EFFECT OF GLOVE PORT HEIGHT ON SHOULDER AND BACK STRESSES

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Six male participants performed liquid mixing and vial filling tasks within a glove box for a duration of 15 minutes. Participants repeated the tasks in standing posture with the glove port heights set at 122 cm and at 132 cm from the floor. At the lower glove port height (122 cm), the average discomfort ratings (scale 0-10) for the shoulder and upper arm were decreased by 27% and 21%, respectively, but the average discomfort rating for the lower back was significantly (α = 5%) increased by 83%. Pouring water in a beaker was perceived to be the most stressful task, most likely due to the constrained posture and precise muscular control required for the task. At the lower glove port height, the average NEMG levels for trapezious, anterior deltoid and biceps were decreased by 53% (significant at α=5%), 17%, 8%, respectively, but the average erector spinae NEMG level was increased by 27%. This research demonstrated the trade off between the shoulder-arm and lower back stresses with varying glove port height and provided a set of quantitative data on upper body stresses in such situations.

Keywords: glove box, work height, upper body

INTRODUCTION

Glove boxes are sealed and environmentally controlled work enclosures where operators work by inserting their arms through the glove port gloves. Glove boxes provide a physical barrier between the operator and the work area to prevent contamination and to protect worker safety. Fixed height of the glove ports requires a constrained upper body posture, and the mismatch between the operator's anthropometry and the glove port height may induce considerable static muscle stress. Static muscle stress can lead to muscle fatigue and pain, since glove boxes are often used for prolonged periods of time. Too low glove port height will impose leaning forward of torso and consequent increased static muscle stress in the lower back and neck. Too high glove port level will cause constant arm and shoulder elevation by the users and consequently static stress in arm and shoulder muscles.

For light manipulative type of work, work surface height of about plus or minus 5 cm from the worker's elbow height is found to be ideal in terms of worker comfort and productivity (Kroemer and Grandjean, 1997). Only two articles in the literature (Whitemore et al, 1995; Whitemore and Mount, 1995) studied ergonomic aspects of glove box design, but no studies have been conducted on the effect of glove port height. Based on anthropometry, Eastman Kodak (1983) recommended that the center of the glove ports for standing glove box configurations should be 132 cm from the floor for the 95th percentile tall American males. For shorter workers they recommended raising the worker by providing an adjustable height platform. The 95th percentile elbow height for a male adult American is 115.3 cm (Konz and Johnson, 2004), and after adding 2.5 cm for shoe thickness, the working elbow height is 117.8 cm for this population, which is 132-117.8=14.2 cm below the recommended glove port height.

American Glovebox Society (1998) has developed detailed standards and ergonomic design guidelines for glove boxes. They are in the process of revising their guidelines and they think that the Eastman Kodak's 132 cm glove port height recommendation is bit too high even for the taller population, and propose a reduction of the current recommendation from 132 to 122 cm. The objective of this pilot study was to evaluate the effect of reducing the glove port height on the upper body stress and on the discomfort levels of glove box users through a laboratory experiment.

EXPERIMENTAL METHOD

The university institutional review board approved the experimental protocol. From a pool of college students, six tall male subjects were randomly selected for this laboratory experiment. Their average (standard deviation) height, weight, and ages were 184.6 (3.5) cm, 85.7 (16.6) Kg, and 22.7 (2.4) years, respectively. The height of the subjects ranged between 77th and 98th percentile of US male population (Konz and Johnson, 2004), with an average height at 91st percentile. Each participant performed an identical set of experimental tasks in two sessions separated by at least 48 hour interval. The glove port height was set either at 132 cm or at 122 cm from the floor for these two sessions and the order was randomized to eliminate the learning effect. Also, the glove port height was not revealed to the participants to avoid subjective bias.

