the very large visibility increase. The increased proportion of glass surface area makes it possible to utilize the supporting surfaces and backrest of the driver's seat to a higher degree than in the old cab, with reduced muscular stress as a result. The driver has a wider view of the operating area of the machine and loading apparatus from his position in the new cab.

The results show that VME's investments in a more ergonomically correct cab have been successful because muscular stress has been reduced to a considerable extent. Furthermore, the study of stress conditions has produced results that will enable the designers to make further improvements in the cab. The project has generated several ideas for future development.

Introduction

Loaders are one of the most common types of machines belonging to the construction machine group in Sweden. Altogether, there are about 9000 such machines in production today.[1] In their work, drivers of wheeled construction machines run the risk of being afflicted with ailments localized in the musculoskeletal system, which are often caused by poor working postures in the cab as well as repeated, uncomfortable, and physically stressing operating maneuvers.[1–3]

A very large proportion of machine drivers experience muscular stress symptoms. A recently completed investigation[4] of the working conditions of 1000 excavator operators shows that the most common symptoms occur in the nape of the neck (51%), shoulders (51%), and the lumbar region (55%). More than 80 percent of all the drivers complained of symptoms involving the neck and shoulders or back during the past year. More than 17 percent of them had symptoms for more than 30 days and 5 percent had daily manifestations of muscular stress symptoms.[4]

Many factors play a part in the development of muscular stress symptoms; however, a few factors often recur in different studies, and researchers agree they really have a harmful effect, viz. the degree of static stress and the frequency and duration of various movements.[3,5] These factors are considered to cause damage to the musculature due to what one might describe in simplified terms as prolonged overloading. Another factor that leads indirectly to involuntary muscular stress and tension is inadequate visibility. The visual demands determine the working posture and, as a consequence, the driver may not be able to utilize the ergonomic properties of the cab. Visibility improvements are very important and should be prioritized to meet comfort and safety requirements and to increase the productivity of the machines.

This study was made to compare the muscular stress conditions in two different loader cabs. One is the cab found most frequently today on VME's loaders of the Volvo BM type. The other is a new type of cabin designed to provide even better ergonomic properties and driver comfort (Care Cab).

To determine in an objective manner whether the new cab confers the intended comfort under realistic conditions, tests were performed with mobile measuring apparatus. The goal was to carry out representative maneuvers in a natural manner.

Aim of the Study

The aim of the study was to compare the muscular load conditions in two different wheeled loader cabs: an original cab and the recently developed Care Cab. Two questions were to be answered:

- How is the stress in the musculature of the shoulders and the lumbar region affected when driving an older cab model or the new Care Cab?
- Which of the studied muscles are jointly activated when driving an older cab model, or the Care Cab?

Methods and Material

A total of 11 male operators, aged 28 to 60 years, participated in a comparison of

FIGURE 1. Volvo BM L120 with original cab.

muscular stress conditions in two different cabs. The mean age of the operators was 42.2 years (SD 10.5), the mean height was 177.8 cm (SD 5.4), and the mean weight was 83.7 kg (SD 12.4). All were professional operators who had many years of driving experience and were thoroughly familiar with the different operating maneuvers. The muscles studied were chosen on functional anatomy and clinical grounds. They were, in the shoulder, *m. trapezius* (*pars descendens*) and, in the lumbar region, the paravertebral musculature at the L3 level (*erector spinae*).

Muscle activity was recorded with the aid of electromyographic (EMG) equipment. This measuring method is suitable for data collection in the field and has been used in a number of investigations.[6,7] The signals emitted are collected in a data logger and are transferred after the measuring procedure to a personal computer for further analysis. The measurements were determined with a portable device (Muscle Tester ME 3000, MEGA Elektroniikka OY, Finland).

In the measurements, the stress is described as a ratio of muscle activity in a standardized test over muscle activity during loader operation (reference contraction, RC%), presented in the Results section as the *level of stress*. In addition, we evaluated the *stress dose*, which is a composite of muscle activity (μV) and exposure time (operating time in seconds) and is defined as the area with stress on the Y-axis and time on the X-axis (μVs).

Vehicles Used

The vehicles used in the study were two Volvo BM loaders, type L120 (Figure 1) and L120 B (Figure 2). The two machines were basically technically identical, except that L120 B had been fitted with a new cab (Care Cab), which had been altered to improve safety and driver comfort.

The new steering system in the L120 B has been developed to facilitate steering. Compared to the old machine, the new steering system requires less steering force, a reduction of about 50 percent. Fewer revolutions of the steering wheel are required to achieve maximal turning. The number of revolutions for maximal turning has been reduced from 4.4 to 3.5.

