Optimal Mobile IT Location Based on Ergonomics

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OPTIMAL MOBILE IT CONFIGURATION BASED ON ERGONOMICS

by

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ABSTRACT
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U.S. and Canadian electric utility companies are in the process of integrating mobile computers into their fleet vehicle cabs. The placement of the mobile computer in the vehicle cab could have a significant effect on biomechanical loading, performance, and subjective assessment. The objective of this research is to determine the best location to place a mobile computer in a truck cab.

In this experiment, four locations of mobile computers in a truck cab were selected and tested 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. Along with location, subject size and type of computer task were also considered in the analysis. Twenty-two participants were tested in this study. Placing the mobile computer closer to the steering wheel reduced the low back and shoulder muscle activity required to use the mobile computer. Joint angles of the shoulders, elbows and wrists were also closer to neutral angle. 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. It was also found that using the touchscreen required more muscle force and less neutral joint angles than the keyboard.

Locating the mobile computer close to the steering wheel reduces risk of injuries such as low back pain and shoulder tendonitis. Also, mobile computer users prefer the location to be close to the steering wheel. Results from this 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 truck-like vehicles, such as construction.

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OPTIMAL MOBILE IT CONFIGURATION BASED ON ERGONOMICS

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1 INTRODUCTION

Due to 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 75% of the U.S. work force are predicted to be mobile workers in 2013 by the IDC (Ryan, Jaffe, Drake, & Boggs, 2009). (International Data Corporation is a global provider of market intelligence, advisory services, and events for the information technology, telecommunications, and consumer technology markets.) Although the definition of mobile worker in the IDC report is broad, it shows that there is high demand from employers for workers to be mobile. The decrease in price of mobile IT products and services along with their improved performance has enabled workers to be productive while they are in their vehicles.

There is a wide variety of mobile devices currently being used in vehicles including cell phones, GPS units, manufacturer integrated computers, and laptop PCs. However, the device that makes the vehicle most like an office is the mobile computer, whether it is a computer integrated into the cab by the vehicle manufacturer, a mobile data terminal (MDT) with a simplified touchscreen, or a laptop PC installed in the cab. In this thesis, the term "mobile computer" will be used, to refer to laptop PC or MDT. Laptops are by far the most frequent configuration, and many utilities are reducing the use of MDTs -- which are less versatile – and increasing the use of laptop PCs; however MDTs are still used in fleet vehicles, specifically emergency response vehicles.

There are many suppliers who sell after-market kits to install a laptop PC into a vehicle cab. These kits include simple options such as:

- A single pivot point post attached to the cab floor or -- more frequently -- the passenger seat mounting frame,
- A plastic desk strapped to the passenger seat.
- More costly designs, such as a post with multiple pivot points so a laptop PC can be moved throughout the vehicle cab.

Electric utility companies across North America are in the process of incorporating mobile computers into their field vehicles so workers can perform various tasks such as:

- Send/receive work orders
- Navigate to destinations with the most efficient route
- Track progress of jobs and location of other workers
- Digitally store work manuals and maps of infrastructure.

These mobile computers allow the workers to communicate digitally with the service center and work coordinators and stay in the field between jobs, consequently making the workers more productive. As utilities and other employers of mobile workers install portable computers into vehicles, they often do not have guidance for the optimal location of the mobile computer. 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 safety driving the vehicle.

2 LITERATURE REVIEW

2.1 Background Information and Studies

The in-vehicle technology devices that affect physical ergonomics the most are the computers as they are typically the largest devices and their limited movement in the vehicle requires the driver to change trunk and upper extremity posture. To date, no research has been published that assesses the risk of musculoskeletal disorders (MSDs) such as low back pain and shoulder tendonitis from cumulative trauma or from acute injuries due to accidents from using a mobile computer in a vehicle. However, a 3-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).

The case study consisted of 3 males between 30-49 years of age. The case study was used to collect information about work carried out in the vehicle; the participant -- such as job and available technologies; and the vehicle used for work. The case study served as a precursor for the interviews and diaries. The interview survey had 90 participants (87 males, 3 females, 49% in 35-49, 33% in 25-34, and 18% in 50-69 years age group), all of whom were in a variety of sales jobs. The survey asked questions about the type of office activities carried out in a car such as paperwork and communication. The diary study had 6 males: 3 in the age group 35-49, and one each from the age groups 25-34 years and 50-59 years (one age unknown). Five of the diaries were returned completed and one incomplete. The diaries required the participant to log every task worked on during the day along with times and the precise location in the vehicle that the participant used to complete the work (driver seat, passenger seat, or backseat).

The results of the 3-part study completed by Eost and Galer Flyte (1998) consisted mainly of a compilation of the details of the work carried out in a vehicle and design recommendations. The researchers found that 4 hours per day were spent driving and 30 min. to one hour was spent working in the car. The work was typically split into short sessions. Similar results were found in the diary studies with average times of 4 hours and 27 min. spent driving and 27 min. spent working. Based on the interview, approximately 20 people worked only on paperwork, 18 people made only phone calls, and 52 people did both. Using a computer and even sending faxes from the car were tasks that 16% of the participants reported performing. The majority (95%) of the participants of the interview said they remained in the driver's seat to complete office work and used a clipboard.

The system design recommendations given by Eost and Galer Flyte (1998) were based on the responses of the studies. The main recommendations for future in-vehicle IT include that the devices be lightweight and compact, but also durable because the device will be subject to abuse and will be removed from the vehicle often. The devices also need to have safety features such as disabling the device when the vehicle is in motion. Finally, the system needs to be easy to setup and take-down as it will be used frequently but for short durations.

In a follow-up article by Galer Flyte (2000), more design recommendations for vehicles and in-vehicle IT were presented. The first recommendation was to make computer systems integrated into the vehicle, creating a dedicated workspace. The integrated workspace should accommodate the user's unique size and shape and also provide space for paperwork. The system needs to be securely mounted in the case of an accident, so that the system does not injure the driver. The system also needs to be mounted in a fashion that reduces the risk of theft.

Recommendations regarding the car as an office environment are a flat surface to rest work on, more space for the user to work in, and better storage facilities for all systems and materials for organization. The vehicle needs to provide adequate temperature and lighting control for all environments and ambient light conditions (provide enough light to use the system, but reduce glare). The system needs to be easy to use from the driver's seat because most users will not move to a different location in the car, and be adjustable to allow a good working posture. The vehicle essentially becomes a mobile office; therefore, ergonomic design practices for conventional offices need to be adapted for vehicles.

Although the recommendations provided by Eost and Galer Flyte do not consider biomechanical loading of the mobile IT user, there are many other studies that suggest an increased risk of musculoskeletal disorders due to awkward postures possibly required by the location of mobile computers in a vehicle. The risk of muscle fatigue, shoulder tendonitis, and low back pain have all been shown to be influenced by awkward postures.

According to studies performed by von Rohmert (1960), an isometric muscle contraction at 15% MVC or less has indefinite endurance time theoretically, or a very long endurance time in the practical sense. However when a muscle is exerted over 15% MVC tension, then muscle fatigue develops and reduces endurance time significantly. At 20% MVC, endurance time is reduced to approximately 10 min or less (Rohmert, 1960).

After 10 min of exertion at 20% MVC level, the user will not be able to maintain the same level of tension due to physiological changes in the muscle, and thus the user will need to change posture or take a rest. Muscle fatigue occurs in static contractions due to impaired blood circulation. When blood flow is impeded, metabolic byproducts such as lactic acid accumulates, and the muscle is no longer able to maintain the same level of tension. Severe muscle pain can develop if the user attempts to maintain the same level of tension when a muscle is fatigued. Some of the possible mobile computer locations could require shoulder or trunk muscles to exceed 20 %MVC to use the computer. For these locations the user would only be able to use the computer for 10 min or less before they would need a break.

Elevation (abduction and forward flexion) of the arms increases the risk of shoulder tendinitis. Kuorinka and Forcier (1995) conducted an extensive review of the literature associating shoulder posture and risk of shoulder tendinitis, and they found that occupations that required workers to elevate the arms (abduction in the frontal plane and flexion in the sagittal plane) had a much higher risk of shoulder tendinitis than the control group. A noteworthy study by Bjelle et al. (1981) revealed that assemblers with acute shoulder pain (myofascial syndrome and tendinitis) elevated their arms more frequently and with longer duration during compared to the control group. Kuorinka and Forcier (1995) theorize that elevation (abduction or flexion) as low as 30 deg could reduce blood circulation in the tendons that that elevate the arm, thus increasing the risk of shoulder tendinitis. The location of a mobile computer could require the user to excessively elevate their arms relative to their trunk, thus increasing the risk of shoulder tendonitis.

The epidemiology literature reports that twisting of the trunk while exerting applied axial torque increases the risk of low back pain (LBP) (Marras, 2008). Other studies calculated the odds ratios of risk of LBP with reference to trunk posture were performed in industries on workers moving their trunks dynamically, such as manufacture of concrete elements (Burdorf, Govaert, & Elders, 1991), automotive assembly (Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991), and manual material handling (Marras, et al., 1995). Marras et al. developed a model that predicted risk of LBP based on trunk posture and movement. A static, twisted trunk posture under with no axial external torque, has not been reported as causal in the epidemiology literature, possibly because sedentary jobs that required static, twisted torso posture were not measured in these studies. 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-Asl, Shrivastavi, and Ahmed (1984, 1985) 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. Mobile computer locations that require the user to hold a twisted trunk posture could increase the risk of low back pain.

2.2 Cognitive Ergonomics Issues

In the context of in-vehicle mobile IT, cognitive research is focused on driver distraction, meaning the driver is using the device while driving.

In 2004, *Human Factors* published a special section on driver distraction as it was and still is drawing much attention from human factors researchers. In a preface to this section John Lee and David Strayer introduced some of the current research on potential distractions and methods to understand the safety consequences of the distractions. The research focused on displays and controls for in-vehicle technology and how age affects safety while using these technologies.

Also, in this preface, Lee and Strayer discussed a macro view of the ultimate effect of new technology on driver safety. There is a wide array of interactions that new technology can affect. **Figure 2.1** shows a breakdown of these interactions. There are 3 levels of driver behavior associated with distraction. Strategic behavior is macro and has a time scale of minutes to days, tactical behavior examines behavior at a finer level with a time scale of 5 to 60 sec, and operational behavior looks at the micro level with a time scale of 0.5 to 5 sec.

In the case of cell phones, strategic behavior is the decision to bring a cell phone into the car. Societal norms might discourage using a cell phone while driving, but productivity pressure might encourage this behavior. At the tactical level, current driving conditions might discourage answering the phone; on the other hand, the driver could slow down or increase headways while using the phone. On the operational level, the cognitive demands of using the phone and driving can affect the conversation or lane-keeping performance.

There are other macro level concerns with human factors research in this field. If the device is well designed to reduce distraction it could actually reduce roadway safety as drivers might increase the frequency of use of this device. This is known as the usability paradox.

The issue of roadway safety is the biggest concern as injury and death can be consequences of distraction. From a standpoint of the productivity of using the device, driving can cause a breakdown in the ability to use IT, which can cause poor business judgment, misinformation, wrong directions, etc.

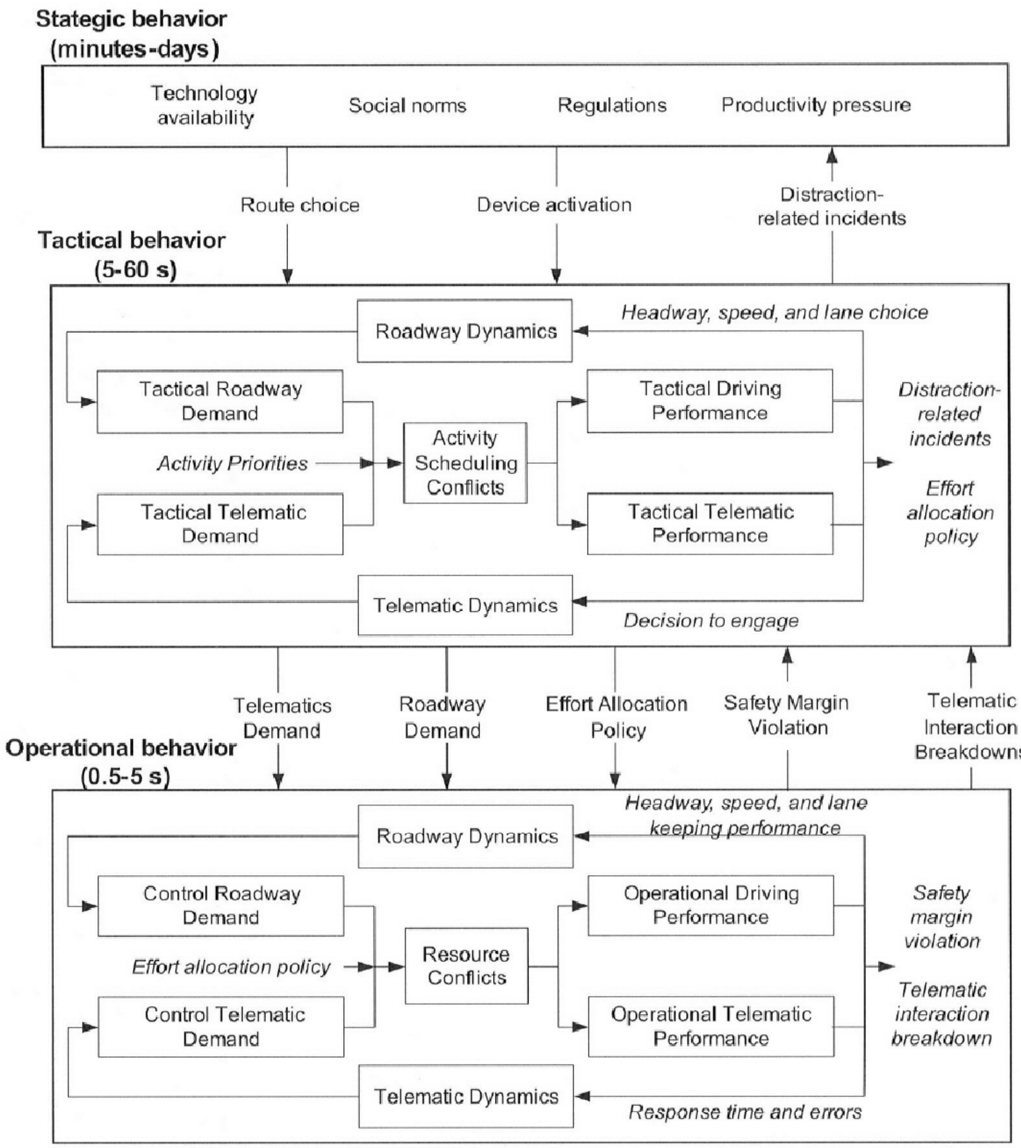

Figure 2.1. Multilevel control shared between IT interactions and driving **(Lee & Stayer, 2004)**

There are many types of displays available for use with in-vehicle technologies (IVTs). Horrey and Wickens (2004) performed a study to determine the effects of different displays on driving performance and IVT task performance. A fixed-base driving simulator was used in this study and 4 different displays were tested: a heads up display superimposed on the horizon (overlay), a heads up display superimposed just above the hood of the car on the roadway 7° below the horizon (adjacent), a heads down LCD screen on the center console of the vehicle (HDD), and a 3D-surround sound auditory display (auditory).

Twenty-two young drivers (14 male and 8 female), ages 18 to 29, volunteered for the study, all with a valid driver's license. The fixed-base simulator used simulated routes consisting of three road types: two-lane bidirectional rural roads (curved and straight) and four-lane bidirectional urban roads (straight only) with roughly the same amount of time on each road type. Eight critical events occurred at random locations throughout the drives that required the driver to maneuver around an obstacle. The events would occur unexpectedly, but in conjunction with the onset of the side task.

Participants were told to drive as they normally would and obey speed limits. While the participants were driving they were asked to complete a side task that consisted of vocally entering a 4, 7, or 10 digit phone number that was displayed. Four blocks of trials used each of the displays. When the numbers were displayed the participant would push a button on the steering wheel, repeat the numbers vocally, and push the button again, all while maintaining safe driving.

Driving performance measures consisted of absolute lane position, variability in lane keeping, and variability in speed control. Side task performance was measured by time to initiate, time to complete, and accuracy. During each block two or three critical events would occur coincidentally with the side task and perception-response times were recorded.

Hypotheses were tested to determine if there were display differences due to clutter (overlay vs. adjacent), separation (adjacent vs. HDD), or modality (adjacent vs. auditory). The summary of results is presented in **Table 2.1** in terms of the impact of dual-task performance (vs. single task).

Table 2.1. Summary of driving and IVT performance results **(Horrey & Wickens, 2004)**

	Multiple Tasks: Single → Dual Task	Overlay: Adjacent → Overlay	Separation: Adjacent → HDD	Modality: Adjacent → Auditory
MAE lane keeping	Loss	0	0	0
Variability in lane keeping	Loss	0	Loss (↑DL)	Loss (↑TL)
Variability in speed	Loss	0	0	Loss (↑DL)
Hazard RT	0	0	Loss	0
Initial hazard collisions	n.a.	Loss	n.a.	n.a.
IVT RT	0 (auditory) Loss (visual)	0	Loss	n.a.
IVT response duration	Loss (auditory) Gain (visual)	0	Loss (↑TL)	Loss (↑TL)

Notes. Data are presented along the dimensions of multiple task performance (going from single- to dual-task conditions), clutter (adjacent to overlay conditions), display separation (adjacent to HDD), and display modality (adjacent to auditory). MAE = mean absolute error; 0 = no loss or gain in performance between the two conditions; loss = a loss in performance in the second condition, relative to the first condition; gain = a gain in performance in the latter condition; ↑DL = a loss in performance that increases with driving load (i.e., driving difficulty; e.g., curved roads); ↑TL = a loss in performance that increases with task load; n.a. = not applicable.

In general there was a loss in driving performance due to concurrent tasks; however, there was no loss in responding to critical events during dual-tasks as compared to control conditions. Apparently the participants were able to protect the important task of hazard awareness while engaging in the side-task (except the HDD side-tasks). There were no significant differences between the overlay and adjacent displays in this experiment. This indicates that the display was not cluttered. However, the display was only active while the digits were being displayed. A heads up display that is continuously active with more information could have overlay penalties. The HDD requires the user to look away from the road. **Table 2.1** shows that this display degraded response time to hazardous conditions. However, lane keeping and speed variability did not suffer. This suggests that users developed a scanning pattern between the screen and driving to maintain their driving performance. This is evident in the longer side task response time and response duration. The auditory display degraded driving performance, as well as side task performance. This type of display requires more working memory as the information is only displayed once. This could have caused the user to focus on repeating the digits to themselves, consequently distracting them from the road. Also, relying on working memory for 7 or 10 digit number strings is difficult which leads to degradation of side task performance.

The results of this study suggest that the best visual display is the adjacent heads up display. An auditory display for this type of task is not appealing, but if shorter messages were being displayed, an auditory display would be a good choice as it does not block the field of view.

Another experiment using an auditory display system in a vehicle was conducted by Jamson, Westerman, Hockey, and Carsten (2004). For their experiment, they used a fixed-base driving simulator and focused on a speech-based e-mail interface. Twenty drivers volunteered for the study (10 male and 10 female) and the mean age was 30.2 years of age. Three factors were studied in this experiment: distraction (two levels – e-mail, no e-mail), e-mail interface (two levels – driver control, system control), and driving scenario (four levels – baseline, and three different driving conditions with varying difficulty).

The e-mail system consisted of a LCD screen mounted to the center of the dashboard with a pair of speakers. For the system-controlled condition, when an e-mail arrived, a chime would sound as an envelope appeared on the screen, then after 2 seconds, an automated device delivered the message to the driver. For the driver-controlled condition, the chime would sound and the envelope would appear just as before, but the message would not be read until the driver pressed a button on the steering wheel. For both conditions, the email message would consist of a true/false statement about the order of letters that was asked using the negative passive tense ("b" is not preceded by "a"). The driving scenarios consisted of following a lead car and occasionally having to brake due to intersections. The scenarios varied in difficulty, but no hazard conditions (crash avoidance due to a surprising event) were presented.

The results of this study pertaining to the performance of using the e-mail system show a significant difference in response time (time to respond "true" or "false" after the end of the voice message) with the system-controlled interface being faster than the driver-controlled interface. Driving scenario was a main effect with response times taking longer in more difficult scenarios. The rates for incorrect "true/false" responses to the e-mails were typically higher for the system-controlled interface. **Figure 2.2** shows a graphical summary of the e-mail performance results.

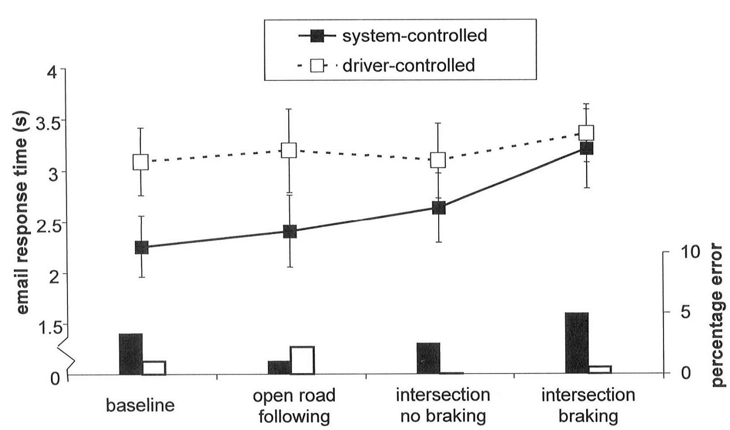

Figure 2.2. E-Mail response time and response error rates for different driving conditions **(Jamson, Westerman, Hockey, & Carsten, 2004)**.

The results of this study indicate that the e-mail system distracted the participants from the primary task of driving. Participants did not anticipate braking as quickly while interacting with the e-mail system as they did when not interacting with the e-mail system. The time to collision was reduced (meaning the participant's vehicle would come closer to colliding with the lead car), while using either e-mail system. Drivers also had fewer responses to lane keeping while using the e-mail system. The reduced amount of braking and steering wheel use suggests that participants would "freeze" cognitive resources from the primary task of driving and use them for processing the secondary task. Drivers did, however, increase headway when responding to e-mails, but the lack of anticipation for braking and steering outweighed the safety margin of the increased headway. The net safety margin was decreased.

The effects of the system-controlled and driver-controlled message acceptance are mixed. When the driver controlled when the messages were displayed, they would wait until they perceived the driving task load to be lower, however, this adds an extra cognitive load to the driver by forcing them to decide when to take the message. Overall, the driver-controlled e-mail interface is preferable to the system-controlled e-mail interface as driving performance was degraded about the same between the two systems, but the performance using the e-mail system was best with the driver-controlled interface (a longer response time, but fewer errors).

Controls for mobile IT devices are necessarily different from controls for IT outside of a vehicle. Mobile IT controls cannot require prolonged physical contact from the user as a driver needs both hands for driving at any given moment. An obvious alternative to using your hands to control a device is using speech. Speech recognition systems are still developing and are not capable of a large vocabulary, but are sufficient for simple dedicated commands. Tsimhoni, Smith, and Green (2004) used a driving simulator to determine the effects of entering addresses into a navigation system while driving.

In this experiment 3 types of navigation entry were explored: word-based speech recognition, letter-based speech recognition, and a touch-screen keyboard. Twenty-four participants, 12 from each age range, younger (20 to 29 years of age) and older (65-72 years of age), with an equal number of males and females in each age group, were tested. Each participant used the 3 levels of address entry combined with 4 levels of driving workload: parked, driving straight, driving on moderate curves, and driving with sharp turns. The participants drove behind a simulated lead vehicle in the right lane. In the left lane, cars were next to the driver and headed in the same direction.

The touch-screen keyboard was mounted in the center console and displayed a standard QWERTY keyboard. Another screen to the right of the driver displayed the addresses that were to be entered into the navigation system. For the speech recognition methods, the experimenter acted as a speech recognition system, in other words, the experimenter used keyboard shortcuts to display the words the participant said on the navigation screen. The participants were not informed that the speech recognition system was not real, and most did not realize it wasn't real.

The results of this study show significant differences between the word-based speech recognition, character-based speech recognition, and touch-screen keyboard entry methods. From **Figure 2.3** it is apparent that a word-based speech recognition system is far quicker to use.

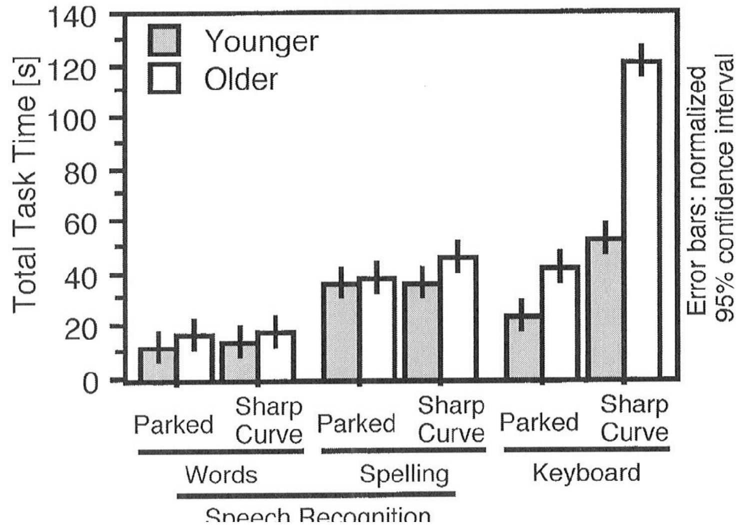

Figure 2.3. Total task times for each combination of task and driving workload **(Tsimhoni, Smith, & Green, 2004)**.

It should also be noted that for almost all conditions the character-based speech recognition system is faster to use than the touch-screen keyboard, except when the vehicle is parked. The task of more importance is driving. Measures of lateral control of the vehicle show that lateral control was the worst with keyboard entry, the portion of trials with at least one lane departure was 20.6%, compared to the baseline of 1.5%. There was no significant difference between baseline conditions and either of the speech recognition methods. Longitudinal control measures showed that the participants would slow down and increase following distance when using the keyboard entry, and following distance was least during word-based speech recognition.

From these results it is obvious that a speech recognition system for address entry is preferred over keyboard entry while driving. Keyboard entry degrades driving performance and address entry performance greatly. The word-based speech recognition system degraded driving performance only slightly and had the best address entry performance.

Dual task processing is known to have differences in mental ability between younger and older people. Driving is a task that is frequently paired with another side task, such as using a cell-phone, eating, etc. Strayer and Drews (2004) conducted a driving simulator study to see if there were differences in driving performance between younger and older drivers while using a hand-free cell phone.

Twenty younger (ages 18 to 25) and 20 older (ages 65 to 74) subjects participated in the study. The simulated drive consisted of following a pace car on a multilane highway that would intermittently brake. For the dual-task trials (driving and conversing on the cell phone) the participants did not need to manually touch the phone to answer the call or make any adjustments.

Strayer and Drews found that, for the participants in this study, the older drivers did not suffer greater penalties for using a cell phone than the younger drivers. The distracting effects of the cell phone were equivalent for both age groups. The brake onset times (in response to the lead car braking) were 18% slower, there was a 12% greater following distance, and it took 17% longer to reaccelerate after braking. It was possible to rear end the lead car in the simulator, and drivers on the phone had more rear-end collisions. The older drivers did not suffer a greater penalty than the younger drivers, but the reaction time of the younger drivers on the cell phone was equal to the reaction time of the older drivers not on the cell phone. Many dual-task studies find large differences in the amount performance is degraded between younger and older people; the lack of difference in this study might be the exceptional health of the participants or the familiarity of the task of driving.

The interesting result of the study is that driving performance was degraded for both age groups while on the cell phone. The researchers wanted to eliminate the effects of manipulating a phone from the results of the study, so they made sure that the cell phone was hands-free and the participants were only talking on the phone while data was collected (they weren't handling or manipulating the functions of the phone). The task of using the cell phone consisted of a naturalistic conversation with a research assistant. This indicates that the cognitive load of the conversation on the cell phone alone was enough to degrade driving performance as compared to not using a cell phone.

From the 5 studies discussed above it is clear that driving performance is degraded when using a mobile IT device. Even when the mobile IT system does not require physical interaction (speech-based recognition and auditory displays), there is still a high enough cognitive workload to distract the users from the primary task of driving. It is apparent that speech-based recognition, heads up displays, and many other advances in technologies can have a smaller negative impact on driving performance. Within the scope of laboratory experiments this is positive, however, the effects of these technologies in real driving situations needs more attention. As Lee and Strayer (2004) mentioned in their preface, the usability paradox could occur. The decrease in distraction for a single use could increase the frequency of use, which could cause a net increase in driver distraction. This phenomenon has been shown in other similar situations.

Most laboratory experiments focus on the tactical and operational behaviors outlined in **Figure 2.1**. For overall roadway safety to not suffer due to the use of in-vehicle technologies, lawmakers and drivers alike need to make connections between the results of these experiments and strategic behaviors of drivers using in-vehicle technology.

2.3 Research Voids and Objectives

There are several publications that discuss the safety of driver distraction due to using mobile IT in a vehicle. There have not, however, been any 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 extremity and shoulders, muscle activity of the major shoulder and trunk muscles, and ultimately risk of injury. These issues can affect computer performance and ease of use of the IT system.

The objective of this research study was to find the optimal location of a mobile computer in a truck cab to maximize computer performance and safety while minimizing risk of MSDs to the driver. The authors hypothesized that the optimal location for the mobile computer is to place the computer as close as possible to the steering wheel as the steering wheel is designed to be in a comfortable position for the driver. This location should minimize trunk twisting and long reaches with the upper extremities that could strain the driver's back and upper extremity muscles.

3 METHODOLOGY

3.1 General Approach

Four mobile computer locations were assessed in this study to determine which one was the optimal location based on 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 truck cab. In addition, task time and number of mistakes were measured.

3.2 Hypotheses

Hypothesis 1: Placing the mobile computer as close as possible to the side of the steering wheel will reduce biomechanical loading on the participant, compared to the other locations.

Hypothesis 2: Placing the mobile computer as close as possible to the side of the steering wheel will improve the participant's performance completing the tasks.

Hypothesis 3: Larger participants will have less biomechanical loading compared to smaller participants for locations farther from the steering wheel.

Hypothesis 4: Placing the mobile computer closer to the steering wheel will improve subjective assessment.

3.3 Independent Variables

There were three independent variables, mobile computer location, with 4 levels (locations of mobile laptop), task type, with 2 levels, and subject size, with 2 levels in this experiment. Location and task are both within subjects variables and size is a between subjects variable.

3.3.1 Location

The 4 levels of the independent variable consist of 4 mobile computer locations that are commonly used in current electric utility vehicles (**Figure 3.1**). A cab from a 2002 Chevrolet Silverado pick-up truck was used for participants to test the mobile computer in the 4 locations. A Panasonic Toughbook CF-29 laptop PC was selected for this experiment for 3 of the 4 locations because it is commonly used by electric utilities. The keyboard is 12 in. wide, 10 in. long, and 1.75 in. thick and the screen is 12 in. wide, 9.5 in. tall, and 13 in. on the diagonal. A Gamber Johnson laptop mount attached to the passenger seat base with two articulating arms, adjustable clevis, and docking station was used to place the laptop in 3 of the 4 locations.

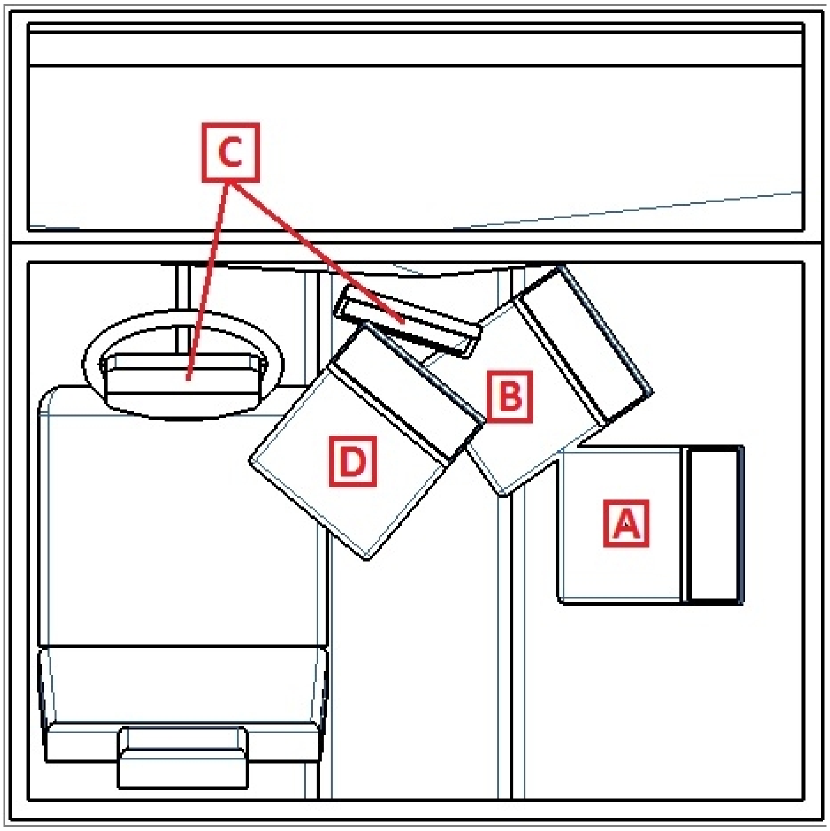

Figure 3.1. Mobile computer locations A, B, C, and D tested in study

As shown in **Figure 3.2**, Location A places the laptop (Panasonic Toughbook) 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. There are several options available on the market for this type of in-vehicle desk, such as the Mobile Desk brand product shown in **Figure 3.2**. Location A simulates the exact position the laptop would be in when using the Mobile Desk. The actual commercial product could not be used due to the need for the passenger seat to be removed. In Location A the driver was only allowed to tilt the angle of the laptop's display.

In Location A the point between the middle of the G and H keys on the laptop (referred to as the reference point on the laptop) was 34.4 in. perpendicular to a line connecting the seat reference point (SRP) and the middle of the steering wheel. The distance along the fore-aft axis between the middle of the steering wheel and the laptop reference point was 7.9 in.   The height of the G key on the laptop was 13.0 in. above the SRP and 24.0 above the cab floor. Refer to **APPENDIX A: DIMENSIONED LINE DRAWINGS OF FOUR LOCATIONS** for line drawings of Location A.

Figure 3.2. Location A - mobile computer mounted over passenger seat (Left) and passenger seat desk unit (Right)

Location B consists of the laptop (Panasonic Toughbook) mounted over a post located between the instrument panel and passenger seat (**Figure 3.3**). Location B is typical of a first generation commercial design for mounting a laptop in a truck cab because it was relatively easy to bolt the post to the cab floor in front of the passenger seat. In this location, the driver was able to adjust the vertical tile angle of the laptop’s base and display and rotate the laptop’s base around the post.

The exact location of the reference point on the laptop in Location B was 25.5 in. to the side of the steering wheel – SRP line and 0.1 in. aft of the middle of the steering wheel. The height of the G key on the laptop was 24.0 in. above the cab floor and 13.0 in. above the SRP. **APPENDIX A: DIMENSIONED LINE DRAWINGS OF FOUR LOCATIONS** shows dimensions of the reference point on the laptop to the steering wheel and SRP for Location B.

Figure 3.3. Location B - laptop mounted over post between instrument panel and passenger seat

Location C is a location that is commonly used in police and emergency vehicles. The keyboard and display are separated, with the display mounted on the instrument panel and to the right of the steering wheel and the keyboard can be used anywhere in the cab (**Figure 3.4**). A Hub Data 911 M6 computer was used for this location as it is a popular mobile computer purchased by police and emergency aid departments. The base computer unit, which is attached to the display and keyboard with coiled cables, can be mounted in any place in the truck cab or behind the instrument panel. For Location C the keyboard sat on the surface of the steering wheel on a wire stand, which was hooked around the top to the steering wheel. This location of the keyboard is temporary as it is meant to be used when the vehicle is not moving. (If the vehicle were moving, the keyboard would obstruct the path of the airbag.) In this location the driver was allowed to adjust the tilt angle of the steering wheel to select the tilt angle for the keyboard.

The dimensions of the keyboard are 12 in. wide, 7.5 in. long, and 1.25 in. thick and the display dimensions are 11 in. wide, 9.5 in. tall with a 12 in. diagonal viewing area. Detailed line drawings of Location C are shown in **APPENDIX A: DIMENSIONED LINE DRAWINGS OF FOUR LOCATIONS**.

Figure 3.4. Location C - computer with display mounted on instrument panel and keyboard on steering wheel

Location D places the laptop (Panasonic Toughbook) closely to the right of the driver (**Figure 3.5**). This location was obtained with two articulating arms between the laptop and the mounting post. The mount used in this location has been seen in some utility vehicles but is not as common as the simpler mount for Location B. The mount for Location D, which is a second generation mount for vehicles, employs 2 articulating arms so the driver can place the computer in many different positions. In this location the driver, along with help from the investigator, chose the location of the laptop base so it appeared to be comfortable to use. 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 steering wheel and seat back were not impeding movement of the driver's left hand or right arm
- The side to side rotation of the left and right wrists (radial/ulnar angle) appeared close to neutral
- The computer was in a comfortable reach zone (not too close nor distant).

Detailed drawings of the location of the laptop's reference point relative to the steering wheel and seat are shown in **APPENDIX A: DIMENSIONED LINE**

DRAWINGS OF FOUR LOCATIONS. A scatter plot of the locations selected by all the participants is also shown in **Figure 3.6** to reveal points of central tendency and dispersion.