A Captar Field Pyramid Model 2200A portable glove box constructed with transparent plastic was used (Figure 3.1) to simulate the restrictive nature of the glove box work. This glove box was designed for industrial use and had integrated thick latex gloves in the glove ports. It was placed on an adjustable height table. The participants were instructed to stand as close as was necessary to the glove box to be able to perform the experimental tasks conveniently.

Six 250 mL graduated cylinders with screw tops, 3 plastic spoons, two porcelain bowls, one pipette, 12 microfuge tubes, 1 microfuge tube rack, 1 half gallon container of water, and sugar and colored lemonade mix were used to simulate commonly found mixing and filling tasks in laboratories. The tasks included a series of measuring, pouring, and stirring tasks within the portable glove box. The order of tasks was verbally instructed to the participants during the experimental sessions. The participants were asked to complete the tasks at their normal pace. The total experimental task was designed to be completed approximately within 15 minutes per session.

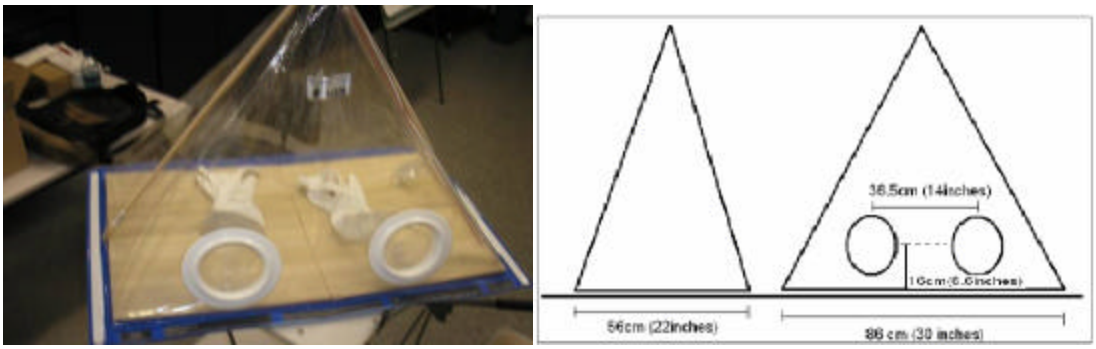

Figure 1. Captar Field Pyramid Model 2200A **p**ortable glove box along with relevant dimensions.

An eight channel Biometrics Data Link base Unit, a Biometrics amplifier and four bipolar skin electrodes with pre-amplifiers were used in this study to collect the electromyography (EMG) signals. The equipment was connected to a desktop computer and the Bio-analysis Software facilitated the data collection and analysis of the EMG signals. The four skin electrodes were connected to the participant on the right erector spinae at the lower back, right middle trapezius, right anterior deltoid and the right biceps muscles according to NIOSH (1992) guidelines for electrode placements. Double-sided adhesive tapes were used to secure the skin electrodes. The ground electrode was attached to the bony portion of the wrist. After initialization of the electrode voltages, the participant performed a normalization task of holding a 2.3 kg mass in the right hand for approximately 15 seconds while the arm was kept vertical and the forearm was kept horizontal in the sagittal plane. Average amplitudes of the rectified EMGs were used later to normalize the task EMG amplitudes. After a brief rest period of approximately 2 minutes, the experimental task began. EMG signals were collected at a rate of 1000 Hz for the entire period of the experimental task. The Bio-analysis software provided a real-time display of the plot of the acquired EMG signals which was monitored to ensure data integrity. In the event any of the skin electrodes becomes loose, the signals show an erratic pattern. During the data collection phase no such event occurred. Immediately after the end of the experimental task, the subject filled out a post survey form, which was used to collect subjective discomfort ratings in different body regions, and stress levels perceived in performing various activities during the experimental tasks.

