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User Experience and Task Completion Time Evaluation of Impact Protective Gloves

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Abstract: Petroleum production industry employees suffer from high severity hand injuries due to crushing and caught by incidents. Impact protective gloves are worn as personal protective equipment (PPE) to protect hands from these impact events. User acceptance is an important consideration when choosing PPE. Employees are less likely to wear PPE if it fits poorly or limits their dexterity, placing them at increased risk for injury. The goal of this study was to evaluate and quantify user experience and task completion time between different impact protective gloves.

Thirty-six subjects (28 males, 8 females, 24-33 years old) participated in testing 16 different pairs of impact protective gloves in addition to a bare hand condition for comparison. Subjects completed two different timed functional tasks in a randomized sequence. The functional tasks consisted of a bolt disassembly task from a fixture and a rope-tying task. After completing each task with each glove condition subjects rated the gloves for dexterity. Subjects also rated each glove for fit and comfort outside of task completion. Functional task completion times were compared to the subjective dexterity, fit, and comfort ratings. The results indicate that task completion times for the bolt disassembly and rope-tying tasks were inversely correlated with higher dexterity ratings (r= -.89 and r= -.87) respectively. In addition, the higher fit and comfort ratings were correlated (r=.89) with each other. Gloves with higher dexterity, fit, and comfort user experience ratings also had faster functional task completion times. Getting workers to use PPE is essential to improving safety, and workers are more likely to use PPE that is comfortable and does not interfere with their tasks. For impact gloves, fit, comfort, and dexterity were correlated, suggesting that consideration of fit and comfort in selected impact protective gloves will increase their use on the job.

Keywords: dexterity, impact protective gloves, user experience

1. Introduction

Petroleum production industry employees suffer from a high frequency and severity of hand injuries, making up 20% of overall injuries (WorkSafe BC, 2013). Upper extremities are the most common body part injured in petroleum industries, accounting for over 30% of total private and government injuries; hand and wrist injuries accounted for more than 53% of the 347,590 injuries to the upper extremities in 2012 (BLS, 2012b). In the petroleum industry, struck by and caught in incidents comprise 13% and 6% of incidents (WorkSafe BC, 2017). Fractures of the hand accounted for 42% of all hand injuries (Trybus, 2005) for emergency room visits with a chief complaint of hand injury.

Oil and Gas industry workers wear impact protective gloves as personal protective equipment (PPE) to protect hands from impact injuries. Hand function is decreased when wearing gloves (Kinoshita, 1999, Tsaousidis and Freivalds, 1998, and Muralidhar and Bishu, 2000) and workers experience decreased dexterity, prehension, and functional strength. User acceptance is an important consideration when choosing PPE. Workers are less likely to wear PPE if it fits poorly, is uncomfortable, or limits their dexterity, increasing their risk for injury. The aim of this study was to evaluate and quantify user experience and task completion time between 16 different pairs of impact protective gloves. It was hypothesized that gloves that had higher user experience ratings would have faster task completion times than gloves with lower user experience ratings.

2. Methods

2.1 Subjects

Thirty-six subjects (28 males, 8 females, 21-60 years old) tested gloves for comfort, fit, dexterity, and pinch and grip strength. Comfort and fit were determined subjectively, while dexterity, pinch strength, and grip strength were objectively measured. All subjects had no known hand injuries or symptoms of hand pathology. Before initiating testing, all participants underwent hand measuring and had their glove size determined using a glove-sizing chart.

2.2 Protocol

16 pairs of gloves were subdivided into three similar material and construction type groups for comparison: knit gloves, leather gloves, and oil/gas industry heavy duty gloves. After measurement for sizing, and before any tasks were undertaken, the gloves were rated for fit on a scale of 1-5 with one being the lowest rating (does not fit) and five being the highest (fits perfectly) using the verbal anchors referenced below (Figure 1). Fit was defined as the gloves being sized correctly to the hand. Subjects were asked to consider if the gloves were loose or tight, if the finger portions of the glove were too short or too long for their fingers, and if their hand could move freely, unconstrained within the glove.

Rate the fit of each glove….

1	2	3	4	5
Doesn't fit		**Somewhat fits**		**Fits perfectly**

Figure 1: Glove user fit rating

Glove comfort was also rated on a scale of 1-5 (Figure 2), with 1 being not comfortable and 5 being very comfortable. Comfort was defined as the ease of wearing the gloves. Subjects were asked to think about how long they could wear the gloves based on their feel, was the sensation of wearing the gloves distracting, and was there anything about the glove's feel that was unpleasant.