Figure 3.5. Location D - laptop mounted next to steering wheel

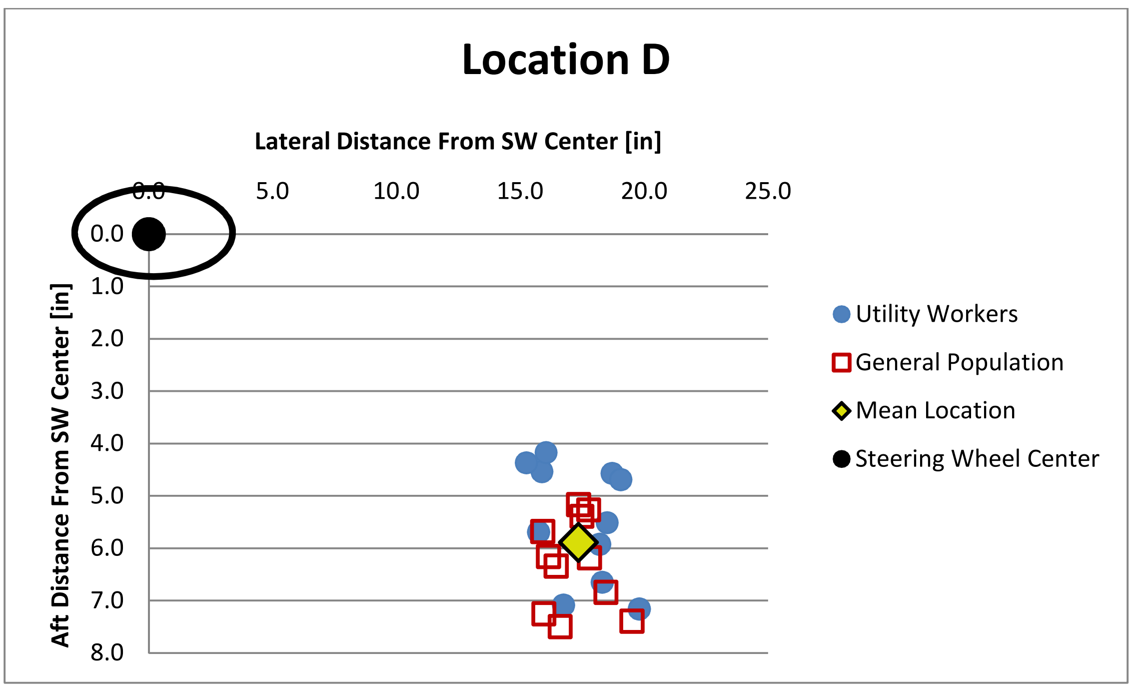

Figure 3.6. Location of the middle of the computer keyboard (between G and H keys) selected by the participants and experimenter for Location D

3.3.2 Task Type

Task type had 2 levels, keyboard and touchscreen. In each location the subjects performed software tasks that required only the keyboard (including the touchpad) and other tasks that required only the touchsceen. The software tasks and their respective input method are described in section **3.11 Software Tasks** below.

3.3.3 Subject Size

Subject size also had 2 levels, small and large. The participant's combination of height and weight were used to determine if the participant fits into large or small. After all of the data were collected, the half of the subjects with the largest height and weight combination were considered large, and the other half were considered small. See **Figure 3.21** below for a plot of all of the participant's heights and weights.

3.4 Dependent Variables

There were 3 types of dependent variables categorized according to biomechanics, task performance, and subjective assessment. For biomechanical analysis, joint angles and muscle activity were recorded using goniometers, video cameras, and EMG sensors. Performance was evaluated by measuring the time and accuracy while participants completed software tasks. The subjective assessment consisted of a survey that each participant completed after performing the tasks in each location.

The joint angles of the participants' left and right wrists and elbows were recorded using Biometrics Ltd. goniometers. **Figure 3.7** shows the goniometers taped to the subject's wrist and elbow. The goniometers recorded the extension/flexion angle and radial/ulnar angle of both wrists and extension/flexion angle of both elbows. **Figure 3.9** and **Figure 3.10** show how the goniometers were calibrated to neutral angles for radial/ulnar and flexion/extension (for the wrist) and flexion/extension (for the elbow).

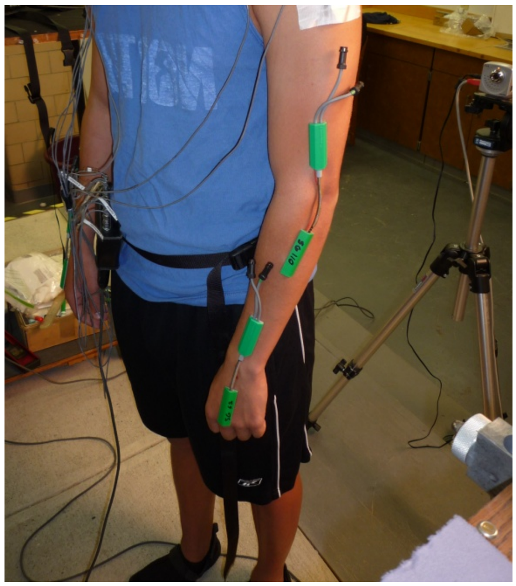

Figure 3.7. Goniometers on subject's wrist and elbow

The neutral position for the wrist ulnar/ radial deviation was defined as a line formed by the middle finger metacarpophalangeal joint, the lunate and the lateral epicondyle of the forearm. Neutral wrist extension/flexion position was defined as a line formed by the ulnar aspect of the little finger metacarpal, the ulnar styloid process, and the ulnar bisection of the forearm **Figure 3.8**. The goniometers were applied to the subjects forearm along the line formed by the middle finger metacarpophalangeal joint, the lunate and the lateral epicondyle and the upper arm along the line formed by the lateral epicondyle and the lateral aspect of the acromion **Figure 3.8**. The neutral position for the elbow extension flexion was defined as full extension of the joint.

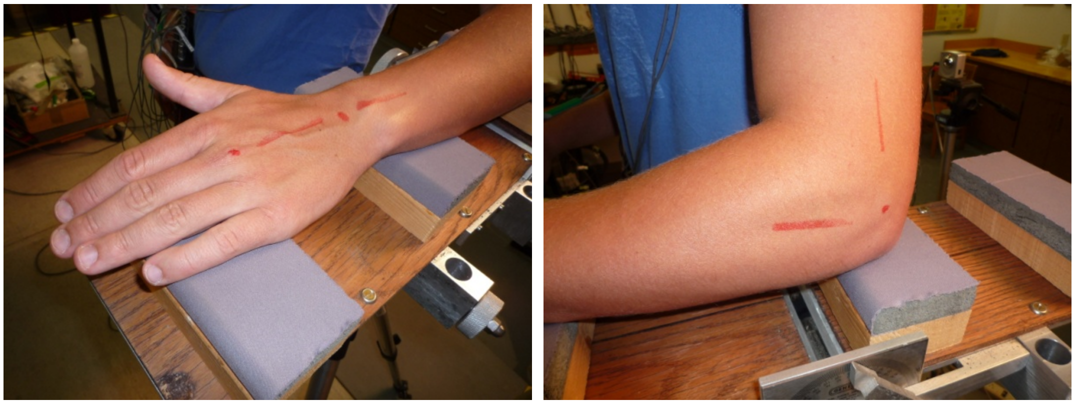

Figure 3.8. Bony landmarks used for goniometer placement on subject's wrist and elbow

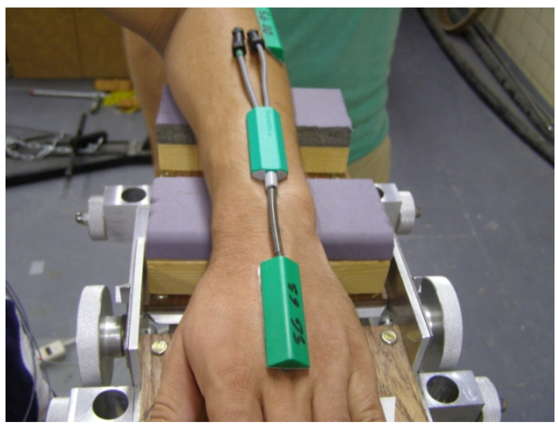

Figure 3.9. Calibrating the wrist goniometer to neutral angle

Figure 3.10. Calibrating the elbow goniometer to neutral angle

Two digital cameras were mounted to the truck cab, one above the top of the cab recording the top view of the driver through a hole in the roof, and one outside of the driver's door recording the left side of the driver. With this video setup, the shoulder angle, shoulder displacement, and hip displacement were measured.

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 3.11**). 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 3.12**). The shoulder angle indicates how much the participant has to rotate away from the back of the seat but does not indicate which parts of the trunk, shoulders, or hips contribute to the rotation (i.e. by rotating only the shoulders or rotating the hips in the seat).

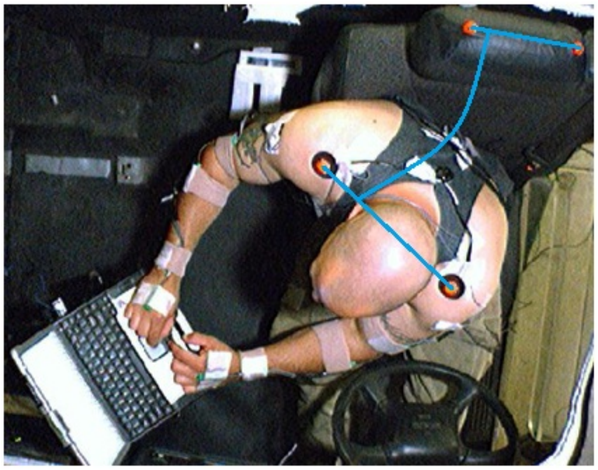

Figure 3.11. Shoulder angle of a participant with hips touching the seat back

Figure 3.12. Participant with left hip moved forward

Shoulder displacement is the distance the center of the line across the left and right acromion (middle of the neck) has moved from a reference position where the participant was sitting relaxed against the back of the seat (**Figure 3.13** and **Figure 3.14**). In these figures, the red dot is in the middle of the neck at the level of the top of the shoulders (it looks to be on the side of the participant due to the parallax from the camera).

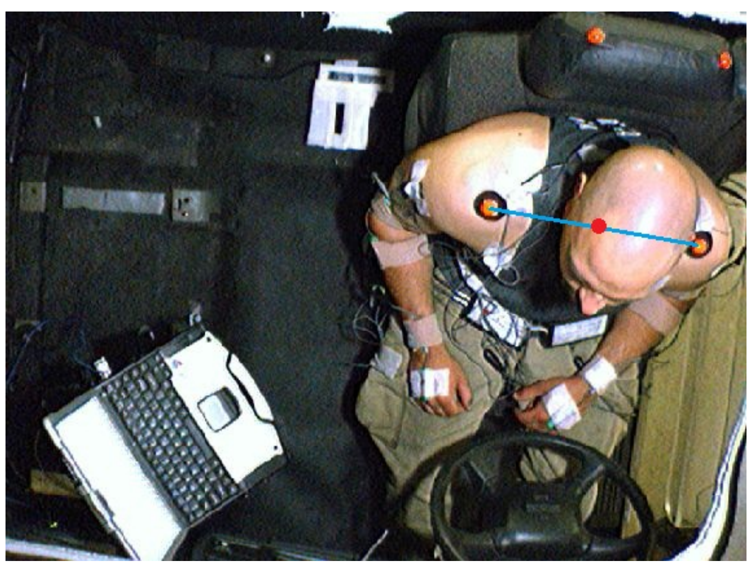

Figure 3.13. Middle of shoulders reference point (Red Dot) of a participant sitting relaxed against back of seat

Figure 3.14. Shoulder displacement. green line indicates distance that the middle of shoulders moved between relaxed position and using the computer

Hip displacement is the distance the marker on the subject's hip has moved from a reference position where the subject was sitting relaxed against the back of the seat (**Figure 3.15** and **Figure 3.16**).

Figure 3.15. Hip displacement reference position

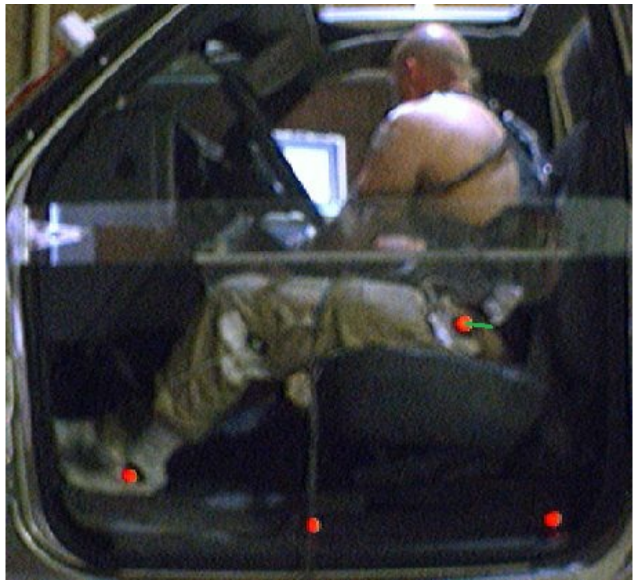

Figure 3.16. Hip displacement (green line)

Electrical activity of 4 muscles was measured on each side of the body: pectoralis major (**Figure 3.17**), middle deltoid (**Figure 3.18**), trapezius (**Figure 3.19**), and erector spinae (**Figure 3.20**) with Biometrics Ltd. 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.

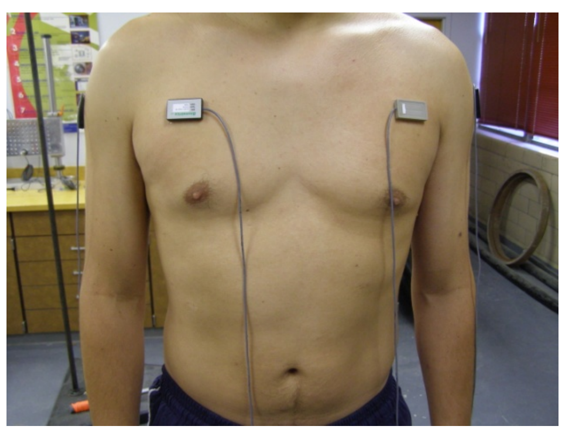

Figure 3.17. EMG sensor placement for pectoralis major

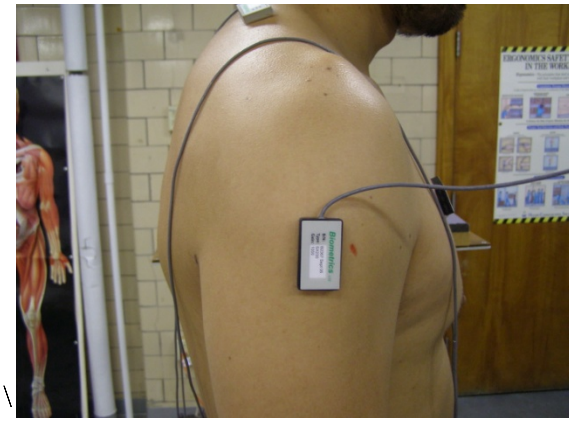

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Figure 3.18. EMG sensor placement for middle deltoid

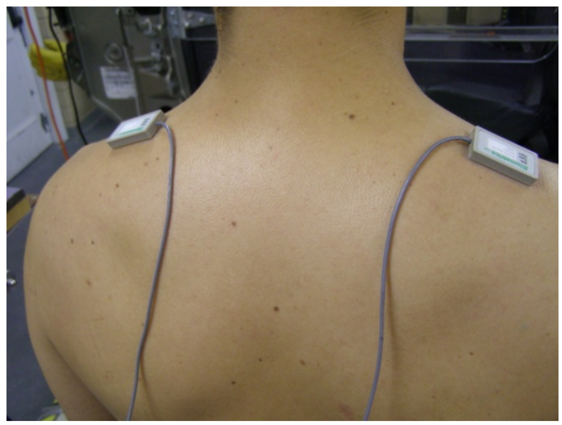


Figure 3.19. EMG sensor placement for upper trapezius

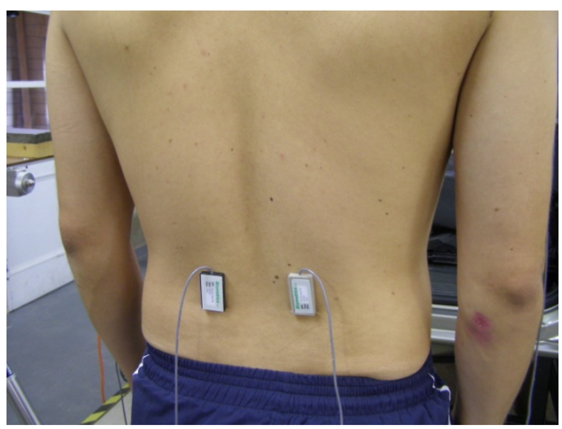


Figure 3.20. EMG sensor placement for erector spinae

3.5 Performance

Performance was measured on some of the tasks the participants were required to complete in each of the computer locations. All of the tasks are described later in the "Tasks" section, but only the touching task and keying task were used for performance. For the touching task and keying task, the total time the participants needed to complete the task and the number of mistakes were measured. Performance was not measured for the work-order form as the instructions were delivered to the participant verbally.

3.6 Subjective Assessment

The participants were required to complete a 6 question subjective assessment questionnaire after completing the tasks in each computer location. The questionnaire shown in **APPENDIX C: FORMS** uses a 7-point Likert scale to measure the ease of use, comfort, and productivity for each task, and whether the participant liked or disliked the location. After all of the locations were completed, the participant was asked to provide an ordinal rank of the locations (from best to worst).

3.7 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 subject began testing in the cab, the seat was adjusted so that the left foot could reach the base of the firewall with the knee joint at 110 degrees. This was done to ensure the driver's seat was in the position the participant would use for comfortable driving.

The computer system used for Location C was different than the rest of the locations, so the participants were required to practice using the keyboard, touchpad, and touchscreen with the Data 911 until they were comfortable with the system.

Due to the fact that the touchscreen tasks only require one hand, all of the participants were only allowed to use their right hand on the touchscreen and the participant was instructed to leave his left hand on the base of the computer. Participants were monitored and reminded if the left hand moved from the computer during touchscreen tasks.

To remove any effects of glare, the participants were allowed to adjust the screen angle before data collection for Locations A, B, and D. Before applying all of the goniometers or EMG sensors, the subjects were trained to complete all of the tasks so that the subjects were familiar with the tasks.

The presentation order of the locations to each subject 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 fingers on the display. The script order was also counterbalanced against the location order. See **Table 3.1** below.

3.8 Participants

3.8.1 Eligibility Criteria

The following criteria were used to determine eligibility for this study.

- 18-65 years of age
- Physically able to operate a vehicle
- Able to operate a laptop computer. Minimal computer experience was required.
- No past or present physical injuries that could be exacerbated by participation in this study (i.e. if a prospective participant has had severe back pain and has not fully recovered, then he or she was not eligible to participate).

3.8.2 Determination of Sample Size

After 7 subjects were tested, their data were conditioned and analyzed and used to perform a power analysis to determine the minimum number of subjects 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. Based on the power analysis results, 13 subjects were needed for the left erector spinae and 12 subjects were needed for right elbow flexion to ensure statistical power of at least 80%. To add a factor of safety, it was determined to test 22 subjects in case data had to be excluded and to ensure enough power for all of the results. The process for calculating sample size based on power analysis is shown in **APPENDIX B: POWER ANALYSIS**.

3.8.3 Height, Weight, and Occupation of Participants

Participants were recruited based on the low, medium and high height and weight shown in **Figure 3.21**. The height and weight cut-offs used in the matrix are the 33rd and 66th percentiles of the general population of males and females, ages 18-65, calculated from a combination of the NHANES 2005-06 (National Health and Nutrition Examination Survey) and NHANES 2007-08 surveys collected by the National Center for Health Statistics.

Electric utility field workers were first recruited and tested. Utility workers are a little taller and heavier than the general population (Marklin, Saginus, Seeley, & Freier, 2010), so participants from the general population were also tested to balance out the size of the participants. In **Figure 3.21**, the dashed red line divides the participants into two groups, smaller and larger with 11 participants in each group.

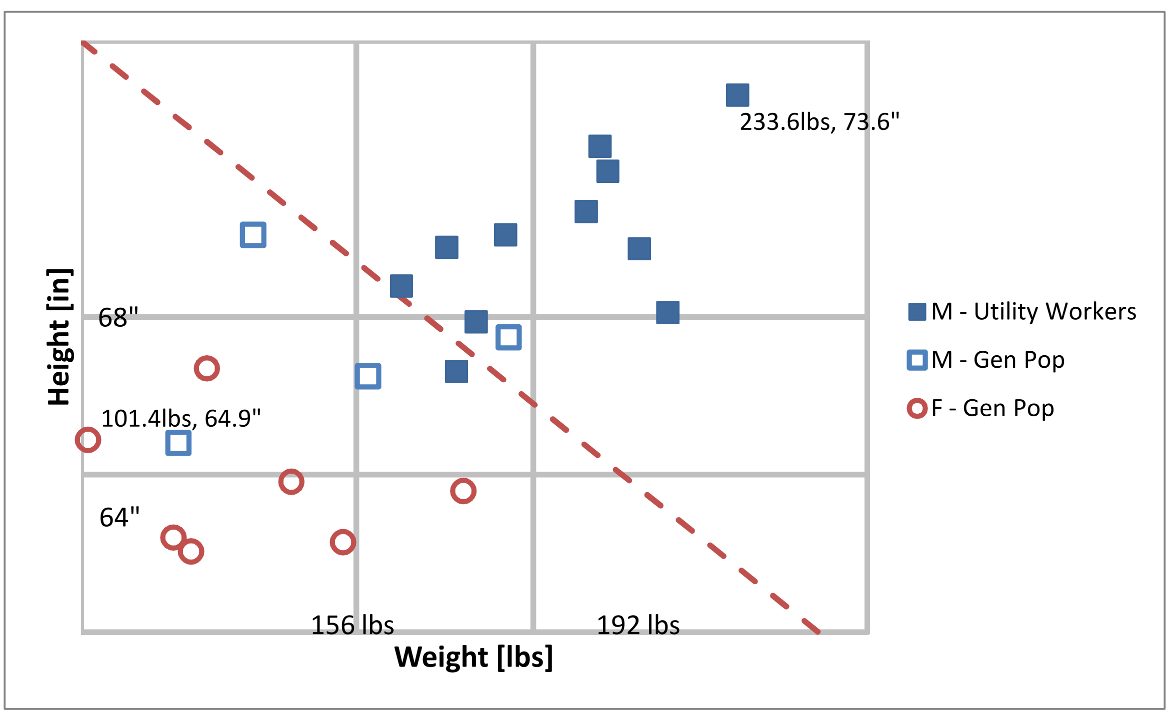


Figure 3.21. Height and weight distribution of all participants

The following demographic information was collected from all of the participants. The average age (±SD) in years of the subjects was 34 (±12). Eleven (50%) of the subjects were electric utility field workers, all male, 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 the truck per day was 1 hour and 15 minutes (±1 hour). For the other eleven non-utility participants, eight were students, two were engineers, and one was in sales. The average time spent on a computer (not in a vehicle) was 5.6 hrs (±2.8) hours per day.

3.9 Testing Order

All of the participants in this study performed the same software tasks in each location. To eliminate carry-over and order effects, the presentation order the locations was counterbalanced between the subjects (D'Amato, 1979). As the laptop over the passenger seat, laptop over the post, screen mounted to dashboard with separate keyboard, and laptop next to the steering wheel are Locations A, B, C, and D, respectively, the order of presentation for each participant was determined by the following sequence (**Table 3.1**).

Table 3.1. Presentation order.

Subject	Location Order	Script Order
S01	ABDC	ABDC
S02	BCAD	CDBA
S03	CDBA	ABDC
S04	DACB	CDBA
S05	ABDC	CDBA
S06	BCAD	ABDC
S07	CDBA	CDBA
S08	DACB	ABDC

The sequence was repeated almost three times to include all 22 subjects. This method of complete counter balancing only allows each configuration to precede the other configurations exactly once (A precedes B, C, and D only once, etc.) for each set of four subjects. The script order was determined by letting each script be used with each location only once for the first four subjects. This resulted in only two script orders, so the orders were reversed after each set of four subjects.

3.10 Testing Location and Equipment

3.10.1 Chevrolet Silverado Truck Cab

In Marquette University's ergonomics laboratory a Chevrolet Silverado 1500 truck cab was setup as the main fixture for this experiment (**Figure 3.22** and **Figure 3.23**). The truck cab was modified by removing doors, the passenger seat, and most of the roof to allow for video equipment and the four locations of mobile computers.

Figure 3.22. Chevrolet Silverado 1500 truck cab

Figure 3.23. Inside of truck cab

3.10.2 Panasonic Toughbook

A Panasonic Toughbook model CF-29 (**Figure 3.24**) running Windows® XP was used as the mobile computer for Locations A, B, and D. The interface consists of a standard QWERTY keyboard, touchpad, and touchscreen. This computer was chosen for this experiment as it is a common choice for electric utility field work and other field work due to its ruggedness and water and dust resistance. It is also wireless capable.

Figure 3.24. Panasonic Toughbook CF-29

3.10.3 Hub-Data 911 Mobile Display Terminal

For Location C, a Hub- Data911 Mobile Display Terminal model M6 (**Figure 3.25**) running Widows® XP was used as the mobile computer. This unit was used as the investigators wanted to include a dashboard mounted screen and separate keyboard. The CPU can be mounted anywhere in the vehicle. In this experiment the CPU was mounted under the passenger side instrument panel. The interface consists of a standard QWERTY keyboard, touchpad on the bottom of the keyboard, and a touchscreen. This unit was chosen as it is a popular choice for emergency response vehicles and is an attractive option for electric utilities. It also features a back-lit keyboard and anti-glare screen. There are many ways to mount this device. The investigators chose to mount the keyboard on the steering wheel to ensure it would be usable by all of the subjects.

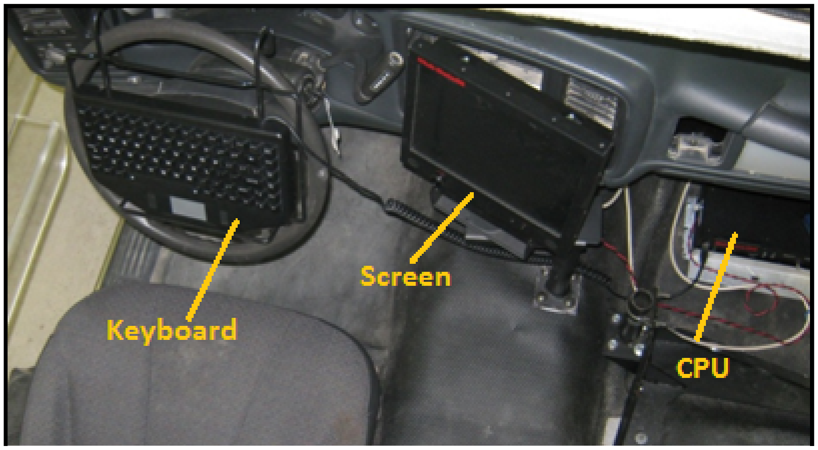
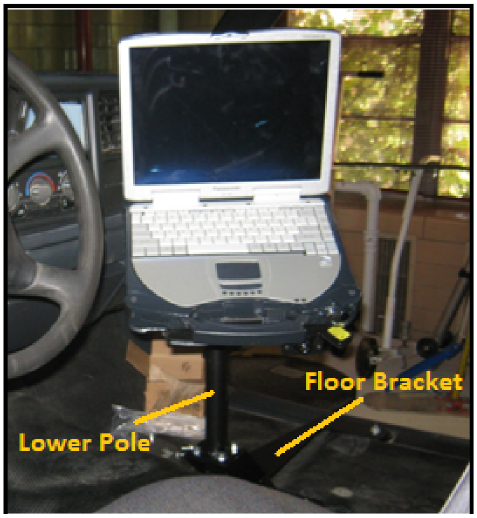


Figure 3.25. Hub-Data911 M6 mobile display terminal

3.10.4 Laptop Mount

A Gamber Johnson automobile laptop mount was used in this experiment to mount the Panasonic Toughbook in Locations A, B, and D. The same mount was used for all three locations to save setup time between testing locations. The mount places the laptop in the exact position of the passenger seat desk (Location A) and only allows tilt and swivel (Location B). The mount consists of a floor bracket bolted to the floor using the passenger seat bolts, a 13” lower pole, a 9” long quick-adjust upper pole, a 6” long articulating arm, a clevis with 30° tilt forward and backward, 60° swivel left and right, and a Panasonic Toughbook docking station (**Figure 3.26**).



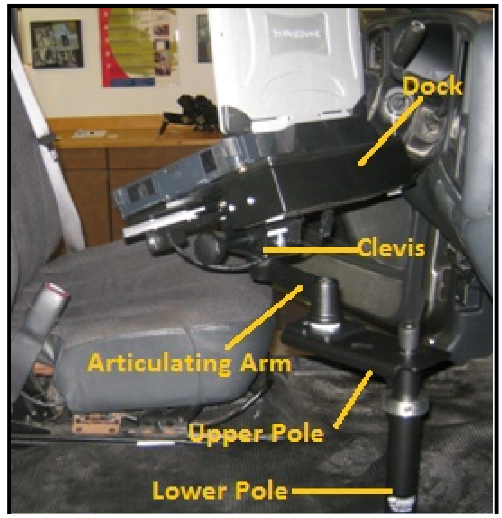


Figure 3.26. Laptop mount components

3.10.5 Biometrics Ltd. Data Acquisition System

The muscle activity data were collected using eight Biometrics SX230 EMG sensors and a DataLINK DLK900 subject and base unit. The joint angle data were collected using two Biometrics SG65 or SG75 electromechanical goniometers (depending on hand size) for the wrists and two SG110 electromechanical goniometers for the elbows and another DataLINK DLK900 subject and base unit. Data collection and storage was controlled with the DataLINK Management & Analysis Software version 7.5. Data were collected simultaneously from both sets of subject and base units. Biometrics DataLINK DLK900 is a 13 bit system.

All of the data from the EMG sensors were collected at a sampling rate of 1000Hz and an excitation output voltage of 4500mV. The channel sensitivity was adjusted for each channel and subject during the maximal calibration so the maximum output was above 70% of full scale, but not saturated. All of the data from the goniometers was collected at 200Hz and a manufacturer preset "goniometer" channel setting.

3.10.6 Video Camera System

A two-camera video recording system, consisting of two Unibrain Fire-i™ digital firewire cameras, one mounted above the roof of the cab and the other on a tripod outside the driver's door (**Figure 3.27**), was used for video data collection.

Figure 3.27. Video camera locations

Custom designed motion capture software in LabVIEW was used to simultaneously record video from both cameras (**Figure 3.28**). The software also allowed sequence markers to mark the frame that muscle activity and joint angle data collection starts and stops at the click of a button. These frame markers allow the data collected with the video cameras and Biometrics units to be synchronized for analysis. Video data were recorded at 10fps.

Figure 3.28. Screenshot of motion capture software

3.11 Software Tasks

The tasks the subjects had to complete in each of the four mobile computer locations consisted of a work order form, activity selection, touching task, 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.

A screenshot of the work order form is shown in **Figure 3.29**. 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 form was always filled out from top to bottom and left to right. As the participant was filling out the form, muscle activity and joint angle data were collected in three short periods. The green circles indicate when data collection started and the red squares indicate when data collection stopped (video data were continuously recorded and sequence markers were used to indicate the start and stop of data collection in the video).

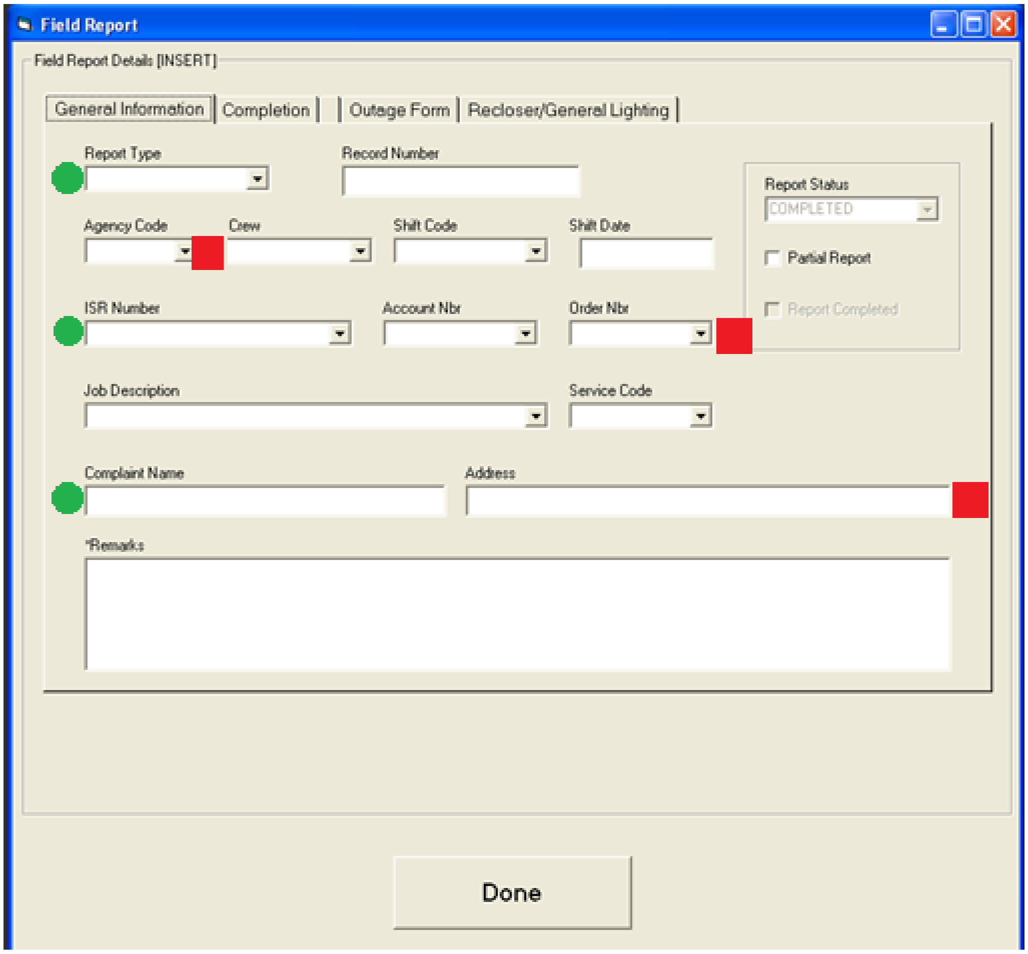


Figure 3.29. Work order screenshot

The activity selection form (**Figure 3.30)** required the participant to select the radio button that the investigator asked for and press "Start Activity". No data were collected during this task.

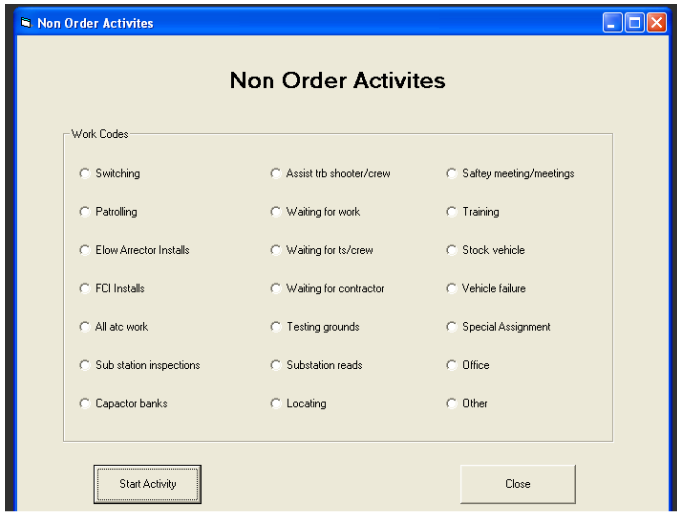


Figure 3.30. Activity form screenshot

The square touching task was used to measure the participants' performance in each location. A three-by-three matrix of squares was employed, with only one square visible at a time (**Figure 3.31**). When the participant touches the visible square the next square in the sequence appears and so on until the participants touched 36 squares. The participants completed this task only using their right hand on the touchscreen. Six different sequences were used in this experiment so the participants would not see the same sequence more than once. The total travel distance for each sequence was approximately the same. The total time and number of mistakes (touching the screen, but missing the square) to complete this task was measured. Muscle activity and joint angle data were collected throughout the duration of the task.

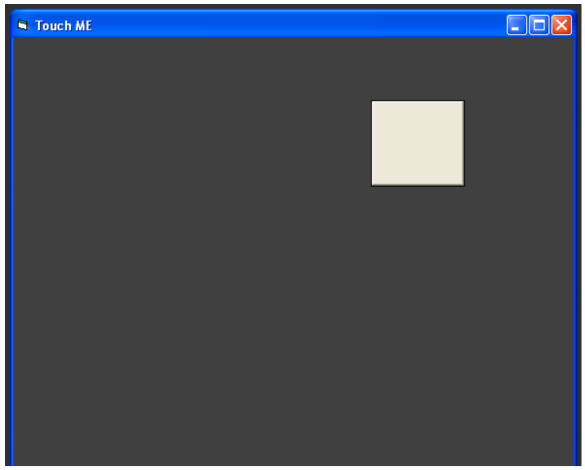


Figure 3.31. Touching task

The letter keying task was also used to measure performance. As shown in **Figure 3.32**, a letter appeared on the screen and once the participant keyed in that letter the next letter appeared. Each letter in the alphabet appears once in each sequence. Six different sequences were used for this task to ensure the participants would not see the same sequence more than once. To keep the difficulty of each sequence approximately the same, the letters in the sequence alternated sides of the keyboard. Performance was measured by recording the total time to complete the sequence and counting the number of mistyped letters.

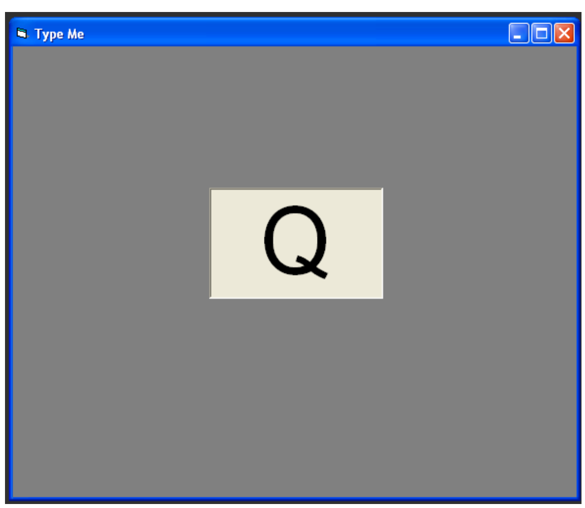


Figure 3.32. Keying task

The map search was completed using 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 asked to name another specified landmark. The participants were only allowed to use the touchscreen with their right hand as they navigated the map. Muscle activity and joint angle data were collected while the subject followed the road to the second landmark, and stopped when the subject named the second landmark.

3.12 Experimental Protocol

1. When participant arrived, he/she was greeted and thanked for coming.
2. The participant was informed that their participation will take less than four hours.
3. The participant was informed that none of the data collection would be physically invasive and all participation is confidential. The EMG sensors and goniometers were shown and described to the participant.
4. The participant was then informed of the terms of the IRB consent form, after which, the participant was offered to read the consent form in private. The participant was able to ask questions after reading the form. If he/she agreed to the terms of the consent form, then he/she signed the form.
5. The participant was trained to complete the software tasks by completing each task following a training script narrated to the participant outside of the experiment area.
6. The participant was then given a shirt with material removed to allow the sensors to be applied and directed to restroom. The participant was also reminded that he/she will not be able to use the restroom for the next 2-3 hours.
7. After the subject returned from the restroom and was ready to begin, the investigators swabbed the back of both hands, forearms, upper arms, upper chest, upper back and lower back with cotton swabs and alcohol to remove excess skin oil.
8. The locations for the EMG sensors and goniometers were marked using a washable marker. If any marks were in areas with thick hair, the subject was told that tape will be applied to skin in that area and the subject can choose to shave the area with

electric shaver. If the hair was too thick for proper contact for the EMG sensors the hair was shaved.

