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Abstract

Objective: The objective of this research is to determine the best location to place a conventional mobile computer supported by a commercially available mount in a light truck cab.

Background: U.S. and Canadian electric utility companies are in the process of integrating mobile computers into their fleet vehicle cabs. There are no publications on the effect of mobile computer location in a vehicle cab on biomechanical loading, performance, and subjective assessment.

Method: The authors tested four locations of mobile computers in a light truck cab in a laboratory study to determine how location affected muscle activity of the lower back and shoulders; joint angles of the shoulders, elbows, and wrist; user performance; and subjective assessment. A total of 22 participants were tested in this study.

Results: Placing the mobile computer closer to the steering wheel reduced low back and shoulder muscle activity. Joint angles of the shoulders, elbows, and wrists were also closer to neutral angle. Biomechanical modeling revealed substantially less spinal compression and trunk muscle force. In general, there were no practical differences in performance between the locations. Subjective assessment indicated that users preferred the mobile computer to be as close as possible to the steering wheel.

Conclusion: Locating the mobile computer close to the steering wheel reduces risk of injuries, such as low back pain and shoulder tendonitis.

Application: Results from the study can guide electric utility companies in the installation of mobile computers into vehicle cabs. Results may also be generalized to other industries that use trucklike vehicles, such as construction.

Keywords

biomechanics, spine and low back, upper extremities, vehicle, utility fleet vehicles, mobile computers, MDT (mobile display terminal)

Introduction

Because of widespread advances in mobile information technology and miniaturization of personal computer technology, many people who are required to travel for their job have the ability to work while they are in their vehicles. These mobile workers are growing rapidly, and an International Data Corporation report predicts that 75% of the U.S. work force will be mobile workers in 2013 (Ryan, 2009).

There is a wide variety of mobile devices being used in vehicles, including cell phones, GPS units, manufacturer integrated computers, and mobile computers. However, the device that makes the vehicle most like an office is the mobile computer. Electric utility companies across North America are in the process of upgrading their field vehicles with mobile computers to make their workers more productive. This research is limited to the location of a laptop computer or mobile display terminal (MDT) supported by a commercially available mount in a light truck cab. This study does not address hardware or software inputs other than keyboard, track pad, and touch screen.

Mobile computers allow the workers to communicate digitally with the service center and work coordinators and stay in the field between jobs, consequently increasing productivity. As utilities install portable computers into vehicles, they do not have guidance for the best location to place a conventional mobile computer in the vehicle. Many fleet vehicles were not designed to incorporate a mobile computer and did not provide dedicated space for this item. Therefore, the mobile computer is often located where there is adequate space, regardless of how the location affects the driver's computer performance, exposure to risks for musculoskeletal disorders (MSDs), and ability to safely drive the vehicle.

Utility workers have complained of discomfort from using mobile computers in vehicles. This discomfort could be attributable to the fact that the body postures required of the driver were not taken into consideration in the location of the mobile computers. Anecdotal observations of drivers' postures while using a mobile computer in the cab indicate the following postural risk factors:

- Severe rotation of the trunk and shoulders with respect to the seat.
- Extended upper extremity reaching, particularly for shorter workers.

Literature Review

Physical Ergonomics Issues

To date, no research has been published that assesses the risk of MSDs based on location of mobile computers in the vehicle cab. However, a three-part study consisting of a case study, interview survey, and diaries was published that provides some insight into the etiology of injuries from using mobile computers in vehicles (Eost & Galer Flyte, 1998). Their recommendations include safety features that disable the device when the vehicle is in motion, easy setup and takedown, ease of use from the driver's seat, and adjustability for a good working posture.

Research Voids and Objectives

There are no publications based on laboratory or field studies regarding the physical ergonomics issues of mobile computers, namely, how the location affects joint angles of the upper extremities and shoulders and muscle activity of the major shoulder and trunk muscles. The objective of this research study was to find the best location for a conventional mobile computer in a light truck cab to maximize computer performance and safety while minimizing risk of MSDs to the driver. The authors hypothesized that the best location for the mobile computer is to place the computer as close as possible to the steering wheel. This location should minimize trunk twisting and long reaches with the upper extremities.

Method

General Approach

We assessed four common mobile computer locations in this study to determine which one of the four was the best location on the basis of biomechanical and task performance data. Muscle activity of major trunk and shoulder muscles and wrist, elbow, and shoulder joint angles were measured on the participants while they performed typical tasks on the mobile computer in a light truck cab. In addition, task time and number of mistakes were measured.