In the old cabin, only the steering-wheel column could be adjusted and the wheel then positioned nearer the body. The closer to the body the steering wheel is adjusted, the lower the steering-wheel hub is placed. The angle of the steering-wheel column in its foremost position, measured from the vertical plane of the old cab, is 22°. From this position, the column can be adjusted through a range of about 13° with seven adjustable positions, resulting in an angular change of approximately 1.9° between positions. The maximum longitudinal adjustment of the wheel is approximately 140 mm.

Individual adjustments of the steering wheel have been expanded in the new Care Cab. The operator can choose different adjustments depending on the work to be done and the need to relieve or alter the working posture. The new cab has a fixed steering column with an angle of 26° to the vertical plane. The steering wheel is adjusted by changing its position in relation to the fixed steering column. The adjustment (tilting) can be made through a range of 40° (16° upward and 24° downward). The central turning point for the tilting is located approximately 180 mm below the plane of the steering wheel. The steering wheel

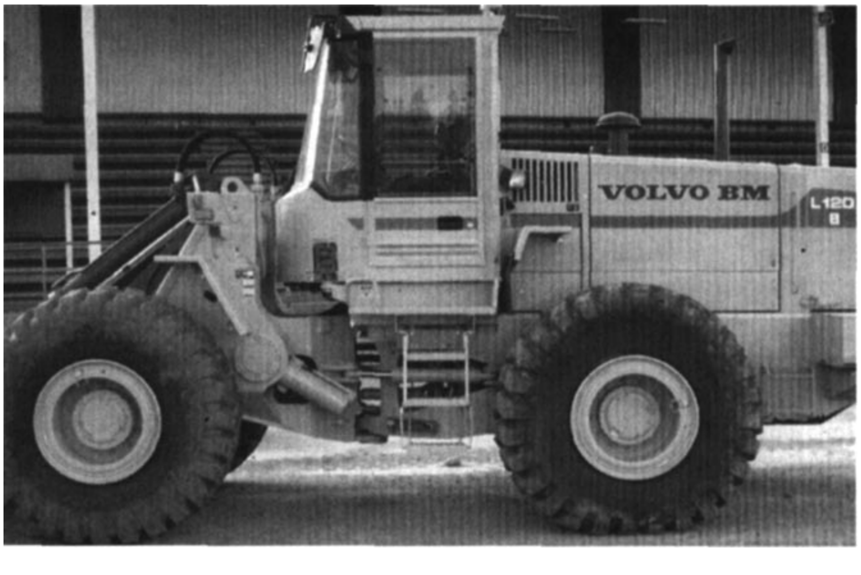

FIGURE 2. L120 B with the new Care Cab. It has a larger glass surface area and therefore confers better visibility. There is also considerably more room in the cab.

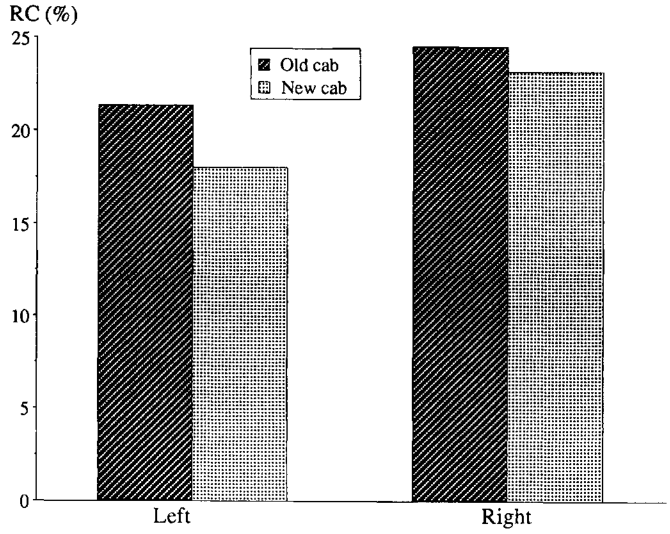

FIGURE 3. Average level of stress for all operating maneuvers in the left and right musculature of the lumbar region during operations in the old and the new wheeled loader cab. RC(%) = relative contraction in percent.

can also be raised and lowered through a range of 80 mm.

The fenders on model L120 B have been made smaller to improve visibility near the loader when the driver is seated in the cab. In addition, the cab is now roomier, has a brighter interior, and the placement of the instruments is better.

Design and Implementation

The project was implemented at VME's demonstration field in Eskilstuna, Sweden, where a special test track was prepared. There were 10 different stations on the test track where a total of 12 maneuvers was performed. The maneuvers studied were:

1. loading of chips in a high load receiver,
2. loading and unloading of timber,
3. hoisting with pallet fork in high position,
4. precision hoisting with crane boom,
5. loading of dumper, normal speed,
6. loading/carrying of material with the Boom Suspension System engaged,
7. loading of dumper, normal speed,
8. loading/carrying of material with turning on track,
9. loading of dumper at piece-work speed,
10. loading/carrying of material without having the Boom Suspension System engaged,
11. loading of dumper at piece-work speed, and
12. driving forward and backing on obstacle course.