9. The EMG sensors were applied to the appropriate locations. Two-sided hypo-allergenic tape was used between the sensor and subject's skin, and one-sided hypo-allergenic tape was used on top of sensor.
10. The self-adhesive ground electrode was attached to the subject's lateral malleolus.
11. The EMG Biometrics DLK900 subject unit with belt was attached to the subject's waist.
12. The EMG sensor cables were then attached to DLK900 subject unit in proper channels including ground cable.
13. The subject was told to relax the upper body completely and let arms hang naturally. All of the channels were zeroed in the Biometrics Acquisition software.
14. All of the EMG sensor cables were pulled over the shoulders and down the front of subject's torso. The cables were taped to subject's chest and abdomen and the subject was offered the electric shaver if tape is necessary in a hairy area.
15. Maximal exertion calibration for the EMG signals were recorded for each of the muscle groups separately by having the participant exert a brief (about 3 seconds) maximal voluntary muscle contraction against a specially designed static apparatus (**Figure 3.33** and **Figure 3.34**). The apparatus was adjusted to position the subject's appropriate joints to the anticipated position for computer use in the cab. If the signal was saturated, adjustments to the channel settings were made.
16. The goniometers were attached to the subject's wrists and elbow joints using two-sided hypo-allergenic tape between the sensor and the subject's skin and one-sided hypo-allergenic tape or wrap on top of the sensor.
17. All of the goniometer cables were directed up the subject's arm and down the front of the torso. The cables were taped to arms and torso.
18. The goniometer Biometrics DLK900 subject unit with belt was attached to the subject's waist.
19. The goniometer cables were attached to DLK900 in proper channels.
20. The subject was asked to place arms in reference positions and channels were zeroed.
21. The signal quality of all channels was checked by instructing the subject to flex and extend wrists, radially and ulnarly deviate wrists, and flex and extend elbows. Necessary adjustments to the channel settings or sensors were made.
22. The subject was asked to move around to see if movement was impeded by any of the sensors or tape.
23. A visual check was performed to ensure all cables were secured to subject.
24. Markers for video capture software were attached to the participant's skin using two-sided hypo-allergenic tape.
25. The participant entered the truck cab.

26. The participant completed the software tasks in the first location with the investigator reading a script to the participant for the work order form, activity form, and map search and the participant completed the touching task and keying task without narration.
27. After the tasks were completed in the first location the participant was asked to complete a subjective assessment form for that location.
28. Steps 26 and 27 were repeated for the next three computer locations.
29. The participant was asked to exit cab.
30. All sensors and tape were removed.
31. Participant was allowed to use the restroom and change clothes.
32. The participant provided an ordinal rank of the computer locations.
33. Fourteen anthropometric dimensions of participant were measured without shoes (**Figure 3.35**).
34. Participant was thanked and released.

Figure 3.33. Maximal calibration apparatus setup for pectoralis major (Left) and middle deltoids (Right)

Figure 3.34. Maximal calibration apparatus setup for upper trapezius (Left) and erector spinae (Right)

3.13 Anthropometric Measurements

Thirteen anthropometric length measurements (two standing and eleven sitting, shown below) and weight were measured on each subject according to (Marklin, Saginus, Seeley, & Freier, 2010). The subjects were wearing a sleeveless t-shirt, jeans or shorts (pockets empty), and no shoes when they were measured. The protocol used is based on the Anthropometric Survey of U. S. Army Personnel (Gordon, 1989) except arm length (middle finger tip instead of thumb-tip) and interscye breadth (beam caliper instead of steel tape).

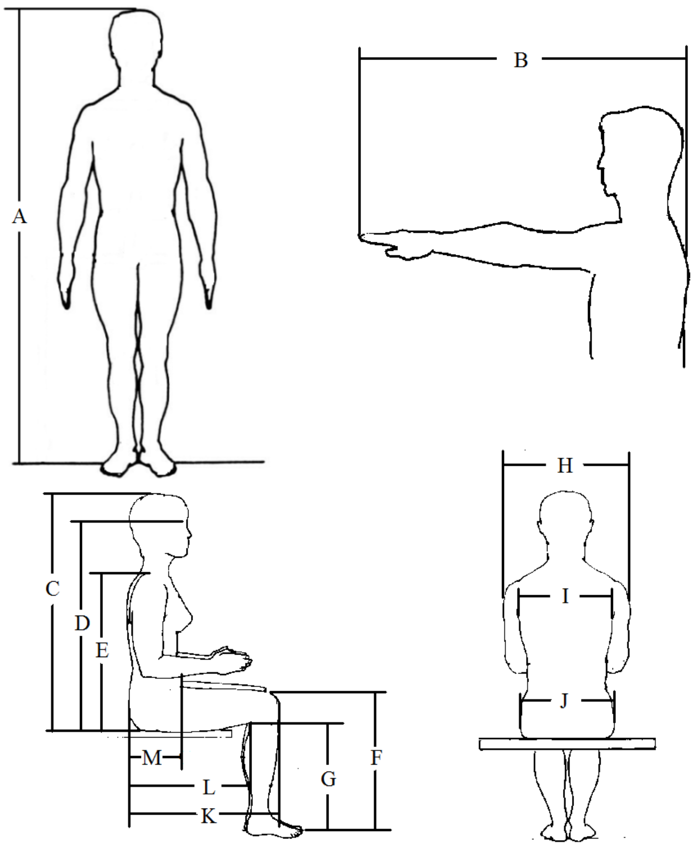


Figure 3.35. Thirteen anthropometric length measurements **(Marklin, Saginus, Seeley, & Freier, 2010)**

The standing dimensions were stature (A), and arm length (B). The sitting dimensions were sitting height (C), sitting eye height (D), shoulder height (E), knee height (F), popliteal height (G), shoulder breadth (H), interscye breadth (I), hip breadth (J), buttock-knee length (K), buttock-popliteal length (L), and trunk depth (M).

3.14 Data Collected and Data Conditioning

3.14.1 Data Collected

As outlined in 4.9 Software Tasks, there were 6 data collection periods for each location. The first 3 periods were during the work-order form and are classified as a keyboard task for the analysis as the subjects only use the keyboard and touchpad below the keyboard. The average time for the sum of the three trials was 45.2 sec. The next period occurred during the entire squares touching task and is classified as a touchscreen task for the analysis. The average time of this data collection was 28.2 sec. Data were collected during the entire letter keying task and are classified as a keyboard task for the analysis. The average time of this data collection was 29.7 sec. The last data collection period was during the second half of the map task and is classified as a touchscreen task for the analysis. The average time of this data collection was 29.8 sec.

3.14.2 Data Conditioning

The EMG data were first converted to %MVC (NIOSH, 1992) using eq. (1)., where V_{max} is the highest 1 second average of the voltage from the maximal calibration data for each muscle with a 250ms RMS filter, V_{rest} is the 1 second average of the voltage from the resting data for each muscle with a 250ms RMS filter, and V_{task} is the voltage of each datum point collected with a 250ms RMS filter. V_{max} and V_{rest} are constant for each subject.

$$\%\text{MVC} = \frac{V_{task} - V_{rest}}{V_{max} - V_{rest}} \tag{1}$$

After the raw EMG signal is converted to %MVC the mean and 90th percentile for each data collection period were calculated. For the 3 work order data collection periods, the weighted average of the mean and 90th percentile %MVC of the 3 trials was then calculated resulting in 2 keyboard trials and 2 touchscreen trials. The 2 keyboard trials and 2 touchscreen trials were then averaged for analysis. Data conditioning for each location yielded 4 data points: an average mean %MVC for keyboard and touchscreen and an average 90th percentile %MVC for keyboard and touchscreen.

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 except the 10th percentile joint angle was also included resulting in 6 data points for each location: an average mean angle for keyboard and touchscreen, an average 10th percentile angle for keyboard and touchscreen, and an average 90th percentile angle for keyboard and touchscreen.

The shoulder angle, shoulder displacement, and hip displacement for each frame were directly output in the correct units by custom designed LabVIEW software. The same conditioning methods were applied as the wrist and elbow joint angle data resulting in 6 data points for each measure and each location: an average mean angle/displacement for keyboard and touchscreen, an average 10th percentile angle/displacement for keyboard and touchscreen, and an average 90th percentile angle/displacement for keyboard and touchscreen.

The performance and subjective assessment data required no conditioning.

3.15 Statistical Analysis

Mixed model repeated measures Analysis of Variance (ANOVA) were conducted for each dependent variable with the factors: Subject Size (between subjects), Location (within subjects), and Task (within subjects). A 3-way ANOVA was used for the right side upper extremity (pectoralis major, middle deltoid, upper trapezius, wrist ext/flex and uln/rad deviation, and elbow flexion) and trunk dependent variables (left and right erector spinae, shoulder angle and displacement, and hip displacement). Task was not included for the left upper extremity variables (pectoralis major, middle deltoid, upper trapezius, wrist ext/flex and uln/rad deviation, and elbow flexion) as the left hand was not used for the touchscreen task, therefore only the keyboard data were used in the 2-way ANOVA of Size and Location.

For the 3-way ANOVA, if there was a significant Location X Task interaction, a post-hoc Tukey test with the 28 Location/Task combinations was performed to determine which of the combinations were significantly different. If no significant interaction existed, but Location had a significant effect, a post-hoc Tukey test with the 6 Location combinations was performed to determine which of the Locations were different. For the left upper extremity variables, if there was a significant Size X Location interaction, a post-hoc Tukey test with the 28 Size/Location combinations was performed to determine which of the combinations were significantly different. If no significant interaction existed, but Location had a significant effect, a post-hoc Tukey test with the 6 Location combinations was performed to determine which of the Locations were different.

A regression analysis was performed to determine if any of the anthropometric variables could be used to predict any of the dependent variables for each location. A backwards stepwise multiple regression model starting with all 14 anthropometric measures was used. A p-value of 0.05 was used to enter and remove variables.

Four 1-way ANOVAs were used to analyze the performance data. For the keyboard and touchscreen task, a 1-way ANOVA was used to determine if Location was a main effect for task completion time and also for misses (2 ANOVAs for each task).

For the subjective assessment data, a non-parametric test (Friedman's statistic) was used to determine if there was a difference in the subjective assessment of each location. If there was a significant main effect a Student-Newman-Keuls post-hoc test was used to determine which Locations were significantly different.

4 RESULTS

4.1 Subject Anthropometry

The summary statistics of the utility workers, general population and combined sample for the 13 anthropometric variables recorded for each subject are presented in **Table 4.1**. The average age (± SD) of the utility workers was 43.0 (10.0) years, general population 25.7 (6.7) years, and combined sample 33.9 (13.2) years. Gender, occupation, and injury/illness data can be seen in **APPENDIX D: BACKGROUND INFORMATION OF SUBJECTS**. The raw anthropometry data and demographic information of the subjects can be seen in **APPENDIX E: ANTHROPOMETERY OF SUBJECTS (RAW DATA)**.

It can be noted that the utility workers were larger on average for all of the measurements. This difference in size could lead to a difference in the results of the analysis of the effect of location on the dependent variables; thus, size was included in the analysis. A regression analysis was also used to see if any of the anthropometry variables can be used as predictors of the dependent variables.

Table 4.1. Summary statistics of the anthropometric variables for the utility workers, general population, and combined sample.

Variable	Statistic	Utility Workers (n=11)	General Population (n=11)	Combined (n=22)	Variable	Statistic	Utility Workers (n=11)	General Population (n=11)	Combined (n=22)
Weight [kgs]	Mean	89.3	63.6	76.4	Buttock-Knee Length [cm]	Mean	60.6	56.7	58.7
	SD	9.8	12.0	16.9		SD	3.2	2.0	3.3
	Min	74.9	46.0	46.0		Min	54.5	54.1	54.1
	Max	106.0	84.8	106.0		Max	65.9	59.9	65.9
Stature [cm]	Mean	177.6	165.0	171.3	Buttock-Popliteal Length [cm]	Mean	49.4	46.7	48.0
	SD	5.3	6.4	8.6		SD	2.8	1.9	2.7
	Min	169.2	157.6	157.6		Min	43.9	43.4	43.4
	Max	187.0	178.0	187.0		Max	54.0	49.3	54.0
Arm Length [cm]	Mean	84.8	76.1	80.5	Knee Height [cm]	Mean	54.7	50.2	52.5
	SD	5.8	3.4	6.4		SD	2.6	2.4	3.4
	Min	72.3	71.3	71.3		Min	49.9	47.0	47.0
	Max	95.5	82.0	95.5		Max	60.3	55.4	60.3
Sitting Height [cm]	Mean	92.6	87.3	89.9	Popliteal Height [cm]	Mean	43.8	41.1	42.4
	SD	3.1	3.1	4.1		SD	1.8	2.5	2.5
	Min	88.5	83.5	83.5		Min	39.9	37.0	37.0
	Max	98.0	93.5	98.0		Max	46.0	44.8	46.0
Sitting Eye Height [cm]	Mean	79.2	75.4	77.3	Shoulder Breadth [cm]	Mean	48.0	42.0	45.0
	SD	2.3	2.9	3.2		SD	2.2	3.5	4.2
	Min	75.5	71.6	71.6		Min	44.6	37.6	37.6
	Max	82.4	80.4	82.4		Max	52.5	47.9	52.5
Shoulder Height [cm]	Mean	61.9	58.7	60.3	Interscye Breadth [cm]	Mean	35.1	28.9	32.0
	SD	2.4	2.2	2.8		SD	2.9	2.4	4.1
	Min	58.5	55.1	55.1		Min	30.8	26.6	26.6
	Max	65.6	62.8	65.6		Max	39.5	34.1	39.5
Trunk Depth [cm]	Mean	25.1	20.4	22.7	Hip Breadth [cm]	Mean	37.5	34.4	35.9
	SD	2.8	3.8	4.1		SD	2.3	3.3	3.2
	Min	19.9	15.3	15.3		Min	34.3	31.0	31.0
	Max	28.5	27.4	28.5		Max	41.1	42.0	42.0

4.2 Analysis of Variance

The approach to the analysis for all of the dependent variables excluding the left upper extremity was a 3-way ANOVA including Size, Location, and Task. For the left upper extremity dependent variables (left pectoralis major, middle deltoid, upper trapezius, wrist, and elbow), the analysis only included Size and Location as independent variables. The main effects and interaction p-values for each dependent variable are shown in **Table 4.2**.

There was a significant 3-way interaction (S x L x T) for only 2 of the dependent variables (right elbow flexion and shoulder angle). There was a significant Location X Task interaction for right pectoralis major, right middle deltoid, right upper trapezius, right erector spinae, left erector spinae, right wrist extension/flexion, right wrist ulnar/radial deviation, and shoulder displacement. Location had a significant main effect for left middle deltoid, left wrist extension/flexion, left elbow flexion, and hip displacement. There was a significant Size X Location interaction for left wrist ulnar/radial deviation, and Size was a main effect for left elbow flexion.

Table 4.2. P-values for each effect (S – size, L – location, T – task) from the mixed model ANOVA. P-values in bold with red shading are <0.05. Left upper extremity dependent variables did not include task for analysis (black cells)

	Dependent Variable	S	L	T	S x L	S x T	L x T	S x L x T
Muscle Activity	**R Pectoralis Major**	0.0533	**0.0118**	0.0721	0.2491	0.4081	**<0.0001**	0.4964
	L Pectoralis Major	0.1817	0.4092		0.2207			
	R Middle Deltoid	0.4508	**0.0015**	**<0.0001**	0.4570	0.1440	**<0.0001**	0.4786
	L Middle Deltoid	0.2061	**0.0093**		0.2707			
	R Upper Trapezius	0.4735	**0.0002**	**<0.0001**	0.9040	0.2763	**<0.0001**	0.4304
	L Upper Trapezius	0.2030	0.4333		0.3081			
	R Erector Spinae	0.9725	0.0711	**0.0055**	0.0814	0.1710	**<0.0001**	0.7174
	L Erector Spinae	0.9816	**<0.0001**	**<0.0001**	0.4009	0.6806	**0.0106**	0.2518
Joint Angles/Displacement	**R Wrist Ext/Flex**	0.6926	**<0.0001**	**0.0006**	0.3358	0.1455	**<0.0001**	0.4002
	L Wrist Ext/Flex	0.1677	**<0.0001**		0.0812			
	R Wrist Uln/Rad Deviation	0.7258	**<0.0001**	**0.0197**	0.1465	0.2318	**0.0002**	0.5395
	L Wrist Uln/Rad Deviation	0.0992	**<0.0001**		**0.0454**			
	R Elbow Flexion	0.0688	**<0.0001**	**<0.0001**	**0.0324**	0.5382	**<0.0001**	**0.0203**
	L Elbow Flexion	**0.0283**	**<0.0001**		0.0671			
	Shoulder Angle	0.5544	**<0.0001**	**<0.0001**	0.2277	0.0965	**<0.0001**	**0.0050**
	Shoulder Displacement	0.3449	**<0.0001**	0.1939	0.7746	0.1774	**0.0002**	0.2296
	Hip Displacement	0.7151	**<0.0001**	0.1984	0.8950	0.3848	0.2476	0.2262

The dependent variables that were found to have the most significance are presented below. The allocation for the degrees of freedom, ANOVA tables, interaction plots, and multiple post-hoc comparisons for all of the dependent variable can be seen in **APPENDIX F: COMPLETE ANOVA RESULTS FOR BIOMECHANICS ANALYSIS**.

Shoulder Angle. There was a significant 3-way interaction for shoulder angle ($p=0.0050$). However, the Tukey post-hoc analysis revealed that there was not a significant difference between the Large and Small Subjects for the same Task in each Location. Therefore, the 3-way interaction was not considered for the post-hoc analysis. The Location X Task interaction was significant ($p<0.0001$) (**Figure 4.1**), and Size was not a main effect. The Keyboard and Touchscreen Tasks were significantly different in Locations A and B, but not Locations C and D. There was a significant difference between all of the Locations for the Keyboard Task and for the Touchscreen Task.

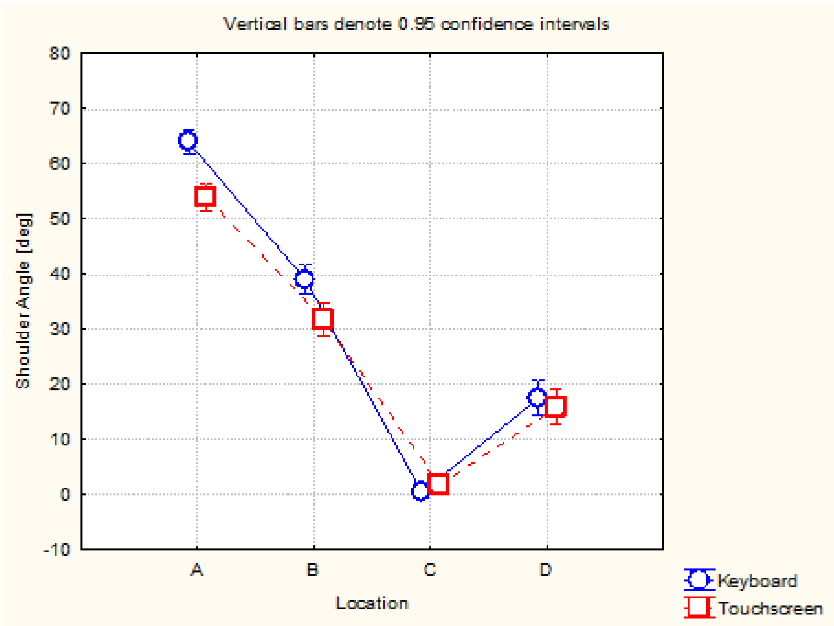


Figure 4.1. Plot of Location/Task interaction means for shoulder angle (degrees)

Right Elbow Flexion. The 3-way interaction was significant (*p=0.0203*). However, the post-hoc analysis showed no significant difference between Subject size for the same Task in each Location. The 3-way interaction was not considered in this analysis. The Location X Task interaction was significant (*p<0.0001*) and is shown in **Figure 4.2**; Size was not a main effect. There was a significant difference between Task in all of the Locations. For the Keyboard Task, there was not a significant difference between Locations A and B, but the rest of the Locations were significantly different. Locations A and B were not significantly different for Touchscreen Task also, and the rest of the Locations were significantly different.

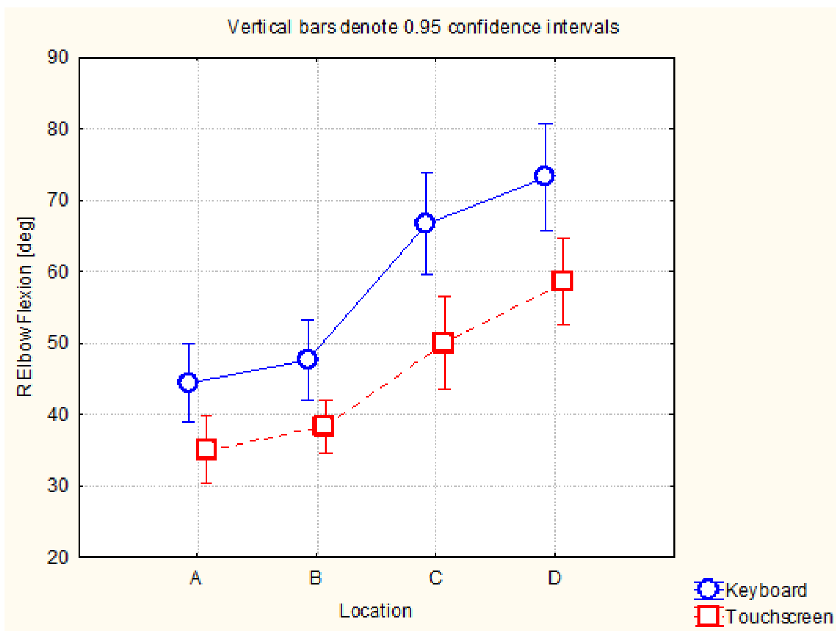


Figure 4.2. Plot of Location/Task interaction means for right elbow flexion (degrees)

Right wrist extension/flexion. The Location X Task interaction was significant (*p<0.0001*) for right wrist extension/flexion (**Figure 4.3**), and Size was not a main effect. There was a significant difference between Task in all of the Locations. Locations A and D were not significantly different for the Keyboard Task, and the rest of the Locations were significantly different. For the Touchscreen Task, there was no significant difference between Location A and the rest of the Locations; Locations B and C were also not significantly different, but they were both significantly different than D.

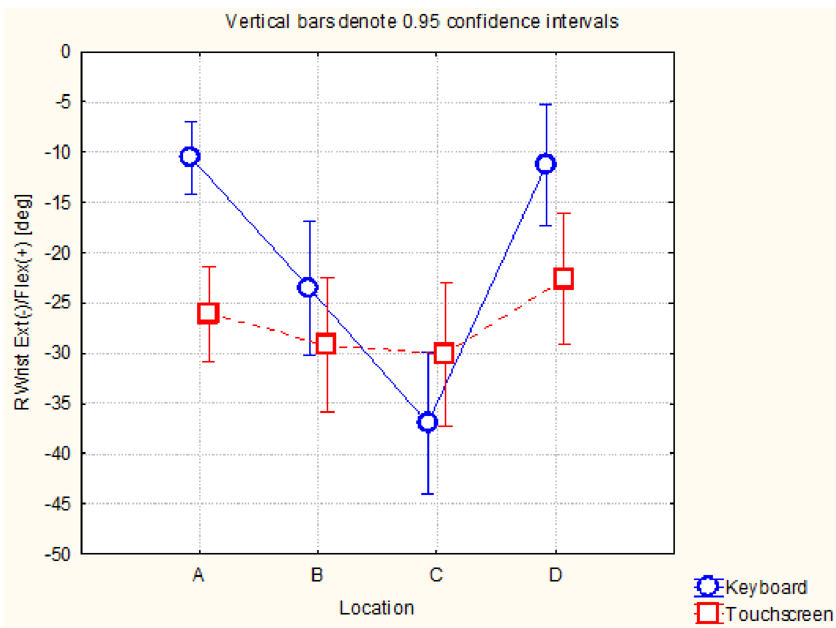


Figure 4.3. Plot of Location/Task interaction means for right wrist extension(-)/flexion(+) (deg)

Left wrist extension/flexion. Location was a main effect (*p<0.0001*). The Size X Location interaction was not significant (**Figure 4.4**), and the Size was not a main effect. All of the Locations were significantly different except for A and D.

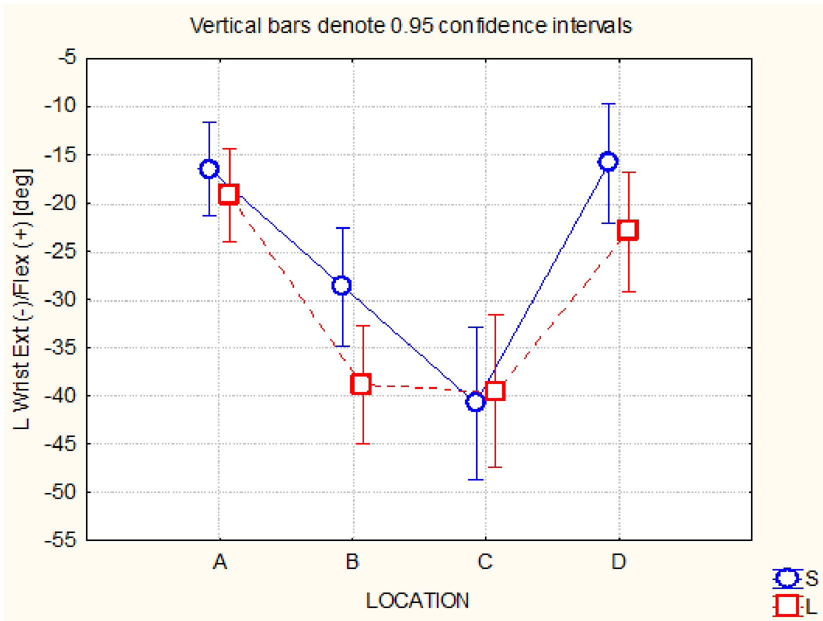


Figure 4.4. Plot of Size/Location interaction means for left wrist extension (-)/flexion (+) (deg)

Right Erector Spinae. The Location X Task interaction was significant ($p<0.0001$) (**Figure 4.5**). Size was not a main effect. The Keyboard task in Location C was significantly different from the rest of the Location/Task combinations. All of the other Location/Task combinations were not significantly different.

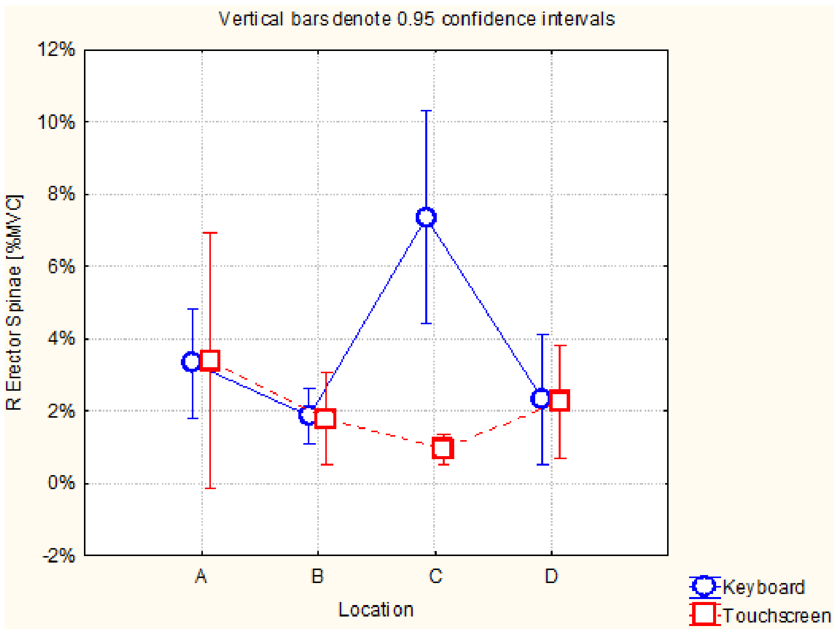


Figure 4.5. Plot of Location/Task interaction means for right erector spinae (%MVC)

Left Erector Spinae. The Location X Task interaction was significant for the left erector spinae (*p<0.0106*) (**Figure 4.6**). Size was not a main effect. The Keyboard and Touchscreen Tasks in Location A were not significantly different, but Task was significantly different in the rest of the Locations. For the Touchscreen Task, all of the Locations were significantly different except C and D. The Keyboard Task was significantly different between all of the Locations except C and D.

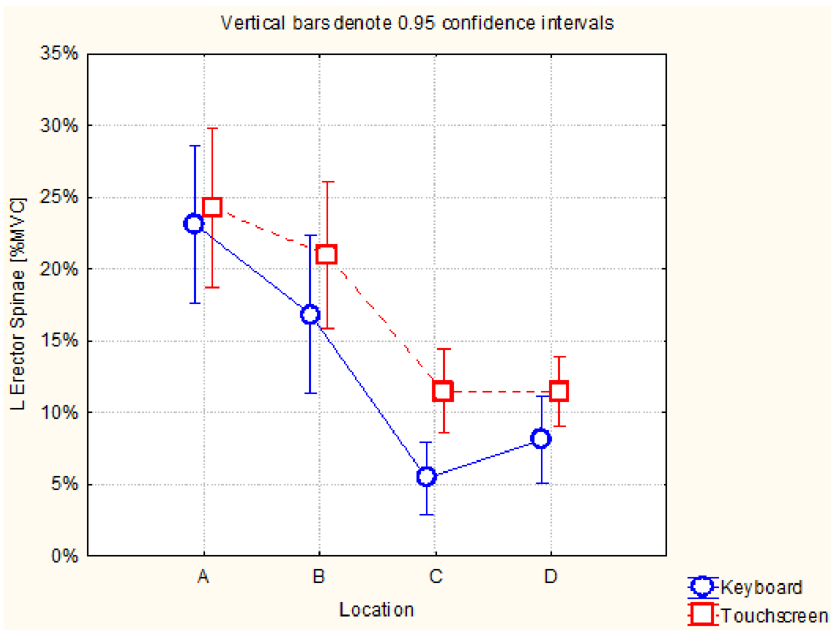


Figure 4.6. Plot of Location/Task interaction means for left erector spinae (%MVC)

Right Middle Deltoid. The Location X Task interaction was significant ($p<0.0001$), as shown in **Figure 4.7**. Size was not a main effect. The Touchscreen Task was significantly different than the Keyboard Task in each Location. The Touchscreen Task did not have a significant difference between Locations A and B or C and D; Locations A and D were significantly different from C and D. The Keyboard Task was not significantly different between any of the Locations.

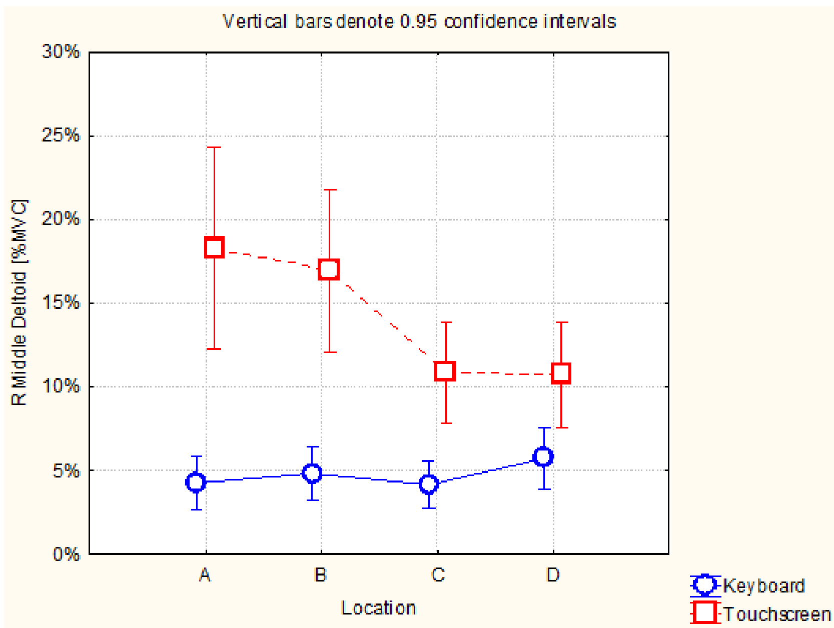


Figure 4.7. Plot of Location/Task interaction means for right middle deltoid (%MVC)

Left Middle Deltoid. For the left middle deltoid Location was a main effect (*p=0.0093*). The Size X Location interaction was not significant(**Figure 4.8**), and Size was not a main effect. Locations A and D were found to be significantly different; no significant difference was found between the rest of the Locations.

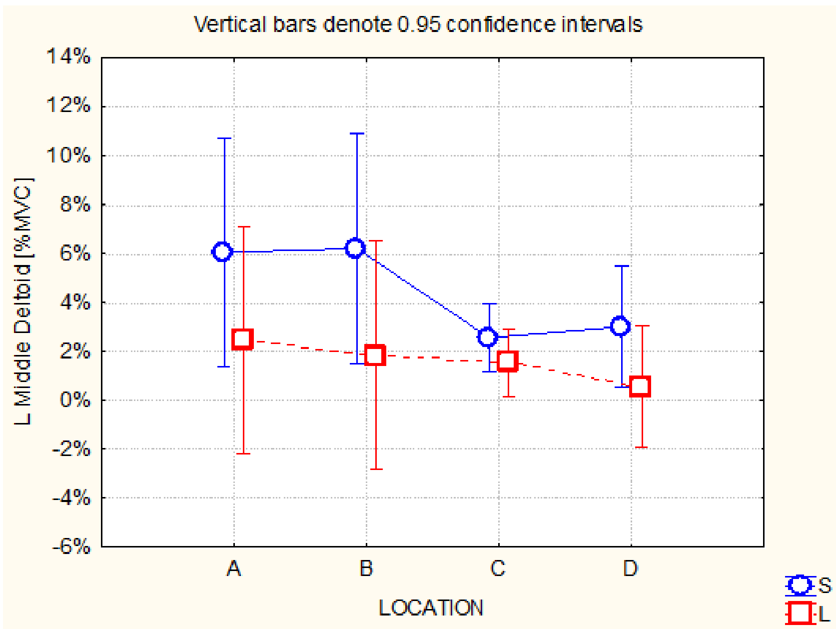


Figure 4.8. Plot of Size/Location interaction means for left middle deltoid (%MVC)

Right Upper Trapezius. The Location X Task interaction was significant for the right upper trapezius (*p<0.0001*) (**Figure 4.9**). Size was not a main effect. There was a significant difference between Task for all of the Locations except C. There was no significant difference between Locations A and B for the Touchscreen Task; Locations C and D were significantly different and were both significantly different from A and B. There was not a significant difference between any of the Locations for the Keyboard Task.

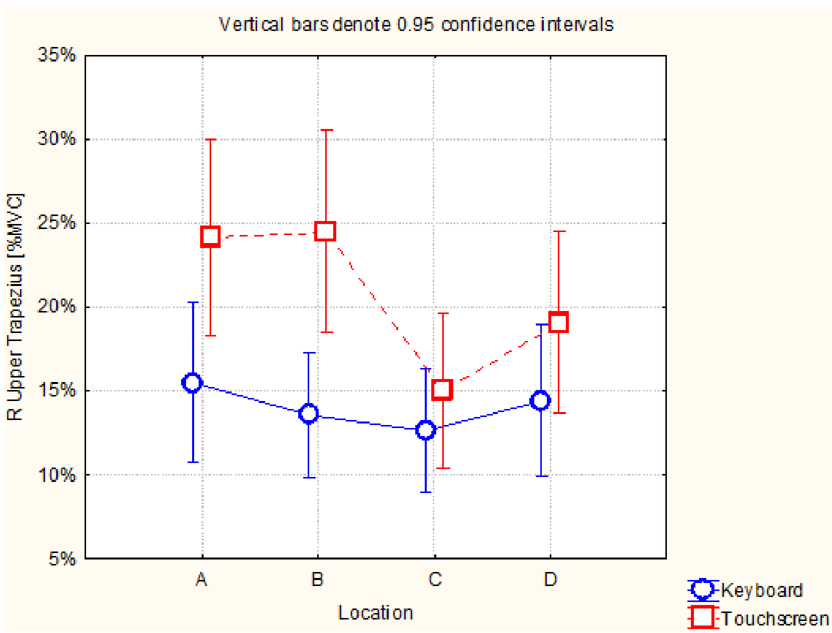


Figure 4.9. Plot of Location/Task interaction means for right upper trapezius (%MVC)

The allocation of the degrees of freedom and ANOVA results for all of the dependent variables with summary statistics, interaction plots, and post-hoc tests can be seen in **APPENDIX F: COMPLETE ANOVA RESULTS FOR BIOMECHANICS ANALYSIS**.

4.3 Regression Analysis

A regression analysis was performed to determine if any of the anthropometric variables measured could be used to predict the joint angles or muscle activity. A backwards stepwise regression starting with all 14 of the anthropometric measurements was used. Location could not be included as a categorical predictor as this study was a repeated measures design. A separate regression had to be performed for each location. **Table 4.3** shows the multiple R^2 values for each regression equation. Almost of the regression equations were significant at the 0.05 level (except left pectoralis major in Location B).

This analysis is focused on the equations with multiple R^2 values greater than 0.6 (shaded in red in **Table 4.3**). Location A only had one regression equation with R^2 >0.6 (left elbow flexion). Locations B, C, and D had more significant regression equations.

Table 4.3. Multiple R^2 values for each regression equation. Values in bold have a p-value of <0.05. Values with red shading have a multiple R^2 value >0.60. Cells with "—" did not have a valid regression equation.