Equipment

A cab from a 2002 Chevrolet Silverado pick-up truck was used for participants to test the mobile computer (Figure 1). A hole was cut into the top of the cab so that a camera mounted above the cab was able to record shoulder posture of the participant. A Panasonic Toughbook CF-29 laptop PC was selected for this experiment for three of the four locations in the cab because it is commonly used by electric utilities. The keyboard is 30.5 cm wide, 25.4 cm long, and 4.4 cm thick; and the display is 30.5 cm wide, 24.1 cm tall, and 33 cm on the diagonal. A Gamber Johnson laptop mount attached to the passenger seat base was used to place the mobile computer in three of the four locations. The mount has two articulating arms, adjustable clevis, and docking station (Figure 2). A Hub Data911 mobile computer (Model M6, Alameda, CA) was used for the remaining location. The dimensions of the keyboard are 30.5 cm wide, 19 cm long, and 3.2 cm thick; the display dimensions are 28 cm wide and 24.1 cm tall with a 30.5 cm diagonal viewing area.

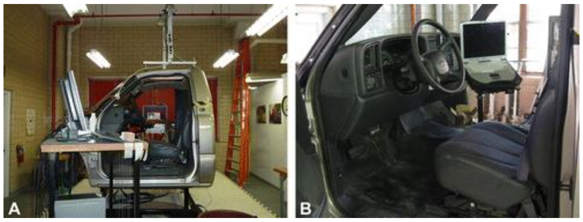

Figure 1. 2002 Chevrolet Silverado 1500 truck cab with laptop computer.

Figure 2. Laptop mount components and Hub Data911 M6 mounted in test cab.

Independent and Dependent Variables

There were two independent variables: mobile computer location, with four levels (Figure 3), and task type, with two levels (keyboard and touch screen), in this experiment. The four mobile computer locations were selected on the basis of conventional computer mounts available for light trucks. As such, these locations were limited by the functionality of the computer mounts and the size of the mobile computer. The locations that were selected represent the range of possible mobile computer locations in a light truck cab.

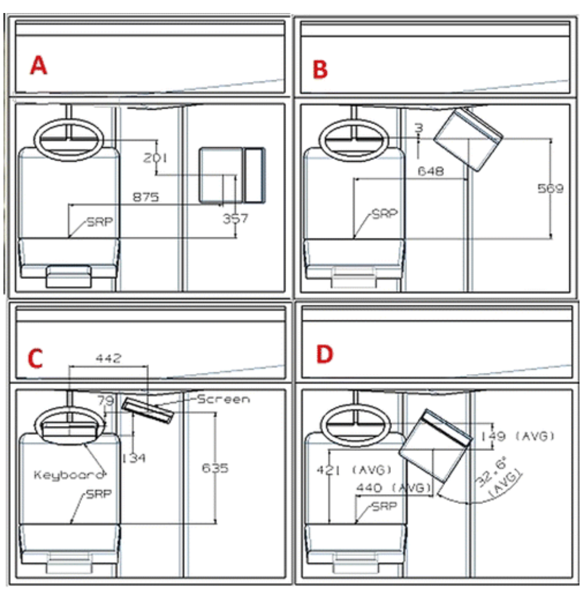

Figure 3. Four mobile computer locations. Dimensions are in millimeters.

In Location A, a laptop PC is placed over the passenger seat and does not allow for any rotation or tilt of the laptop's base. This configuration simulates a passenger seat–mounted desk. The height of the *G* key on the laptop PC was 33 cm above the seat reference point (SRP) and 61 cm above the cab floor.

Location B consists of a laptop PC mounted over a post located between the instrument panel and passenger seat. Location B is typical of a first-generation commercial design for mounting a laptop in a truck cab. In this location, the driver was able to adjust the vertical tilt angle of the laptop PC's base and display and rotate the laptop's base around the post. The height of the *G* key on the laptop was 61 cm above the cab floor and 33 cm above the SRP.

Location C is a location that is commonly used in police and emergency vehicles (Figure 4). The Hub Data911 keyboard and display are separated, with the display mounted on the instrument panel and to the right of the steering wheel; the keyboard can be used anywhere in the cab. The keyboard sat on the surface of the steering wheel on a wire stand, which was hooked around the top of the steering wheel. In this location, the driver was able to adjust the tilt angle of the steering wheel to select the tilt angle for the keyboard.

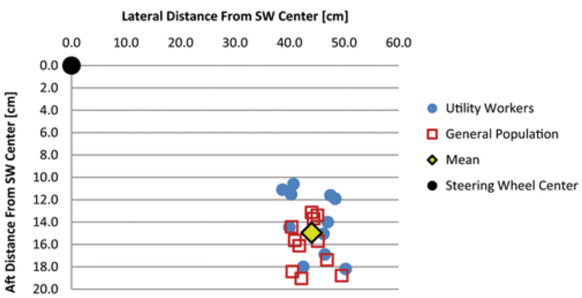

Figure 4. Scatter plot of Location D of laptop computer selected by participants and experimenter. The reference point is the middle of the computer keyboard (between *G* and *H* keys).