All of the drivers test-drove both vehicles and were allowed to adjust the seat and steering wheel as they liked. EMG electrodes were attached to the driver's body while, at the same time, he was informed about the measuring technique and the purpose of the measurements. During the whole series of measurements with one machine, which took about 40 minutes, the driver remained seated in the cab. After completion of the test, the driver rested for about 30 minutes while the data logger was emptied of all measuring data. The tests were completed with the driver repeating the maneuvers with the second loader.

TABLE 1. Comparison of Muscular Stress Levels in Lumbar Region

	Back-Left		Back-Right	
	Old cab	New cab	Old cab	New cab
Activity	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD
1 Chips	17.8 ± 6.0	15.3 ± 7.9^A	23.0 ± 9.8	21.5 ± 10.2^A
2 Timber	20.2 ± 8.2	17.3 ± 8.4^A	23.4 ± 10.1	22.8 ± 10.3
3 Pallet fork	16.1 ± 6.7	14.5 ± 6.3^A	22.2 ± 9.5	22.6 ± 10.4
4 Precision hoist	15.4 ± 5.8	14.0 ± 5.3	21.9 ± 9.2	21.3 ± 9.1
5 Loading-norm	20.2 ± 6.2	18.8 ± 6.6	23.9 ± 9.6	24.1 ± 9.1
6 BSS^B	24.5 ± 9.9	21.1 ± 10.0^C	26.3 ± 10.3	25.0 ± 10.6
7 Loading-norm	21.1 ± 8.2	17.2 ± 8.1^C	24.1 ± 9.7	22.7 ± 9.0
8 Turning	19.8 ± 8.3	16.5 ± 7.9^C	23.5 ± 9.5	21.5 ± 10.4^C
9 Loading-piece-work speed	27.5 ± 13.2	21.9 ± 15.5	30.8 ± 12.7	26.0 ± 13.1^A
10 Without BSS^B	24.0 ± 11.4	21.2 ± 11.9	28.0 ± 12.0	26.6 ± 12.5
11 Loading-piece-work speed	27.7 ± 16.1	22.6 ± 15.7^C	29.0 ± 11.7	26.0 ± 10.9
12 Obstacles	21.5 ± 9.0	15.6 ± 8.6^C	29.3 ± 12.6	23.2 ± 9.3^A
Average mean	21.3 ± 8.2	18.0 ± 8.7^C	24.5 ± 9.9	23.2 ± 10.4^A

Student's t test between old and new cab.
$^A p < 0.05$.
^{B}BSS = Boom Suspension System.
$^C p < 0.01$.
Means and standard deviations in a comparison of muscle activity in the back (L3) during maneuvering in the old and the new wheeled loader cab. Muscle activity = relative contraction in percent (RC%).

Results

The evaluation of the muscular *level of stress*, expressed as RC%, has mainly indicated improvements in the driver's muscular stress situation in comparisons made between work in the old cabin and the new one. The evaluation of the *stress dose* (the area μVs), which is a composite of muscle activity (μV) and the exposure time (operating time in seconds), consistently shows lower stress doses for all muscle groups during work in the new cab. This is a consequence of the fact that the maneuvers are performed in a shorter time with the loader equipped with the Care Cab.

Stress in the Left Lumbar Region

The study shows a systematically lower *level of stress* in the paravertebral musculature of the left side of the back at the L3 level (Figure 3). Lower stress was dem-

TABLE 2. Comparison of Muscular Stress Dose in Lumbar Region

	Back-Left		Back-Right	
	Old cab	New cab	Old cab	New cab
Activity	$\bar{X}$ ± SD	$\bar{X}$ ± SD	$\bar{X}$ ± SD	$\bar{X}$ ± SD
1 Chips	2460 ± 1368	1876 ± 841^{A}	2519 ± 896	2246 ± 817^{B}
2 Timber	6219 ± 3479	4552 ± 2390^{A}	5419 ± 1763	4753 ± 1534
3 Pallet fork	1095 ± 479	965 ± 347	1193 ± 249	1199 ± 316
4 Precision hoist	1344 ± 567	1142 ± 462^{A}	1496 ± 338	1427 ± 437^{B}
5 Loading-norm	1436 ± 759	1143 ± 511^{B}	1291 ± 437	1132 ± 376^{A}
6 BSS^{C}	2203 ± 841	1803 ± 550^{A}	1818 ± 462	1676 ± 309
7 Loading-norm	1380 ± 691	1003 ± 497^{A}	1149 ± 321	1050 ± 404
8 Turning	464 ± 209	388 ± 165	424 ± 147	516 ± 356
9 Loading-piece-work speed	1107 ± 553	1055 ± 476	993 ± 318	1040 ± 364
10 Without BSS^{C}	2611 ± 1828	1537 ± 1039^{A}	1918 ± 793	1513 ± 393
11 Loading-piece-work speed	1271 ± 628	937 ± 561^{B}	1095 ± 473	870 ± 404
12 Obstacles	921 ± 474	512 ± 349^{B}	991 ± 414	632 ± 333^{B}
Average mean	1997 ± 952	1505 ± 574^{A}	1829 ± 547	1625 ± 448^{B}