Rate how comfortable each glove is….

1	2	3	4	5
Not comfortable		**Somewhat comfortable**		**Very comfortable**

Figure 2: Glove user comfort rating

Subjects completed two different timed functional tasks in a randomized sequence. The functional tasks consisted of a bolt disassembly task from a fixture and a rope-tying task. The bolt disassembly task consisted of an assembly that had four sets of bolts, lock washers, and nuts. The disassembly task started with the subject loosening the nut from a bolt, removing the bolt from the assembly, then separating the lock washer from the bolt, and placing it on the table. The task was timed for each bolt removal sequence. For the rope tying task subjects were required to tie six consecutive knots. A rope-tying fixture anchored the approximately 3/8" diameter nylon jacketed cotton rope used for the task. After completing each of the timed tasks with each glove condition in addition to a baseline bare hand condition, subjects provided a dexterity rating on a scale of 1-5, (Figure 3). Dexterity was defined as the ease of completing the task.

1	2	3	4	5
Poor dexterity		**Average dexterity**		**Great dexterity**

Figure 3: Glove dexterity rating for bolt and rope tasks

Subjects also completed dominant hand grip strength testing and lateral pinch testing in a bare hand condition in addition to the 16 different gloves conditions. Hand grip strength was measured with a grip dynamometer (Baseline, New York) and lateral pinch was measured with pinch dynamometer (Baseline, New York). Both tests were completed with the subject standing with their shoulder adducted and elbow flexed to 90°.

Statistical analysis was performed using MINITAB 16 software (Minitab Inc., PA). A general linear model ANOVA was used to determine statistically significant differences between glove versus no glove, between individual gloves, and between glove categories for all measured variables. A pairwise Post-hoc Tukey Test was performed to determine which gloves were different from each other. The alpha value was set at 0.05 with a 95% confidence.

3. Results

Glove fit ratings demonstrated trends by glove type. The knit gloves had the highest fit ratings as a type (Avg. 3.83, SDev. 0.49) followed by the leather gloves (Avg. 3.41, SDev. 0.18) ($p<0.01$). The heavy duty oil/gas gloves included the lower rated gloves (Avg. 3.33, SDev. 0.36). Glove comfort ratings mirrored the fit ratings with the knit gloves rated the highest (Avg. 3.77, SDev. 0.36), followed by the leather glove type (Avg. 3.46, SDev. 0.73), and the oil/gas gloves (Avg. 3.13, SDev. 0.56) ($p<0.01$).

The bolt disassembly and rope tying task completion times were compared to the user experience dexterity, fit, and comfort ratings (Table 1). The results indicate that task completion times for the rope-tying task and bolt disassembly task were inversely correlated with higher dexterity ratings (r= -.87 and r= -.89 respectively), indicating a strong relationship agreement between the task completion times and user dexterity ratings. Fit and comfort ratings were also compared to the rope tying and bolt disassembly tasks and correlated (r= -.64, -.79, -.72, and -.73 respectively). These correlations were not as strong as the dexterity ratings, yet still significant. Table 2 shows the correlations between the rope tying task, bolt disassembly task, and fit and comfort ratings. The relationship between the task completion times and glove's fit and comfort ratings is pronounced. In addition, the user's fit and comfort ratings were correlated with each other (r=.89), suggesting that the two were related.

Table 1: Task completion time correlations with user ratings (* signifies statistically significant correlations)

	Dexterity	Fit Rating	Comfort Rating
Rope Tying Task Time	-0.87*	-0.64*	-0.79*
Bolt Disassembly Task Time	-0.89*	-0.72*	-0.73*

Table 2: Task dexterity rating correlations with comfort and fit ratings (* signifies statistically significant correlations)

	Fit Rating	Comfort Rating
Rope Task Dexterity Rating	0.80*	0.93*
Bolt Task Dexterity Rating	0.83*	0.89*

Hand grip strength testing results showed a decrease in hand grip strength for all gloves in comparison to the bare hand baseline condition ($p<0.01$). The bare hand condition averaged 39 kg of grip and the gloves ranged from 36.7 kg down to 29 kg. For lateral pinch strength all glove conditions resulted in a range of 8.5 kg-9.54 kg of pinch force. The no glove, bare hand condition set a baseline average of 8.8 kg. There was no association noted between glove type and pinch strength.