		Location			
	Dependent Variable	**A**	**B**	**C**	**D**
Joint Angles/Displacement	**R Wrist Ext/Flex**	**0.420**	--	--	--
	L Wrist Ext/Flex	**0.445**	**0.749**	--	--
	R Wrist Uln/Rad Deviation	**0.523**	**0.465**	**0.684**	**0.460**
	L Wrist Uln/Rad Deviation	**0.529**	**0.659**	**0.653**	--
	R Elbow Flexion	**0.375**	**0.491**	**0.529**	**0.553**
	L Elbow Flexion	**0.851**	**0.752**	**0.907**	**0.590**
	Shoulder Angle	**0.194**	--	--	**0.663**
	Shoulder Displacement	--	--	**0.564**	**0.545**
	Hip Displacement	--	--	**0.544**	**0.770**
Muscle Activity	**R Pectoralis Major**	**0.444**	**0.516**	**0.710**	**0.552**
	L Pectoralis Major	**0.422**	0.257	**0.283**	**0.237**
	R Middle Deltoid	**0.193**	**0.218**	--	--
	L Middle Deltoid	**0.358**	**0.204**	**0.198**	**0.250**
	R Upper Trapezius	--	**0.320**	--	--
	L Upper Trapezius	**0.338**	**0.275**	**0.582**	**0.499**
	R Erector Spinae	**0.594**	**0.889**	**0.663**	--
	L Erector Spinae	**0.385**	--	**0.727**	**0.831**

These abbreviations were used for the following equations: St – Stature (cm); A L –Arm Length (cm); S H – Sitting Height (cm); S E H – Sitting Eye Height (cm); Sh H – Sitting Shoulder Height (cm); T D – Trunk Depth (cm); B-K L – Buttock-Knee Length (cm); B-P L – Buttock-Popliteal Length (cm); K H – Knee Height (cm); P H – Popliteal Height (cm); Sh B – Shoulder Breadth (cm); I B – Intersceye Breadth (cm); H B – Hip Breadth (cm); W – Weight (kg)

The left wrist ulnar (-)/radial (+) deviation had a significant regression equation for Location B and C (**Eq. 1** and **2**). Shoulder height and shoulder breadth appeared in both equations, and sitting height, knee height, interscye breadth and hip breadth were predictors for Location C.

L Wrist Uln/Rad Deviation – Location B (deg)

$$\hat{y} = -96.65 - 0.79(\text{A L}) + 1.31(\text{Sh H}) - 1.91(\text{Sh B}) \tag{1}$$

L Wrist Uln/Rad Deviation – Location C (deg)

$$\begin{aligned}\hat{y} = &-130.10 - 2.19(\text{S H}) + 3.79(\text{Sh H}) + 1.12(\text{K H}) + 2.09(\text{Sh B}) \\ &- 2.88(\text{I B}) + 1.10(\text{H B})\end{aligned} \tag{2}$$

Location A, B, and C had significant regression equations for left elbow flexion. The upper leg length variables (B-K L and B-P L) were both predictors in Location A and B with contradicting signs of almost equal magnitude. For all 3 locations, an increase in lower leg height (K H or PH) increases the left elbow flexion angle (brings hands closer to body (**Eq. 3**, **4**, and **5**). A decrease in sitting eye height increases the left arm extension for Locations A and B and decreases extension for Location C (S H).

L Elbow Flexion – Location A (deg)

$$\hat{y} = 206.38 - 1.97(\text{S E H}) - 4.07(\text{B-K L}) + 3.59(\text{B-P L}) + 1.94(\text{P H}) - 1.43(\text{H B}) \tag{3}$$

L Elbow Flexion – Location B (deg)

$$\hat{y} = 244.38 - 1.68(\text{A L}) - 2.47(\text{S E H}) - 6.58(\text{B-K L}) + 4.23(\text{B-P L}) + 5.55(\text{K H}) \tag{4}$$

L Elbow Flexion – Location C (deg)

$$\begin{aligned}\hat{y} = &159.77 - 2.50(\text{St}) + 2.39(\text{S H}) - 2.93(\text{Sh H}) + 2.38(\text{B-P L}) + 4.22(\text{P H}) \\ &+ 2.11(\text{I B}) - 0.88(\text{W})\end{aligned} \tag{5}$$

Right erector spinae had 2 regression equations with multiple R^2 values greater than 0.6: Location B and C (**Eq. 6** and **7)**. Both upper leg lengths (B-K L and B-P L) were predictors for Location B with contradicting signs. The lower leg height measurements (K H and P H) were predictors in both equations with contradicting signs. An increase in shoulder breadth decreased the right erector spinae activity in both

Locations. An increase in sitting height decreases the muscle activity for both Locations; however, increasing sitting eye height increases the muscle activity.

R Erector Spinae – Location B (%MVC)

$$\begin{aligned}\hat{y} = &-1.79 - 0.45(\text{S H}) + 0.56(\text{S E H}) + 1.14(\text{B-K L}) - 0.73(\text{B-P L}) \\ &-1.62(\text{K H}) + 1.72(\text{P H}) - 1.08(\text{Sh B}) + 0.94(\text{I B})\end{aligned} \quad \textbf{(6)}$$

R Erector Spinae – Location C (%MVC)

$$\begin{aligned}\hat{y} = &\,3.25 + 1.14(\text{St}) - 2.10(\text{S H}) + 1.29(\text{S E H}) - 2.70(\text{K H}) + 2.10(\text{P H}) \\ &-1.77(\text{Sh B}) + 0.37(\text{W})\end{aligned} \quad \textbf{(7)}$$

Two of the locations (C and D) had significant regression equations for left erector spinae (**Eq. 8** and **9**). Both upper leg lengths (B-K L and B-P L) were predictors for Location C and D with contradicting signs. Increasing lower leg height (K H) decreases muscle activity for both Locations. Taller subjects (stature) had increased left erector spinae activity in Locations C and D.

L Erector Spinae – Location C (%MVC)

$$\begin{aligned}\hat{y} = &-67.95 + 2.57(\text{St}) - 1.63(\text{Sh H}) + 0.91(\text{T D}) - 4.29(\text{B-K L}) \\ &+ 4.47(\text{B-P L}) - 3.10(\text{K H}) - 1.93(\text{Sh B})\end{aligned} \quad \textbf{(8)}$$

L Erector Spinae – Location D (%MVC)

$$\begin{aligned}\hat{y} = &-91.32 + 1.91(\text{St}) - 5.66(\text{B-K L}) + 7.94(\text{B-P L}) - 3.00(\text{K H}) \\ &- 2.82(\text{I B}) - 1.67(\text{H B}) + 0.41(\text{W})\end{aligned} \quad \textbf{(9)}$$

4.4 Performance Analysis

Location was a main effect (*p=0.0375*) for time to complete the Touchscreen Task. Location C (27.3 (±3.0) sec) was significantly different than Location A (28.9

(±2.4) sec). Locations B and D had an average time of 28.0 (±2.9) sec. There was no significant difference for accuracy for the Touchscreen Task with an average of 0.3 misses. There was no significant difference in accuracy or time to complete the Keyboard Task across all 4 computer locations. The mean time to complete the keyboard task was 29.3 sec with 0.2 misses. Details of task performance are shown in **APPENDIX H: COMPLETE PERFORMANCE RESULTS**.

4.5 Subjective Assessment Analysis

Participants used a 7-point Likert scale to rate the locations for each measure of subjective assessment: comfort, ease of use, and like/dislike for each location, and productivity for each task in each location (**Table 4.4**). Location D was rated highest of all locations for all subjective assessment measures with Location C following closely.

A Friedman's test (ANOVA) was used to determine if there was a significant difference between the locations from the participant's answers. Location was a main effect for all 6 of the subjective assessment questions and the overall rank.

Participants were also asked to rank their preference of computer locations from worst to best (1 to 4) (Overall Rank in **Table 4.4**). The order of worst to best ranking of locations was A, B, C, and then D. Location D was chosen the most preferred with an average rank of 3.41 while location A was rated the least preferred with an average rank of 1.09. See **APPENDIX I: COMPLETE SUBJECTIVE ASSESSMENT RESULTS**.

Table 4.4. Summary statistics of subjective assessment data

		Location			
		A	**B**	**C**	**D**
Comfort	**Mean**	2.05	3.55	4.86	5.64
	Median	2.00	3.00	5.00	6.00
	Std Dev	0.79	1.47	1.13	0.73
	Min	1.00	1.00	3.00	4.00
	Max	3.00	6.00	7.00	7.00
Ease of Use	**Mean**	2.27	3.91	4.95	5.64
	Median	2.50	4.00	5.00	6.00
	Std Dev	1.08	1.11	1.33	0.73
	Min	1.00	2.00	2.00	4.00
	Max	5.00	6.00	7.00	7.00
Like/Dislike	**Mean**	2.23	3.77	4.73	5.27
	Median	2.00	4.00	5.00	5.50
	Std Dev	0.87	1.15	1.03	0.83
	Min	1.00	1.00	3.00	4.00
	Max	4.00	6.00	7.00	6.00
Productivity - Work Order Form	**Mean**	3.18	4.27	5.05	5.77
	Median	3.00	4.00	5.00	6.00
	Std Dev	1.22	1.12	1.13	0.53
	Min	2.00	2.00	2.00	5.00
	Max	6.00	6.00	6.00	7.00
Productivity - Touching Task	**Mean**	3.77	4.64	5.86	5.95
	Median	3.00	4.00	6.00	6.00
	Std Dev	1.34	1.14	1.04	0.58
	Min	2.00	3.00	2.00	5.00
	Max	6.00	7.00	7.00	7.00
Productivity - Keying Task	**Mean**	3.36	4.14	4.64	5.82
	Median	3.00	4.00	5.00	6.00
	Std Dev	1.36	1.04	1.29	0.66
	Min	1.00	2.00	2.00	4.00
	Max	6.00	6.00	7.00	7.00
Overall Rank	**Mean**	1.09	2.50	3.00	3.41
	Median	1.00	2.00	3.00	3.50
	Std Dev	0.29	0.86	0.87	0.67
	Min	1.00	1.00	1.00	2.00
	Max	2.00	4.00	4.00	4.00

5 DISCUSSION

5.1 General

Utilities and other organizations such as police and fire departments that require mobile mounted computers in their vehicles have, until now, had little, if no guidance for their installation in vehicles. They have relied on a limited number of vendors to install these devices, and upon their IT (information technology) departments or outside consultants to select hardware and software. Making mobile computers work in vehicles for field operations has often been a haphazard, trial and error process.

The present study was designed to provide utilities with recommendations on the location of a mobile computer in a vehicle cab, based on ergonomics principles and biomechanical data. Four common Locations of mobile computers in vehicle cabs were tested. Two of the Locations (C and D), which are located close to the driver's trunk, are recommended. In these Locations, workers' performance using the mobile computer is the same as the other Locations tested (in front of and centered on the passenger seat), and participants overwhelmingly rated the 2 recommended Locations higher in terms of ease of use, productivity, and preference. Utilities now have quantitative biomechanical and user preference data to locate a 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. However, each vehicle cab should be assessed individually, and utility personnel must take into consideration whether the recommended Locations of a mobile computer are appropriate for the vehicle cab of interest.

5.2 Biomechanical Loading

Hypothesis 1: *Placing the laptop as close as possible to the side of the steering wheel will reduce biomechanical loading on the participant, compared to the other location.*

Location was a significant factor, either in an interaction or as a main effect, for all of the muscle activity (except left upper trapezius) and joint angle dependent variables. Locations on the passenger side of the vehicle (A and B) typically required more muscle force to complete the tasks. The right middle deltoid exerted about 7 %MVC more for the touchscreen task in Locations A and B than Locations C and D. For the touchscreen task Locations A and B required nearly 25 %MVC compared to 15 %MVC in Location C for the right upper trapezius. For the left erector spinae Locations A and B required 17-24 %MVC for both tasks and Locations C and D required 5-11.5 %MVC. The Location X Task interaction was significant or Location was a main effect for the right and left pectoralis major, left middle deltoid, and right erector spinae; however, the results of these dependent variables are not of practical significance as all of the conditions were under 8 %MVC.

The joint angles were also significantly affected by Location. The right elbow had little flexion (35-47 deg) in Locations A and B for both tasks, but were held closer to the body in Locations C and D (47-80 deg). The left elbow followed a similar trend with 13-28 deg of flexion in Locations A and B and 45-75 deg in Locations C and D. Subjects had to rotate their shoulders away from the back rest more in Location A, 53-66 deg shoulder angle, and Location B, 31-41 deg, compared to Location C, 0 deg, and D, 15-19 deg. The right and left wrists had the highest extension in Location C for the keyboard task as the keyboard was placed on the steering wheel. Wrist extension in this Location can be reduced by placing the keyboard on a flat stand. Locations A and D were not significantly different had had the lowest wrist extension for the keyboard task. The right and left wrist ulnar deviation was highest in Location D, but closer to neutral in Locations B and C.

On the whole biomechanical loading on the participant in reduced by placing the mobile computer closer to the steering wheel than on the passenger side.

5.2.1 Muscle Fatigue

The relatively high EMG activity of the left erector spinae, right deltoid, and right trapezius was measured immediately when the user operated the mobile computer in the Locations near the passenger seat. Thus, the process of muscle fatigue started when the arms were elevated and the trunk was twisted. If users were to operate a mobile computer in a Location that required arm elevation and trunk twisting posture at the levels measured in the present study, then muscle fatigue would develop after only 10 min of sustained usage. Some utilities think that infrequent and short duration usage does not affect occupational health. This assumption is not true if a mobile computer were placed in Locations that required arm elevation and trunk twisting measured in this study. Short durations (10 min or more) or shorter durations performed frequently (resulting in cumulative fatigue) will produce muscle fatigue in the deltoid and erector spinae, which will require rest time for the muscle to recuperate. If a user does not provide sufficient rest time for the muscle, then fatigue will accumulate and develop with subsequent exertions. Additionally, arm elevation and trunk twisting, even with short duration, may increase the risk of reoccurrence of MSDs in those users who have had MSDs in the past and also increase the risk to those who are predisposed.

Based on measurement and analysis of EMG data, the activity of 3 primary muscles (left erector spinae, right deltoid, and right trapezius) required to support the trunk and upper extremities in the tested mobile computer Locations showed that the 2 Locations C and D reduced %MVC to less than 15%, compared to over 15% MVC for the 2 computer Locations near the passenger seat (A and B). 15% MVC is a critical level of EMG activity for isometric muscle contractions as it is the threshold over which localized muscle fatigue can develop (Rohmert, 1960). The left erector spinae muscle was tensed over 15% MVC because the trunk was twisted significantly for users to reach the computer located near the passenger seat with their left hand (for typing tasks). Likewise, in order to use the computer in Locations A and B, a user exerted over 15% MVC in the right deltoid muscle in order to elevate the right arm horizontally (shoulder abduction angle near 90 deg) and maintain an extended arm posture (elbow angle under 40 deg).

According to studies performed by Rohmert (1960), a muscle contracted isometrically (a static contraction in which the muscle length is not changing) at 15% MVC or less has indefinite endurance time theoretically, or a very long endurance time in the practical sense. However when a muscle is exerted over 15% MVC tension, then muscle fatigue develops and reduces endurance time significantly. At 20% MVC, which is the approximate level of tension that the left lower back muscle (erector spinae) and right shoulder muscle (deltoid) exerted for a participant to use the mobile computer in the

Locations near the passenger seat, endurance time is reduced to approximately 10 min or less (Rohmert, 1960). After 10 min of exertion at 20% MVC level, the user will not be able to maintain the same level of tension due to physiological changes in the muscle, and thus the user will need to change posture or take a rest. Blood circulation in the muscle is impaired when a muscle is fatigued. Unimpeded blood flow enables a muscle to use its contractile and metabolic processes optimally, but when blood flow is impeded, metabolic byproducts such as lactic acid accumulates, and the muscle is no longer able to maintain the same level of tension. Severe muscle pain can develop if the user attempts to maintain the same level of tension when a muscle is fatigued.

5.2.2 Shoulder Tendinitis

The arm posture required for using the mobile computer in the Locations near the passenger seat expose the user to shoulder tendinitis. Those users who have had shoulder injuries in the past have even greater risk. The Locations near the driver seat (C and D) require much less arm elevation and present much lower risk of shoulder tendinitis.

Based on video analysis, participants elevated their arms approximately 90 deg in order to use the mobile computer located near the passenger seat (A and B). The experimenter required all participants to type with both hands so all participants elevated both arms when they performed the typing tasks for Locations A and B. The experimenter required each participant to conduct the touchscreen tasks with only the right hand, so the right arm was elevated for these tasks.

Elevation (abduction and forward flexion) of the arms, particularly at the angle required for using the computer in the Locations near the passenger seat, increases the risk of shoulder tendinitis. Kuorinka and Forcier (1995) conducted an extensive review of the literature associating shoulder posture and risk of shoulder tendinitis, and they found that occupations that required workers to elevate the arms (abduction in the frontal plane and flexion in the sagittal plane) had a much higher risk of shoulder tendinitis than the control group. A noteworthy study by Bjelle et al. (1981) revealed that assemblers with acute shoulder pain (myofascial syndrome and tendinitis) elevated their arms more frequently and with longer duration during compared to the control group.

The etiology (anatomical cause) of shoulder tendinitis can occur from degeneration of the shoulder tendons that elevate the arm, resulting in impingement of the tendons (Kuorinka & Forcier, 1995). When the arm is elevated, the supraspinatus tendon is compressed in the coracoacromial arch. Chronic bursitis can develop along with partial or complete tears of the rotator cuff tendons. Workers with long-term disability due to bursitis or tears of the rotator cuff tendons usually have impingement syndrome. Kuorinka and Forcier (1995) theorize that elevation (abduction or flexion) as low as 30 deg could reduce blood circulation in the tendons that that elevate the arm, thus increasing the risk of shoulder tendinitis.

5.2.3 Low Back Pain

In the present study, most of the participants reported that one of the chief reasons they did not like the mobile computer Locations near the passenger seat was that it required twisting the trunk. Based on trunk anatomy and subjective discomfort responses from the participants in the present study, 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.

Trunk angle as measured from above the cab by the angle of the shoulders with respect to the driver's seat back revealed that participants had to significantly twist their trunk in order to reach the computer Locations near the passenger seat. Locations A and B required approximately 60 and 35 deg of trunk twist, respectively, at the shoulder level whereas the recommended Locations (C and D) required around 0 and 17 deg, respectively. Although measurement of 60 deg of torso twist at the shoulder level does not mean that the trunk is twisted 60 deg at the lower back level (due to 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 in order 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.

The epidemiology literature reports that twisting of the trunk while exerting applied axial torque increases the risk of low back pain (LBP) (Marras, The Working Back: A Systems View, 2008). A static, twisted trunk posture under with no axial external torque, which is the posture required for using the computer in the Locations near the passenger seat, has not been reported as causal in the epidemiology literature. However, this does not mean that static, twisted trunk postures do not increase the risk of LBP. Studies that calculated the odds ratios of risk of LBP with reference to trunk posture were performed in industries where workers moved their trunks dynamically, such as manufacture of concrete elements (Burdorf, Govaert, & Elders, 1991), automotive assembly (Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991), and manual material handling (Marras, et al., 1995). Marras et al. developed a model that predicted risk of LBP based on trunk posture and movement. The authors reported that average trunk twisting velocities as low as 9 deg/sec, while supporting an external load, can place the worker at high risk of reporting LBP. Static trunk angle was not reported as a risk factor of LBP in the model developed by Marras et al., possibly because sedentary jobs that required static, twisted torso posture were not measured in this study.

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-Asl, Shrivastavi, and Ahmed (1984, 1985) 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. Subjective reports of discomfort corroborate the theoretical cause-effect relationship between static, twisted trunk posture and LBP.

5.3 Performance

Hypothesis 2: *Placing the laptop as close as possible to the side of the steering wheel will improve the participant's performance completing the tasks.*

This hypothesis was rejected. Location was not a main effect for accuracy or time to complete the keyboard task or for accuracy for the touchscreen task. Location was a main effect for time to complete the touchscreen task. The difference of 1.6 sec between

Locations A and C was significant. There is not enough evidence to suggest that the Location of the mobile computer has an effect on user performance.

5.4 Subject Size

Hypothesis 3: *Larger participants will have less biomechanical loading compared to smaller participants for locations farther from the steering wheel*.

There was a significant Size X Location X Task interaction for right elbow flexion and shoulder angle. However, the post-hoc analysis for right elbow flexion and shoulder angle indicated that there was not a significant difference between the large and small subjects for the same task type in each Location. There was a significant Size X Location interaction for left wrist ulnar/radial deviation, but there was not a significant difference between Size within each Location for left wrist ulnar/radial deviation. Size was also a main effect for left elbow flexion. The post-hoc analysis for left elbow flexion did not show a significant difference in subject size for Locations A and B.

Size was not a main effect or part of a significant interaction for the rest of the joint angle or muscle activity dependent variables. There is not enough evidence to accept this hypothesis. On the whole, subject size does not have an effect on biomechanical loading when using a mobile computer in a truck cab even for the Locations on the passenger side of the vehicle.

5.5 Subjective Assessment

Hypothesis 4: *Placing the mobile computer closer to the steering wheel will improve subjective assessment*.

Locations C and D (closest to the steering wheel) were the most preferred Locations based on all 6 of the subjective measurements used and the overall rank. Locations C and D were not significantly different for all but 1 of the subjective measurements. This indicates that the subjects prefer the mobile computer to be closer to the steering wheel than the passenger side. One of the possible reasons the subjects rated Location C slightly lower than D was the need for touch typists (most of the utility workers) to turn their head away from the screen to use the keyboard. For the keyboard tasks, this required the subject to frequently have to look back-and-forth. Location C might have had higher user preference rating for this or other system differences from the laptop computer used for the rest of the Locations.

5.6 Task Type

The analysis of the effect of Task is limited to the right side upper extremity and trunk dependent variables; however, the Location X Task interaction was significant for all of the muscle activity variables. The touchscreen task required 4-14% MVC more than the keyboard task in almost all of the Locations for the right middle deltoid, right upper trapezius, and left erector spinae. There was not a practical difference between the tasks for the right pectoralis major and right erector spniae as the muscle activity of all the conditions for these variables was below 8% MVC. The keyboard task required less muscle activity as the subjects could rest their palms on the base of the computer to reduce the load on their shoulders and back. As discussed earlier, an increase in muscle activity will lead to a quicker onset of muscle fatigue especially over 15% MVC (Rohmert, 1960).

The joint angles of the right upper extremity and truck were also affected by Task. The right wrist is significantly more extended for the touchscreen task than the keyboard task for all of the Locations other than C (keyboard was on the steering wheel), had more ulnar deviation in Locations B and C for the touchsceen task (no significant difference in A and D), and the right elbow was more extended for the touchscreen task in all of the Locations. On the contrary, the touchscreen task required a smaller shoulder angle in Locations A and B than the keyboard task. For the most part, joint angles were closer to neutral, especially for the wrist and elbow, for the keyboard task.

It is recommended for utilities to design software to use only the keyboard (including the trackpad) and purchase mobile computers that do not have touchscreens.

5.7 Cognitive Issues

As highlighted in the Literature Review section, *Human Factors* journal printed a special section on driver distraction. The term “driver distraction” indicates that the driver is distracted by using an in-vehicle technology while the vehicle is in motion. This includes all types of in-vehicle technologies such as navigation devices, cell phones, radio, and mobile computers, just to name a few.

In the articles reviewed, it is evident that there are input devices and displays that can minimize driver distraction while using an in-vehicle technology and driving simultaneously. One of the studies found that using word-based speech recognition required far less input time and reduced the cognitive load to use the device verses a letter-based or keyboard entry device. This allowed the driver to dedicate more time and attention to driving. Another study found that heads-up displays (on the windshield) allowed drivers to have better performance driving and using the in-vehicle technology than a dashboard mounted screen or an auditory device. The distraction from talking on a cell phone can be reduced by using a hands-free device, but the cognitive load of carrying on a conversation on a cell phone reduces driving performance compared to not talking on a cell phone.

Although driver distraction can be minimized by using heads-up displays and word-based speech recognition, driver distraction from using an in-vehicle technology cannot be eliminated. All of the studies found that driving performance decreased while the driver was using an in-vehicle technology. We recommend that utility workers do not use in-vehicle technologies while the vehicle is in motion. There are systems available that can disable mobile computers while the vehicle is in motion. Some of these systems also allow for selected components of the mobile computer to be disabled while the vehicle is in motion. For example, if the mobile computer is going to be used for navigation, the driver can input the destination while the vehicle is parked. Once the vehicle is in motion or in gear, the keyboard and monitor will be disabled, and the mobile computer will announce the turn-by-turn directions using the speakers. If a utility decides that is necessary to not disable a mobile computer while the vehicle is in motion or in gear, we recommend using heads-up displays and word-based speech recognition to operate the mobile computer.

5.8 Airbag Issues

It is important that in-vehicle technology be outside the air bag deployment zone when the airbags are deployable. According to telephone surveys with the service manager of four major vehicle dealers, airbags are deployable if the ignition is turned to "On", even if the vehicle is in "Park". The engine does not have to be running for the vehicle to be "On". The ignition should be "Off" when workers are using a mobile computer or any of its peripherals (i.e. keyboard) in the airbag deployment zone, even if the engine is not running and the vehicle is in Park. 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.

Electric utilities typically specify only a driver airbag for most field vehicles as these vehicles are intended for use by a driver only and no passenger. This is a cost saving practice and is feasible for most vehicles. This specification needs to be reviewed as some vehicles may have a passenger such as an apprentice. There is a concern that if the vehicle is involved in an accident, the path of travel of a mount, articulating arm, and mobile computer may be within the driver air bag deployment zone. Therefore, utilities need to obtain specific dimensions of the air bag deployment zone for the vehicles that will have in-vehicle technologies mounted. There are three zones of concern regarding air bag deployment:

- Driver airbag deployment zone
- Passenger airbag deployment zone
- Side airbag deployment zone

Within the *driver and passenger airbag* deployments zones, it is necessary to obtain the following air bag dimensions from the vehicle manufacturer:

- Diameter when full
- Depth when full
- Maximum rearward displacement during fill
- Lateral deployment zone

If a vehicle is equipped with *side airbags*, then it is also important to obtain the dimensions of the side airbag deployment zone. There are currently at least five different types of side airbags.

When the dimensions of the airbag deployment zone are determined, it is further recommended that:

- The utility or upfitter install all parts of the in-vehicle technology mounting device(s) outside of the airbag deployment zones.
- Utilities purchase mounting devices that *easily* move in and out of the airbag deployment zone. For example, when the occupant uses a notebook computer, then he should be able to easily slide the platform and mount into the recommended working location, which may be in the airbag deployment zone. In order to easily move the mobile computer, a touch activated system is preferred over levers that must be turned to move as well as lock and are not within easy reach, like most current systems. Touch activated systems are readily available. Then, when the notebook computer is not being used or the vehicle is moving, the occupant is able to quickly and easily move the platform and mount outside of the airbag deployment zone.

- Utilities purchase or develop and install software that deactivates the mobile computer monitor and keyboard whenever the vehicle is in gear and/or the mobile computer unit is in the air bag deployment zone.

The occupants should use in-vehicle technology such as GPS on a notebook computer *outside* of the airbag deployment zone when the vehicle is moving.

5.9 Recommendations

5.9.1 Mobile Computer Location

When installing mobile computers in vehicle cabs, utilities should consider installing the mobile computer in location D (**Figure 5.1** and **Figure 5.2)**). This location was preferred by most participants and shown to have the lowest risk of MSDs. In location D, the computer is placed to the right and in front of the driver's trunk so that the center of the computer keyboard (between the G and H keys) is 6 in. aft (in front) of the steering wheel reference point (SWRP), which is the center of the face of the steering wheel, and 17 in. to the right of the SWRP. A laptop mount should be selected so that the laptop can be easily moved to this location (6 in. aft and 17 in. to the side of SWRP) with adjustability of 2 to 3 inches in all directions from this point. A mount should enable a driver to move the mobile computer easily with a hand touch where it then remains in place.

If location D is not feasible in a vehicle, then Location C should be used for the mobile computer. In this location, the display is mounted vertically in front of the IP to the right of the steering wheel, and the keyboard can be used in various locations, such as on a platform attached to the display, on the steering wheel, on the lap of the driver, or on a platform (console) between the driver and passenger seats.

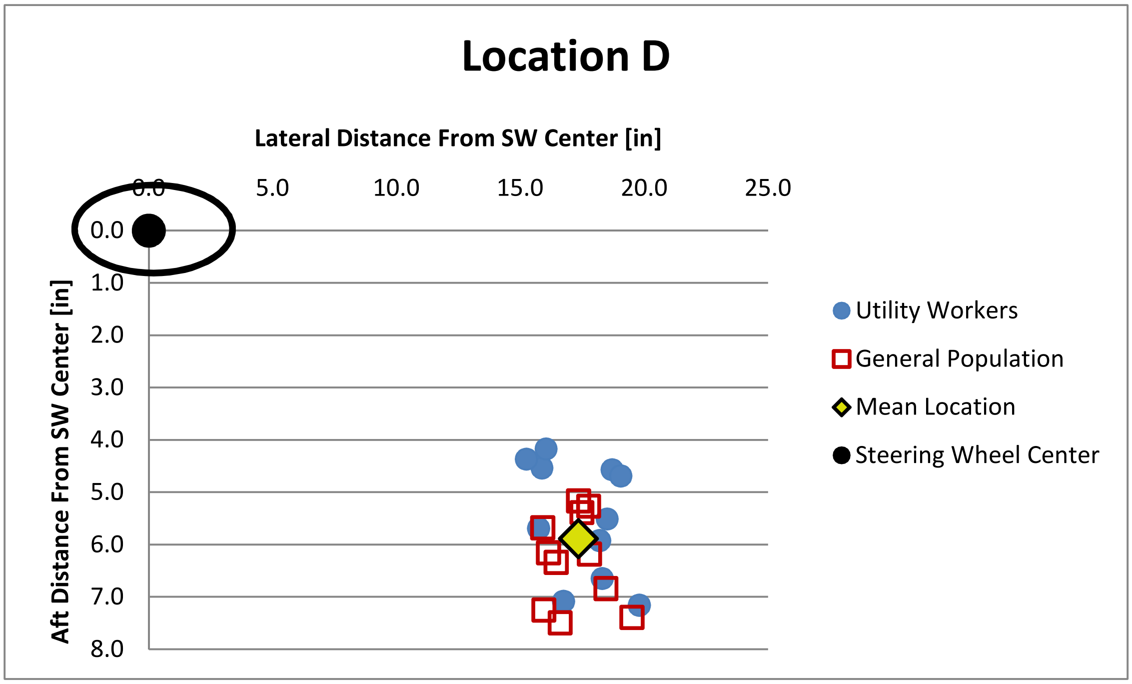


Figure 5.1. Location of the Middle of the Computer Keyboard (Between G and H Keys) Selected by the Participants and Experimenter for Location D, which is the Optimal Location for the Mobile Computer.

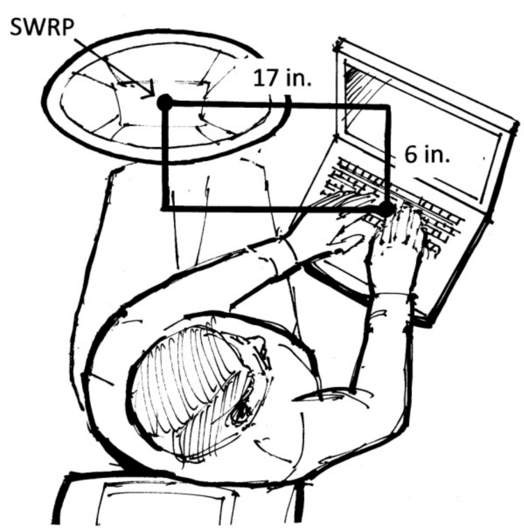


Figure 5.2 Top view of the Initial Set Up of a Mobile Computer in Location D (Optimal Location). The Point of Reference on the Mobile Computer is the Point Between the G and H keys.

If a display is mounted at the center of the IP as in Location C in the laboratory study, then it is important to consider screen, font size, visual clarity in display selection. Many of these MDT displays are considerably smaller than the display on laptop computers. Therefore, there may be visual issues, particularly for older workers or those with long legs who may adjust the seat to its most rearward position. Consideration should also be given to a night display. The IT department at a utility can be of assistance in reviewing what type and amount of data/text will be displayed and recommend alternative font sizes or colors.

The positioning of the keyboard should also be considered. Location C in the laboratory study placed the keyboard on the steering wheel, as shown in **Figure 5.3**. However, an alternative configuration that was not tested in the study is to locate the display as in location C, but locate the keyboard on a vendor provided platform either in front of or nest to the steering wheel.

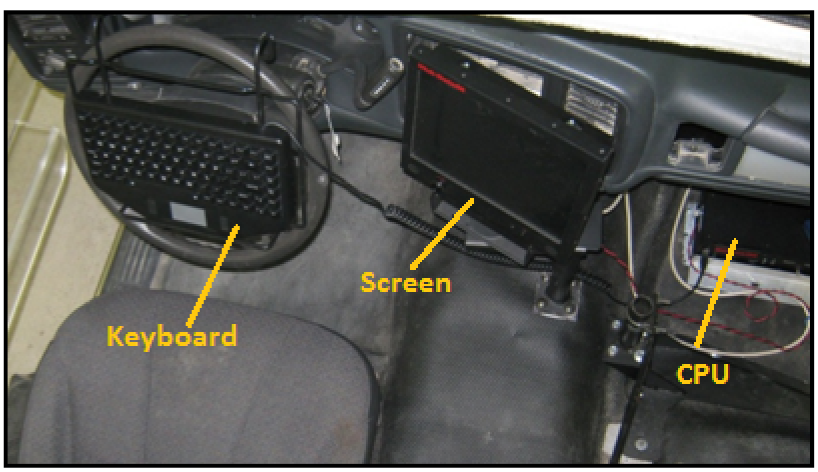


Figure 5.3. Location of the MDT Display in Location C.

6 CONCLUSIONS

The results of the biomechanical analysis provide strong evidence that placing the mobile computer close to the steering wheel reduces the biomechanical loading on the user. It was also found that users preferred the locations next to the steering wheel over the locations on the passenger. There was little effect of Location on performance as well.

The Size of the subjects in this study had little effect on the biomechanical loading of the participant. This indicates that the locations on the passenger side of the vehicle require higher biomechanical loading even for larger populations.

It was also found in this study that task has a significant effect on biomechanical loading. The touchscreen tasks required more muscle force and less neutral joint angles than the keyboard tasks.

It is recommended for utilities to place laptops as close as possible to the steering wheel using location C or D and the recommendations in the Discussion. It is also recommended to design software to primarily use keyboard and trackpad.

7 LIMITATIONS

7.1 Vehicle

The laboratory study was performed in the cab of a 2002 2-door Chevy Silverado pickup truck. However, electric utility companies use other manufacturers and models of pickup trucks and medium duty trucks in their fleets. Vehicle cab dimensions and layouts vary between manufacturers and types of vehicles. Seat dimensions, seat fore-aft travel, instrument panel location, and steering wheel size and location can all affect the placement of the mobile computer in each vehicle cab.

The presence of an arm rest can also assist or hinder the use of a mobile computer. The vehicle used in this study did not have an arm rest; therefore the results of this study do not reflect the best location in vehicles that do have an arm rest. Normally arm rests can be moved to a stowed location.

The results of this study are not readily applicable to passenger vehicles. Passenger vehicles typically have a smaller occupant package and center consoles. It might not be possible to place the mobile computer in the locations suggested by this research.

7.2 Locations

The locations selected for this study, were selected as currently feasible locations for electric utility pickup trucks. The passenger seat is typically not occupied for electric utility work. The mount used for locations A, B, and D could restrict passenger leg room and could be a hazard in the event of an accident. For current electric utility vehicles, this is not typically an issue.

The mobile computer locations chosen for this study were confined to conventional computers. The participants used the touchscreen, 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 could be used to further reduce biomechanical loading in the future

During the site visits workers reported that they drove many vehicles without a passenger. Thus, utilities generally do not put a passenger side air bag into their vehicle specifications. Without a passenger there is a larger lateral area for mobile computer mount and no concern with interference with air bag deployment on the passenger side. The lack of a passenger makes the installation of a mobile computer mount easier and reduces the cost of the vehicle (due to not requiring a passenger airbag). However, this specification strategy may require the purchase of more vehicles. In today’s environment that focuses on productivity, there is a trend toward smaller crews; it is less common to find vehicles with more than one person in the cab.

8 FUTURE WORK

There are many possibilities for follow-up studies regarding the research void that this study has started to fill. With many advances in technology, specifically mobile technology, there are many devices that have recently or will soon be on the market. Some of these devices were discussed in the cognitive ergonomics section of the literature review. Future studies could include heads-up displays, or screens on the visor or overlaying the speedometer. Other input devices such as a wireless mouse or speech based input need to be tested. These devices are being tested for cognitive effects on driving, but not for any physical issues.

Other future studies could include different vehicle types. This study was performed for electric utility workers, so a pick-up truck cab was used. There is a growing trend of mobile workers using computers in their passenger vehicles. Medium duty and heavy duty vehicle cabs could also be tested.

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10 APPENDIX A: DIMENSIONED LINE DRAWINGS OF FOUR LOCATIONS

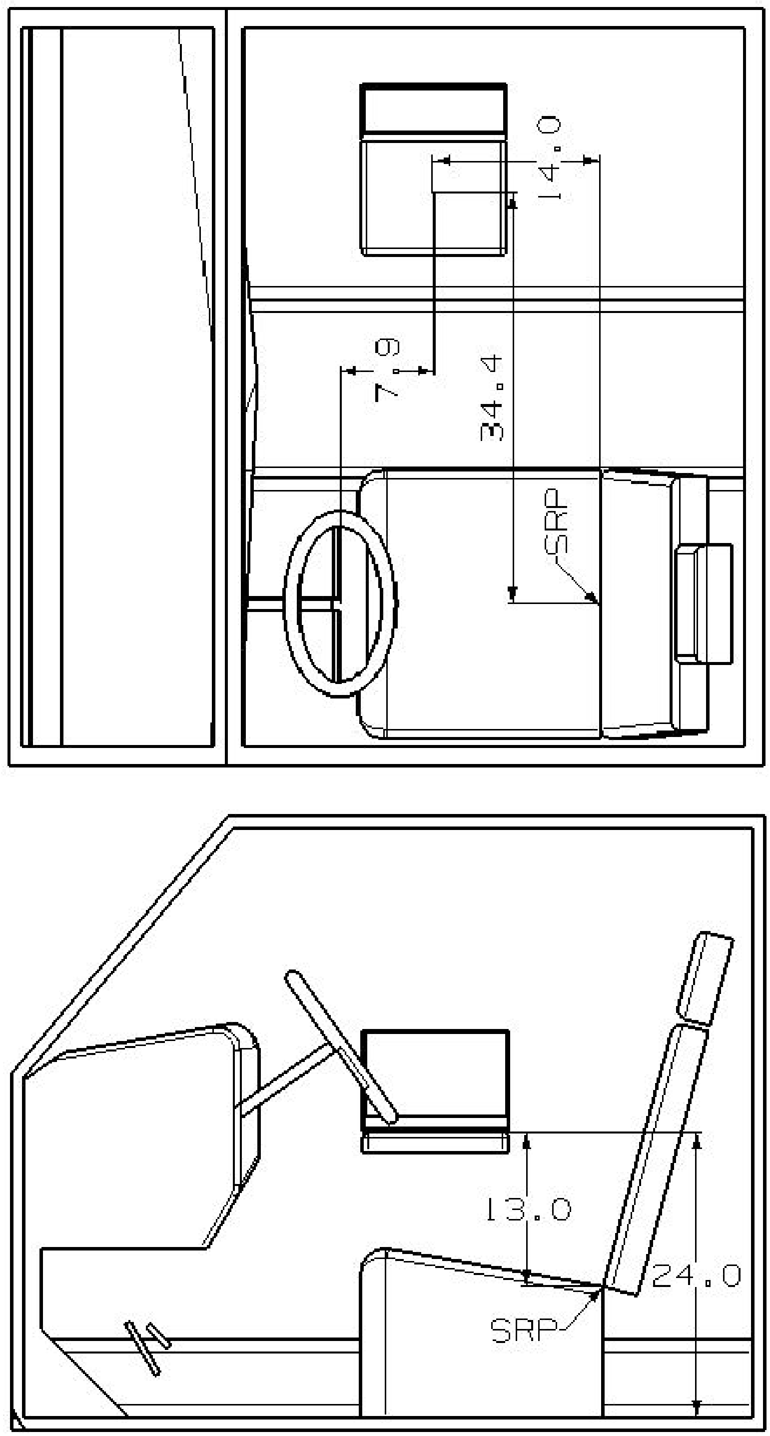


Figure 10.1. Location A. Average screen to keyboard angle: 101.5°. Keyboard tilt angle: 0°. Dimensions in inches.