In Location D, a laptop PC is placed closely to the right of the driver. In this location, the driver, along with help from the investigator, chose the location of the laptop base on the basis of what appeared to be the most comfortable location for the laptop PC. Then the driver adjusted the tilt angle and rotation of the laptop base and then the tilt angle of the display. Some of the criteria that the investigator and driver used to select the location of the laptop base were the following:

- The steering wheel and seat back were not impeding movement of the driver's left hand or right arm.
- The radial-ulnar angle of both wrists appeared close to neutral.
- The computer was in a comfortable reach zone (neither too close nor too distant).

A scatter plot of Location D selected by all the participants is shown in Figure 4 to reveal the central tendency and dispersion of the center of the keyboard in Location D.

There were three types of dependent variables categorized according to biomechanics, task performance, and subjective assessment.

Joint angles

The joint angles of the participants' left and right wrists and elbows were recorded with the use of Biometrics (Cwmfelinfach, Gwent, UK) goniometers. The goniometers recorded the extension-flexion angle and radial-ulnar angle of both wrists and extension-flexion angle of both elbows. Goniometer data were collected at 200 Hz.

A digital camera mounted above the roof of the light truck cab recorded images of the participant's trunk posture. Markers were placed on the right and left acromions of the participant, as shown in Figure 5. Post hoc analysis used the recordings to measure the shoulder angle with respect to the seat back. *Shoulder angle* refers to the angle of a line drawn through the left and right acromion of the participant relative to a line drawn parallel to the backrest of the seat (Figure 5). This angle is not a measure of trunk twist, as the participants were allowed to rotate their hips away from the back of the seat.

Figure 5. Markers located on the participant's acromions. Lines were added post hoc in the photo to indicate the angle of shoulders to seat back.

Electromyography (EMG)

Electrical activity of four muscles was measured on each side of the body—pectoralis major, middle deltoid, upper trapezius, and erector spinae—with Biometrics surface EMG sensors. Location of the electrodes was determined according to recommendations from Delagi, Iazzetti, Perotto, and Morrison (2005) for the middle deltoid and pectoralis major; Leis and Trapani (2000) for the location of the upper trapezius; and Basmajian (1982) for the erector spinae. All of the data from the EMG sensors were collected at a sampling rate of 1000 Hz and an excitation output voltage of 4,500 mV.

Performance

Performance was measured on two of the tasks (a simple keyboard task and touch screen task) the participants were required to complete in each of the computer locations. For the touching task and keying task, the total time the participants needed to complete the task and the number of mistakes were measured.

Subjective assessment

The participants were required to complete a six-question subjective assessment questionnaire after completing the tasks in each computer location. The questionnaire involved a 7-point ordinal Likert-type scale to measure the ease of use, comfort, and productivity for each task and whether the participant liked or disliked the location. After tasks in all of the locations were completed, the participant was asked to provide an ordinal rank of the locations (from best to worst).

Control Conditions

The experimental protocol was designed to minimize or eliminate the effects of confounding variables on the results and generalizations made from the data.

Before the EMG sensors and goniometers were attached, each participant practiced using the laptop PC and the Data 911 for the touch screen and keyboard entry tasks until he or she was comfortable using the mobile computers. Also, the seat was adjusted by the participant to a comfortable driving position.

Because of the fact that the touch screen tasks require only one hand, all of the participants were allowed to use only their right hand for the touch screen tasks and were instructed to leave their left hand on the base of the computer.

The presentation order of the locations to each participant was counterbalanced to eliminate carryover and crossover effects. For the narrated tasks, a different script was used for each location, but all of the scripts required the participant to enter roughly the same amount of data or travel the same distance with his or her fingers on the display. The script order was also counterbalanced against the location order.

Participants

Eligibility criteria

This study tested 22 participants in all four mobile computer locations. All of the participants were physically able to operate a vehicle, were able to operate a laptop computer with some experience, and had no musculoskeletal disorders. The average age (±*SD*) in years of the participants was 34 (±12) with a range of 20 to 58 years. Of the total, 11 (50%) of the participants were male electric utility fieldworkers, eight linemen and three troubleshooters. The average number of years spent in their occupation was 16 years (±9 years). The average reported number of hours spent using a computer in a truck per day was 1 hr 15 min (±1 hr). For the other 11 nonutility participants, 4 were male and 7 were female. The average time spent on a computer (not in a vehicle) was 5.6 hr (±2.8) per day.

Software Tasks

The tasks the participants had to complete in each of the four mobile computer locations consisted of a work order form, square touching task, letter keying task, and map search, in that order. For the tasks that require narration, four different but similar scripts were used for testing and an additional script was used for training.