Bolt disassembly task completion time results show that every glove condition had longer task completion times than the bare hand condition time of 5.59 seconds ($p<0.01$). Gloved task completion times ranged from 6.51 to 10.98 seconds. The knit gloves performed best as a group. The longest task completion time was about two times longer than the bare hand, no glove condition. The highest bolt disassembly task dexterity ratings were from the knit gloves, followed by the leather gloves. The oil/gas heavy-duty gloves had the lowest dexterity ratings. The fastest task completion times coincided with the highest dexterity ratings. Figure 4 shows the relationship between the average dexterity rating and bolt disassembly task completion time with a red line representing the bare hand, no glove condition.

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Overall, the user dexterity ratings for the rope tying task were similar to those of the bolt disassembly task, with the fastest task completion times and highest dexterity ratings coinciding. The fastest task completion time was 14.93 seconds and the longest 23.65 seconds. Note that as with the bolt disassembly task, the longest task completion times were almost twice that of the bare hand, no glove condition of 12.62 seconds. Figure 5 shows the relationship between the average dexterity rating and the rope tying task completion time with a red line representing the bare hand, no glove condition.

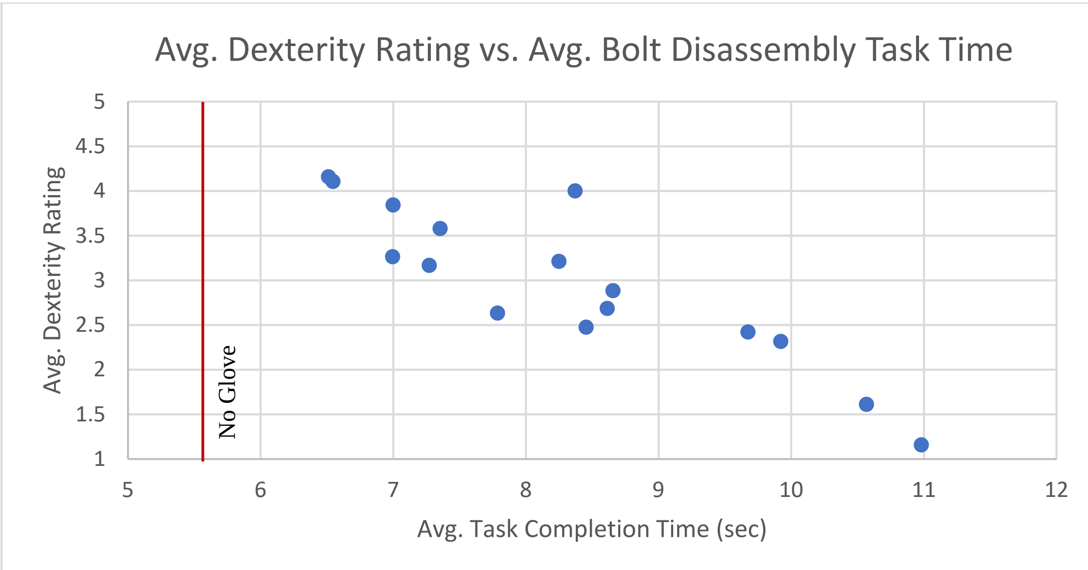

Figure 4: Average dexterity rating vs. avg. bolt task time

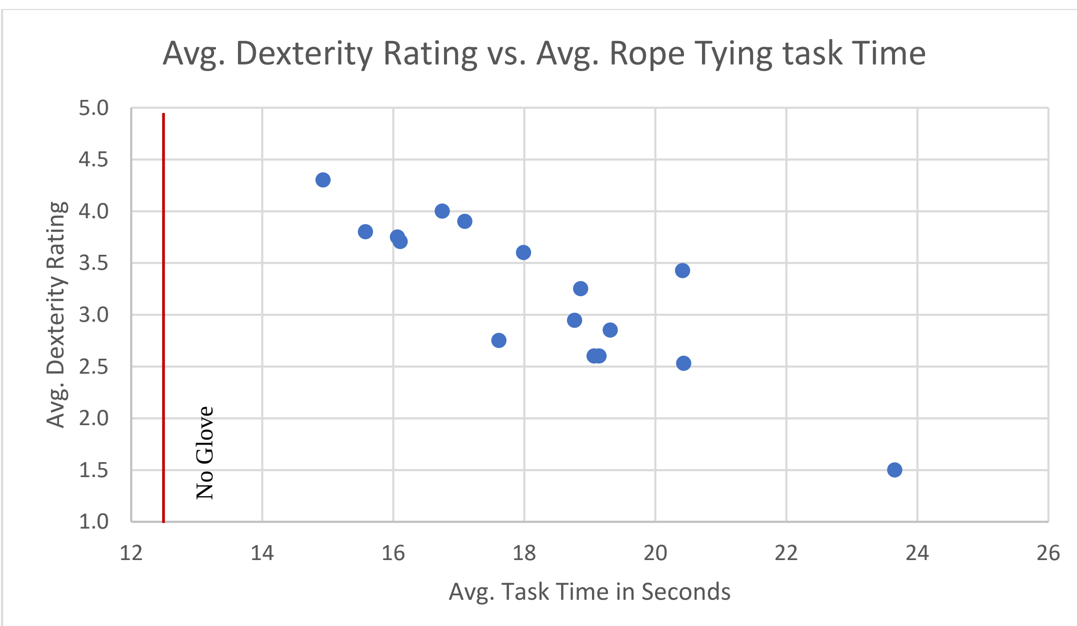

Figure 5: Average dexterity rating vs. avg. rope task time

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4. Discussion

For user fit ratings, a few subjects commented that some gloves were excessively tight or loose in certain areas, such as in-between the fingers, in the web spaces, at the pinky fingers, or at the thumbs, which likely influenced their ratings. The knit gloves were rated the highest for fit. This is possibly due to the knit textiles that can easily stretch and conform to the hand, with less loose and excess material. The leather gloves had more pliability than the heavy duty oil/gas gloves, but not as much as the knit gloves. The heavy duty oil/gas gloves had a wide range of fit ratings, which included the lowest overall ratings. This group tended to have more protective features such as multiple layers of materials, and several impact protective materials that are generally stiff and less pliable than the knit or leather gloves, which likely influenced the ratings.

For glove comfort ratings, some subjects commented that certain gloves made their hands sweat, had uncomfortable inside seams that pressed against their fingers, or had either the presence or absence of padding inside key areas of the glove. Three subjects stated a preference for gloves that had Velcro cuffs that allowed them to adjust the wrist tension. These observations were likely key indicators for their ratings.