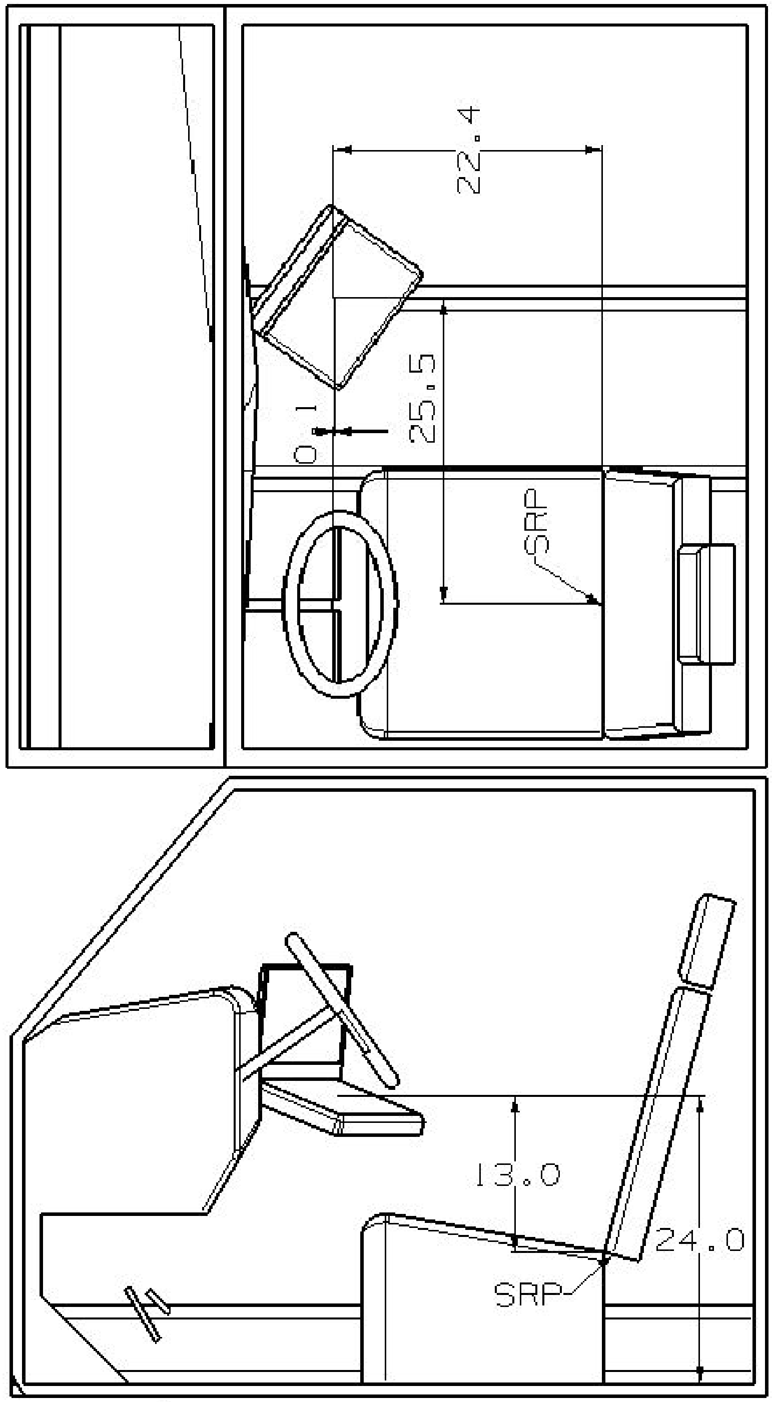


Figure 10.2. Location B. Average screen to keyboard angle: 118.2°. Keyboard tilt angle: 18.4°. Dimensions in inches.

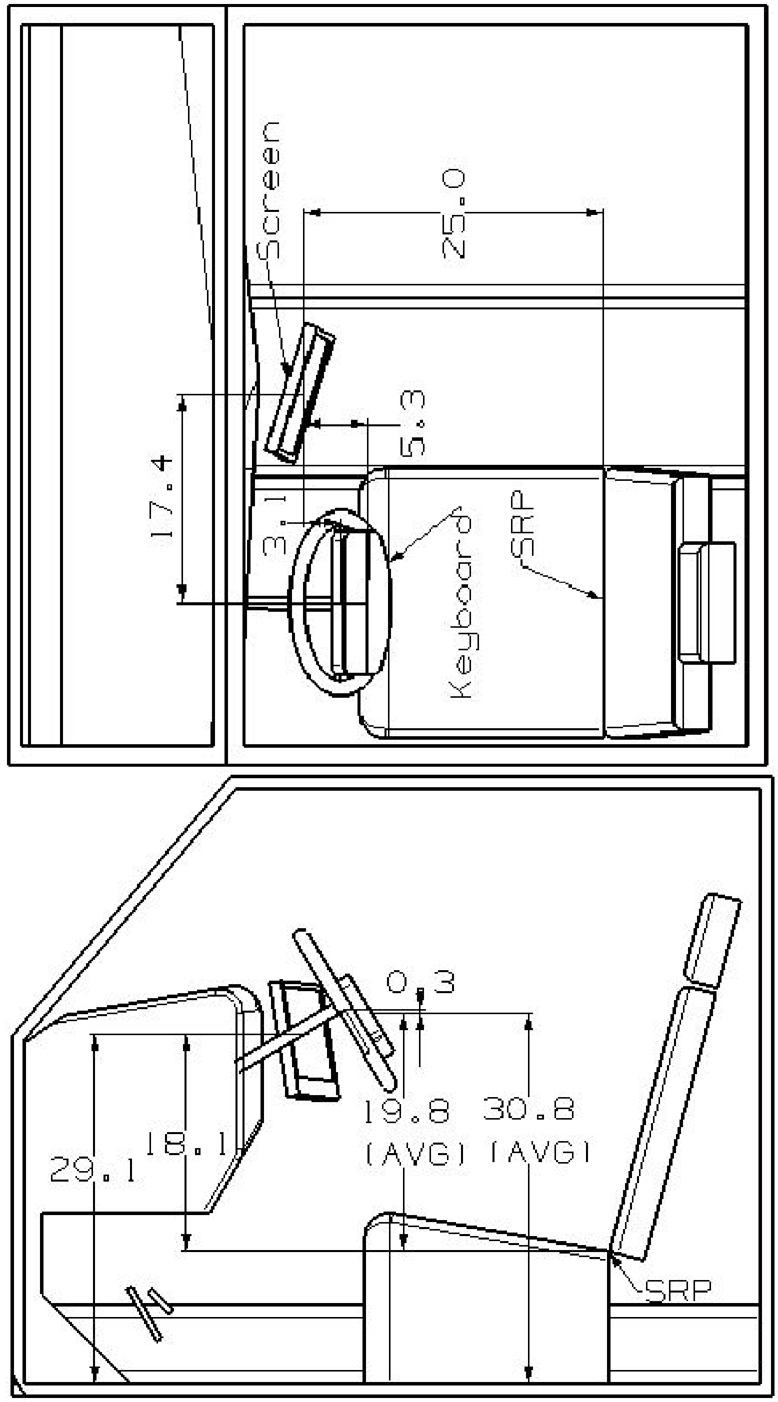


Figure 10.3. Location C. Average steering wheel angle: 59.3°. Average steering wheel bottom above floor: 22.6”. Dimensions in inches.

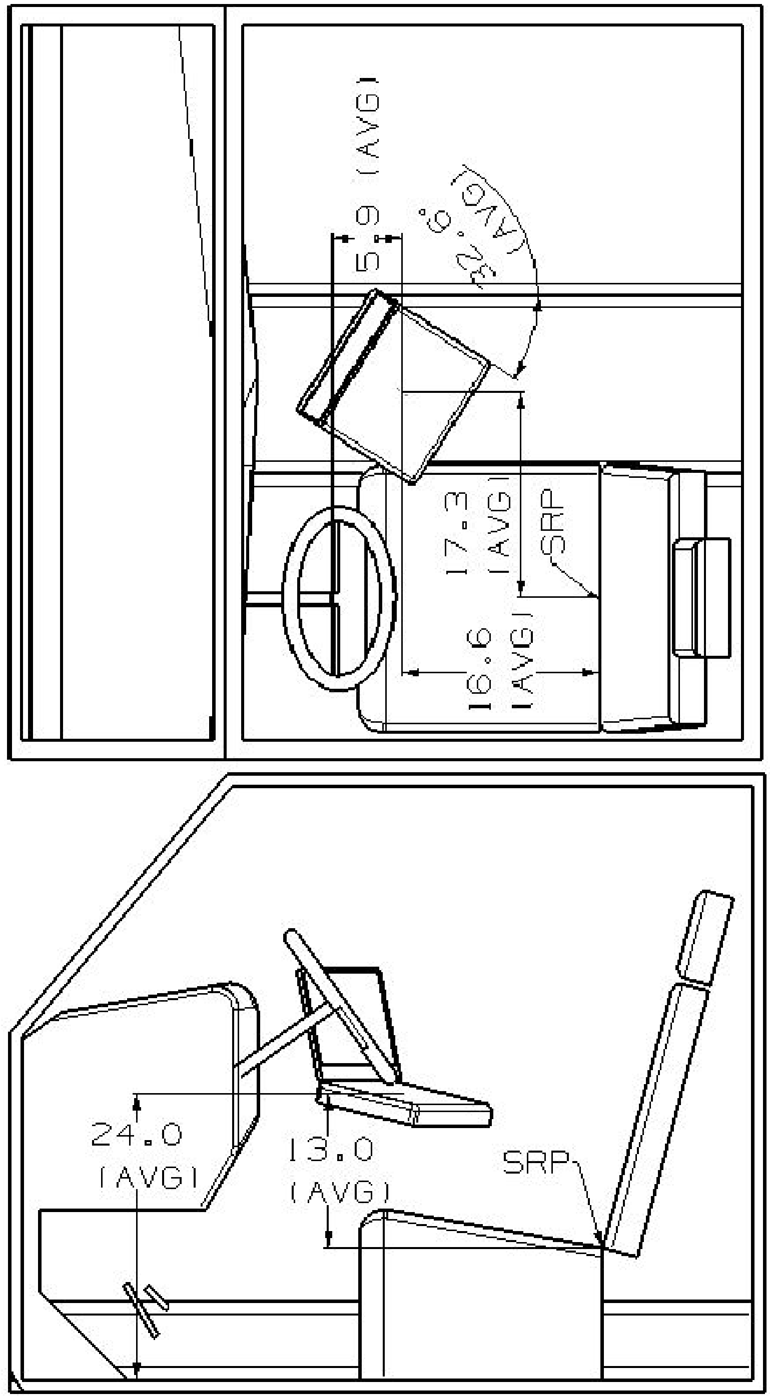


Figure 10.4. Location D. Average screen to keyboard angle: 114.4°. Average keyboard tilt angle: 11.5°. Dimensions in inches.

11 APPENDIX B: POWER ANALYSIS

Left Erector Spinae

Table 11.1. Standard deviation of each cell (n=7)

		Location			
		A	B	C	D
Task	1	0.064716	0.092618	0.024747	0.026377
	2	0.063481	0.093263	0.033424	0.03778
	3	0.07276	0.095655	0.02078	0.0409
	4	0.099355	0.101002	0.040637	0.052967

Average Standard Deviation = 0.06%MVC

Table 11.2. Number of subjects and power for different s_x and D (%MVC)

Standard Deviation	Mean Difference	Number of Subjects	Beta	Power
0.06	0.05	9	0.19	0.81
0.06	0.04	14	0.19	0.81
0.06	0.03	25	0.19	0.81
0.07	0.05	13	0.17	0.83
0.08	0.05	17	0.17	0.83
0.09	0.05	21	0.18	0.82

Results of ANOVA and Tukey Test for Seven Subjects

Table 11.3. 2-way ANOVA results for left erector Spinae (n=7)

	Deg of Freedom	SS	MS	F	P
Subject	6	0.12	0.02	7.547	<0.0001
Location	3	0.23	0.08	28.731	<0.0001
Task	1	0.03	0.03	10.193	0.0019
Location*Task	3	0.01	0.00	0.842	0.474078
Error	98	0.27	0.00		
Total	111	0.66			

The results show that Location is a significant factor.

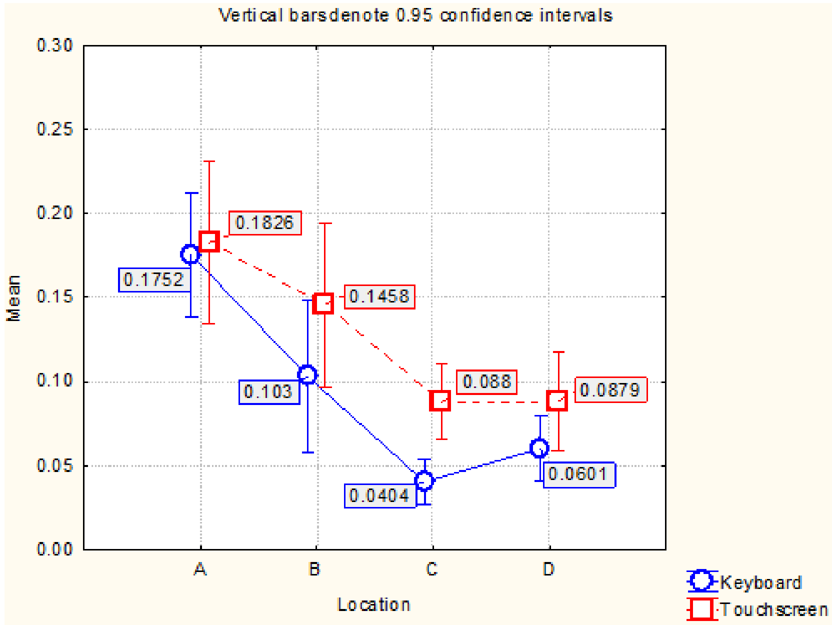


Figure 11.1. Plot of Location/Task interaction for left erector spinae (%MVC)

Table 11.4. Tukey test for significant differences between location means (in parenthesis)

Location	A (0.179)	B (0.124)	C (0.064)	D (0.074)
A		0.001043	0.000139	0.000139
B			0.000335	0.002709
C				0.894612
D				

There is a significant difference between all of the locations except for between C and D. The smallest significant mean difference is between A and B (5.5%MVC).

Right Elbow

Table 11.5. Standard deviation of each cell (n=7)

		Location			
		A	B	C	D
Task	1	10.03263	9.894094	12.18844	12.55413
	2	6.663474	7.145933	10.49593	10.43678
	3	9.605595	9.627265	12.9149	10.65624
	4	9.754599	9.60313	9.744748	8.443233

Average Standard Deviation = 10deg

Table 11.6. Number of subjects and power for different s_x and D (deg)

Standard Deviation	Mean Difference	Number of Subjects	Beta	Power
10	7	13	0.19	0.81
10	6	18	0.19	0.81
10	5	26	0.19	0.81
11	8	12	0.17	0.83
12	8	15	0.17	0.83
13	8	17	0.18	0.82

Results of ANOVA and Tukey Test for Seven Subjects

Table 11.7. 2-way ANOVA Results for Right Elbow Flexion (n=7)

	Deg of Freedom	SS	MS	F	P
Subject	6	6659.60	1109.90	18.432	<0.0001
Location	3	15763.60	5254.50	87.259	<0.0001
Task	1	5199.70	5199.70	86.349	<0.0001
Location*Task	3	398.70	132.90	2.207	0.092085
Error	98	5901.30	60.20		
Total	111	33922.90			

The results show that Location is a significant factor.

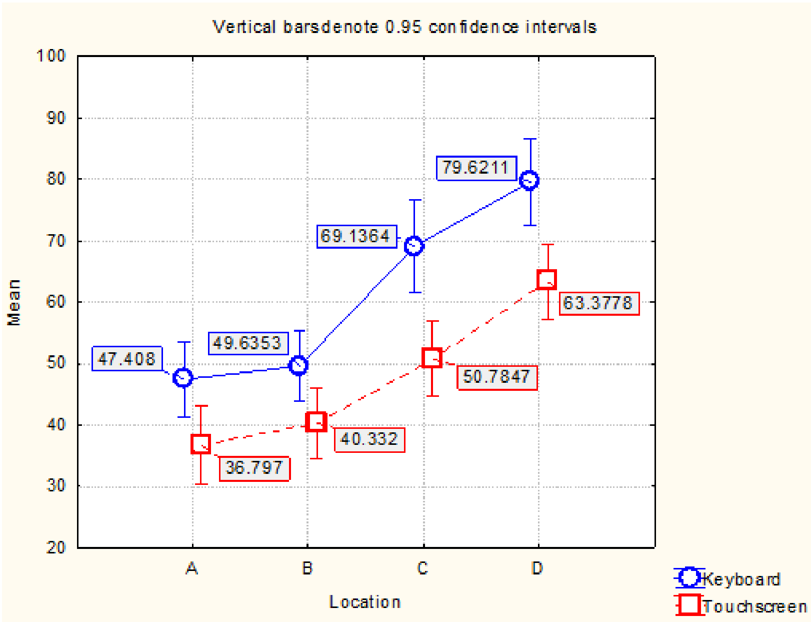


Figure 11.2. Plot of Location/Task interaction for right elbow flexion (deg)

Table 11.8. Tukey test for significant differences between location means (in parenthesis)

Location	**A (42.10)**	**B (44.98)**	**C (59.96)**	**D (71.50)**
A		0.509172	0.000139	0.000139
B			0.000139	0.000139
C				0.000140
D				

There is a significant difference between all of the locations except for between A and B. The smallest significant mean difference is between B and C (11.5deg).

Conclusion

Left Erector Spinae

Based on the results of the Tukey Test (**Table 11.4**) we would like to have enough statistical power for a mean difference of at least 5.5%MVC. From the power analysis (**Table 11.2**), assuming the average standard deviation of all the cells will not exceed 0.07%MVC, we will need 13 subjects.

Right Elbow Angle

Based on the results of the Tukey Test (**Table 11.8**) we would like to have enough statistical power for a mean difference of at least 12deg. From the power analysis (**Table 11.6**), it is apparent that we will easily have enough statistical power with 12 subjects for this difference even if the average standard deviation increases to 12 or 13deg.

From this analysis, we will need **13 subjects** to have enough statistical power for our results. If we collect data from 20-25 subjects we should have enough power to make comparisons between height and weight groups as well.

SAMPLE CALCULATION OF β

Assuming a difference between means, *D*, of 5%MVC, and the standard deviation is 6%MVC, Φ^2 is calculated as:

$$\Phi^2 = \frac{nbD^2}{2as_x^2} = \frac{n(3)(.05)^2}{2(3)(.06)^2} = 0.347n$$

For n=9, $\Phi^2 = 3.125$, $\Phi = 1.768$. From the operating characteristic curve for fixed effects model analysis of variance with $\nu_1 = 3$, and $\nu_2 = 72$, $\beta = 0.19$, therefore the power is 0.81.

12 APPENDIX C: FORMS

MARQUETTE UNIVERSITY
AGREEMENT OF CONSENT FOR RESEARCH PARTICIPANTS
Laboratory Study of Mobile IT Configurations in a Truck Cab
Dr. Richard Marklin, PhD
Mechanical Engineering

You have been invited to participate in this research study. Before you agree to participate, it is important that you read and understand the following information. Participation is completely voluntary. Please ask questions about anything you do not understand before deciding whether or not to participate.

PURPOSE: The purpose of this research study is to determine the optimal physical location and configuration of mobile IT in an electric utility vehicle. This will be determined by measuring muscle activity with surface electrodes attached to your skin, measuring joint angles with surface sensors attached to your skin and video capture, and measuring time and accuracy while using a computer. You will be one of approximately 27 participants in this research study.

PROCEDURES: You will have goniometers and EMG sensors taped to your arms and torso. After the sensors are calibrated to your body you will be asked to complete some common computer software tasks on a mobile IT device in four different configurations. While you are completing the tasks, the investigators will collect data from the sensors on your skin and well as video recordings. The sensors will record muscle activity and joint angles. The video recordings will be used to measure joint angles and as a general record of posture and events. If the video recordings are used in any public setting your identity will be protected by blocking your face. The video recordings will be destroyed 5 years after the completion of the study. After completing the tasks inside of the truck cab, 14 anthropometric dimensions of your body will be measured.

DURATION: Your participation will consist of one session approximately four hours in length.

RISKS: The risk associated with participation in this study is that your skin could become irritated from the tape used to attach non-invasive sensors to your skin possible discomfort from not being able to use the restroom for 2-3 hours, and possible muscle soreness/fatigue while completing tasks. We will minimize these risks by using high quality hypoallergenic 3M tape and making the testing as short as possible (2-3 hours total testing time and 10 minutes max in each testing position). Otherwise the risks associated with this study are no greater than the risks encountered in everyday life.

BENEFITS: There are no direct benefits associated with participation in this study. However, the correct application of the results of this study will help reduce the risk of injury for mobile IT users, specifically electric utility field workers. Generalizations of the results of this study can also be made for the general population and passenger vehicles.

Initial: ______ Date: ___/___/______

CONFIDENTIALITY: All information you reveal in this study will be kept confidential. All your data will be assigned an arbitrary code number rather than using your name or other information that could identify you as an individual. When the results of the study are published, you will not be identified by name. The data will be destroyed by shredding paper documents and deleting electronic files 5 years after the completion of the study. The data from this study will be stored in a locked cabinet and password-protected computers. Five years after the completion of the study all of your paper forms will be shredded and your electronic files will be permanently deleted. Your name will not be used in any reports and will only be recorded on this sheet. All other sheets will only have a subject code number. Your identity will be protected in all video files used outside of the research team by blocking your face. Your research records may be inspected by the Marquette University Institutional Review Board or its designees, the Electric Power Research Institute (EPRI), and (as allowable by law) state and federal agencies.

COMPENSATION: WE-Energies employees will not be compensated by the investigators for this study as they are on paid company time. If you are not a WE-Energies employee, you will be compensated $150.00 cash after the completion of your participation in this study. After completing your participation in this study you will be given a signed form entitling you to $150.00 when presented to the Office of the Bursar (Zilber Hall 1250 W. Wisconsin Ave.).

Voluntary Nature of Participation: Participating in this study is completely voluntary and you may withdraw from the study and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled. If you choose to withdraw during your participation, please notify the researcher and your data will be destroyed. It will not be possible to withdraw your data after participation because the data are collected confidentially and the researchers will not be able to determine which data are yours.

Contact Information: If you have any questions about this research project, you can contact Richard Marklin, PhD, the principle investigator at (414) 288-3622 or (414) 399-3622 (cell) before, during, or after the course of testing and ask any questions. If you have questions or concerns about your rights as a research participant, you can contact Marquette University's Office of Research Compliance at (414) 288-7570.

I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE RESEARCH PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT.

______________________________ ____________________

Participant's Signature Date

____

Participant's Name

______________________________ ____________________

Researcher's Signature Date

Subject ID (e.g. S01, S02, etc.): ____________________________ Date: ______/_____/______

Laboratory Study of Mobile IT Configurations
In Truck Cabs

Marquette University

Occupational and Health Background Information Form

Age: ______________ Gender: ____________

Occupation: ____

How long have you been in this occupation? ____

Have you ever had an injury or illness of a musculoskeletal nature? *YES* or *NO*.

If *YES*, please describe ____

____

____

Do you have any current injury or illness or pain of a musculoskeletal nature? *YES* or *NO*.

Please describe and when it occurred ____

____

If *YES*, would participating in this experiment worsen your injury, or illness or pain? *YES* or *NO*.

If *YES*, Please describe ____

Laboratory Study of Mobile IT Configurations In Truck Cabs

Marquette University

Typing Information Form

How many digits do you type with? ______________________________

Do you type with one hand or both hands? ______________________________

Are you Right or Left handed? ______________________________

Comments: ______________________________

____

____

____

Subjective Assessment Form

Ergonomics Lab Experiment: Laboratory Study of Mobile IT Configurations in a Truck Cab
Subject ID: ____________________ Date: ____________________ Location: ____________________

1. How uncomfortable or comfortable was completing the tasks with the laptop in this location

1	2	3	4	5	6	7
Very Uncomfortable	Uncomfortable	Somewhat Uncomfortable	Neutral	Somewhat Comfortable	Comfortable	Very Comfortable

2. How difficult or easy was it to enter the work order

1	2	3	4	5	6	7
Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy

3. How difficult or easy was it to complete the Touch Me square task

1	2	3	4	5	6	7
Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy

4. How difficult or easy was it to complete the alphabet task

1	2	3	4	5	6	7
Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy

5. How difficult or easy was it to complete the map task

1	2	3	4	5	6	7
Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy

6. Please rate how much you disliked/liked the laptop in this location

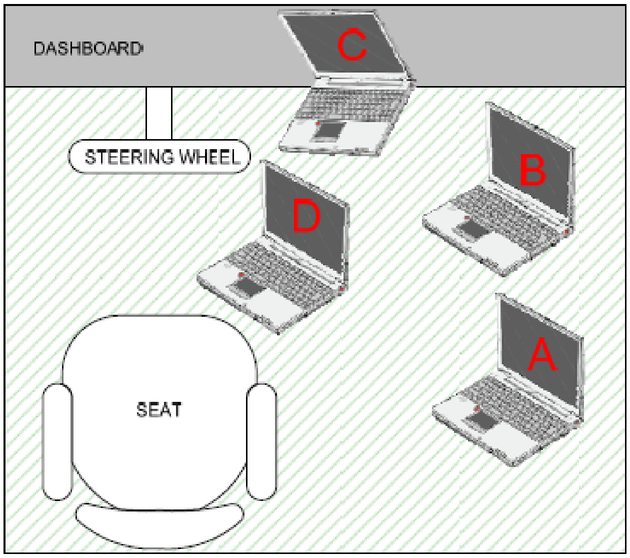
1	2	3	4	5	6	7
Very Strongly Disliked	Strongly Disliked	Disliked	Neutral	Liked	Strongly Liked	Very Strongly Liked

7. Overall, how difficult or easy was it to use the laptop in this location

1	2	3	4	5	6	7
Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy

Comments ____

Please rank the four configurations overall from 1 to 4, with 1 – most preferred and 4 – least preferred



A ☐

B ☐

C ☐

D ☐

Data Collection Form

Subject ID (e.g. S01, S02, etc.): ____________________________ Date: ______/_____/______

Laboratory Study of Mobile IT Configurations
In Truck Cabs
Data Collection

Presentation Order of Mobile IT Configurations (ABCD): __________________________

Presentation Order of Scripts (ABCD): __________________________

Maximal: ☐ Deltoids ☐ Trapezius ☐ Pectoralis ☐ Erector Spinae ☐ Goniometers

Resting: ☐ Standing ☐ Sitting

Config	File Type	File Names	Seq. I/O	Description/Comments
A: Laptop Mounted over Passenger Seat	Video			
	Biometrics			
B: Laptop Mounted Over Post	Video			
	Biometrics			

Config	File Type	File Names	Seq. I/O	Description/Comments
C: Screen Mounted to Dashboard with Separate Keyboard	Video			
	Biometrics			
D: Laptop Mounted Next to Steering Wheel	Video			
	Biometrics			

Config: A	Sequence	Time (s)	Misses
Squares Task			
Letter Task			

Config: C	Sequence	Time (s)	Misses
Squares Task			
Letter Task			

Config: B	Sequence	Time (s)	Misses
Squares Task			
Letter Task			

Config: D	Sequence	Time (s)	Misses
Squares Task			
Letter Task			

Anthropometry Data Form

Subject ID (e.g. S01, S02, etc.): ______________________________ Date: ______/_____/______

Laboratory Study of Mobile IT Configurations
In Truck Cabs
Anthropometric Dimensions

Gender: ______________________ Hand Dominance: *R L*

Race: *White (non-Hispanic) Black (African-American) Hispanic Asian Native American Other*

Standing Dimensions

Weight ………………………………………………………… _________lbs

Stature………………………………………………………… _________cm

Arm Length …………………………………………………… _________cm

Sitting Dimensions

Sitting Height (from seatpan) ……………………………………. _________cm

Shoulder Height (from seatpan) ………………………………… _________cm L R

Trunk depth (at abdomen)………………………………………… _________cm

Buttock-Knee Length ……………………………………………… _________cm L R

Buttock-Popliteal Length…………………………………………… _________cm L R

Knee Height………………………………………………………… _________cm L R

Popliteal Height……………………………………………………… _________cm L R

Shoulder Breadth (outside of shoulders)………………………… _________cm

Interscye Breadth (between arm pits)……………………………… _________cm

Hip Breadth…………………………………………………………… _________cm

Comments:

Reimbursement Form

Laboratory Study of Mobile IT Configurations
In Truck Cabs
Reimbursement Acknowledgement

I, ______________________________ have completed my participation in the laboratory study of Mobile IT configurations as determined by the investigators. By signing this form I am acknowledging that I understand that I will receive payment for my participation in the form of a check mailed to the address I provided.

_______________________________________ _________________

Participant Signature Date

_______________________________________ _________________

Investigator Signature Date

This form will be stored along with your consent form in a locked file cabinet separate from all other forms and data collected in this experiment.

13 APPENDIX D: BACKGROUND INFORMATION OF SUBJECTS

Table 13.1. Occupation and health background information of participants

Subject ID	Date	Age	Gender	Occupation	Years in Occ.	Injury/Illness History	Comments	Currently
S01	4/6/2010	22	F	Student	4	Yes	Femur stress fracture	No
S02	4/13/2010	22	M	Student	4	Yes	Small Muscle Strains	No
S03	4/20/2010	20	F	Student	2	No		No
S04	4/27/2010	34	M	Lineman	13	Yes	Shoulder Surgery	No
S05	5/4/2010	43	M	Lineman	21	No		No
S06	5/12/2010	54	M	Troubleman	4	No		No
S07	5/13/2010	33	M	Lineman	10	Yes	Hip Fracture	No
S08	5/20/2010	49	M	Lineman	18	Yes	Rotator Cuff	No
S09	6/8/2010	58	M	Lineman	25	Yes	Broken Wrist/ankle	No
S10	6/9/2010	51	M	Lineman	22	No		No
S11	6/10/2010	29	M	Troubleman	9	Yes	Tennis Elbow	No
S12	6/24/2010	21	M	Student	3	Yes	Stress Fractures	No
S13	6/25/2010	21	F	Student	3	No		No
S14	6/30/2010	48	M	Lineman	27	Yes	Shoulder	No
S15	7/1/2010	31	M	Troubleman	0	No		No
S16	7/7/2010	43	M	Lineman	22	Yes	Disc Surgery	No
S17	7/19/2010	31	F	Sales for a bank	2	No		No
S18	7/23/2010	40	F	Student	3	No		No
S19	7/27/2010	29	M	Engineer	5	No		No
S20	7/28/2010	21	F	Student	3	No		No
S21	8/9/2010	34	M	Engineer	4	No		No
S22	8/10/2010	22	F	Student	4	Yes	Broken Femur	No

14 APPENDIX E: ANTHROPOMETERY OF SUBJECTS (RAW DATA)

Table 14.1. Raw demographic and background information

Subject	Date	Age	Gender	Race	Current Job	Years at Current Job	Hand Dominance
S01	4/6/2010	22	F	White	Student	4	R
S02	4/13/2010	22	M	White	Student	4	R
S03	4/20/2010	20	F	White	Student	2	R
S04	4/27/2010	34	M	White	Lineman	13	R
S05	5/4/2010	43	M	White	Lineman	21	L
S06	5/12/2010	54	M	White	Troubleman	4	R
S07	5/13/2010	33	M	White	Lineman	10	R
S08	5/20/2010	49	M	White	Lineman	18	R
S09	6/8/2010	58	M	White	Lineman	25	R
S10	6/9/2010	51	M	White	Lineman	22	R
S11	6/10/2010	29	M	White	Troubleman	9	R
S12	6/24/2010	21	M	White	Student	3	L
S13	6/25/2010	21	F	White	Student	3	R
S14	6/30/2010	48	M	White	Lineman	27	R
S15	7/1/2010	31	M	White	Troubleman	0	R
S16	7/7/2010	43	M	White	Lineman	22	R
S17	7/19/2010	31	F	White	Sales for a bank	2	R
S18	7/23/2010	40	F	White	Student	3	R
S19	7/27/2010	29	M	Hispanic	Engineer	5	R
S20	7/28/2010	21	F	White	Student	3	R
S21	8/9/2010	34	M	White	Engineer	4	R
S22	8/10/2010	22	F	White	Student	4	R

Table 14.2 Summary statistics of the anthropometric variables for the utility workers, general population, and combined sample.

		Utility Workers (n=11)	General Population (n=11)	Combined (n=22)			Utility Workers (n=11)	General Population (n=11)	Combined (n=22)
Weight [kgs]	**Mean**	89.3	63.6	76.4	**Buttock-Knee Length [cm]**	**Mean**	60.6	56.7	58.7
	SD	9.8	12.0	16.9		**SD**	3.2	2.0	3.3
	Min	74.9	46.0	46.0		**Min**	54.5	54.1	54.1
	Max	106.0	84.8	106.0		**Max**	65.9	59.9	65.9
Stature [cm]	**Mean**	177.6	165.0	171.3	**Buttock-Popliteal Length [cm]**	**Mean**	49.4	46.7	48.0
	SD	5.3	6.4	8.6		**SD**	2.8	1.9	2.7
	Min	169.2	157.6	157.6		**Min**	43.9	43.4	43.4
	Max	187.0	178.0	187.0		**Max**	54.0	49.3	54.0
Arm Length [cm]	**Mean**	84.8	76.1	80.5	**Knee Height [cm]**	**Mean**	54.7	50.2	52.5
	SD	5.8	3.4	6.4		**SD**	2.6	2.4	3.4
	Min	72.3	71.3	71.3		**Min**	49.9	47.0	47.0
	Max	95.5	82.0	95.5		**Max**	60.3	55.4	60.3
Sitting Height [cm]	**Mean**	92.6	87.3	89.9	**Popliteal Height [cm]**	**Mean**	43.8	41.1	42.4
	SD	3.1	3.1	4.1		**SD**	1.8	2.5	2.5
	Min	88.5	83.5	83.5		**Min**	39.9	37.0	37.0
	Max	98.0	93.5	98.0		**Max**	46.0	44.8	46.0
Sitting Eye Height [cm]	**Mean**	79.2	75.4	77.3	**Shoulder Breadth [cm]**	**Mean**	48.0	42.0	45.0
	SD	2.3	2.9	3.2		**SD**	2.2	3.5	4.2
	Min	75.5	71.6	71.6		**Min**	44.6	37.6	37.6
	Max	82.4	80.4	82.4		**Max**	52.5	47.9	52.5
Shoulder Height [cm]	**Mean**	61.9	58.7	60.3	**Interscye Breadth [cm]**	**Mean**	35.1	28.9	32.0
	SD	2.4	2.2	2.8		**SD**	2.9	2.4	4.1
	Min	58.5	55.1	55.1		**Min**	30.8	26.6	26.6
	Max	65.6	62.8	65.6		**Max**	39.5	34.1	39.5
Trunk Depth [cm]	**Mean**	25.1	20.4	22.7	**Hip Breadth [cm]**	**Mean**	37.5	34.4	35.9
	SD	2.8	3.8	4.1		**SD**	2.3	3.3	3.2
	Min	19.9	15.3	15.3		**Min**	34.3	31.0	31.0
	Max	28.5	27.4	28.5		**Max**	41.1	42.0	42.0

Table 14.3. Summary statistics of the anthropometric variables for the general population males and females.