The work order form required the participant to select options from drop-down boxes and type brief statements into text boxes that were read to the participant by the investigator.

The square touching task was used to measure the participants' performance in each location. A 3 × 3 matrix of squares was employed, with only one square visible at a time. When the participant touches the visible square, the next square in the sequence appears, and so on until the participant has touched 36 squares. The participants completed this task using only their right hand on the touch screen. For the letter keying task, a letter appeared on the screen, and after the participant keyed in that letter, the next letter appeared. Each letter in the alphabet appears once in each sequence. The total time and number of mistakes (touching the screen but missing the square or keying the wrong letter) to complete this task were measured.

The map search was completed with the use of Google Maps. Following the directions of the investigator, the participant zoomed into a city until a landmark, such as an airport or forest preserve, could be located and named to the investigator. Then the participant was asked to follow a major highway to another location and to name another specified landmark. The participant was allowed to touch the screen with only his or her right hand while navigating the map.

Data Collection and Conditioning

Data collection periods

There were six data collection periods for each location. The first three periods were during completion of the work order form. The average time for the sum of the three trials was 45.2 s. The next period occurred during the entire squares touching task. The average time of this data collection was 28.2 s. Data were collected during the entire letter keying task. The average time of this data collection was 29.7 s. The last data collection period was during the second half of the map task. The average time of this data collection was 29.8 s. The work order form and keying tasks were classified as keyboard tasks, and the touching and map tasks were classified as touch screen tasks for the analysis.

Data conditioning

The EMG data were normalized to $\%MVC_{EMG}$ (percentage maximum voluntary contraction; National Institute for Occupational Safety and Health [NIOSH], 1992) with the use of Equation (1), where V_{max} is the highest 1-s average of the voltage from the maximal calibration data for each muscle with a 250-ms root mean square (RMS) filter, V_{rest} is the 1-s average of the voltage from the resting data for each muscle with a 250-ms RMS filter, and V_{task} is the voltage of each datum point collected with a 250-ms RMS filter. V_{max} and V_{rest} are constant for each participant.

$$\%\mathrm{MVC}_{\mathrm{EMG}} = \frac{V_{\mathrm{task}} - V_{\mathrm{rest}}}{V_{\mathrm{max}} - V_{\mathrm{rest}}} \quad (1)$$

V_{max} was measured before test conditions while the participant exerted maximal force against a static-strength test fixture. The apparatus was adjusted to position the participant's joints to the muscle length that corresponded to the body posture in the cab.

After the raw EMG signal was converted to $\%MVC_{EMG}$, the mean for each data collection period was calculated. For each location, the weighted average of the mean $\%MVC_{EMG}$ of all the trials was then calculated, resulting in data for two keyboard trials and two touch screen trials. The two keyboard trials and two touch screen trials were then averaged for analysis. Data conditioning for each location yielded two data points: an average mean $\%MVC_{EMG}$ for keyboard and touch screen tasks, respectively.

The wrist and elbow joint angle data from the electromechanical goniometers were automatically converted from voltage to degrees by the Biometrics software. The data conditioning for these data was the same as the data conditioning for $\%MVC_{EMG}$, resulting in two data points for each location: an average mean angle for keyboard and touch screen tasks, respectively.

The shoulder angle for each frame was directly output in degrees by custom-designed LabVIEW software. The same conditioning methods were applied as for the wrist and elbow joint angle data, resulting in two data points for each measure and each location: an average mean angle for keyboard and touch screen, respectively.

Statistical Analysis

Determination of sample size

After 8 participants were tested, their data were conditioned and analyzed and used to perform a power analysis to determine the minimum amount of participants needed to obtain statistical power of at least 80%. The factors used for the power analysis were muscle activity of the left erector spinae and right elbow flexion. On the basis of the power analysis results, 13 participants were needed to ensure statistical power of at least 80% with $\alpha < .05$. To add a factor of safety, 22 participants were tested.

Anova

For the right upper-extremity joint angles and EMG dependent variables, a repeated-measures ANOVA was conducted to determine significant main effects and interaction of location and task. If there was a significant interaction, a post hoc Tukey test with the 28 location-task combinations was performed to determine which of the combinations were significantly different. Task was not included for the left upper-extremity variables (pectoralis major, middle deltoid, upper trapezius, wrist extension-flexion and ulnar-radial deviation, and elbow flexion), as the left hand was not used for the touch screen task. Therefore, only the keyboard data were used in the one-way ANOVA of location. If location was a main effect, a post hoc Tukey test with the six location pairwise comparisons was performed to determine which of the locations were significantly different. For the subjective assessment data, a nonparametric test (Friedman's statistic) was used to determine whether there was a difference in the subjective assessment of each location.