Student's t test between old and new cab.
$^{A}p < 0.05$.
$^{B}p < 0.01$.
^{C}BSS = Boom Suspension System.
Means and standard deviations in a comparison of the muscular stress dose in the back (L3) during maneuvering in the old and the new wheeled loader cab. Stress dose = Area, microvolt seconds (μVs).

onstrated in all operating maneuvers and, in 8 out of 12 maneuvers, significantly lower levels were shown during operations in the new cab (Table 1). An assessment of the total value for all maneuvers results in an average muscular load of 21.3 RC% during work in the old cab and 18.0 RC% during work in the new one ($p < 0.01$). The relative difference can be described as an approximately 20 percent decrease in the stress load in the new cab.

The evaluation of the stress dose presents a similar picture. The dose for all maneuvers had an average value of 1997 μVs for the old cab and 1505 μVs for the new one ($p < 0.05$) (Table 2). The relative difference can be described as a decrease in the stress dose in the new cab of about one third, compared to the old one.

Stress in the Right Lumbar Region

The level of stress in the paravertebral musculature of the lumbar region at the L3 level on the right side also showed a decrease in muscular stress in the new cabin. Ten out of 12 maneuvers were found to produce a lower level of stress, with 4 maneuvers significantly lower and 2 maneuvers higher (Table 1). An assessment of the total value for all maneuvers results in an average muscular load of 24.5 RC% during work in the old cab and 23.2 RC% during work in the new one ($p < 0.05$). The relative difference can be described as a 5.6 percent decrease in the stress level in the new cab.

The evaluation of the stress dose (Figure 4) presents a similar picture for the right side too. The dose for all maneuvers had an average value of 1829 μVs for the old cab and 1625 μVs for the new one ($p < 0.01$) (Table 2). The relative difference can be described as a decrease in the stress dose in the new cab of 12.6 percent.

Stress in Left Shoulder

For the shoulder muscles on the left side, the results indicated an increase in the level of muscular stress, expressed as RC%, in the new cab (Table 3). The left arm is the arm used for steering and steering-wheel movements during driving (steering-wheel arm). A systematically higher muscular stress level could be observed in all 12 operating maneuvers in shoulder muscles on the left side (Figure 5). The difference was not statistically significant, but it was large enough to be demonstrable in all of the operating maneuvers.

The assessment of the total value for all maneuvers indicates an average muscular stress of 18.8 RC% during work in the old cab and 21.6% during work in the new one. The relative difference may be described as a 13 percent increase in the level of stress in the new cab, which was a consequence of the setting of the steering wheel chosen by the drivers.

The evaluation of the muscular stress dose (the area μVs) presents an opposite picture compared to the level of stress. In 10 out of 12 maneuvers, the stress dose was lower, with 2 significantly lower and 2 higher (Table 4). The stress dose for all maneuvers had an average value of 4061 μVs for the old cab and 3719 μVs for the new one (Table 4). The relative difference can be described as a decrease of approximately 9 percent in the stress dose in the new cab. The relative decrease in the stress dose is a consequence of the fact that the operating maneuvers were per-

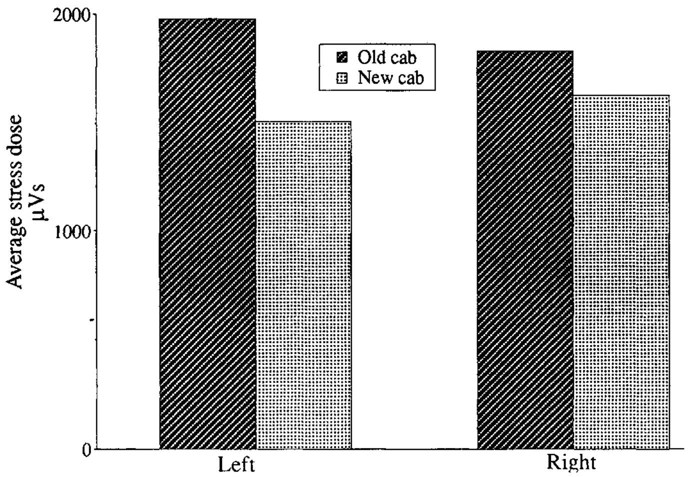

FIGURE 4. Average stress dose for all operating maneuvers in the left and right musculature of the lumbar region during operations in the old and the new wheeled loader cab.