RESULTS AND ANALYSIS

The average time taken to complete the experimental task was 13.3 minute and was not significantly different for the two glove port heights. The post experiment survey indicated that the experimental task was not too long and not too hard according to the participants' perception. All participants found the lighting level was adequate for the experimental task. The average scores of survey questions about the task difficulty levels are summarized in Table 1. Task difficulty ratings were assessed in a scale of 0 to 10 with 10 being stressful, 5 being some (moderate) stress and 0 being no stress. Highest average score for stressfulness was a score of 5.3 for the task of "pouring water to the beaker …". It appeared that within the compact enclosure of the glove box, handling of liquid filled bottle was perceived to be most stressful. This was probably due to the precise muscular control required for the task, and the attention required to make sure that no liquid was spilled. The average scores for the specific tasks were not significantly different between the two glove port levels.

Table 1. Average rating scores of task difficulty levels in a scale of 0 to 10

Task #	Specific task	Score	
		122 cm	132 cm
1	Holding your arms through the arm ports and into the gloves	3.0	2.3
2	Using the plastic spoon to scoop either drink mix or sugar into the container	2.3	2.2
3	Pouring water into either the beaker or the 250mL bottles	5.8	4.8
4	Using the plastic pipette	1.6	1.6
5	Screwing the caps onto the plastic bottles	1.3	1.6
Average score		2.8	2.5

Body discomfort rating was assessed in a scale of 0 to 10, with 10 being discomfort, 5 being some (moderate) discomfort and 0 being no discomfort. Figure 2 summarizes the average body discomfort ratings by the participants for 122 cm and 132 cm glove port height sessions. The majority of the average discomfort ratings were below 2. The low scores in the body regions indicated minor or no discomfort, which was expected because the experimental task was light and the duration was less than 15 minutes. The individual scores varied widely among the subjects as shown by the comparatively large standard deviations of the ratings for all body regions. This was expected due to the inherent difference in discomfort perception among the participants. The three highest average discomfort ratings over both sessions were in the lower back (2.85), upper arm (2.05) and shoulder (2.15) regions, which were consistent with the expected muscle group that were most likely to be stressed by the experimental task. When the discomfort ratings were compared for two glove port heights by using a two-tailed matched pair *t*-test, the mean lower back discomfort score was significantly decreased for the higher glove port height at $\alpha = 5\%$. The average rating for the lower back discomfort was 1.7 points (83%) lower for the higher glove port level. As expected, the upper arm and shoulder average scores were 0.7 (27%) and 0.5 (21%) points lesser for the lower glove port height, respectively, however these differences were not statistically significant.

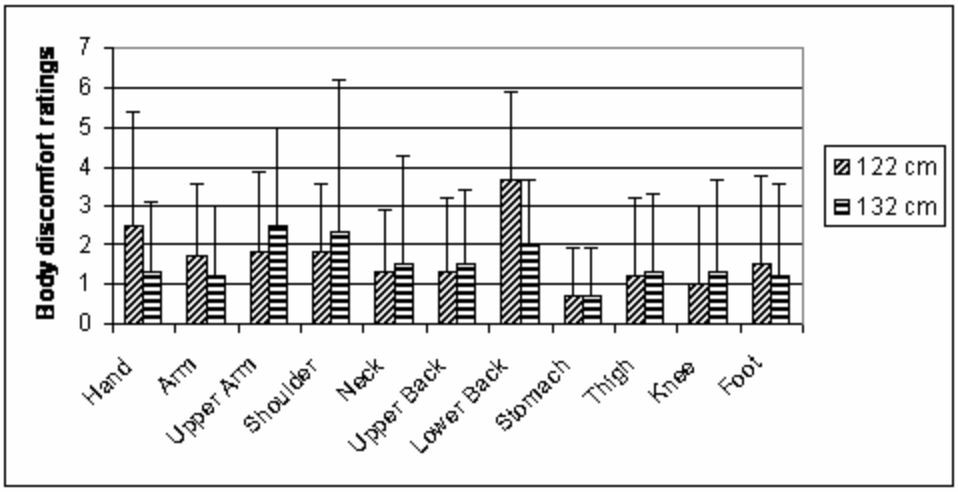

Figure 2. Average and standard deviation scores of body discomfort ratings in 0 to 10 scale after completing the experimental task.