Results

Joint Angles

Shoulder angle

The Location × Task interaction was significant ($p < .0001$; Figure 6). There was a difference between all of the locations for the keyboard task and for the touch screen task. The shoulders generally did not rotate off the seat back for Location C, with a mean of 1.1° (*SD* = 1.3). For Location D, the shoulders were rotated minimally, with an average angle of 16.7° (±7.2). However, the computer locations in front of and on the passenger seat required significant shoulder rotation (means of 39° [±5.9] to 31.7° [±6.8] for Location B and 63.9° [±4.7] to 53.9° [±5.8] for Location A).

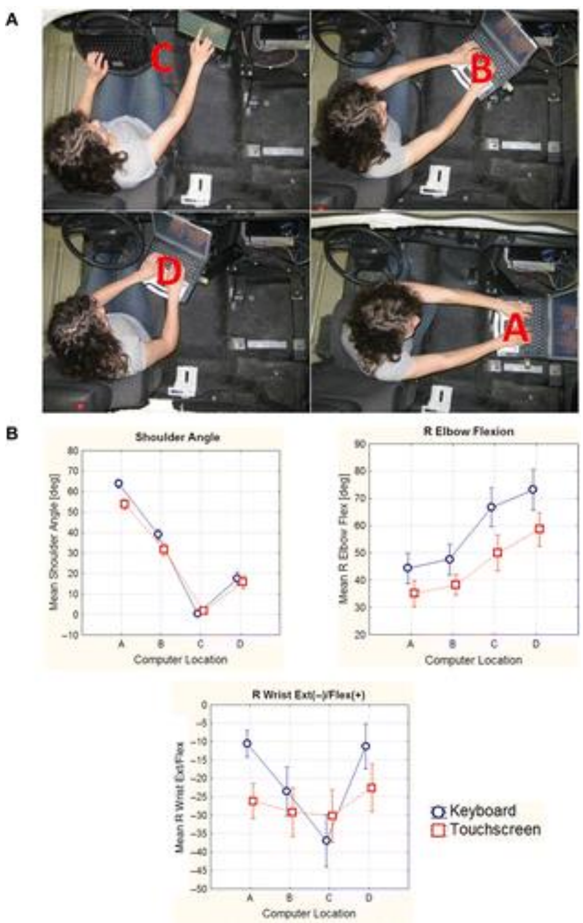

Figure 6. Mean angle of shoulders, right elbow, and right wrist angle for each computer location and task (*N* = 22). Photo shows the letter designation of each computer location.

Right elbow angle

The Location × Task interaction was significant ($p < .0001$; Figure 6). There was a difference between tasks in all of the locations. For both tasks, there was not a difference between Locations A and B, but the rest of the locations were different. Computer locations in front of and on the passenger seat (A and B) required participants to hold their right arm almost horizontally at shoulder level, whereas the locations near the driver seat (C and D) allowed the participants to hold their right elbow lower and closer to the trunk. The mean right elbow angles for Locations A and B were 36.9° (±8.4) and 46.2° (±8.7), and 40.1° (±7.0) and 49.4° (±8.4), for touch screen and keyboard tasks, respectively, and were 51.8° (±11.4) and 68.5° (±12.0), and 60.5° (±10.0) and 75.0° (±12.2), for touch screen and keyboard tasks in Locations C and D, respectively.

Right wrist extension angle

The Location × Task interaction was significant ($p < .0001$) for right wrist extension-flexion (Figure 6). There was a difference between tasks in all of the locations. The mean extension angle of the right wrist was approximately the same for Locations A (touch screen, 26.1° [±10.7]; keyboard, 10.5° [±8.2]) and D (touch screen, 22.6° [±14.6]; keyboard, 11.3° [±13.7]). Mean right wrist extension angle for Location C was greater for keyboard task compared with other locations because the keyboard was mounted on the steering wheel for Location C, whereas the keyboard was placed horizontally for the three other computer locations.

Emg

Left erector spinae

The Location × Task interaction was significant for the left erector spinae ($p < .0114$; Figure 7). The keyboard and touch screen tasks in Location A were not different, but the tasks were different in the rest of the locations. For the touch screen task, all of the locations were different except C and D. The keyboard task was different between all of the locations except C and D. Computer locations in front of and on the passenger seat (A and B) required users to exert more than twice the muscular force in the left erector spinae than in locations near the driver (C and D). Location A required the most muscular force, expressed as $\%MVC_{EMG}$, with a mean of 24 $\%MVC_{EMG}$ (±12). Computer Locations C and D had means of 5 $\%MVC_{EMG}$ (±6) and 8 $\%MVC_{EMG}$ (±7) for the keyboard task, respectively.