TABLE 3. Comparison of Muscular Stress Level in Shoulder

	Back-Left		Back-Right	
	Old cab	New cab	Old cab	New cab
Activity	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD
1 Chips	17.5 ± 11.1	17.7 ± 15.6	10.2 ± 4.4	9.5 ± 5.2
2 Timber	16.8 ± 10.3	20.9 ± 18.1	11.7 ± 4.3	11.1 ± 5.2
3 Pallet fork	16.6 ± 10.7	18.5 ± 13.9	10.2 ± 4.5	10.3 ± 5.8
4 Precision hoist	18.7 ± 10.3	20.1 ± 15.5	13.0 ± 5.4	13.0 ± 6.8
5 Loading-norm	18.2 ± 10.9	19.9 ± 14.9	12.2 ± 6.8	12.1 ± 6.5
6 BSS[A]	18.6 ± 10.2	21.2 ± 14.0	14.4 ± 5.8	13.8 ± 5.9
7 Loading-norm	18.0 ± 11.1	20.2 ± 14.5	11.9 ± 7.3	12.2 ± 7.0
8 Turning	21.0 ± 10.8	23.6 ± 20.6	17.2 ± 8.2	15.9 ± 7.0
9 Loading-piece-work speed	20.8 ± 11.4	24.9 ± 18.9	13.8 ± 7.4	16.7 ± 8.8
10 Without BSS[A]	19.0 ± 10.7	22.8 ± 16.9	14.2 ± 6.7	14.9 ± 6.9
11 Loading-piece-work speed	20.7 ± 12.0	25.6 ± 19.1	13.5 ± 7.1	16.8 ± 8.3[B]
12 Obstacles	19.6 ± 9.6	24.0 ± 16.9	14.6 ± 6.4	15.3 ± 5.9
Average mean	18.8 ± 10.4	21.6 ± 16.3	13.1 ± 5.7	13.5 ± 5.9

Student's t test between old and new cab.
[A]BSS = Boom Suspension System.
[B]$p < 0.05$.
Means and standard deviations in a comparison of muscle activity in the shoulder during maneuvering in the old and the new wheeled loader cab. Muscle activity = relative contraction in percent (RC%).

formed in a shorter time during work in the new cab.

Stress in Right Shoulder

For the shoulder musculature on the right side (control column arm), the evaluation indicated a lower level of stress in 5 of the 12 maneuvers studied, an unchanged level in 1 maneuver and a higher one in 6 maneuvers in the new cab. An assessment of the total value for all maneuvers indicates an average muscular load of 13.1 RC% during work in the old cab and 13.5 RC% during work in the new one. The relative difference can be described as a 3 percent increase in the muscular stress level in the new cab.

The evaluation of the stress dose indicates a lower dose on the right side as well (Figure 6). The stress dose for all maneuvers had an average value of 2774 μVs for the old cab and 2647 μVs for the new one (Table 4). The relative difference can be described as an approximately 4 percent decrease in the stress dose in the new cab.

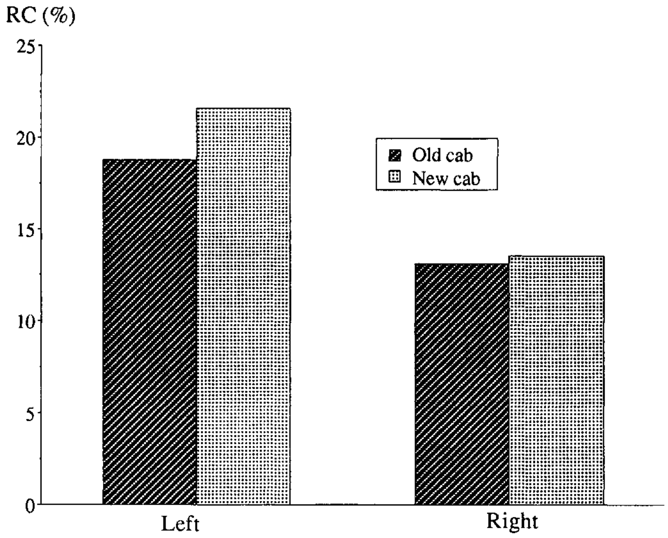

FIGURE 5. Average level of stress for all operating maneuvers in the left and the right muscles of the shoulder during operations in the old and the new wheeled loader cab. RC(%) = relative contraction in percent.

Comparison of Muscular Stress in Shoulders

The data obtained in the study were analyzed to determine which operating maneuvers (turning the steering wheel, manipulating the control column) cause the most muscular stress. The evaluation clearly shows that the left shoulder is engaged most heavily, with regard to both the *level of stress* and the *stress dose.* This means that the steering-wheel work should be regarded as a harder type of work than the operation of the lever controls, which is performed with the right hand.

The muscular stress was found to be higher in the left shoulder (18.8 RC%) than in the right shoulder (13.1 RC%) in both the old cab and the new one (Table 3). This means that the relative difference may be described as a 44 percent higher load on the steering-wheel arm.