The raw EMG signals were first rectified, and then averaged over the whole experimental duration and then normalized to obtain the normalized EMG (NEMG). Figure 3 summarizes the average NEMG's over all participants for the four muscle groups. The average NEMG levels of the first three muscle groups, i.e., trapezius, anterior deltoid and biceps, decreased by 53%, 17%, 8%, respectively, for a the lower glove port height, but the erector spinae muscle group experienced 27% increase in NEMG for the lower glove port height. This was exactly the effect that was anticipated. A two tailed matched pair *t*-test of difference of mean NEMG found that the increase in trapezius NEMG was statistically significant ($\alpha = 0.05$).

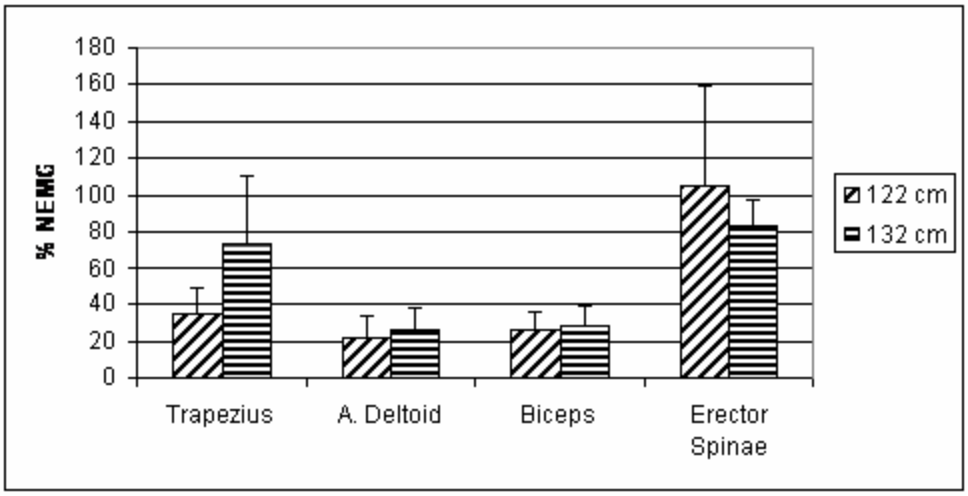

Figure 3. Average and standard deviation of Normalized EMG scores for 122 cm and 132 cm glove port heights.

CONCLUSION

This research investigated the effect of glove port height on upper body stress in a simulated laboratory experiment. The experiment allowed for a wide range of muscle groups to be used along with varying degrees of dexterity while being constrained in an effective simulation of a real glove box workstation. The results of this study support the importance of posture sensitivity in glove box workstation design. On average, the lower glove port level (122 cm) produced significantly higher (83%) perceived stress and 27% higher NEMG levels at the lower back region among the participants. This is attributable to the static muscle stress in lower back and the requirement of forward bending due to the lower glove port height. It was anticipated that higher glove port height (132 cm) would impose the necessity of constant arm and shoulder elevation and consequent static muscle work of the shoulder and arm muscles. The average discomfort rating scores and NEMG levels in arm and shoulder region were consistent with this notion. Arm and shoulder discomfort ratings were decreased by 27% and 21%, respectively, and NEMG levels in trapezeous, anterior deltoid and biceps were decreased by 53%, 17% and 8% in, respectively, at the lower glove port level. Out of these, NEMG reduction of trapezious muscle was statistically significant.

In conclusion, results from this study supported the ergonomic guidelines for work height and demonstrated the trade off between the shoulder-arm and lower back stress with varying height of the glove port. The research also provided, for the first time, a set of quantitative data on upper body stresses in such situations. Future studies with larger number of participants and longer duration of tasks will be necessary to better understand the muscle fatigue characteristics due to static muscle loading in glove box operation and to determine the optimum glove port heights for the user population.

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