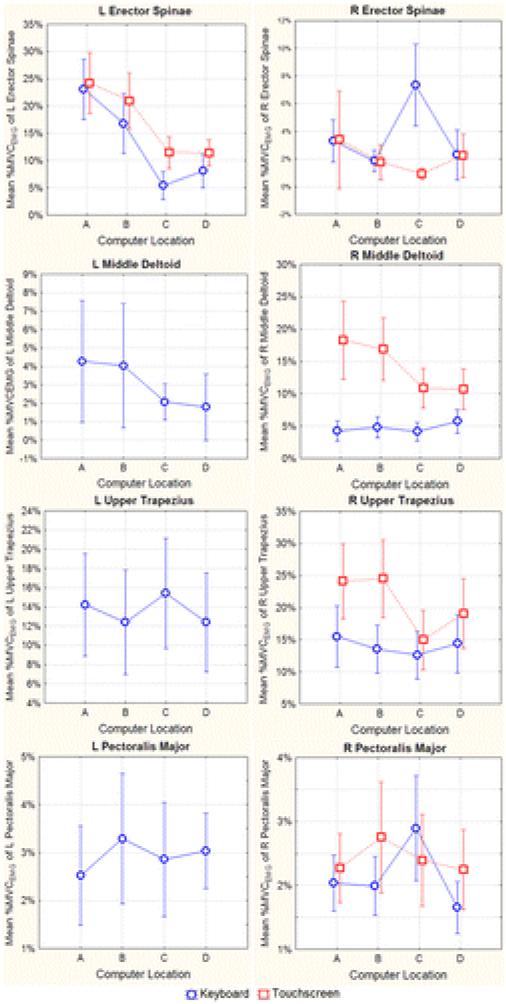

Figure 7. Mean %MVC_{EMG} muscle activity of right and left erector spinae, middle deltoid, upper trapezius, and pectoralis major for the computer locations and tasks (*N* = 22).

Right erector spinae

The Location × Task interaction was significant ($p < .0001$; Figure 7). The keyboard task in Location C was significantly different from the rest of the location-task combinations with a mean of 7 %MVC_{EMG} (±7). All of the other location-task combinations were not different and had means less than 4 %MVC_{EMG}.

Left middle deltoid

Location was a main effect ($p = .0098$; Figure 7). Locations A and D were found to be different. All of the locations had a mean less than 5 %MVC_{EMG}.

Right middle deltoid

The Location × Task interaction was significant ($p < .0001$), as shown in Figure 7. The touch screen task was significantly different from the keyboard task in each location. For the touch screen task, Locations A and B had significantly higher means than Locations C and D. The keyboard task was not different between any of the locations. Locations A and B required means of 18 %MVC_{EMG} (±14) and 16 %MVC_{EMG} (±11) for the touch screen tasks, much greater than the mean of 11 %MVC_{EMG} (±7) required by both C and D. The keyboard task had an overall mean of 14 %MVC_{EMG} (±10).

Left upper trapezius

Location was not a main effect ($p = .4387$). All of the locations had an overall mean of 14 %MVC$_{EMG}$ (±12) (Figure 7).

Right upper trapezius

The Location × Task interaction was significant for the right upper trapezius ($p < .0001$; Figure 7). There was a difference between tasks for all of the locations except C. For the touch screen task, Locations C and D were different and were both different from A and B. There was not a difference between any of the locations for the keyboard task. The pattern of right upper trapezius muscle activity was similar to that of the right middle deltoid. The touch screen tasks required approximately 25 %MVC$_{EMG}$ (±13) for Locations A and B, and 15 %MVC$_{EMG}$ (±10) and 19 %MVC$_{EMG}$ (±12) for Locations C and D. The keyboard task had an overall average of 14 %MVC$_{EMG}$ (±9).

Left pectoralis major

Location was not a main effect ($p = .4198$). All of the locations had means less than 4 %MVC$_{EMG}$ (Figure 7).

Right pectoralis major

The Location × Task interaction was significant ($p < .0001$) as shown in Figure 7. All of the means were less than 3 %MVC$_{EMG}$.