		Gen. Pop. Male (n=4)	Gen. Pop. Female (n=7)			Gen. Pop. Male (n=4)	Gen. Pop. Female (n=7)
Weight [lbs]	**Mean**	68.1	61.0	**Buttock-Knee Length [cm]**	**Mean**	57.3	56.4
	SD	13.3	11.5		**SD**	2.3	2.0
	Min	54.3	46.0		**Min**	54.5	54.1
	Max	84.8	80.6		**Max**	59.9	59.3
Stature [cm]	**Mean**	170.7	161.7	**Buttock-Popliteal Length [cm]**	**Mean**	46.6	46.7
	SD	5.6	4.3		**SD**	1.9	2.1
	Min	164.6	157.6		**Min**	44.8	43.4
	Max	178.0	169.4		**Max**	48.3	49.3
Arm Length [cm]	**Mean**	78.5	74.8	**Knee Height [cm]**	**Mean**	52.0	49.1
	SD	3.1	3.0		**SD**	2.4	1.9
	Min	74.5	71.3		**Min**	50.1	47.0
	Max	82.0	81.1		**Max**	55.4	52.6
Sitting Height [cm]	**Mean**	90.6	85.4	**Popliteal Height [cm]**	**Mean**	42.9	40.0
	SD	2.5	1.5		**SD**	1.8	2.4
	Min	87.7	83.5		**Min**	41.1	37.0
	Max	93.5	87.3		**Max**	44.8	42.9
Sitting Eye Height [cm]	**Mean**	78.2	73.8	**Shoulder Breadth [cm]**	**Mean**	45.0	40.4
	SD	2.3	1.7		**SD**	2.5	2.9
	Min	75.9	71.6		**Min**	42.0	37.6
	Max	80.4	76.2		**Max**	47.9	46.2
Shoulder Height [cm]	**Mean**	60.8	57.5	**Interscye Breadth [cm]**	**Mean**	30.3	28.0
	SD	1.8	1.4		**SD**	3.0	1.6
	Min	58.5	55.1		**Min**	26.8	26.6
	Max	62.8	59.7		**Max**	34.1	31.1
Trunk Depth [cm]	**Mean**	20.3	20.5	**Hip Breadth [cm]**	**Mean**	33.8	34.8
	SD	4.0	4.1		**SD**	2.7	3.8
	Min	16.6	15.3		**Min**	31.3	31.0
	Max	25.4	27.4		**Max**	37.5	42.0

The following abbreviations for the anthropometric variables are used in **Table 14.4**: St – Stature; A L – Arm Length; S H – Sitting Height; S E H – Sitting Eye Height; Sh H – Sitting Shoulder Height; T D – Trunk Depth; B-K L – Buttock-Knee Length; B-P L – Buttock-Popliteal Length; K H – Knee Height; P H – Popliteal Height; Sh B – Shoulder Breadth; I B – Intersceye Breadth; H B – Hip Breadth; W – Weight

Table 14.4. Raw anthropometric data of all subjects

Subject	**St [cm]**	**A L [cm]**	**S H [cm]**	**S E H [cm]**	**Sh H [cm]**	**T D [cm]**	**B-K L [cm]**	**B-P L [cm]**	**K H [cm]**	**P H [cm]**	**Sh B [cm]**	**I B [cm]**	**H B [cm]**	**W [kg]**
S01	158.5	73.3	85.5	74.6	58.5	17.5	55.4	45.4	47.9	37.7	37.6	27.7	32.7	53.9
S02	164.6	74.5	87.7	76.5	58.5	16.6	54.5	44.8	50.4	41.5	42.0	26.8	32.6	54.3
S03	157.6	71.3	86.5	76.2	59.7	18.1	54.2	45.1	47.0	37.0	38.5	27.4	32.9	55.5
S04	169.2	72.3	91.9	82.0	63.4	28.2	54.5	43.9	49.9	39.9	46.7	33.6	34.3	80.0
S05	187.0	95.5	97.0	82.4	65.6	28.2	65.9	54.0	60.3	46.0	49.4	39.5	40.9	106.0
S06	173.0	84.9	90.4	77.0	59.5	28.5	63.9	51.8	54.3	42.6	46.3	34.6	38.5	99.5
S07	177.1	86.9	93.7	81.8	63.5	26.0	60.6	50.6	54.0	42.5	50.2	39.0	38.8	96.9
S08	172.4	82.4	89.6	77.5	59.4	24.2	58.5	47.1	52.7	42.9	48.7	32.8	37.1	81.8
S09	174.7	83.0	88.5	75.5	60.5	19.9	61.0	49.0	54.3	43.5	44.6	30.8	36.1	74.9
S10	183.7	91.0	98.0	80.5	63.5	25.5	60.3	49.6	57.1	45.7	47.1	35.7	41.1	93.3
S11	178.0	82.7	94.2	78.8	61.2	25.2	60.0	47.5	53.7	43.9	47.2	33.2	36.5	84.5
S12	178.0	79.1	93.5	80.4	62.8	17.6	59.9	48.3	55.4	44.8	44.4	30.0	31.3	61.3
S13	164.8	74.5	86.2	74.5	57.4	15.3	54.1	43.4	49.6	42.9	38.5	26.7	31.0	46.0
S14	182.1	86.3	94.4	78.9	64.9	23.6	61.3	50.0	55.4	45.0	48.0	35.3	36.0	94.0
S15	179.5	85.4	89.5	76.9	58.5	25.6	63.1	52.3	55.9	45.0	52.5	39.1	34.5	92.0
S16	177.2	82.7	91.0	80.0	60.4	20.8	57.2	47.6	54.5	44.5	46.9	32.8	38.5	79.1
S17	158.2	74.6	83.5	71.6	56.8	21.3	56.6	47.6	50.2	41.0	39.3	27.4	37.0	69.5
S18	169.4	81.1	85.6	72.5	57.9	20.1	59.3	49.3	52.6	42.8	41.1	26.6	32.3	57.0
S19	168.9	82.0	89.6	75.9	60.3	21.7	56.6	45.2	50.1	41.1	45.5	30.3	33.7	71.8
S20	161.5	74.6	87.3	74.8	57.3	27.4	58.5	48.7	47.5	38.4	46.2	31.1	42.0	80.6
S21	171.4	78.4	91.4	79.9	61.4	25.4	58.1	48.1	51.9	44.0	47.9	34.1	37.5	84.8
S22	162.1	74.2	83.5	72.3	55.1	23.5	57.0	47.5	49.2	40.5	41.3	29.3	35.5	64.8

15 APPENDIX F: COMPLETE ANOVA RESULTS FOR BIOMECHANICS ANALYSIS

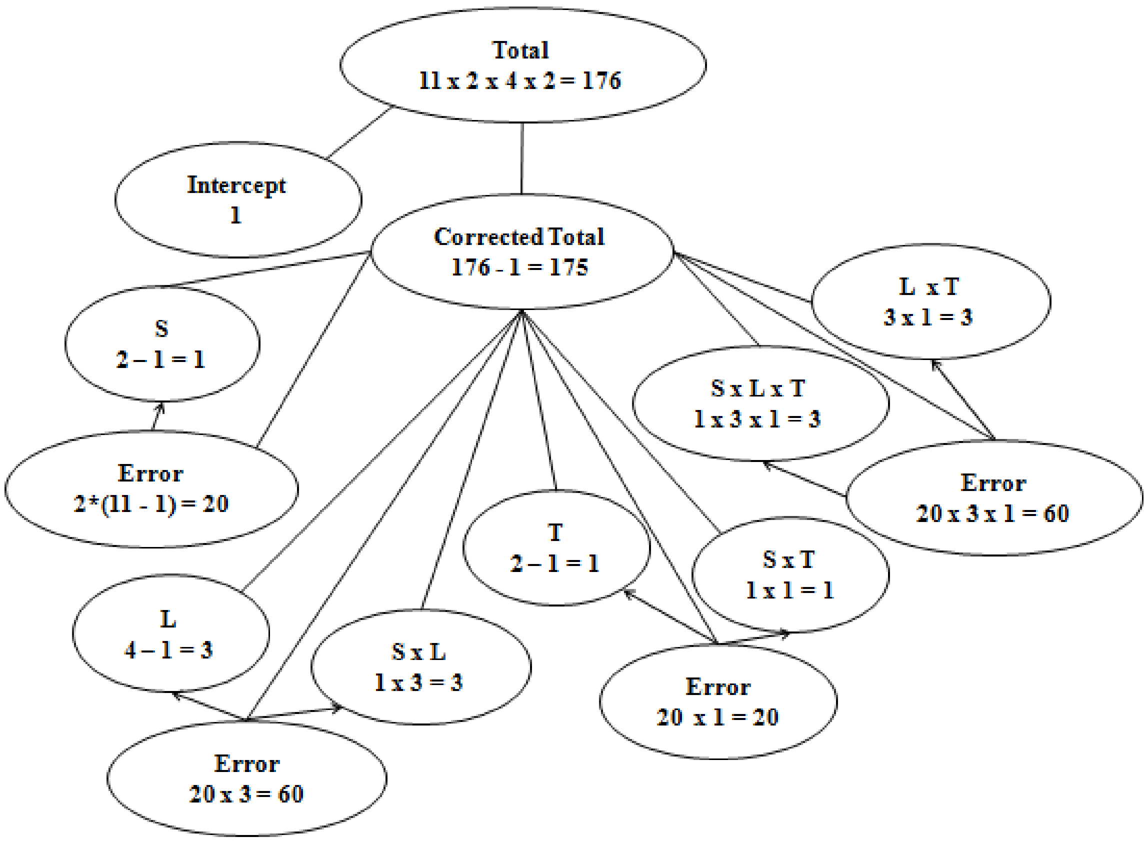


Figure 15.1. Degrees of freedom break down for three-way ANOVA

The breakdown of the degrees of freedom for the three-way mixed model analysis was based on Stevens, 2007 (**Figure 15.1**). The three-way analysis was used for the right side upper extremity dependent variables (pectoralis major, middle deltoid, upper trapezius, wrist ext/flex and uln/rad deviation, and elbow flexion) and trunk dependent variables (left and right erector spinae, shoulder angle and displacement, and hip displacement).

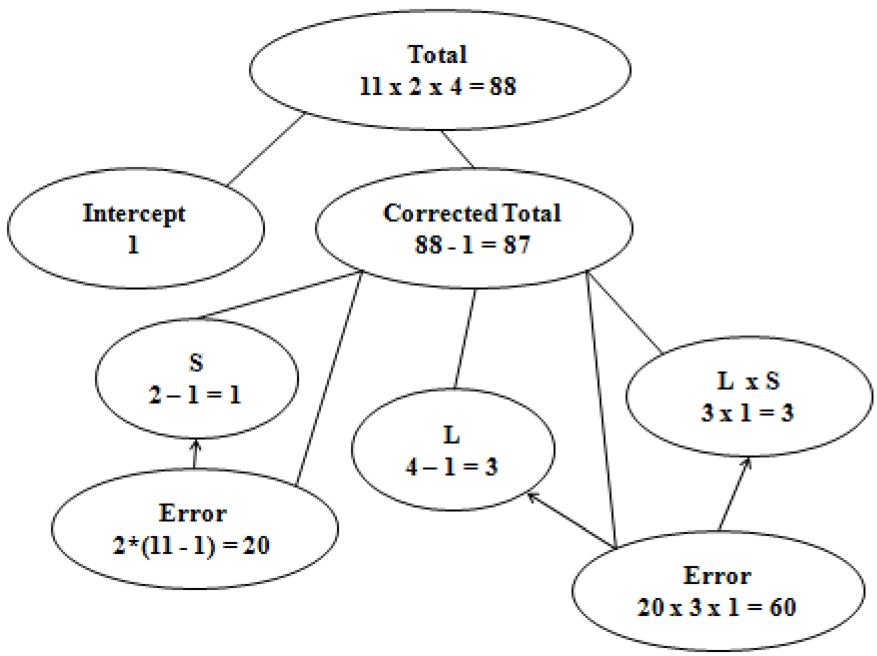


Figure 15.2. Degrees of freedom breakdown for two-way ANOVA

The breakdown of the degrees of freedom for the two-way mixed model (Size and Location) analysis was based on Turner and Thayer 2001 (**Figure 15.2**). The two-way analysis was used for the left side upper extremity dependent variables (pectoralis major, middle deltoid, upper trapezius, wrist ext/flex and uln/rad deviation, and elbow flexion). Task was not included for the left side upper extremity as the left hand was not used for the pointing tasks. This analysis only uses the keyboard data.

Table 15.1. P-values for each effect (S – size, L – location, T – task) from the mixed model ANOVA. P-values in bold with red shading are <0.05. Left upper extremity dependent variables did not include task for analysis (black cells)

	Dependent Variable	S	L	T	S x L	S x T	L x T	S x L x T
Muscle Activity	**R Pectoralis Major**	0.0533	**0.0118**	0.0721	0.2491	0.4081	**<0.0001**	0.4964
	L Pectoralis Major	0.1817	0.4092		0.2207			
	R Middle Deltoid	0.4508	**0.0015**	**<0.0001**	0.4570	0.1440	**<0.0001**	0.4786
	L Middle Deltoid	0.2061	**0.0093**		0.2707			
	R Upper Trapezius	0.4735	**0.0002**	**<0.0001**	0.9040	0.2763	**<0.0001**	0.4304
	L Upper Trapezius	0.2030	0.4333		0.3081			
	R Erector Spinae	0.9725	0.0711	**0.0055**	0.0814	0.1710	**<0.0001**	0.7174
	L Erector Spinae	0.9816	**<0.0001**	**<0.0001**	0.4009	0.6806	**0.0106**	0.2518
Joint Angles/Displacement	**R Wrist Ext/Flex**	0.6926	**<0.0001**	**0.0006**	0.3358	0.1455	**<0.0001**	0.4002
	L Wrist Ext/Flex	0.1677	**<0.0001**		0.0812			
	R Wrist Uln/Rad Deviation	0.7258	**<0.0001**	**0.0197**	0.1465	0.2318	**0.0002**	0.5395
	L Wrist Uln/Rad Deviation	0.0992	**<0.0001**		**0.0454**			
	R Elbow Flexion	0.0688	**<0.0001**	**<0.0001**	**0.0324**	0.5382	**<0.0001**	**0.0203**
	L Elbow Flexion	**0.0283**	**<0.0001**		0.0671			
	Shoulder Angle	0.5544	**<0.0001**	**<0.0001**	0.2277	0.0965	**<0.0001**	**0.0050**
	Shoulder Displacement	0.3449	**<0.0001**	0.1939	0.7746	0.1774	**0.0002**	0.2296
	Hip Displacement	0.7151	**<0.0001**	0.1984	0.8950	0.3848	0.2476	0.2262

Right Pectoralis Major

Table 15.2. Summary statistics of right pectoralis major (%MVC) (n=22)

			Location A	Location B	Location C	Location D	Mean/S.D. of Keyboard	
Task	Keyboard	Mean	1.540%	1.490%	2.390%	1.160%	1.640%	1.320%
		S. D.	0.990%	1.030%	1.850%	0.920%		
		Min	0.350%	0.120%	0.280%	0.120%		
		Max	3.330%	3.340%	6.650%	3.140%		
	Touchscreen	Mean	1.770%	2.250%	1.890%	1.750%	Mean/S.D. of Touchscreen	
		S. D.	1.210%	1.950%	1.620%	1.400%	1.920%	1.560%
		Min	0.070%	0.170%	0.220%	0.220%		
		Max	4.520%	7.950%	6.670%	5.010%		
		Mean/S.D. of Location	1.650%	1.870%	2.140%	1.450%	Grand Mean/S.D.	
			1.100%	1.590%	1.730%	1.210%	1.780%	1.440%

Table 15.3. Three-way ANOVA results of right pectoralis major (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	0.05572	1	0.05572	56.18756	<0.0001	1.00000
Size	0.00418	1	0.00418	4.21942	0.0533	0.49812
Error	0.01983	20	0.00099			
Task	0.00033	1	0.00033	3.60641	0.0721	0.43960
Task*Size	0.00006	1	0.00006	0.71405	0.4081	0.12690
Error	0.00181	20	0.00009			
Location	0.00116	3	0.00039	3.98013	0.0118	0.81109
Location*Size	0.00041	3	0.00014	1.40856	0.2491	0.35529
Error	0.00583	60	0.00010			
Task*Location	0.00103	3	0.00034	11.89747	<0.0001	0.99938
Task*Location*Size	0.00007	3	0.00002	0.80422	0.4965	0.21346
Error	0.00174	60	0.00003			

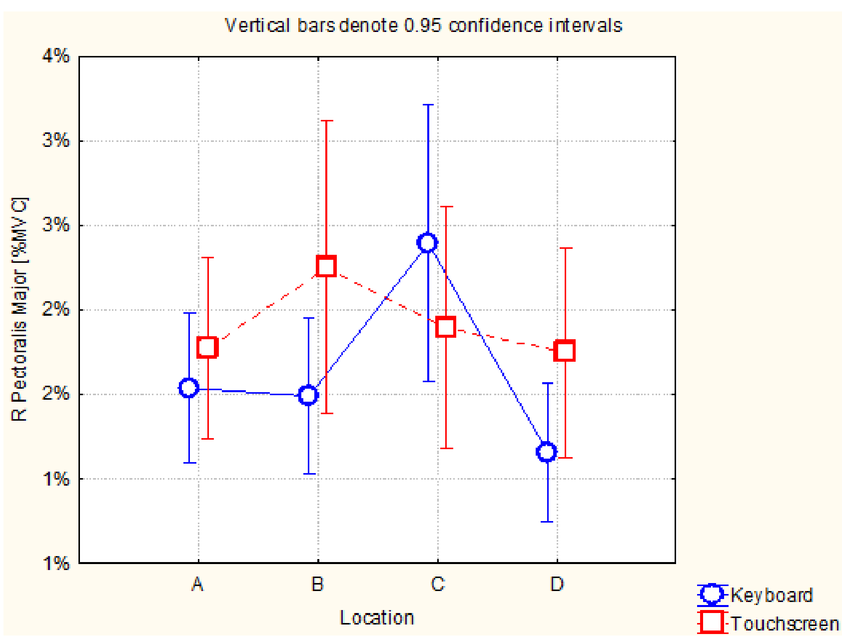


Figure 15.3. Plot of Location/Task interaction means for right pectoralis major (%MVC)

Table 15.4. Post-hoc comparison of Location/Task means for right pectoralis major (n=22)

	A (Key)	**A (Touch)**	**B (Key)**	**B (Touch)**	**C (Key)**	**C (Touch)**	**D (Key)**	**D (Touch)**
A (Key)		0.8248	1.0000	0.0011	0.0002	0.3679	0.2894	0.8973
A (Touch)			0.6599	0.0785	0.0073	0.9955	0.0077	1.0000
B (Key)				0.0005	0.0001	0.2240	0.4527	0.7618
B (Touch)					0.9886	0.3530	0.0001	0.0519
C (Key)						0.0581	0.0001	0.0044
C (Touch)							0.0008	0.9847
D (Key)								0.0127
D (Touch)								

Left Pectoralis Major – Keyboard Task

Table 15.5. Summary statistics of left pectoralis major (%MVC) (n=22)

			Location					
			A	**B**	**C**	**D**		
Size	**Small**	**Mean**	3.072%	3.469%	4.011%	3.609%	**Mean/S.D. of Small**	
		Std Dev	2.997%	2.847%	3.328%	1.977%	3.540%	2.752%
		Min	0.839%	0.867%	0.865%	1.560%		
		Max	10.769%	11.429%	10.868%	9.029%		
	Large	**Mean**	1.973%	3.113%	1.712%	2.462%	**Mean/S.D. of Large**	
		Std Dev	1.319%	3.412%	1.046%	1.411%	2.315%	2.030%
		Min	0.227%	0.414%	0.255%	0.516%		
		Max	3.869%	12.401%	3.802%	5.018%	**Grand Mean/S.D.**	
	Mean/S.D. of Location		2.523%	3.291%	2.861%	3.035%	2.928%	2.482%
			2.328%	3.072%	2.679%	1.776%		

Table 15.6. Two-way ANOVA results of left pectoralis major (n=22)

	SS	DOF	MS	F	p	Observed Power
Intercept	0.07542	1	0.07542	43.7255	<0.0001	1.0000
Size	0.00330	1	0.00330	1.9146	0.1817	0.2609
Error	0.03450	20	0.00172			
Location	0.00069	3	0.00023	0.9779	0.4092	0.2538
Location*Size	0.00106	3	0.00035	1.5115	0.2207	0.3794
Error	0.01404	60	0.00023			

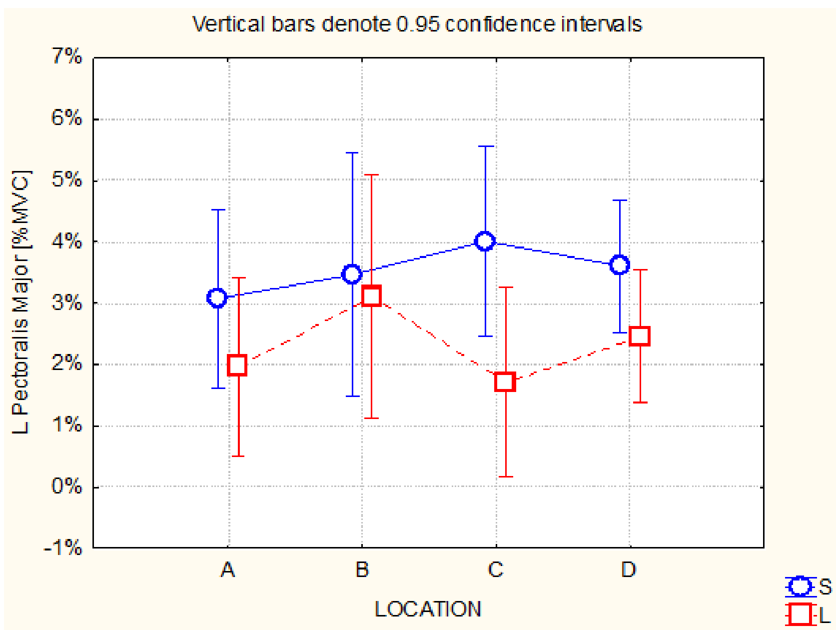


Figure 15.4. Plot of Size/Llocation interaction means for left pectoralis major (%MVC)

Right Middle Deltoid

Table 15.7. Summary statistics of right deltoid (%MVC) (n=22)

			Location					
			A	B	C	D	Mean/S.D. of Keyboard	
Task	Keyboard	Mean	4.250%	4.830%	4.150%	5.730%	4.740%	3.640%
		S. D.	3.540%	3.660%	3.160%	4.150%		
		Min	0.400%	0.420%	0.110%	0.310%		
		Max	14.160%	12.710%	10.730%	18.590%		
	Touchscreen	Mean	18.290%	16.910%	10.850%	10.730%	Mean/S.D. of Touchscreen	
		S. D.	13.580%	10.900%	6.870%	7.110%	14.200%	10.430%
		Min	1.590%	3.450%	1.290%	1.200%		
		Max	62.380%	48.030%	24.440%	28.100%		
		Mean/S.D. of Location	11.270%	10.870%	7.500%	8.230%	Grand Mean/S.D.	
			12.110%	10.090%	6.280%	6.280%	9.470%	9.120%

Table 15.8. Three-way ANOVA results of right middle deltoid (n=22)

	SS	DOF	MS	F	P	Observed power
Intercept	1.57761	1	1.57761	63.14843	<0.0001	1.00000
Size	0.01478	1	0.01478	0.59169	0.4508	0.11343
Error	0.49965	20	0.02498			
Task	0.39338	1	0.39338	44.85675	<0.0001	0.99999
Task*Size	0.02027	1	0.02027	2.31184	0.1440	0.30460
Error	0.17539	20	0.00877			
Location	0.04676	3	0.01559	5.81102	0.0015	0.93892
Location*Size	0.00707	3	0.00236	0.87918	0.4571	0.23076
Error	0.16094	60	0.00268			
Task*Location	0.06081	3	0.02027	16.77107	<0.0001	0.99999
Task*Location*Size	0.00304	3	0.00101	0.83747	0.4786	0.22111
Error	0.07252	60	0.00121			

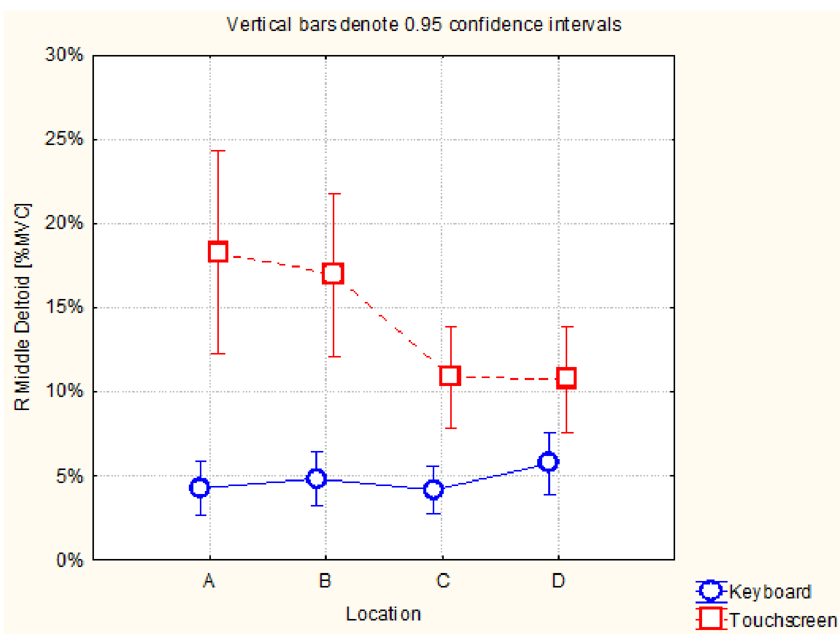


Figure 15.5. Plot of Location/Task interaction means for right middle deltoid (%MVC)

Table 15.9. Post-hoc comparison of Location/Task means for right middle deltoid (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.0001	0.9994	0.0001	1.0000	0.0001	0.8501	0.0001
A (Touch)			0.0001	0.8878	0.0001	0.0001	0.0001	0.0001
B (Key)				0.0001	0.9980	0.0001	0.9884	0.0001
B (Touch)					0.0001	0.0001	0.0001	0.0001
C (Key)						0.0001	0.7987	0.0001
C (Touch)							0.0003	1.0000
D (Key)								0.0004
D (Touch)								

Left Middle Deltoid – Keyboard Task

Table 15.10. Summary statistics of left middle deltoid (%MVC) (n=22)

			Location					
			A	**B**	**C**	**D**		
Size	**Small**	**Mean**	6.053%	6.217%	2.569%	3.016%	**Mean/S.D. of Small**	
		Std Dev	10.177%	10.372%	2.674%	5.606%	4.464%	7.808%
		Min	0.656%	0.664%	0.058%	0.025%		
		Max	32.048%	35.176%	8.986%	19.139%		
	Large	**Mean**	2.492%	1.844%	1.564%	0.569%	**Mean/S.D. of Large**	
		Std Dev	2.376%	1.805%	1.611%	0.346%	1.617%	1.787%
		Min	0.596%	0.344%	0.088%	0.048%		
		Max	8.869%	6.435%	4.931%	1.151%	**Grand Mean/S.D.**	
	Mean/S.D. of Location		4.273%	4.030%	2.066%	1.792%	3.040%	5.810%
			7.438%	7.602%	2.215%	4.073%		

Table 15.11. Two-way ANOVA results of left middle deltoid (n=22)

	SS	DOF	MS	F	p	Observed Power
Intercept	0.08135	1	0.08135	7.7934	0.0113	0.7567
Size	0.01783	1	0.01783	1.7077	0.2061	0.2378
Error	0.20876	20	0.01044			
Location	0.01101	3	0.00367	4.1883	0.0093	0.8324
Location*Size	0.00352	3	0.00117	1.3375	0.2707	0.3386
Error	0.05259	60	0.00088			

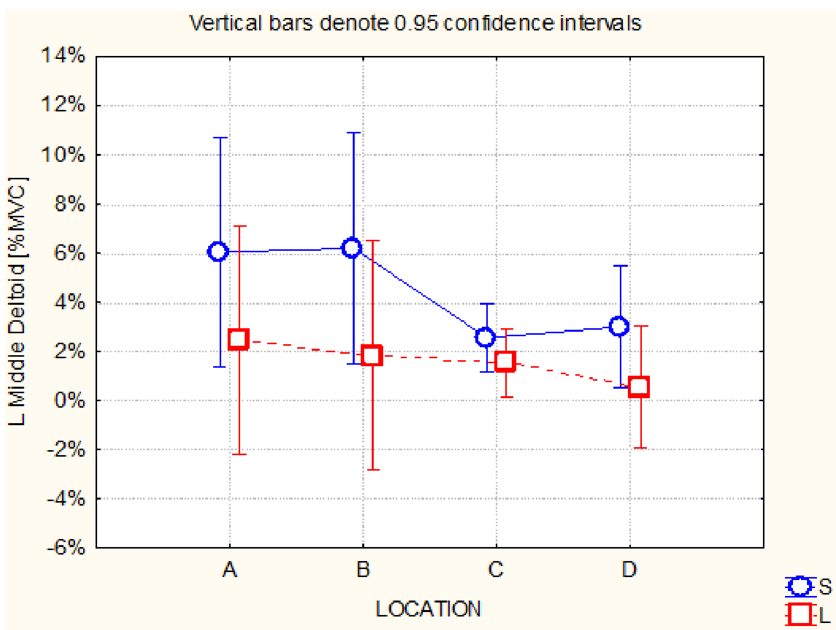


Figure 15.6. Plot of Size/Location interaction means for left middle deltoid (%MVC)

Table 15.12. Post-hoc comparison of Location means for left middle deltoid (n=22)

	A	B	C	D
A		0.9930	0.0749	0.0357
B			0.1350	0.0690
C				0.9899
D				

Right Upper Trapezius

Table 15.13. Summary statistics of right trapezius (%MVC) (n=22)

			Location A	Location B	Location C	Location D	
Task	Keyboard	Mean	15.490%	13.550%	12.600%	14.400%	Mean/S.D. of Keyboard: 14.010% / 9.360%
		S. D.	10.730%	8.430%	8.270%	10.190%	
		Min	0.800%	0.040%	3.040%	0.210%	
		Max	46.880%	28.830%	28.280%	40.450%	
	Touchscreen	Mean	24.120%	24.510%	14.980%	19.070%	Mean/S.D. of Touchscreen: 20.670% / 12.800%
		S. D.	13.090%	13.630%	10.400%	12.200%	
		Min	2.090%	1.700%	1.710%	2.000%	
		Max	55.270%	54.470%	34.820%	47.830%	
		Mean/S.D. of Location	19.810% / 12.610%	19.030% / 12.500%	13.790% / 9.360%	16.730% / 11.360%	Grand Mean/S.D.: 17.340% / 11.670%

Table 15.14. Three-way ANOVA results of right upper trapezius (n=22)

	SS	DOF	MS	F	P	Observed power
Intercept	5.29161	1	5.29161	69.36453	<0.0001	1.00000
Size	0.04072	1	0.04072	0.53382	0.4735	0.10709
Error	1.52574	20	0.07629			
Task	0.19502	1	0.19502	26.74324	0.0001	0.99841
Task*Size	0.00913	1	0.00913	1.25247	0.2763	0.18690
Error	0.14585	20	0.00729			
Location	0.09630	3	0.03210	7.74807	0.0002	0.98411
Location*Size	0.00234	3	0.00078	0.18827	0.9040	0.08309
Error	0.24858	60	0.00414			
Task*Location	0.04913	3	0.01638	14.67886	<0.0001	0.99994
Task*Location*Size	0.00312	3	0.00104	0.93295	0.4305	0.24327
Error	0.06694	60	0.00112			

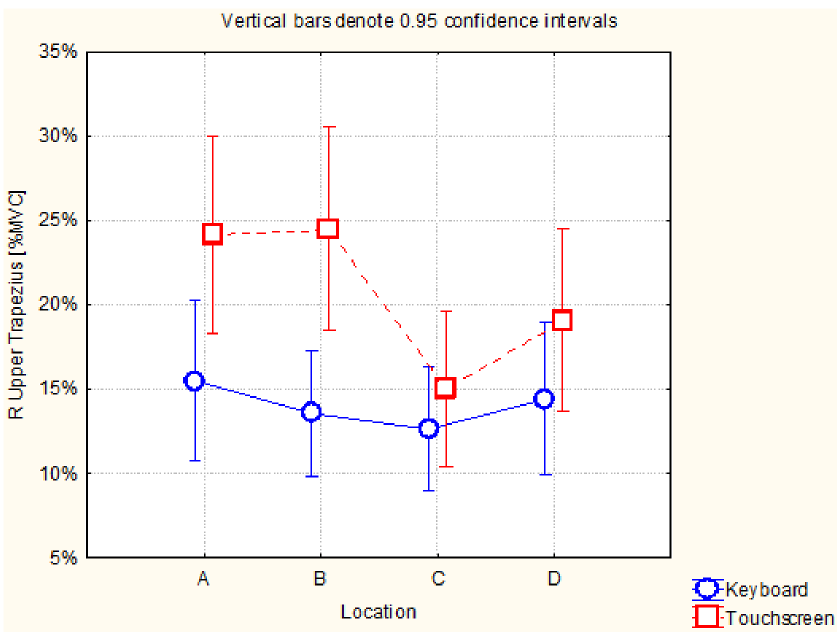


Figure 15.7. Plot of Location/Task interaction means for right upper trapezius (%MVC)

Table 15.15. Post-hoc comparison of Location/Task means for right upper trapezius (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.0001	0.5375	0.0001	0.0982	0.9996	0.9576	0.0163
A (Touch)			0.0001	0.9999	0.0001	0.0001	0.0001	0.0002
B (Key)				0.0001	0.9810	0.8441	0.9897	0.0001
B (Touch)					0.0001	0.0001	0.0001	0.0002
C (Key)						0.2805	0.6346	0.0001
C (Touch)							0.9991	0.0035
D (Key)								0.0006
D (Touch)								

Left Upper Trapezius – Keyboard Task

Table 15.16. Summary statistics of left upper trapezius (%MVC) (n=22)

			Location					
			A	**B**	**C**	**D**		
Size	**Small**	**Mean**	13.423%	10.120%	11.524%	7.800%	**Mean/S.D. of Small**	
		Std Dev	13.241%	12.302%	9.706%	6.917%	10.717%	10.645%
		Min	2.150%	0.528%	1.455%	0.141%		
		Max	43.454%	41.712%	30.951%	23.488%		
	Large	**Mean**	15.003%	14.688%	19.318%	16.989%	**Mean/S.D. of Large**	
		Std Dev	11.324%	12.462%	14.900%	13.680%	16.499%	12.829%
		Min	1.819%	1.638%	5.044%	5.452%		
		Max	35.451%	42.413%	52.555%	49.964%	**Grand Mean/S.D.**	
	Mean/S.D. of Location		14.213%	12.404%	15.421%	12.394%	13.608%	12.075%
			12.050%	12.308%	12.903%	11.576%		

Table 15.17. Two-way ANOVA results of left upper trapezius (n=22)

	SS	DOF	MS	F	p	Observed Power
Intercept	1.62960	1	1.62960	38.3737	<0.0001	1.0000
Size	0.07356	1	0.07356	1.7323	0.2030	0.2406
Error	0.84933	20	0.04247			
Location	0.01446	3	0.00482	0.9270	0.4333	0.2419
Location*Size	0.01913	3	0.00638	1.2261	0.3081	0.3123
Error	0.31206	60	0.00520			

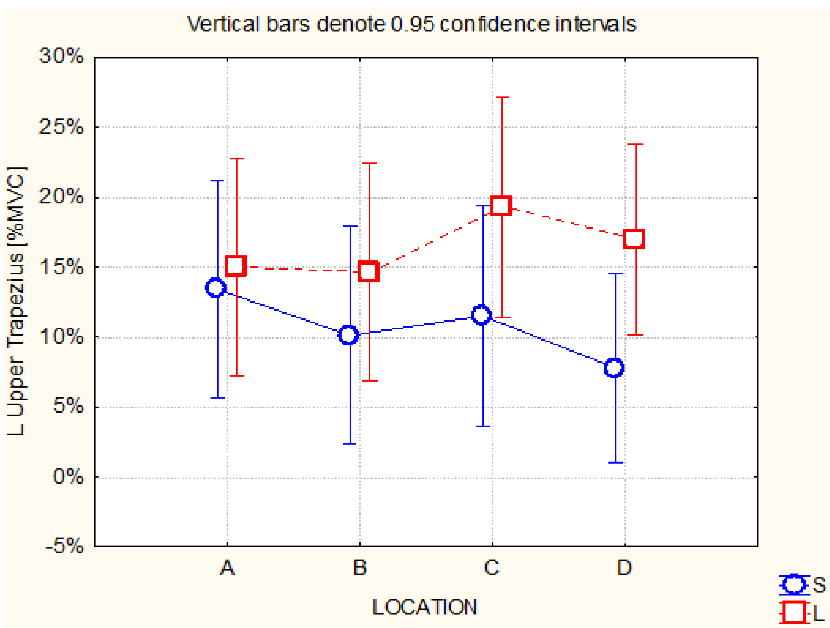


Figure 15.8. Plot of Size/Location interaction means for left upper trapezius (%MVC)

Right Erector Spinae

Table 15.18. Summary statistics of right erector spinae (%MVC) (n=22)

			Location					
			A	B	C	D	Mean/S.D. of Keyboard	
Task	Keyboard	Mean	3.320%	1.860%	7.350%	2.310%	3.710%	4.790%
		S. D.	3.420%	1.740%	6.630%	4.060%		
		Min	0.170%	0.000%	0.340%	0.050%		
		Max	14.460%	7.270%	22.630%	18.580%		
	Touchscreen	Mean	3.400%	1.780%	0.930%	2.260%	Mean/S.D. of Touchscreen	
		S. D.	7.960%	2.850%	0.930%	3.510%	2.090%	4.610%
		Min	0.070%	0.010%	0.010%	0.060%		
		Max	38.630%	13.470%	3.620%	16.620%		
		Mean/S.D. of Location	3.360%	1.820%	4.140%	2.280%	Grand Mean/S.D.	
			6.060%	2.340%	5.700%	3.750%	2.900%	4.750%

Table 15.19. Three-way ANOVA results of right erector spinae (n=22)

	SS	DOF	MS	F	P	Observed power
Intercept	0.14811	1	0.14811	24.80021	<0.0001	0.99719
Size	0.00001	1	0.00001	0.00122	0.9725	0.05013
Error	0.11944	20	0.00597			
Task	0.01152	1	0.01152	9.68469	0.0055	0.84126
Task*Size	0.00240	1	0.00240	2.01615	0.1710	0.27212
Error	0.02378	20	0.00119			
Location	0.01456	3	0.00485	2.46318	0.0711	0.58444
Location*Size	0.01389	3	0.00463	2.34953	0.0814	0.56217
Error	0.11820	60	0.00197			
Task*Location	0.03382	3	0.01127	11.91308	<0.0001	0.99939
Task*Location*Size	0.00128	3	0.00043	0.45117	0.7174	0.13543
Error	0.05677	60	0.00095			

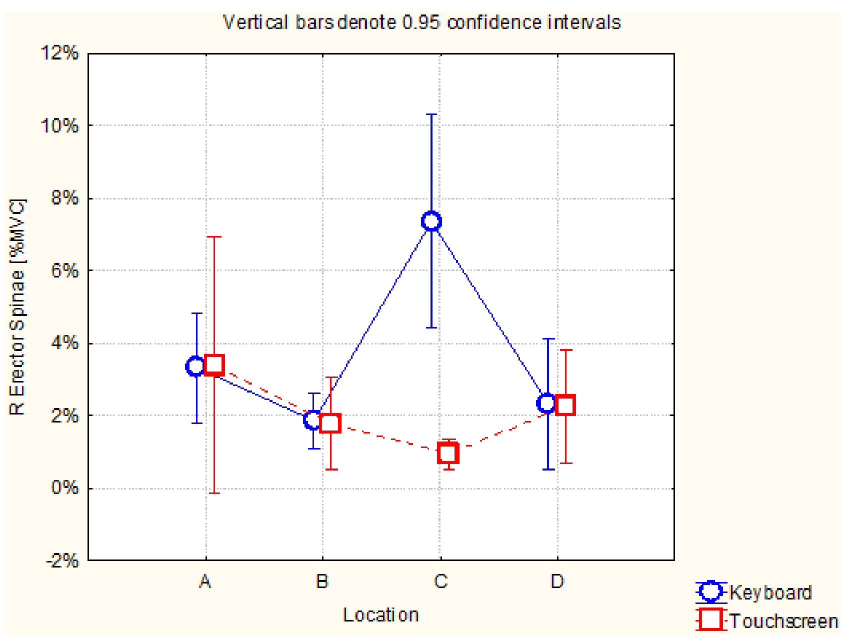


Figure 15.9. Plot of Location/Task interaction means for right erector spinae (%MVC)