The evaluation of the stress dose shows that the left shoulder has a value of 4061 μVs and the right shoulder a value of 2774 μVs in the old cab (Table 4). This means that the relative difference can be described as a 46 percent higher muscular load on the steering-wheel arm.

Analysis of Operating Pattern

An analysis of the operating pattern in the two machines was made by analyzing the four muscle groups in a multiple linear regression analysis. The aim was to describe the way in which the investigated muscle groups are activated to understand how they influence one another. The degree of mutual influence, the *covariation,* is expressed as the degree of correlation (r). The correlation may range from −1.0 to 1.0 (Table 5). An analysis of the operating pattern for the different muscles in the shoulder and back revealed systematic differences between the old cab and the new one.

In the machine with the old cab, the muscular stress covaried between the left and right shoulder in 8 of the 12 maneuvers and between the left and right lumbar regions in all 12 of the maneuvers. Covariation between the left shoulder

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TABLE 4. Comparison of Muscular Stress Dose in Shoulders

	Back-Left		Back-Right	
	Old cab	New cab	Old cab	New cab
Activity	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD	$\bar{X}$ SD
1 Chips	5381 ± 4156	4708 ± 3841^A	3409 ± 2018	2878 ± 1966^B
2 Timber	12160 ± 8626	9931 ± 7691^B	8339 ± 4461	7126 ± 5479
3 Pallet fork	2408 ± 1538	2621 ± 1711	1646 ± 845	1610 ± 1042
4 Precision hoist	3635 ± 2137	3305 ± 2249	2771 ± 1320	2544 ± 1606
5 Loading-norm	2761 ± 2017	2460 ± 1779	1937 ± 1229	1768 ± 1235
6 BSS^C	3569 ± 2283	3234 ± 2210	3027 ± 1397	2794 ± 1051
7 Loading-norm	2465 ± 1694	2395 ± 1801	1677 ± 1132	1740 ± 1327
8 Turning	1142 ± 603	1161 ± 940	1002 ± 499	1073 ± 792
9 Loading-piece-work speed	2089 ± 1451	2475 ± 1625	1345 ± 829	1824 ± 1134
10 Without BSS^C	3545 ± 2221	3518 ± 2766	2894 ± 1434	2749 ± 2165
11 Loading-piece-work speed	2185 ± 1396	2180 ± 1667	1500 ± 815	1646 ± 1103
12 Obstacles	1883 ± 1012	1582 ± 1052	1573 ± 1025	1268 ± 728
Average mean	4061 ± 2590	3719 ± 2496	2774 ± 1371	2674 ± 1706

Student's *t* test between old and new cab.
^A $p < 0.01$.
^B $p < 0.05$.
^C BSS = Boom Suspension System.
Means and standard deviations in a comparison of the muscular stress dose in the shoulders during maneuvering in the old and the new wheeled loader cab. Stress dose = Area, microvolt seconds (μVs).

and the left lumbar region of the back was noted in one maneuver.

In the machine with the new cab, the left shoulder covaried with the left lumbar region of the back in 10 of the 12 maneuvers. There was covariation between the left and right shoulders in one maneuver.

One important conclusion that can be drawn from the analysis is that covariation between the left shoulder muscles (steering-wheel arm) and the musculature of the lumbar region occurs in the new cab. This is a consequence of the steering-wheel setting chosen in the new cab.

Discussion

The first goal of the project was to quickly obtain analytical results for a discussion with the designers. The discussion turned out to be very important because the preliminary analysis of the results indicated an increased muscular stress in the left shoulder (steering-wheel arm) during operation of the machine with the new cab. Apart from this discussion, it was possible to confirm that one had succeeded otherwise in designing a cab that substantially decreases the ergonomic stress on the driver, compared to the old cab.

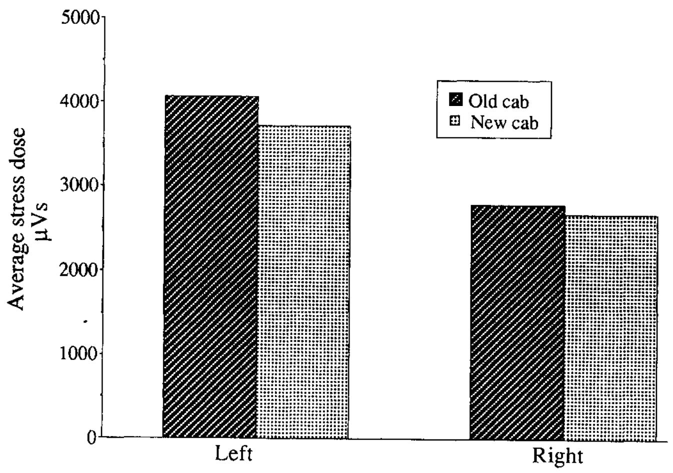

FIGURE 6. Average stress dose for all operating maneuvers in the left and the right muscles of the shoulder during operations in the old and the new wheeled loader cab.