Biomechanical Model

The University of Michigan 3D SSPP software (Version 6.0.4) was used to model a 50th percentile female and 50th and 95th percentile male in the posture required to use the mobile computer in each location. The postures used in the model were based on the hand locations required to use the computer in each location and the video recordings from the study. The model was then used to determine L4/L5 disk compression and muscle force required to extend the torso. As shown in Table 1, Computer Locations A and B resulted in the following:

- Much higher compression on the L4/L5 spine (more than 500 lbs compression for A and B compared with less than 300 lbs for C and D for 50th percentile male and female)
- More than twice as much force of the muscles to extend the torso (for 50th percentile, more than 20 %MVC for A and B to less than 10 %MVC for C and D)

Table 1 Results of Spinal Compression and Torso Extension Muscle Forces From University of Michigan 3D SSPP Modeling

	Location A	Location B	Location C	Location D
50th L4/L5 compression (lbs)	683	614	232	298
percentile Torso extension 5th strength percentile	53	45	11	18
male (%MVC) 25th strength percentile	33	28	7	11
50th strength percentile	26	22	5	9
50th L4/L5 compression (lbs)	434	538	291	244
percentile Torso extension 5th strength percentile	59	61	35	28
female (%MVC) 25th strength percentile	33	34	20	16
50th strength percentile	25	26	15	12
95th L4/L5 compression (lbs)	766	850	437	487
percentile Torso extension 5th strength percentile	63	64	28	34
male (%MVC) 25th strength percentile	39	39	17	21

50th strength percentile	31	31	14	16

Note. %MVC = percentage maximum voluntary contraction.

Task Performance

The only significant effect for performance was location (p = .038) for time to complete the touch screen task, but the difference was not of practical significance. Time for the keyboard task and accuracy for both tasks was not significant across all four computer locations. Mean time to complete the touch screen task averaged 28.1 s (±2.8) with 0.3 (±0.7) misses; mean time to complete the keyboard task was 29.3 s (±7) with 0.2 (±0.5) misses.

Subjective Assessment

Participants rated the locations from best to worst in the order D, C, B, and A for all measures of subjective assessment: comfort, ease of use, like and dislike, and productivity. Location was a main effect for all of the subjective assessment questions with the use of Friedman's nonparametric analysis (p < .0001). Location D was rated highest of all locations for all subjective assessment measures, and Location C was a close second.

Similar to results of subjective assessment, the preference order of best-to-worst ranking of locations was D, C, B, and then A (p < .0001). Location D had a median rank of 3.5, and Location A was rated the least preferred, with a median rank of 1.0 (ranking ranged from a 1.0 to 4.0).

Discussion

General

Utilities and other organizations, such as police and fire departments, that require mobile mounted computers in their vehicles have had, until now, little if no guidance for their installation in vehicles. They have relied on a limited number of vendors to select hardware and software and install the mobile system.

The present study was designed to provide utilities with recommendations on where to locate a conventional mobile PC supported by a commercially available mount in a light truck cab based on ergonomics principles and biomechanical data. The four selected locations were limited by the functionality of the computer mounts and the size of the mobile computer. The four locations are representative of the range of feasible locations provided by the hardware and are also the common locations selected by users.

Of the four locations tested, two are recommended (C and D), which are located close to the driver's trunk. In these locations, workers' performance using the mobile computer is the same as in the other locations tested, and participants overwhelmingly rated the two recommended locations higher in terms of ease of use, productivity, and preference. Additionally, EMG activity of a low back muscle was much lower in Locations C and D than in the locations on the passenger side for both keyboard and touch screen tasks, and right shoulder EMG activity was lower for the keyboard tasks. Utilities now have quantitative biomechanical and user preference data to locate a conventional mobile computer in a vehicle cab that is similar to a pickup truck. Although vehicle cabs vary in a utility's fleet, the general locations recommended in this report should apply to most vehicles in a fleet department.

There may be other recommended locations of a mobile computer in the vehicle cab other than those recommended in this study (C and D). However, these locations will require more compact computer hardware, more versatile mounts, or other input methods, such as speech recognition. These possibilities were outside of the scope of this study and can be explored in future research.

Biomechanical Issues and Risk of MSDs

Biomechanical model

Results of 3D SSPP modeling show that when a person operated the computer in Locations A and B (passenger side), compression on the L4/L5 spine was near or exceeded the NIOSH threshold for spinal compression (770 lbs). For locations on the driver's side (C and D), L4/L5 compression was at least 200 lbs less than at A and B. Force of the torso extension muscles was at least twice as great and more than 20 %MVC for Locations A and B. These results demonstrate that Locations A and B result in much higher loading on the spinal musculoskeletal system than Locations C and D and would increase the risk of a low back injury if a worker were to use the mobile computer for an extended period of time in the cab.

Muscle force and endurance time

EMG activity of three primary muscles (left erector spinae, right deltoid, and right trapezius) required to support the trunk and upper extremities in the computer locations showed that locations on the driver's side (C and D) reduced $\%MVC_{EMG}$ substantially compared with locations near the passenger seat (A and B). The difference in $\%MVC_{EMG}$ was approximately 15 %MVC for the erector spinae for both the keyboard and touch screen tasks and 5 %MVC to 8 %MVC for the right trapezius and deltoid for only the touch screen tasks (Figure 7). Because the muscles monitored by EMG were static during the computer tasks, then one can assume that $\%MVC_{EMG}$ is indicative of relative muscle force. Research has shown that endurance time to perform a static contraction at a specified relative force decreases exponentially as muscle force increases (Bjorksten & Jonsson, 1977; Jonsson, 1988). Hagberg (1981) showed a rapid decrease of endurance time for sustained isometric exertions at contraction levels above 15 %MVC to 20 %MVC force for upper-extremity muscles.