Table 15.20. Post-hoc comparison of Location/Task means for right erector spinae (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		1.0000	0.7632	0.7082	0.0014	0.1856	0.9559	0.9433
A (Touch)			0.7100	0.6516	0.0019	0.1542	0.9340	0.9176
B (Key)				1.0000	0.0001	0.9727	0.9997	0.9999
B (Touch)					0.0001	0.9842	0.9991	0.9995
C (Key)						0.0001	0.0002	0.0001
C (Touch)							0.8138	0.8408
D (Key)								1.0000
D (Touch)								

Left Erector Spinae

Table 15.21. Summary statistics of left erector spinae (%MVC) (n=22)

			Location					
			A	B	C	D	Mean/S.D. of Keyboard	
Task	Keyboard	Mean	23.100%	16.810%	5.410%	8.090%	13.350%	12.010%
		S. D.	12.460%	12.450%	5.720%	6.880%		
		Min	7.220%	1.280%	0.230%	0.750%		
		Max	60.130%	41.010%	23.230%	26.860%		
	Touchscreen	Mean	24.230%	20.970%	11.480%	11.410%	Mean/S.D. of Touchscreen	
		S. D.	12.500%	11.550%	6.620%	5.440%	17.020%	10.970%
		Min	1.150%	4.790%	0.480%	3.590%		
		Max	62.620%	39.780%	28.390%	27.940%		
		Mean/S.D. of Location	23.660%	18.890%	8.440%	9.750%	Grand Mean/S.D.	
			12.340%	12.060%	6.840%	6.360%	15.190%	11.620%

Table 15.22. Three-way ANOVA results of left erector spinae (n=22)

	SS	DOF	MS	F	P	Observed power
Intercept	4.05891	1	4.05891	81.81379	<0.0001	1.00000
Size	0.00003	1	0.00003	0.00055	0.9816	0.05006
Error	0.99223	20	0.04961			
Task	0.05929	1	0.05929	33.97023	<0.0001	0.99982
Task*Size	0.00030	1	0.00030	0.17449	0.6806	0.06834
Error	0.03491	20	0.00175			
Location	0.70649	3	0.23550	30.79262	<0.0001	1.00000
Location*Size	0.02286	3	0.00762	0.99617	0.4009	0.25806
Error	0.45887	60	0.00765			
Task*Location	0.01382	3	0.00461	4.07159	0.0107	0.82071
Task*Location*Size	0.00475	3	0.00158	1.39945	0.2518	0.35315
Error	0.06786	60	0.00113			

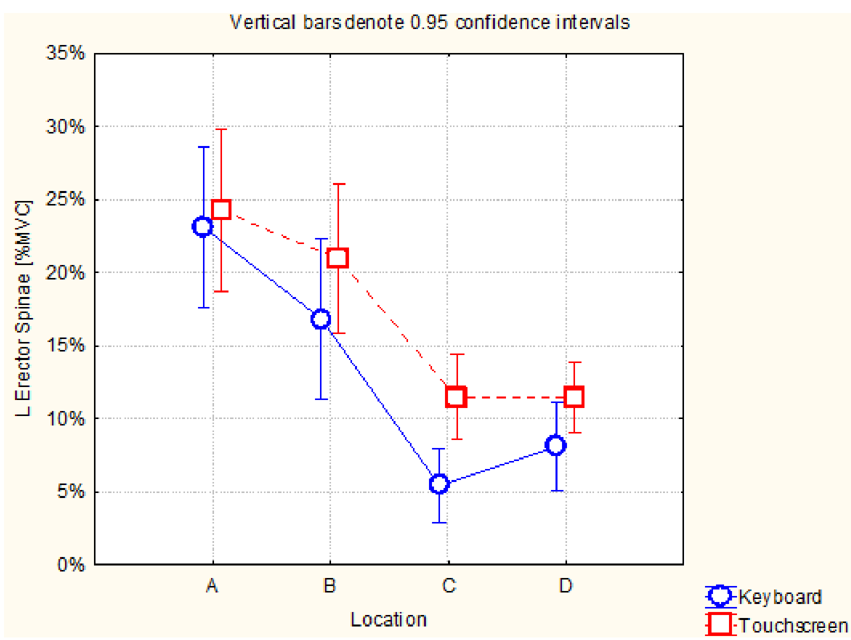


Figure 15.10. Plot of Location/Task interaction means for left erector spinae (%MVC)

Table 15.23. Post-hoc comparison of Location/Task means for left erector spinae (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.9513	0.0001	0.4260	0.0001	0.0001	0.0001	0.0001
A (Touch)			0.0001	0.0412	0.0001	0.0001	0.0001	0.0001
B (Key)				0.0030	0.0001	0.0002	0.0001	0.0002
B (Touch)					0.0001	0.0001	0.0001	0.0001
C (Key)						0.0001	0.1620	0.0001
C (Touch)							0.0293	1.0000
D (Key)								0.0347
D (Touch)								

Right Wrist Extension/Flexion

Table 15.24. Summary statistics of right wrist extension (-)/flexion(+) (deg) (n=22)

			Location A	Location B	Location C	Location D	
			A	**B**	**C**	**D**	**Mean/S.D. of Keyboard**
Task	**Keyboard**	**Mean**	-10.5	-23.5	-37.0	-11.3	-20.6 17.2
		S. D.	8.2	15.1	16.0	13.7	
		Min	-21.5	-51.3	-62.5	-36.8	
		Max	8.0	4.3	3.4	13.6	**Mean/S.D. of Touchscreen**
	Touchscreen	**Mean**	-26.1	-29.2	-30.2	-22.6	-27.0 14.3
		S. D.	10.7	15.0	16.1	14.6	
		Min	-46.7	-56.1	-59.1	-44.7	
		Max	-6.3	11.1	15.9	11.8	**Grand Mean/S.D.**
		Mean/S.D. of Location	-18.3 12.3	-26.4 15.1	-33.6 16.2	-16.9 15.1	-23.8 16.1

Table 15.25. Three-way ANOVA results of right wrist extension/flexion (n=22)

	SS	DOF	MS	F	P	Observed power
Intercept	99659.78	1	99659.78	93.66	<0.0001	1.0000
Size	171.19	1	171.19	0.16	0.6926	0.0669
Error	21280.83	20	1064.04			
Task	1817.29	1	1817.29	16.34	0.0006	0.9701
Task*Size	255.16	1	255.16	2.29	0.1455	0.3027
Error	2224.30	20	111.21			
Location	7885.29	3	2628.43	24.51	<0.0001	1.0000
Location*Size	370.56	3	123.52	1.15	0.3358	0.2947
Error	6435.65	60	107.26			
Task*Location	3123.74	3	1041.25	36.13	<0.0001	1.0000
Task*Location*Size	86.27	3	28.76	1.00	0.4002	0.2584
Error	1729.24	60	28.82			

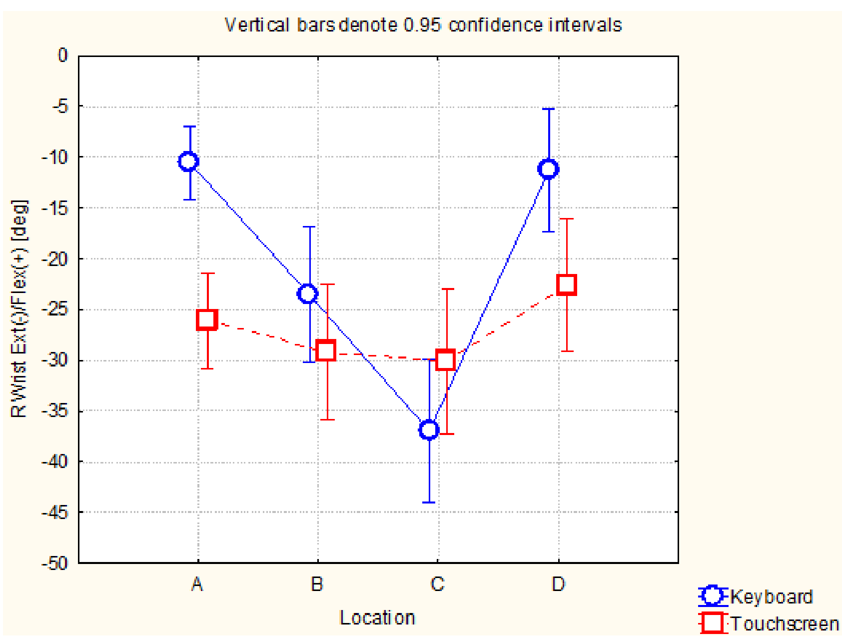


Figure 15.11. Plot of Location/Task interaction means for right wrist extension(-)/flexion(+) (deg)

Table 15.26. Post-hoc comparison of Location/Task means for right wrist ext/flex (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.0001	0.0001	0.0001	0.0001	0.0001	0.9998	0.0001
A (Touch)			0.7435	0.5666	0.0001	0.2243	0.0001	0.3576
B (Key)				0.0192	0.0001	0.0032	0.0001	0.9987
B (Touch)					0.0004	0.9989	0.0001	0.0031
C (Key)						0.0021	0.0001	0.0001
C (Touch)							0.0001	0.0005
D (Key)								0.0001
D (Touch)								

Left Wrist Extension/Flexion – Keyboard Task

Table 15.27. Summary statistics of left wrist extension (-)/flexion (+) (deg) (n=22)

			Location					
			A	B	C	D		
Size	Small	Mean	-16.43	-28.59	-40.72	-15.84	Mean/S.D. of Small	
		Std Dev	8.97	11.65	11.13	10.18	-25.40	14.48
		Min	-33.38	-48.36	-61.35	-36.00		
		Max	-1.40	-9.55	-22.96	-2.45		
	Large	Mean	-19.13	-38.75	-39.48	-22.92	Mean/S.D. of Large	
		Std Dev	5.95	7.31	13.89	9.66	-30.07	13.14
		Min	-27.01	-52.96	-61.85	-36.85		
		Max	-10.42	-30.45	-14.65	-6.93	Grand Mean/S.D.	
	Mean/S.D. of Location		-17.78	-33.67	-40.10	-19.38	-27.73	13.95
			7.55	10.82	12.30	10.34		

Table 15.28. Two-way ANOVA results of left wrist extension/flexion (n=22)

	SS	DOF	MS	F	p	Observed Power
Intercept	67679.69	1	67679.69	288.6006	0.0000	1.0000
Size	480.72	1	480.72	2.0499	0.1677	0.2758
Error	4690.20	20	234.51			
Location	7852.87	3	2617.62	44.9154	0.0000	1.0000
Location*Size	411.23	3	137.08	2.3521	0.0812	0.5627
Error	3496.74	60	58.28			

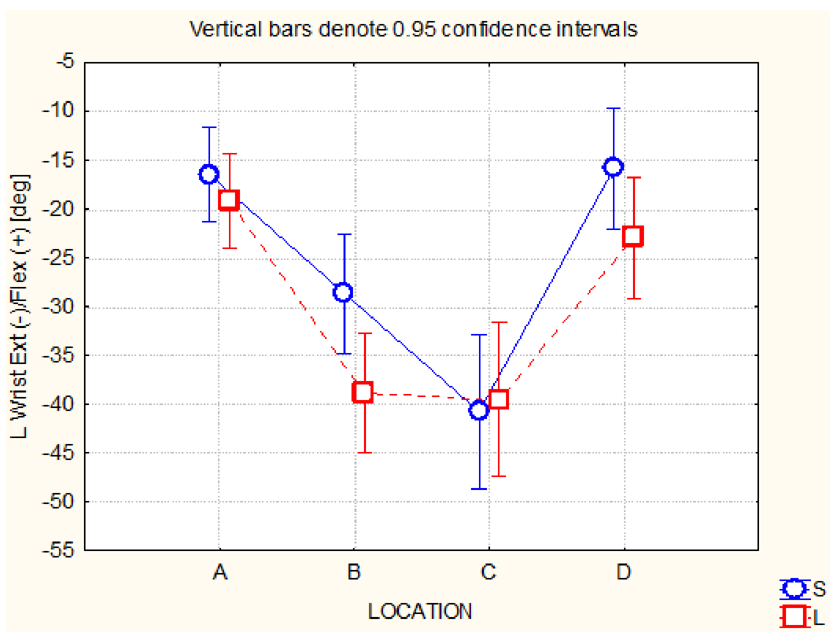


Figure 15.12. Plot of Size/Location interaction means for left wrist extension (-)/flexion (+) (deg)

Table 15.29. Post-hoc comparison of Location means for left wrist ext/flex (n=22)

	A	B	C	D
A		0.0002	0.0002	0.8986
B			0.0345	0.0002
C				0.0002
D				

Right Wrist Ulnar/Radial Deviation

Table 15.30. Summary statistics of right wrist radial (-)/ulnar(+) deviation (deg) (n=22)

			Location					
			A	B	C	D	Mean/S.D. of Keyboard	
Task	Keyboard	Mean	9.5	2.0	1.7	11.0	6.0	8.6
		S. D.	5.4	8.9	9.3	6.3		
		Min	-0.1	-25.8	-29.3	-1.9		
		Max	17.1	15.0	15.1	26.6		
	Touchscreen	Mean	12.2	8.1	8.5	11.1	Mean/S.D. of Touchscreen	
		S. D.	7.9	9.7	9.0	9.0	10.0	8.9
		Min	-6.1	-21.1	-15.6	-9.9		
		Max	25.2	21.9	22.1	21.3		
		Mean/S.D. of Location	10.9	5.1	5.1	11.0	Grand Mean/S.D.	
			6.8	9.7	9.7	7.7	8.0	9.0

Table 15.31. Three-way ANOVA results of right wrist ulnar/radial deviation (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	11305.61	1	11305.61	43.05	<0.0001	1.0000
Size	33.23	1	33.23	0.13	0.7258	0.0633
Error	5252.18	20	262.61			
Task	687.03	1	687.03	6.43	0.0197	0.6744
Task*Size	162.61	1	162.61	1.52	0.2318	0.2170
Error	2138.23	20	106.91			
Location	1521.76	3	507.25	10.52	<0.0001	0.9981
Location*Size	268.76	3	89.59	1.86	0.1465	0.4582
Error	2893.97	60	48.23			
Task*Location	320.63	3	106.88	7.63	0.0002	0.9827
Task*Location*Size	30.59	3	10.20	0.73	0.5395	0.1960
Error	840.64	60	14.01			

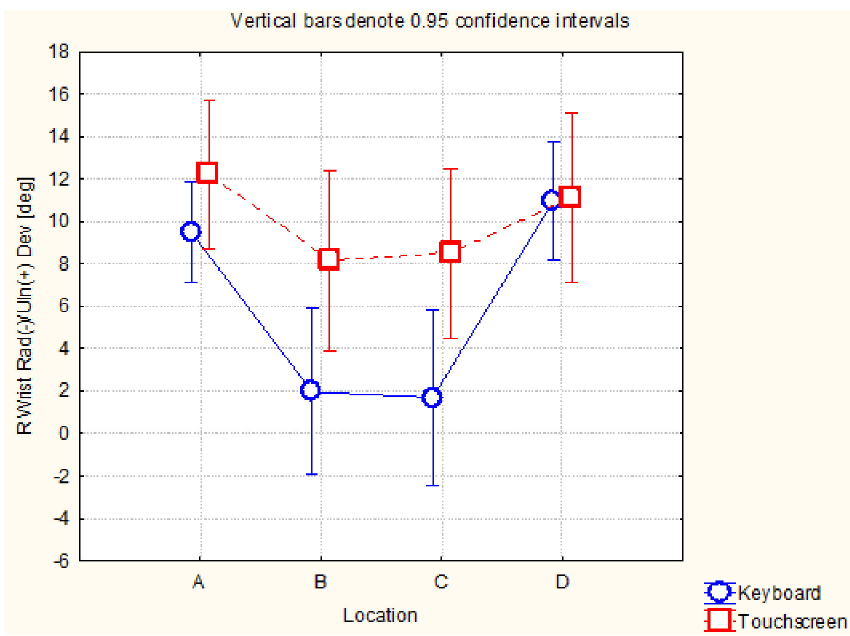


Figure 15.13. Plot of Location/Task interaction means for right wrist radial(-)/ulnar(+) deviation (deg)

Table 15.32. Post-hoc comparison of Location/Task means for right wrist radial/ulnar deviation (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.2574	0.0001	0.9222	0.0001	0.9845	0.8991	0.8523
A (Touch)			0.0001	0.0130	0.0001	0.0318	0.9508	0.9723
B (Key)				0.0001	1.0000	0.0001	0.0001	0.0001
B (Touch)					0.0001	1.0000	0.2107	0.1675
C (Key)						0.0001	0.0001	0.0001
C (Touch)							0.3694	0.3063
D (Key)								1.0000
D (Touch)								

Left Wrist Ulnar/Radial Deviation – Keyboard Task

Table 15.33. Summary statistics of left wrist ulnar (-)/radial (+) deviation (deg) (n=22)

			Location					
			A	B	C	D		
Size	Small	Mean	1.88	-1.39	0.47	-9.58	Mean/S.D. of Small	
		Std Dev	7.06	8.42	6.60	7.24	-2.15	8.40
		Min	-4.51	-12.66	-13.08	-22.15		
		Max	20.03	15.42	8.23	0.17		
	Large	Mean	7.17	7.69	3.04	-7.19	Mean/S.D. of Large	
		Std Dev	6.82	7.63	8.08	8.38	2.67	9.61
		Min	-4.40	-9.38	-10.90	-21.05		
		Max	16.90	15.65	11.91	0.96	Grand Mean/S.D.	
	Mean/S.D. of Location		4.52	3.15	1.75	-8.39	0.26	9.30
			7.29	9.11	7.32	7.74		

Table 15.34. Two-way ANOVA results of left wrist ulnar/radial deviation (n=22)

	SS	DOF	MS	F	p	Observed Power
Intercept	5.94	1	5.94	0.0346	0.8543	0.0536
Size	513.02	1	513.02	2.9898	0.0992	0.3770
Error	3431.81	20	171.59			
Location	2276.77	3	758.92	40.0382	<0.0001	1.0000
Location*Size	161.48	3	53.83	2.8397	0.0454	0.6530
Error	1137.30	60	18.95			

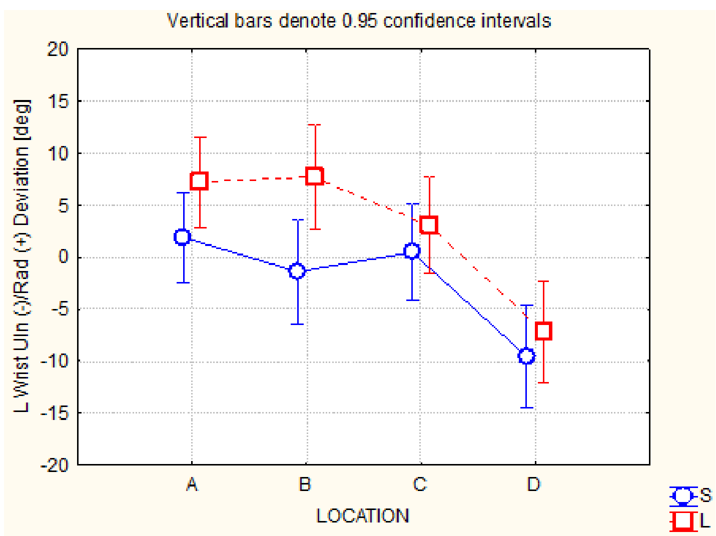


Figure 15.14. Plot of Size/Location interaction means for left wrist ulnar (-)/radial (+) deviation (deg)

Table 15.35. Post-hoc comparison of Size/Location means for left wrist ulnar/radial deviation (n=22)

	A (Small)	B (Small)	C (Small)	D (Small)	A (Large)	B (Large)	C (Large)	D (Large)
A (Small)		0.9998	0.9429	0.0058	0.6243	0.2681	0.9998	0.9822
B (Small)			0.9968	0.0220	0.4649	0.1694	0.9969	0.9974
C (Small)				0.1291	0.2552	0.0748	0.9578	1.0000
D (Small)					0.0077	0.0015	0.1883	0.9067
A (Large)						0.9549	0.2387	0.0003
B (Large)							0.0166	0.0001
C (Large)								0.2539
D (Large)								

Right Elbow Flexion

Table 15.36. Summary statistics of right elbow flexion (deg) (n=22)

Size	Task		Location A	Location B	Location C	Location D				
Small	Keyboard	**Mean**	45.5	51.5	74.7	79.9	**Mean/S.D. of Keyboard**			
		S. D.	11.1	9.8	13.2	12.1	62.9	18.6		
		Min	21.3	35.6	52.7	66.6				
		Max	61.1	67.5	93.0	102.7				
	Touchscreen	**Mean**	38.3	41.4	56.6	62.6	**Mean/S.D. of Touchscreen**			
		S. D.	9.0	6.3	12.3	11.3	49.7	14.1		
		Min	17.6	32.0	35.9	49.2				
		Max	51.1	54.7	76.4	82.6				
		Mean/S.D. of Location	41.9	46.4	65.6	71.2	**Small Grand Mean/S.D.**			
			10.5	9.6	15.5	14.4	56.3	17.7		
Large	Keyboard	**Mean**	46.9	47.4	62.2	70.1	**Mean/S.D. of Keyboard**			
		S. D.	6.0	6.6	6.5	10.6	56.7	12.5		
		Min	30.7	37.9	50.8	49.0				
		Max	53.6	61.1	69.7	84.8				
	Touchscreen	**Mean**	35.5	38.8	47.1	58.3	**Mean/S.D. of Touchscreen**		**Mean/S.D. of Keyboard**	
		S. D.	8.0	7.7	8.5	8.5	44.9	11.9	59.8	16.0
		Min	18.2	28.3	31.2	43.2			**Mean/S.D. of Touchscreen**	
		Max	43.6	53.3	57.8	70.4			47.3	13.2
		Mean/S.D. of Location	41.2	43.1	54.6	64.2	**Large Grand Mean/S.D.**		**Grand Mean/S.D.**	
			9.0	8.3	10.7	11.2	50.8	13.5	53.5	15.9
	Combined Mean/S.D. of Location		41.5	44.8	60.1	67.7				
			9.7	9.0	14.3	13.2				

Table 15.37. Three-way ANOVA results of right elbow flexion (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	470925.51	1	470925.51	472.02	<0.0001	1.0000
Size	3689.76	1	3689.76	3.70	0.0688	0.4486
Error	19953.57	20	997.68			
Task	6824.66	1	6824.66	117.99	<0.0001	1.0000
Task*Size	22.69	1	22.69	0.39	0.5382	0.0917
Error	1156.83	20	57.84			
Location	20505.57	3	6835.19	96.85	<0.0001	1.0000
Location*Size	661.18	3	220.39	3.12	0.0324	0.6992
Error	4234.34	60	70.57			
Task*Location	461.05	3	153.68	12.11	<0.0001	0.9995
Task*Location*Size	134.08	3	44.69	3.52	0.0203	0.7562
Error	761.57	60	12.69			

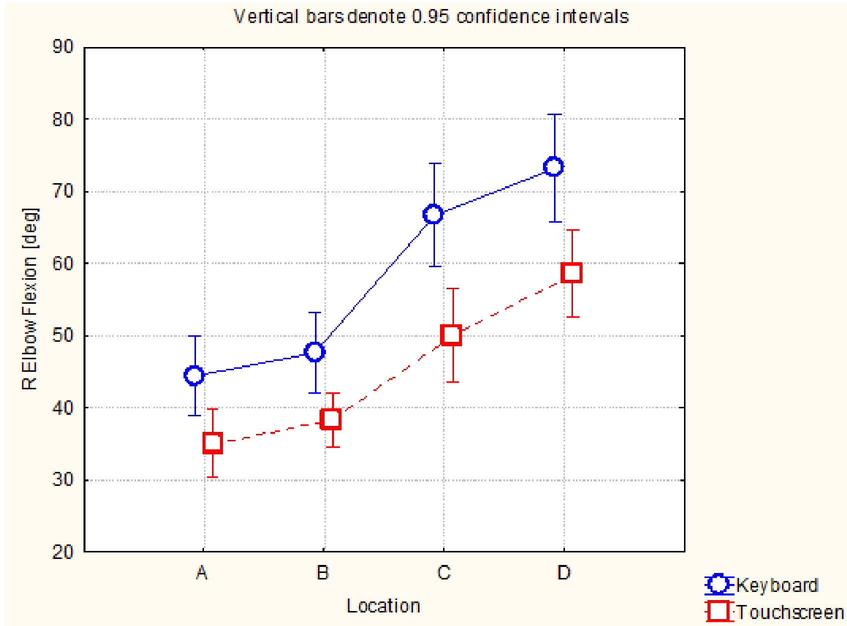


Figure 15.15. Plot of Location/Task interaction means for right elbow flexion (deg)

Table 15.38. Post-hoc comparison of Size/Location/Task means for right elbow flexion (n=22)

		Small							
		A (Key)	**A (Touch)**	**B (Key)**	**B (Touch)**	**C (Key)**	**C (Touch)**	**D (Key)**	**D (Touch)**
Small	**A (Key)**		0.0013	0.0193	0.3533	0.0001	0.0001	0.0001	0.0001
	A (Touch)			0.0001	0.7819	0.0001	0.0001	0.0001	0.0001
	B (Key)				0.0001	0.0001	0.0890	0.0001	0.0001
	B (Touch)					0.0001	0.0001	0.0001	0.0001
	C (Key)						0.0001	0.0850	0.0001
	C (Touch)							0.0001	0.0151
	D (Key)								0.0001
	D (Touch)								
		Large							
		A (Key)	**A (Touch)**	**B (Key)**	**B (Touch)**	**C (Key)**	**C (Touch)**	**D (Key)**	**D (Touch)**
Large	**A (Key)**		0.0001	1.0000	0.0003	0.0001	1.0000	0.0001	0.0001
	A (Touch)			0.0001	0.7323	0.0001	0.0001	0.0001	0.0001
	B (Key)				0.0002	0.0001	1.0000	0.0001	0.0001
	B (Touch)					0.0001	0.0002	0.0001	0.0001
	C (Key)						0.0001	0.0004	0.4394
	C (Touch)							0.0001	0.0001
	D (Key)								0.0001
	D (Touch)								
		Large							
		A (Key)	**A (Touch)**	**B (Key)**	**B (Touch)**	**C (Key)**	**C (Touch)**	**D (Key)**	**D (Touch)**
Small	**A (Key)**	1.0000	0.6838	1.0000	0.9731	0.0642	1.0000	0.0013	0.3174
	A (Touch)	0.8553	1.0000	0.7970	1.0000	0.0018	0.8349	0.0002	0.0127
	B (Key)	0.9994	0.0907	0.9998	0.3296	0.5786	0.9996	0.0248	0.9692
	B (Touch)	0.9962	0.9918	0.9906	1.0000	0.0086	0.9946	0.0003	0.0584
	C (Key)	0.0003	0.0002	0.0004	0.0002	0.3496	0.0004	0.9994	0.0732
	C (Touch)	0.7227	0.0076	0.7901	0.0386	0.9944	0.7483	0.2388	1.0000
	D (Key)	0.7227	0.0076	0.7901	0.0386	0.9944	0.7483	0.7227	0.0059
	D (Touch)	0.0976	0.0004	0.1235	0.0018	1.0000	0.1066	0.9376	0.9997

Table 15.39. Post-hoc comparison of Location/Task means for right elbow flexion (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.0001	0.0683	0.0001	0.0001	0.0002	0.0001	0.0001
A (Touch)			0.0001	0.0767	0.0001	0.0001	0.0001	0.0001
B (Key)				0.0001	0.0001	0.3595	0.0001	0.0001
B (Touch)					0.0001	0.0001	0.0001	0.0001
C (Key)						0.0001	0.0001	0.0001
C (Touch)							0.0001	0.0001
D (Key)								0.0001
D (Touch)								

Left Elbow Flexion – Keyboard Task

Table 15.40. Summary statistics of left elbow flexion (deg) (n=22)

			Location A	B	C	D	Mean/S.D.	
Size	Small	Mean	21.47	28.41	74.91	50.67	Mean/S.D. of Small	
		Std Dev	8.23	10.57	12.42	12.82	43.86	23.74
		Min	4.89	10.51	50.35	21.97		
		Max	34.24	43.25	90.72	70.00		
	Large	Mean	13.74	21.03	59.82	45.31	Mean/S.D. of Large	
		Std Dev	6.98	11.82	10.70	7.72	34.97	20.85
		Min	2.22	3.78	48.87	32.46		
		Max	26.28	36.83	81.49	59.17	Grand Mean/S.D.	
	Mean/S.D. of Location		17.60	24.72	67.36	47.99	39.42	22.66
			8.43	11.58	13.70	10.69		

Table 15.41. Two-way ANOVA results of left elbow flexion (n=22)

	SS	DOF	MS	F	p	Observed Power
Intercept	136741.40	1	136741.40	439.6737	<0.0001	1.0000
Size	1738.80	1	1738.80	5.5909	0.0283	0.6141
Error	6220.13	20	311.01			
Location	34015.91	3	11338.64	285.0373	<0.0001	1.0000
Location*Size	299.68	3	99.89	2.5111	0.0671	0.5936
Error	2386.77	60	39.78			

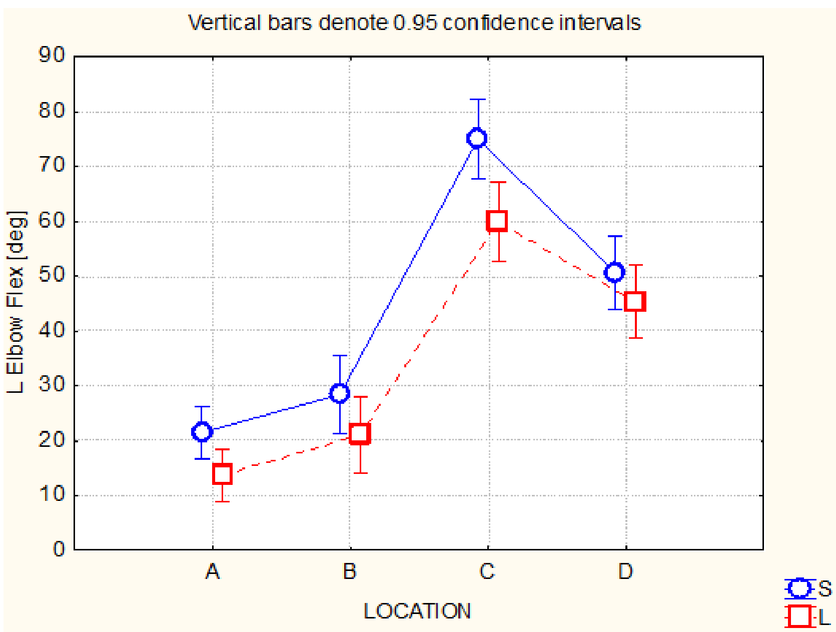


Figure 15.16. Plot of Size/Location interaction means for left elbow flexion (deg)

Table 15.42. Post-hoc comparison of Location means for left elbow flexion (n=22)

	A	B	C	D
A		0.0024	0.0002	0.0002
B			0.0002	0.0002
C				0.0002
D				

Shoulder Angle

Table 15.43. Summary statistics of shoulder angle (deg) (n=22)

			Location							
			A	B	C	D				
Small	Keyboard	Mean	66.4	41.3	0.4	16.5	Mean/S.D. of Keyboard			
		S. D.	4.2	4.5	0.8	7.5	31.2	25.8		
		Min	61.0	31.8	-0.4	6.4				
		Max	75.3	49.7	1.9	31.5				
	Touchscreen	Mean	54.8	31.4	1.8	15.3	Mean/S.D. of Touchscreen			
		S. D.	7.0	7.2	1.5	7.3	25.8	20.8		
		Min	44.4	18.0	-0.3	3.7				
		Max	65.6	44.6	3.7	30.1				
		Mean/S.D. of Location	60.6	36.3	1.1	15.9	Small Grand Mean/S.D.			
			8.2	7.7	1.4	7.2	28.5	23.5		
Large	Keyboard	Mean	61.3	36.7	0.3	18.5	Mean/S.D. of Keyboard			
		S. D.	3.6	6.4	0.6	7.2	29.2	23.4		
		Min	56.4	29.0	-0.2	4.4				
		Max	67.1	47.5	1.9	27.5				
	Touchscreen	Mean	53.0	32.0	1.7	16.5	Mean/S.D. of Touchscreen		Mean/S.D. of Keyboard	
		S. D.	4.6	6.7	3.0	7.8	25.8	20.0	30.2	24.5
		Min	47.4	23.8	-2.0	3.8			Mean/S.D. of Touchscreen	
		Max	63.0	43.7	9.4	25.5			25.8	20.3
		Mean/S.D. of Location	57.2	34.4	1.0	17.5	Large Grand Mean/S.D.		Grand Mean/S.D.	
			5.9	6.9	2.2	7.4	27.5	21.7	28.0	22.5
	Combined Mean/S.D. of Location		58.9	35.3	1.1	16.7				
			7.3	7.3	1.8	7.3				

Table 15.44. Three-way ANOVA results of shoulder angle (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	137934.80	1	137934.80	1215.43	<0.0001	1.0000
Size	41.03	1	41.03	0.36	0.5544	0.0884
Error	2269.73	20	113.49			
Task	843.00	1	843.00	61.94	<0.0001	1.0000
Task*Size	41.39	1	41.39	3.04	0.0965	0.3824
Error	272.20	20	13.61			
Location	81904.55	3	27301.52	768.67	<0.0001	1.0000
Location*Size	158.25	3	52.75	1.49	0.2277	0.3732
Error	2131.08	60	35.52			
Task*Location	901.76	3	300.59	67.42	<0.0001	1.0000
Task*Location*Size	63.14	3	21.05	4.72	0.0050	0.8780
Error	267.50	60	4.46			

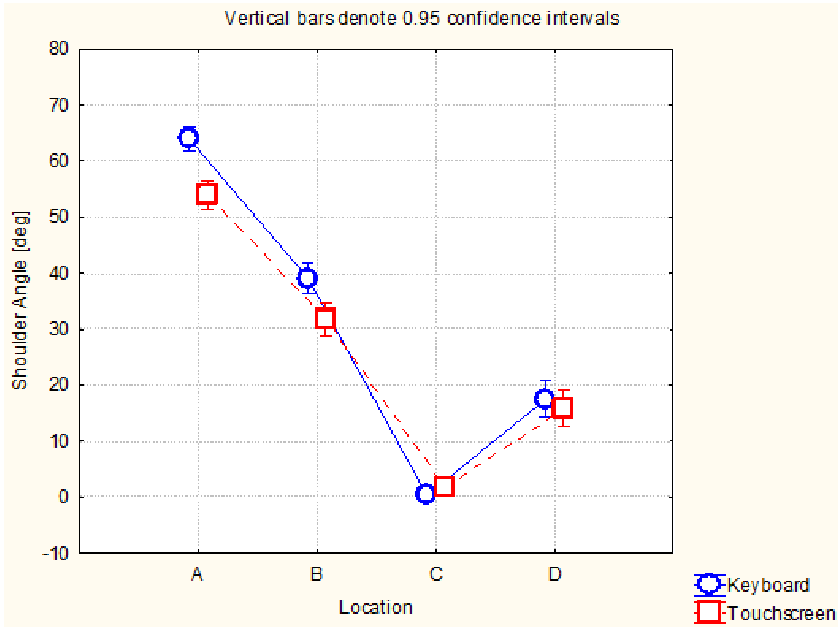


Figure 15.17. Plot of Location/Task interaction means for shoulder angle (deg)

Table 15.45. Post-hoc comparison of Size/Location/Task means for shoulder angle (n=22)

		Small							
		A (Key)	**A (Touch)**	**B (Key)**	**B (Touch)**	**C (Key)**	**C (Touch)**	**D (Key)**	**D (Touch)**
Small	**A (Key)**		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	A (Touch)			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	B (Key)				0.0001	0.0001	0.0001	0.0001	0.0001
	B (Touch)					0.0001	0.0001	0.0001	0.0001
	C (Key)						0.9595	0.0001	0.0001
	C (Touch)							0.0001	0.0001
	D (Key)								0.9878
	D (Touch)								
		Large							
		A (Key)	**A (Touch)**	**B (Key)**	**B (Touch)**	**C (Key)**	**C (Touch)**	**D (Key)**	**D (Touch)**
Large	**A (Key)**		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	A (Touch)			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	B (Key)				0.0003	0.0001	0.0001	0.0001	0.0001
	B (Touch)					0.0001	0.0001	0.0001	0.0001
	C (Key)						0.9648	0.0001	0.0001
	C (Touch)							0.0001	0.0001
	D (Key)								0.7170
	D (Touch)								
		Large							
		A (Key)	**A (Touch)**	**B (Key)**	**B (Touch)**	**C (Key)**	**C (Touch)**	**D (Key)**	**D (Touch)**
Small	**A (Key)**	0.7376	0.0008	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	A (Touch)	0.3626	1.0000	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
	B (Key)	0.0001	0.0041	0.8626	0.0436	0.0001	0.0001	0.0001	0.0001
	B (Touch)	0.0001	0.0001	0.6600	1.0000	0.0001	0.0001	0.0013	0.0003
	C (Key)	0.0001	0.0001	0.0001	0.0001	1.0000	1.0000	0.0002	0.0002
	C (Touch)	0.0001	0.0001	0.0001	0.0001	1.0000	1.0000	0.0002	0.0003
	D (Key)	0.0001	0.0001	0.0001	0.0001	1.0000	1.0000	1.0000	1.0000
	D (Touch)	0.0001	0.0001	0.0001	0.0002	0.0003	0.0008	0.9899	1.0000

Table 15.46. Post-hoc comparison of Location/Task means for shoulder angle (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
A (Touch)			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
B (Key)				0.0001	0.0001	0.0001	0.0001	0.0001
B (Touch)					0.0001	0.0001	0.0001	0.0001
C (Key)						0.3310	0.0001	0.0001
C (Touch)							0.0001	0.0001
D (Key)								0.2044
D (Touch)								

Shoulder Displacement

Table 15.47. Summary statistics of shoulder displacement (cm) (n=22)

			Location A	Location B	Location C	Location D		
Task	Keyboard	Mean	29.6	19.9	2.7	5.9	Mean/S.D. of Keyboard: 14.5	12.4
		S. D.	8.3	5.4	5.0	4.3		
		Min	17.9	11.5	0.2	0.6		
		Max	53.3	38.6	24.8	23.4		
	Touchscreen	Mean	29.6	19.6	4.9	5.7	Mean/S.D. of Touchscreen: 14.9	11.9
		S. D.	7.8	6.1	5.1	4.4		
		Min	20.2	11.0	0.5	1.2		
		Max	54.6	39.4	26.5	23.2		
		Mean/S.D. of Location	29.6	19.7	3.8	5.8	Grand Mean/S.D.: 14.7	12.1
			8.0	5.7	5.1	4.3		