Visibility Improvement Beneficial

The increased visibility in the new cab has been the one factor that has meant the most for the decrease in muscular stress. It is primarily the musculature of the lumbar region that has benefited from a large relative decrease in stress compared to the working conditions in the old cab; the decrease in the stress dose is as large as 33 percent and 13 percent, respectively, in the left and right lumbar region. The stress dose for the right lumbar region probably would have been even lower if the stress in the left shoulder had been lower, as a consequence of the covariation of muscle activity between the left shoulder and the right lumbar region.

The increased visibility in the new cab has enabled the operator to utilize, to a greater extent than in the old cab, the supporting surfaces and backrest of the driver's seat, with reduced muscular stress as a consequence. The operator does not have to lean forward and sideway and twist his body to the same extent as before. He has a better overview of the operating area of the loader from his position in the new cab.

Steering System Results in a Faster Machine

Operation of the loader, especially in connection with full-capacity loading of materials, is characterized by very intensive steering-wheel work. Many working cycles comprise a large number of jointly activated maneuvering movements. For instance, it may be a matter of keeping the vehicle in motion, maneuvering the loading apparatus, selecting gears and, not least important, steering the loader.

In many cases, the steering of the loader may be the maneuver that governs the amount of time in the working cycle. This is demonstrated, for instance, by the use of Comfort Drive Control (CDC), which gives shorter cycle times. A very important alteration in the new cab is the new steering system's low maneuvering force, in combination with a smaller number of steering-wheel revolutions. This makes it possible to maneuver the

TABLE 5. Analysis of Operating Patterns

Activity	Old cab	r	New cab	r
1 Chips	L-shoulder, R-shoulder	0.84	L-shoulder, L-back	0.75
	L-back, R-back	0.92	L-shoulder, R-back	0.66
			L-back, R-back	0.97
2 Timber	L-shoulder, R-shoulder	0.84	L-shoulder, L-back	0.80
	L-back, R-back	0.86	L-shoulder, R-back	0.67
			L-shoulder, R-back	0.87
3 Pallet fork	L-shoulder, R-shoulder	0.70	L-shoulder, L-back	0.64
	L-back, R-back	0.90	L-back, R-back	0.95
4 Precision hoist	L-shoulder, R-shoulder	0.61	L-back, R-back	0.87
	L-back, R-back			
5 Loading-norm	L-shoulder, R-shoulder	0.63	L-shoulder, L-back	0.59
	L-back, R-back	0.89	L-back, R-back	0.81
6 BSS*	L-back, R-back	0.88	L-back, R-back	0.90
7 Loading-norm	L-shoulder, R-shoulder	0.63	L-shoulder, L-back	0.67
	L-back, R-back	0.87	L-back, R-back	0.85
8 Turning	L-back, R-back	0.95	L-shoulder, L-back	0.83
			L-shoulder, R-back	0.73
			L-back, R-back	0.90
9 Loading-piece-work speed	L-back, R-back	0.65	L-shoulder, L-back	0.72
			L-shoulder, R-back	0.64
			L-back, R-back	0.94
10 Without BSS*	L-back, R-back	0.73	L-shoulder, L-back	0.73
			L-shoulder, R-back	0.69
11 Loading-piece-work speed	L-shoulder, R-shoulder	0.59	L-shoulder, L-back	0.79
	L-back, R-back	0.95	L-shoulder, R-back	0.59
			L-back, R-back	0.85
12 Obstacles	L-shoulder, R-shoulder	0.70	L-shoulder, L-back	0.79
	L-shoulder, L-back	0.74	L-back, R-back	0.86
	L-back, R-back	0.83		

*BSS = Boom Suspension System.
Analysis of operating patterns, expressed as the degree of correlation (r) between the different muscles in the shoulder and back during maneuvering in the old and the new cab.

machine faster and thereby reduce the muscular stress dose. This is a very welcome feature since the steering-wheel work is the heaviest operating maneuver in manual operation. All of the drivers showed their appreciation for the new steering system.

New Steering-Wheel Adjustment Under Investigation

The increase in muscular stress in the left shoulder surprised both the investigators and the designers. Compared with the old cab, the increase was 13 percent. The stress dose, which is affected by the new, faster steering system, showed a decrease of 9 percent, however.

This effect was surprising because the choice of possible adjustments was considered to have been improved in the new cab, a view also shared by the drivers who appreciated being able to tilt, raise, and lower the steering wheel. After modification of the sitting position and the setting of the steering wheel by several of the drivers in the project and studies of photographs and videos, it was ascertained that the position of the steering wheel in relation to the posture of the driver gives rise to an unfavorable position during the operating maneuvers. The left arm and shoulder had to be elevated when working the steering wheel in the new cab and they ended up a little farther away from the body. The reason for the unfavorable position of the steering wheel was that the tilt was greater than in the old cab (Figure 7). The new steering-wheel setting (Figure 8) was natural if the driver was not driving, but not while driving because the steering column could not be adjusted.