For the touch screen tasks, the substantial decrease in $\%MVC_{EMG}$ for the right middle deltoid and upper trapezius for the locations near the steering wheel indicate that a worker would be able to use the laptop computer for a longer period than if the computer were located on the passenger side. On the contrary, this effect was not noticed for the keyboard tasks, probably because the participants supported some of the weight of the upper extremities on the keyboard with their wrists. The time that a worker would be able to sustain the trunk posture without pain required by computer locations near the steering wheel would also be longer because of the substantial decrease in erector spinae EMG activity. However, the time that a worker would be able to operate the mobile computer in the recommended locations is not unlimited, as Sjogaard, Kiens, Jorgensen, and Saltin (1986) reported that muscular fatigue can occur at a level as low as 5 $\%MVC_{EMG}$ after 1 hr of static contraction.

Shoulder tendonitis

According to video analysis, participants elevated their arms (shoulder abduction) approximately 90° to use the mobile computer located near the passenger seat (A and B). This level of arm elevation (shoulder abduction and forward flexion) increases the risk of shoulder tendinitis (Ohlsson et al., 1995). Bjelle, Hagberg, and Michealson (1981) found that workers in occupations that required them to elevate the arms (abduction in the frontal plane and flexion in the sagittal plane) had a much higher risk of shoulder tendinitis than did the control group.

Low back pain

Most of the participants reported that they did not like the mobile computer locations near the passenger seat, as it required twisting the trunk. On the basis of trunk anatomy and subjective discomfort responses, the mobile computer locations near the driver's seat (C and D) are recommended because the computer can be operated with minimal or no trunk twisting.

Locations A and B required approximately 60° of trunk twist at the shoulder level, whereas the recommended locations (C and D) required 10°. Although measurement of 60° of torso twist at the shoulder level does not mean that the trunk is twisted 60° at the lower back level (because of the varying capability of the vertebral structures to enable trunk twisting at different levels of the trunk), the trunk at the lower back level was twisted substantially for users to reach the mobile computer in the locations near the passenger seat. For the recommended mobile computer locations, the trunk at the lower back level was near neutral posture. From an anatomy point of view, twisting the vertebral joints with respect to each other indicates the possibility of injury to the intervertebral discs. Shirazi-Adl, Shrivastavi, and Ahmed (1984) showed from an anatomical perspective how twisting the discs can degenerate the annulus rings of the disc and increase the risk of a herniated disc.

Air Bag Issues

It is important that in-vehicle technology be outside the air bag deployment zone when the vehicle is moving. The force of the air bag when deploying could propel a notebook computer or other in-vehicle technology into the driver or passenger. Not only could the occupants sustain injuries from in-vehicle technology, but the airbag may not fully protect them from impact with other parts of the vehicle. Therefore, utilities need to obtain specific 3-D dimensions of the air bag deployment zone for the vehicles that will have in-vehicle technologies.

Limitations

The mobile computer locations studied are confined to conventional mobile computers. The participants used the touch screen, track pad, and built-in keyboard for input. There are other pointing devices and input controls, such as wireless mice, keyboards, or speech recognition, that may be used to further reduce muscle force and promote more neutral joint postures in the future.

Conclusion

For touch screen and keyboard tasks, the recommended locations, Location D (center of keyboard 15 cm front of steering wheel reference point (SWRP) and 44 cm to right of SWRP) and Location C (center of screen 8 cm behind the SWRP and 44 cm to right of SWRP), significantly reduced lower back muscle activity and angle of the shoulders to the seat compared with the locations near the passenger seat. Force in the right shoulder muscles was also decreased in the recommended locations for the touch screen tasks.

A mount for the mobile computer should provide enough adjustability so that the mobile computer can be placed in the recommended locations. In addition, the mount should allow the driver to move it with a light hand touch.

Air bag zones must remain clear while the airbags are deployable. If a mobile computer is placed in an air bag zone while being used, then the airbag must not be deployable.

The recommended locations of a mobile computer from this study may be generalized to other types of vehicles.

Key Points

- Mobile computer location has an effect on upper-extremity and lower back muscle force and joint angles.
- Locating the mobile computer on the driver’s side reduces back and shoulder muscle force in general.
- Users prefer the mobile computer to be located on the driver’s side.

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