Table 15.48. Three-way ANOVA results of shoulder displacement (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	38207.80	1	38207.80	229.02	<0.0001	1.0000
Size	156.13	1	156.13	0.94	0.3449	0.1515
Error	3336.65	20	166.83			
Task	7.88	1	7.88	1.81	0.1939	0.2489
Task*Size	8.52	1	8.52	1.95	0.1774	0.2653
Error	87.18	20	4.36			
Location	19610.17	3	6536.72	174.99	<0.0001	1.0000
Location*Size	41.51	3	13.84	0.37	0.7746	0.1187
Error	2241.33	60	37.36			
Task*Location	47.02	3	15.67	7.68	0.0002	0.9834
Task*Location*Size	9.04	3	3.01	1.48	0.2296	0.3715
Error	122.38	60	2.04			

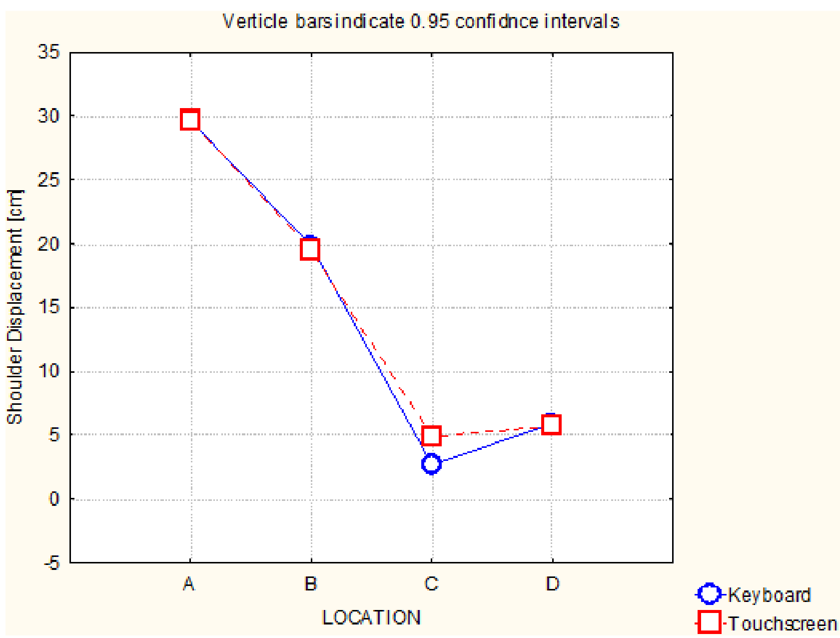


Figure 15.18. Plot of Location/Task interaction means for shoulder displacement (cm)

Table 15.49. Post-hoc comparison of Location/Task means for shoulder displacement (n=22)

	A (Key)	A (Touch)	B (Key)	B (Touch)	C (Key)	C (Touch)	D (Key)	D (Touch)
A (Key)		0.8638	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
A (Touch)			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
B (Key)				0.6682	0.0001	0.0001	0.0001	0.0001
B (Touch)					0.0001	0.0001	0.0001	0.0001
C (Key)						0.0258	0.0004	0.0006
C (Touch)							0.8595	0.9123
D (Key)								1.0000
D (Touch)								

Hip Displacement

Table 15.50. Summary statistics of hip displacement (cm) (n=22)

			Location					
			A	**B**	**C**	**D**	**Mean/S.D. of Keyboard**	
Task	**Keyboard**	**Mean**	20.4	9.4	2.0	4.0	9.0	10.3
		S. D.	13.5	4.9	3.2	3.2		
		Min	6.7	2.8	0.1	0.0		
		Max	61.4	20.4	15.1	13.1		
	Touchscreen	**Mean**	19.2	9.4	2.0	4.0	**Mean/S.D. of Touchscreen**	
		S. D.	11.0	5.0	3.2	3.2	8.6	9.2
		Min	6.1	2.8	0.1	0.0		
		Max	57.0	20.4	15.5	13.1		
		Mean/S.D. of Location	19.8	9.4	2.0	4.0	**Grand Mean/S.D.**	
			12.2	4.9	3.2	3.2	8.8	9.8

Table 15.51. Three-way ANOVA results of hip displacement (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	12067.86	1	12067.86	108.87	<0.0001	1.0000
Size	15.19	1	15.19	0.14	0.7151	0.0644
Error	2216.84	20	110.84			
Task	5.24	1	5.24	1.77	0.1984	0.2448
Task*Size	2.34	1	2.34	0.79	0.3848	0.1353
Error	59.18	20	2.96			
Location	8455.66	3	2818.55	35.85	<0.0001	1.0000
Location*Size	47.51	3	15.84	0.20	0.8950	0.0855
Error	4717.85	60	78.63			
Task*Location	13.05	3	4.35	1.41	0.2476	0.3565
Task*Location*Size	13.76	3	4.59	1.49	0.2262	0.3745
Error	184.58	60	3.08			

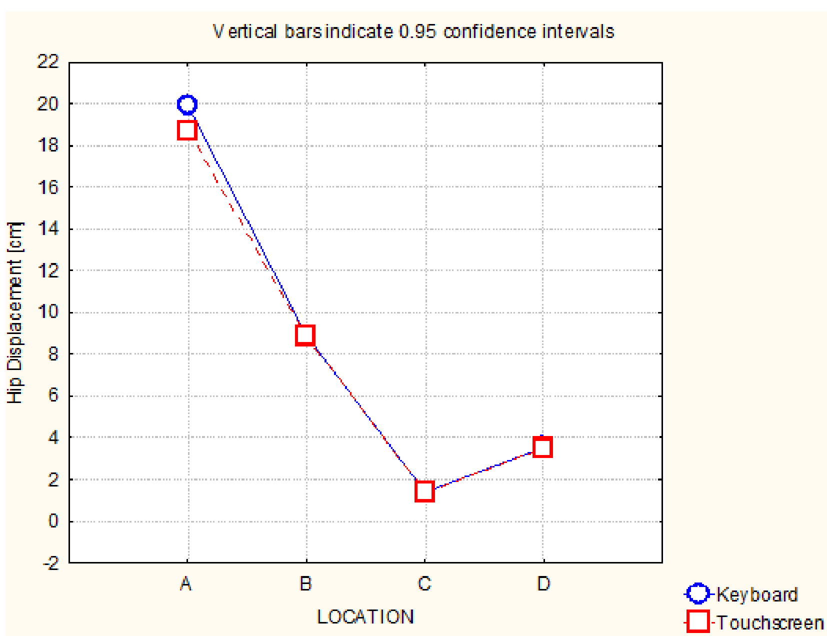


Figure 15.19. Plot of Location/Task interaction means for hip displacement (cm)

Table 15.52. Post-hoc comparison of Location means for hip displacement (n=22)

	A	**B**	**C**	**D**
A		0.0002	0.0002	0.0002
B			0.0012	0.0309
C				0.6731
D				

16 APPENDIX G: COMPLETE REGRESSION ANALYSIS RESULTS FOR BIOMECHANICS ANALYSIS

Table 16.1. Multiple R^2 values for each regression equation. Values in bold have a p-value of <0.05. Cells with red shading have a multiple R^2 value >0.60. Cells with "—" did not have a valid regression equation.

		Location			
	Dependent Variable	**A**	**B**	**C**	**D**
Joint Angles/Displacement	**R Wrist Ext/Flex**	**0.420**	**0.000**	**0.000**	**0.000**
	L Wrist Ext/Flex	**0.445**	**0.749**	--	--
	R Wrist Uln/Rad Deviation	**0.523**	**0.465**	**0.684**	**0.460**
	L Wrist Uln/Rad Deviation	**0.529**	**0.659**	**0.653**	--
	R Elbow Flexion	**0.375**	**0.491**	**0.529**	**0.553**
	L Elbow Flexion	**0.851**	**0.752**	**0.907**	**0.590**
	Shoulder Angle	**0.194**	--	--	**0.663**
	Shoulder Displacement	--	--	**0.564**	**0.545**
	Hip Displacement	--	--	**0.544**	**0.770**
Muscle Activity	**R Pectoralis Major**	**0.444**	**0.516**	**0.710**	**0.552**
	L Pectoralis Major	**0.422**	0.257	**0.283**	**0.237**
	R Middle Deltoid	**0.193**	**0.218**	--	--
	L Middle Deltoid	**0.358**	**0.204**	**0.198**	**0.250**
	R Upper Trapezius	--	**0.320**	--	--
	L Upper Trapezius	**0.338**	**0.275**	**0.582**	**0.499**
	R Erector Spinae	**0.594**	**0.889**	**0.663**	--
	L Erector Spinae	**0.385**	--	**0.727**	**0.831**

Table 16.2. Total number of occurrences in regression equations shaded in red in **Table 16.1**

St [cm]	**A L [cm]**	**S H [cm]**	**S E H [cm]**	**Sh H [cm]**	**T D [cm]**	**B-K L [cm]**
4	5	7	7	5	3	6
B-P L [cm]	**K H [cm]**	**P H [cm]**	**Sh B [cm]**	**I B [cm]**	**H B [cm]**	**W [kg]**
7	7	6	8	6	4	4

St – Stature (cm); A L – Arm Length (cm); S H – Sitting Height (cm); S E H – Sitting Eye Height (cm); Sh H – Sitting Shoulder Height (cm); T D – Trunk Depth (cm); B-K L – Buttock-Knee Length (cm); B-P L – Buttock-Popliteal Length (cm); K H – Knee Height (cm); P H – Popliteal Height (cm); Sh B – Shoulder Breadth (cm); I B – Intersceye Breadth (cm); H B – Hip Breadth (cm); W – Weight (kg)

Regression Equations for Bold/Red Cells:

L Wrist Ext/Flex – Location B (deg)

$$\hat{y} = 76.45 - 6.29(\text{B-K L}) + 7.35(\text{B-P L}) - 2.09(\text{Sh B})$$

R Wrist Uln/Rad Deviation – Location C (deg)

$$\hat{y} = 86.00 - 1.11(\text{A L}) + 3.15(\text{S H}) - 2.82(\text{S E H}) - 3.06(\text{Sh B}) + 4.22(\text{I B}) - 1.51(\text{H B})$$

L Wrist Uln/Rad Deviation – Location B (deg)

$$\hat{y} = -96.65 - 0.79(\text{A L}) + 1.31(\text{Sh H}) - 1.91(\text{Sh B})$$

L Wrist Uln/Rad Deviation – Location C (deg)

$$\hat{y} = -130.10 - 2.19(\text{S H}) + 3.79(\text{Sh H}) + 1.12(\text{K H}) + 2.09(\text{Sh B}) - 2.88(\text{I B}) + 1.10(\text{H B})$$

L Elbow Flexion – Location A (deg)

$$\hat{y} = 206.38 - 1.97(\text{S E H}) - 4.07(\text{B-K L}) + 3.59(\text{B-P L}) + 1.94(\text{P H}) - 1.43(\text{H B})$$

L Elbow Flexion – Location B (deg)

$$\hat{y} = 244.38 - 1.68(\text{A L}) - 2.47(\text{S E H}) - 6.58(\text{B-K L}) + 4.23(\text{B-P L}) + 5.55(\text{K H})$$

L Elbow Flexion – Location C (deg)

$$\hat{y} = 159.77 - 2.50(\text{St}) + 2.39(\text{S H}) - 2.93(\text{Sh H}) + 2.38(\text{B-P L}) + 4.22(\text{P H}) \\ + 2.11(\text{I B}) - 0.88(\text{W})$$

Shoulder Angle - Location D (deg)

$$\hat{y} = 111.27 - 1.99(\text{A L}) - 3.00(\text{S E H}) + 2.34(\text{Sh H}) + 2.72(\text{P H}) + 0.54(\text{W})$$

Hip Displacement - Location D (deg)

$$\hat{y} = 8.47 - 0.99(\text{A L}) + 1.39(\text{S H}) - 1.66(\text{S E H}) - 0.69(\text{T D}) + 1.29(\text{K H}) + 0.80(\text{I B})$$

R Pectoralis Major – Location C (%MVC)

$$\hat{y} = 22.24 - 0.28(\text{S H}) + 0.33(\text{T D}) + 0.38(\text{P H}) - 0.41(\text{Sh B})$$

R Erector Spinae – Location B (%MVC)

$$\hat{y} = -1.79 - 0.45(\text{S H}) + 0.56(\text{S E H}) + 1.14(\text{B-K L}) - 0.73(\text{B-P L}) \\ -1.62(\text{K H}) + 1.72(\text{P H}) - 1.08(\text{Sh B}) + 0.94(\text{I B})$$

R Erector Spinae – Location C (%MVC)

$$\hat{y} = 3.25 + 1.14(\text{St}) - 2.10(\text{S H}) + 1.29(\text{S E H}) - 2.70(\text{K H}) + 2.10(\text{P H}) \\ -1.77(\text{Sh B}) + 0.37(\text{W})$$

L Erector Spinae – Location C (%MVC)

$$\hat{y} = -67.95 + 2.57(\text{St}) - 1.63(\text{Sh H}) + 0.91(\text{T D}) - 4.29(\text{B-K L}) \\ + 4.47(\text{B-P L}) - 3.10(\text{K H}) - 1.93(\text{Sh B})$$

L Erector Spinae – Location D (%MVC)

$$\hat{y} = -91.32 + 1.91(\text{St}) - 5.66(\text{B-K L}) + 7.94(\text{B-P L}) - 3.00(\text{K H}) - 2.82(\text{I B}) \\ -1.67(\text{H B}) + 0.41(\text{W})$$

17 APPENDIX H: COMPLETE PERFORMANCE RESULTS

Touchscreen

Table 17.1. Summary statistics of touchscreen task time and misses (n=22)

		Location					
		A	**B**	**C**	**D**	**Mean/S.D. of Time**	
Time	**Mean**	28.9	28.0	27.3	28.0	28.1	2.8
	S. D.	2.4	3.3	3.0	2.4		
	Min	24.8	21.1	24.3	24.4		
	Max	34.4	38.3	33.8	34.9		
Misses	**Mean**	0.32	0.14	0.36	0.18	**Mean/S.D. of Misses**	
	S. D.	0.72	0.47	1.00	0.50	0.3	0.7
	Min	0	0	0	0		
	Max	3	2	4	2		

Table 17.2. One-way ANOVA results of time for touchscreen task (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	69333.80	1	69333.80	3163.420	<0.0001	1.0000
Error	460.26	21	21.92			
Location	28.47	3	9.49	2.990	0.0375	0.6797
Error	199.92	63	3.17			

Table 17.3. One-way ANOVA results of misses for touchscreen task (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	5.5000	1	5.5000	12.1579	0.0022	0.9136
Error	9.5000	21	0.4524			
Location	0.7727	3	0.2576	0.5035	0.6812	0.1469
Error	32.2273	63	0.5115			

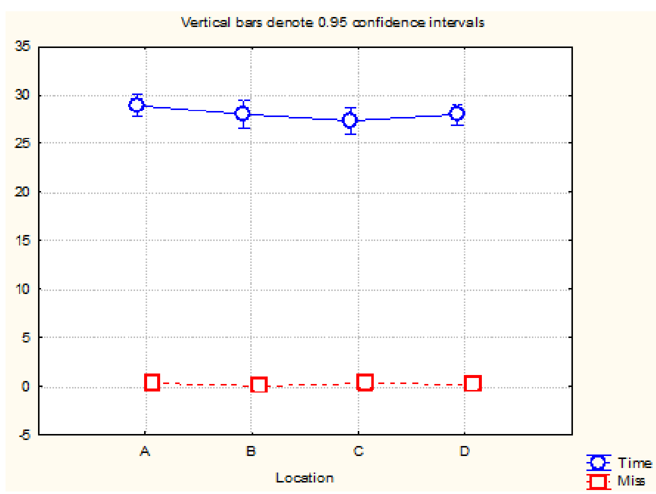


Figure 17.1. Plot of location means of time (sec) and misses for touchscreen task

Table 17.4. Post-hoc comparison of location means for time (n=22)

	A	B	C	D
A		0.3206	0.0214	0.2915
B			0.5994	0.9999
C				0.6364
D				

Keyboard

Table 17.5. Summary statistics of keyboard task time and misses (n=22)

		Location				Mean/S.D. of Time	
		A	**B**	**C**	**D**		
Time	**Mean**	29.3	29.3	29.6	29.1	29.3	7.0
	S. D.	6.7	7.9	7.0	7.0		
	Min	18.5	18.9	19.4	18.4		
	Max	42.4	47.5	46.6	44.6		
						Mean/S.D. of Misses	
Misses	**Mean**	0.18	0.32	0.18	0.23	0.2	0.5
	S. D.	0.39	0.57	0.50	0.69		
	Min	0	0	0	0		
	Max	1	2	2	3		

Table 17.6. One-way ANOVA results of time for keyboard task (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	75650.47	1	75650.47	381.4441	<0.0001	1.0000
Error	4164.86	21	198.33			
Location	2.19	3	0.73	0.3416	0.795337	0.1131
Error	134.80	63	2.14			

Table 17.7. One-way ANOVA results of misses for keyboard task (n=22)

	SS	DOF	MS	F	p	Observed power
Intercept	4.5455	1	4.5455	11.2903	0.0030	0.8931
Error	8.4546	21	0.4026			
Location	0.2727	3	0.0909	0.3424	0.7947	0.1132
Error	16.7273	63	0.2655			

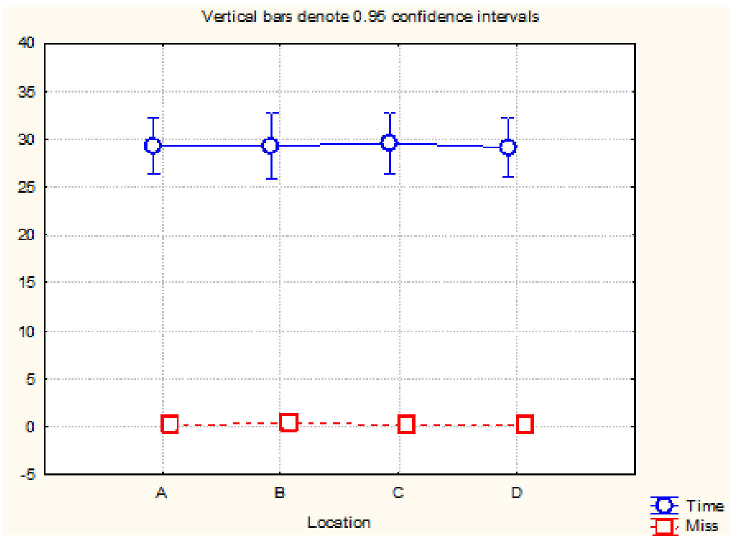


Figure 17.2. Plot of location means of time (sec) and misses for keyboard task

18 APPENDIX I: COMPLETE SUBJECTIVE ASSESSMENT RESULTS

Post-hoc comparisons were made using Student-Newmam-Keuls test.

$$q = \frac{R_A - R_B}{\sqrt{\frac{pn(p+1)}{12}}} = \frac{R_A - R_B}{\sqrt{\frac{(4)(22)(4+1)}{12}}}$$

Where R_A and R_B are the rank sums of the groups (locations) being compared, p is the number of groups spanned, and n is the number of subjects. The critical value of q is then compared (Glantz, 1992).

Comfort/Discomfort

Table 18.1. Summary statistics for comfort/discomfort (n=22)

	Location			
	A	B	C	D
Mean	2.05	3.55	4.86	5.64
Median	2.00	3.00	5.00	6.00
Std Dev	0.79	1.47	1.13	0.73
Min	1.00	1.00	3.00	4.00
Max	3.00	6.00	7.00	7.00

Table 18.2. Rank and verbal tag for comfort/discomfort

1	2	3	4	5	6	7
Very Uncomfortable	Uncomfortable	Somewhat Uncomfortable	Neutral	Somewhat Comfortable	Comfortable	Very Comfortable

Table 18.3. Friedman's ANOVA for comfort/discomfort

	SS	DOF	MS	Chi-sq	p
Location	79.6591	3	26.553	51.04	<0.0001
Error	23.3409	63	0.3705		
Total	103	87			

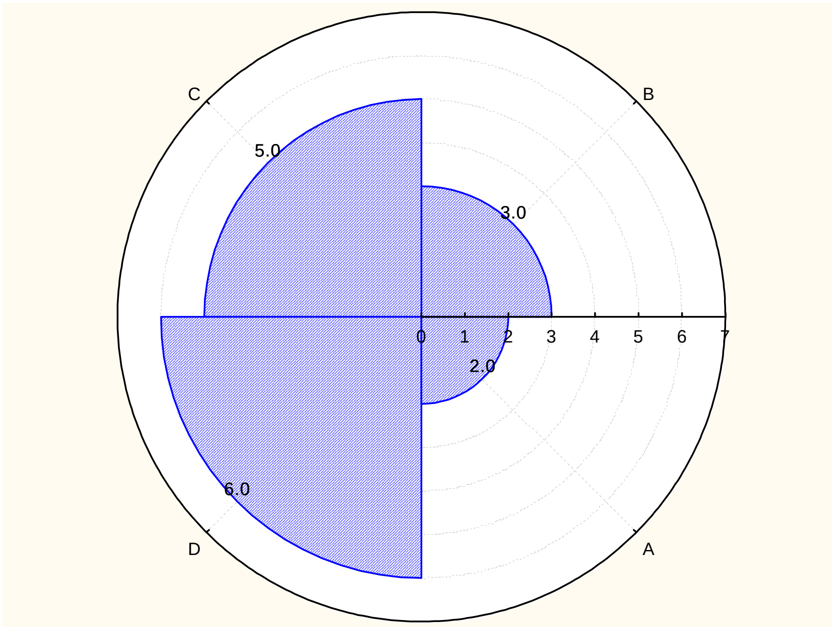


Figure 18.1. Plot of median response for each location for comfort/discomfort (n=22)

Table 18.4. Post-hoc comparison of location means for comfort/discomfort (n=22)

	A	B	C	D
A		<0.01	<0.01	<0.01
B			<0.01	<0.01
C				>0.05
D				

Ease of Use

Table 18.5 Summary statistics for ease of use (n=22)

	Location			
	A	B	C	D
Mean	2.27	3.91	4.95	5.64
Median	2.50	4.00	5.00	6.00
Std Dev	1.08	1.11	1.33	0.73
Min	1.00	2.00	2.00	4.00
Max	5.00	6.00	7.00	7.00

Table 18.6. Rank and verbal tag for ease of use

1	2	3	4	5	6	7
Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy

Table 18.7. Friedman's ANOVA for ease of use

	SS	DOF	MS	Chi-sq	p
Location	68.75	3	22.9167	47.51	<0.0001
Error	26.75	63	0.4246		
Total	95.5	87			

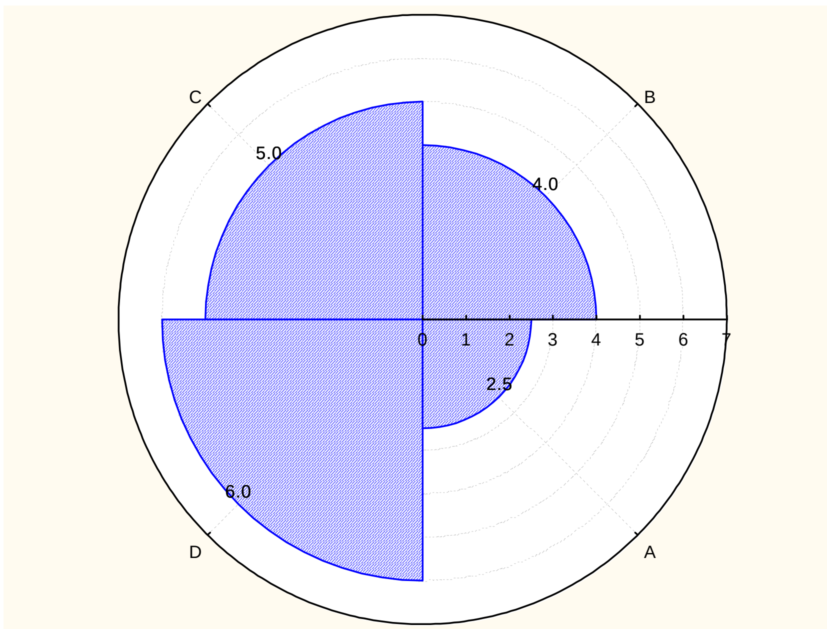


Figure 18.2. Plot of median response for each location for ease of use (n=22)

Table 18.8. Post-hoc comparison of location means for ease of use (n=22)

	A	B	C	D
A		<0.01	<0.01	<0.01
B			<0.05	<0.01
C				>0.05
D				

Like/Dislike

Table 18.9. Summary statistics for like/dislike (n=22)

	Location			
	A	B	C	D
Mean	2.23	3.77	4.73	5.27
Median	2.00	4.00	5.00	5.50
Std Dev	0.87	1.15	1.03	0.83
Min	1.00	1.00	3.00	4.00
Max	4.00	6.00	7.00	6.00

Table 18.10. Rank and verbal tag for like/dislike

1	2	3	4	5	6	7
Very Strongly Disliked	Strongly Disliked	Somewhat Disliked	Neutral	Somewhat Liked	Strongly Liked	Very Strongly Liked

Table 18.11. Friedman's ANOVA for like/dislike

	SS	DOF	MS	Chi-sq	p
Location	73.6136	3	24.5379	49.58	<0.0001
Error	24.3864	63	0.3871		
Total	98	87			

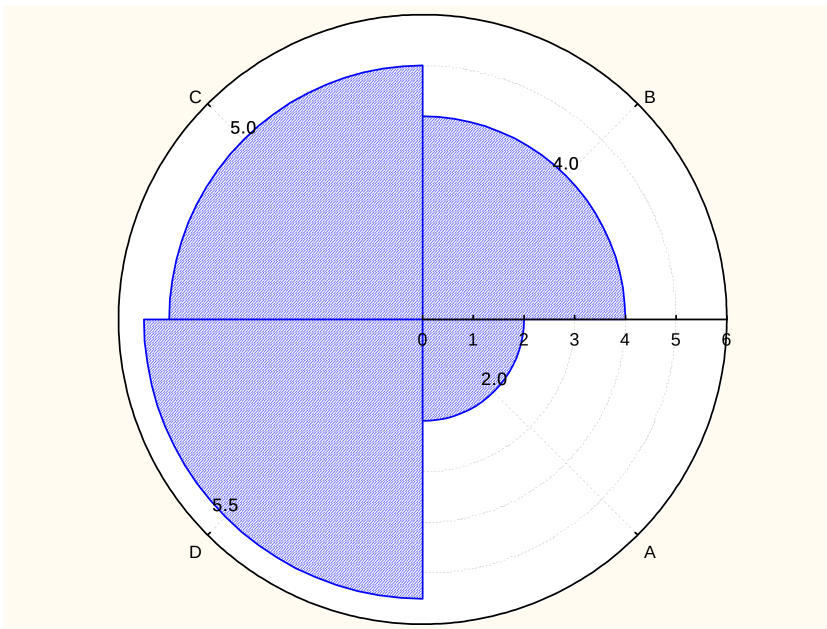


Figure 18.3. Plot of median response for each location for like/dislike (n=22)

Table 18.12. Post-hoc comparison of location means for like/dislike (n=22)

	A	B	C	D
A		<0.01	<0.01	<0.01
B			>0.05	<0.01
C				>0.05
D				

Productivity – Work Order Form

Table 18.13. Summary statistics for work order form productivity (n=22)

	Location			
	A	**B**	**C**	**D**
Mean	3.18	4.27	5.05	5.77
Median	3.00	4.00	5.00	6.00
Std Dev	1.22	1.12	1.13	0.53
Min	2.00	2.00	2.00	5.00
Max	6.00	6.00	6.00	7.00

Table 18.14. Rank and verbal tag for work order form productivity

1	2	3	4	5	6	7
Very Unproductive	Unproductive	Somewhat Unproductive	Neutral	Somewhat Productive	Productive	Very Productive

Table 18.15. Friedman's ANOVA for work order form productivity

	SS	DOF	MS	Chi-sq	p
Location	54.3864	3	18.1288	41.5	<0.0001
Error	32.1136	63	0.5097		
Total	86.5	87			

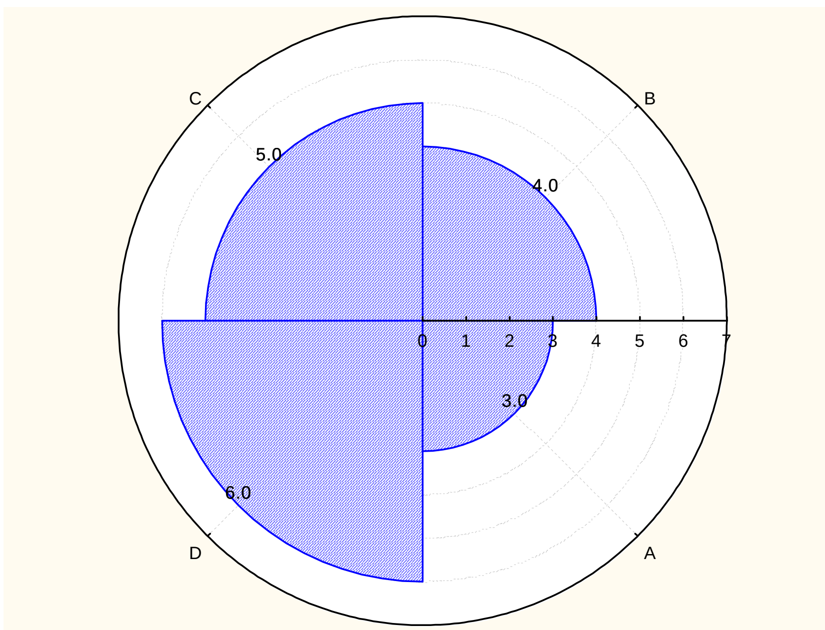


Figure 18.4. Plot of median response for each location for work order form productivity (n=22)

Table 18.16. Post-hoc comparison of location means for productivity (n=22)

	A	B	C	D
A		<0.05	<0.01	<0.01
B			>0.05	<0.01
C				>0.05
D				

Productivity – Touchscreen Task

Table 18.17. Summary statistics for touchscreen task productivity (n=22)

	Location			
	A	**B**	**C**	**D**
Mean	3.77	4.64	5.86	5.95
Median	3.00	4.00	6.00	6.00
Std Dev	1.34	1.14	1.04	0.58
Min	2.00	3.00	2.00	5.00
Max	6.00	7.00	7.00	7.00

Table 18.18. Rank and verbal tag for touchscreen task productivity

1	2	3	4	5	6	7
Very Unproductive	Unproductive	Somewhat Unproductive	Neutral	Somewhat Productive	Productive	Very Productive

Table 18.19. Friedman's ANOVA for touchscreen task productivity

	SS	DOF	MS	Chi-sq	p
Location	45.75	3	15.25	36.16	<0.0001
Error	37.75	63	0.5992		
Total	83.5	87			

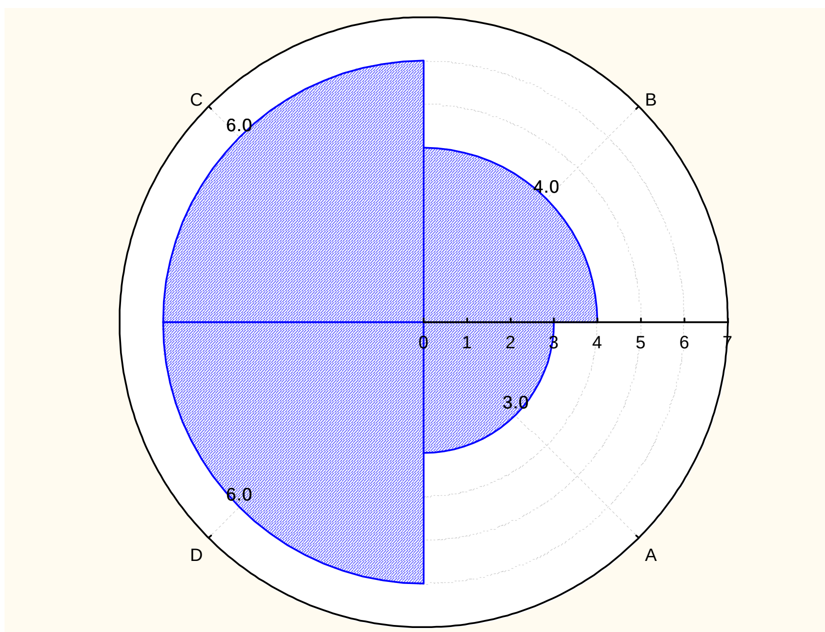


Figure 18.5. Plot of median response for each location for touchscreen task productivity (n=22)

Table 18.20. Post-hoc comparison of location means for productivity (n=22)

	A	B	C	D
A		>0.05	<0.01	<0.01
B			<0.01	<0.01
C				>0.05
D				

Productivity – Keyboard Task

Table 18.21. Summary statistics for keyboard task productivity (n=22)

	Location			
	A	**B**	**C**	**D**
Mean	3.36	4.14	4.64	5.82
Median	3.00	4.00	5.00	6.00
Std Dev	1.36	1.04	1.29	0.66
Min	1.00	2.00	2.00	4.00
Max	6.00	6.00	7.00	7.00

Table 18.22. Rank and verbal tag for keyboard task productivity

1	2	3	4	5	6	7
Very Unproductive	Unproductive	Somewhat Unproductive	Neutral	Somewhat Productive	Productive	Very Productive

Table 18.23. Friedman's ANOVA for keyboard task productivity

	SS	DOF	MS	Chi-sq	p
Location	46.1818	3	15.3939	33.68	<0.0001
Error	44.3182	63	0.7035		
Total	90.5	87			

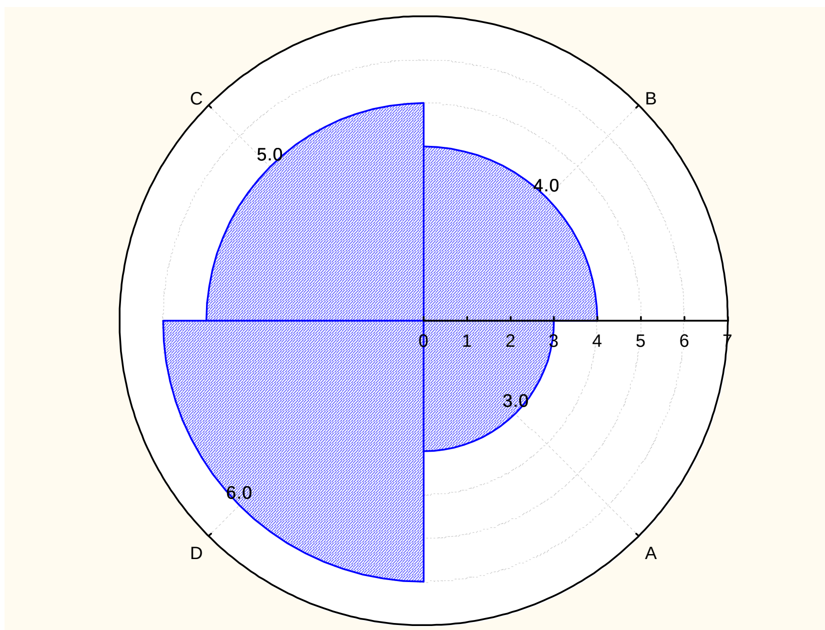


Figure 18.6. Plot of median response for each location for keyboard task productivity (n=22)

Table 18.24. Post-hoc comparison of location means for productivity (n=22)

	A	B	C	D
A		>0.05	<0.01	<0.01
B			>0.05	<0.01
C				<0.05
D				

Overall Rank

Table 18.25. Summary statistics for overall rank (n=22)

	Location			
	A	B	C	D
Mean	1.09	2.50	3.00	3.41
Median	1.00	2.00	3.00	3.50
Std Dev	0.29	0.86	0.87	0.67
Min	1.00	1.00	1.00	2.00
Max	2.00	4.00	4.00	4.00

Four locations ranked from worst (1) to best (4).

Table 18.26. Friedman's ANOVA for overall rank

	SS	DOF	MS	Chi-sq	p
Location	67.3636	3	22.4545	40.42	<0.0001
Error	42.6364	63	0.6768		
Total	110	87			

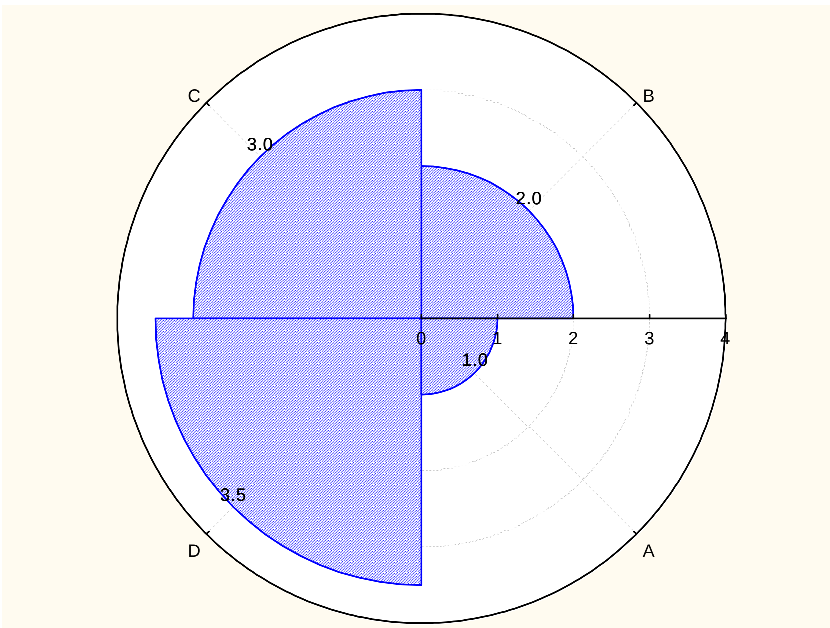


Figure 18.7. Plot of median overall rank of each location (n=22)

Table 18.27. Post-hoc comparison of location means for overall rank (n=22)

	A	B	C	D
A		<0.01	<0.01	<0.01
B			>0.05	>0.05
C				>0.05
D				

Marquette University

This is to certify we have examined this copy of the thesis by

Kyle A. Saginus, B.S.

and have found that it is complete and satisfactory in all respects

The thesis has been approved by

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Dr. Richard Marklin
Thesis Director, Department of Mechanical Engineering

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Dr. Kyuil Kim, Committee Member

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Dr. Guy Simoneau, Committee Member

Approved on

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(Date filled in by thesis director)