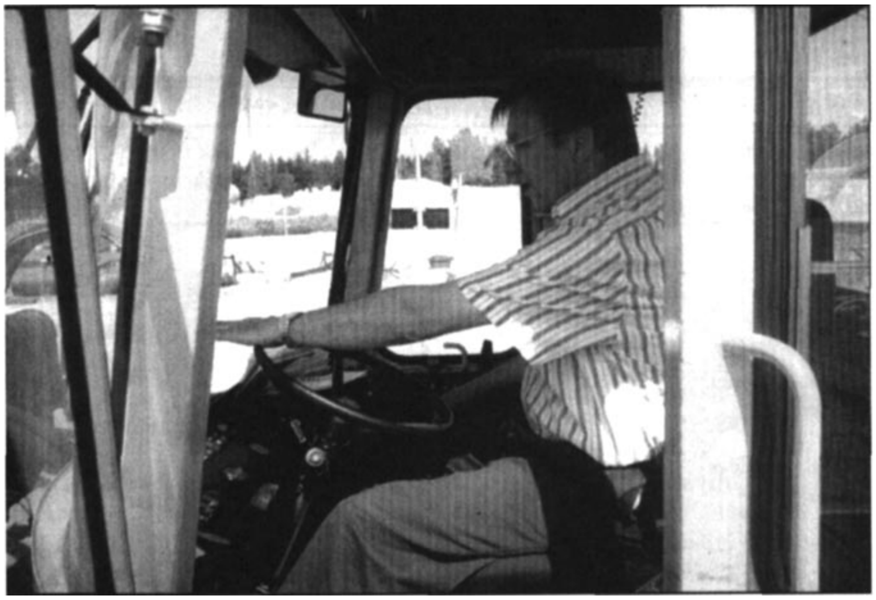

FIGURE 7. Steering wheel setting in the old cab.

The raised level of muscular stress in the steering-wheel arm is important, especially considering that the steering-wheel work constitutes the heavier maneuvering work. The increase in stress is relatively low, but it can become significant in the long run.

The highly sensitive EMG method was able to differentiate variations in muscle activities in the intended manner in the project. In this respect, the objective measuring method was superior to the subjective impressions of the drivers during the tests.

Dialogue with the designers about the steering system gave them additional basic data to find the final solution to the system's adjustment possibilities. One measure that is being discussed is adjusting the steering column to bring the steering wheel closer to the body, thereby reducing the elevation of the shoulder joint and thus making better use of the fine tilting properties. There are also plans to work out instructions describing the possible ways of adjusting the new steering system.

FIGURE 8. The steering-wheel setting in the new cab shows that the driver lifts his arm and shoulder a little higher and also loses a little contact with the backrest of the seat.

Steering-Wheel Arm Stressed the Most

The study clearly shows that the steering-wheel work is much more physically stressful than operating the loader control levers. The evaluation for the old cab shows a 44 percent higher relative level of stress in the left shoulder than in the right shoulder. From an ergonomic point of view, one should strive for a balance in the stress between different comparable muscle groups. One way to achieve this is to alter the steering system so that less force is required to work the steering wheel.

The new steering system in the Care Cab, requiring less maneuvering force and fewer revolutions of the steering wheel, is a big step in the right direction. The introduction of CDC is also a measure that gives a better balance in muscular work between the right and left shoulders.

Conclusions

The *level of stress*, expressed as RC%, has been considerably reduced in the paravertebral musculature of both the right and left side in the new cab, as a consequence of ergonomic improvements. The *stress dose* in the lumbar region, expressed as μVs, has also been considerably reduced in the paravertebral musculature of both the right and left side in the new cab, partly as a consequence of the reduced level of stress, but also because of the shorter operating time.

The *level of stress* in the left shoulder (steering-wheel arm) has increased in the new cab as a consequence of the setting of the steering wheel during the tests. The results of the study have provided a good basis for further development work to reduce the level of muscular stress in the left shoulder as well. The *level of stress* in the right shoulder remains essentially unchanged in a comparison between the old cab and the new one.

The *stress dose* in both the left and right shoulder is lower, however, in the new cab, which is a consequence of the shorter operating time.

An analysis of the operating pattern in the new loader cab shows that the activity in the musculature of the lumbar region of the back covaries with the muscle activity in the left shoulder, as a consequence of the chosen position of the steering wheel.

The visibility in the new cab has been

substantially increased compared to the old one. This is judged to be the single most important factor for the improved ergonomics of the new cab. Work in the Care Cab is substantially easier than in the old cab, which is chiefly reflected in reduced muscular stress in the lumbar region.

The low operating force required by the new steering system, in combination with a smaller number of steering-wheel revolutions, makes the loader faster and this results in a lower stress dose.

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