Some of the gloves showed a minimal increase in lateral pinch force generation, possibly a result of increased fingertip friction between the glove and the pinch dynamometer contact surface. Many gloves, such as those in the leather group, only increased lateral pinch grip strength by a few hundredths of a kg. Pinch strength has been studied with several different types of gloves in the academic literature, showing that the effect of gloves is minimal at best (Kamal, 1992, Hallbeck and McMullin, 1991, 1993, Tsaousidis and Freivalds, 1998). This study found similar results, with only a 1 kg difference across the whole range of gloves and the bare hand, no glove condition.

Hand grip strength was shown to be decreased by 2.3kg. to 10 kg all gloves from the bare hand, no glove condition. This agrees with other grip force testing, (Wang et al., 1997, Sudhakar et al., 1988) and is a common finding in the literature. The increasing thickness of the palmar material has been shown to further decrease grip strength (Batra et al. 1994). In addition, thinner materials tend to have less grip force reduction than thicker materials, as found by Bensel, (1993). Thicker materials, multiple layers of materials as opposed to single or fewer layers of materials, less friction between the glove material and the object being grasped, and decreased tactile sensation (load feedback) are associated with decreased glove grip strength (Bishu, 1987, Batra et al., 1994).

The bolt disassembly task completion was dependent on glove construction and materials. Gloves that had thicker or less pliable material in the fingertip and lateral finger prehensile areas likely reduced sensation and prehension, increasing task completion times. The bolt disassembly task was chosen for evaluation since it requires a three-point finger prehension manipulation, making it an ideal fine motor task. The results from this task should generalize to fine motor dexterity work tasks, but not gross grasp tasks such as handling chains, slings, pipes, or turning large diameter valves. Compared to the bare hand, no glove condition the knit gloves had the fastest task completion times, followed by the leather gloves. The heavy-duty oil/gas industry gloves have much more material and tended to have multiple layers that would predictably lengthen task completion times.

Unlike the three point fine motor prehension of the bolt disassembly task, the rope tying task requires different areas of the fingers be used, focusing on the lateral aspects of each pointer finger and larger areas of the thumbs. There was also some gross grasp involved in this task. Gloves tested had a wide variety of different materials and thickness variations in the pointer and thumb areas utilized. Therefore, this task provides insight into a different aspect of prehension. A glove from the oil/gas heavy-duty glove type performed this task the fastest, yet had a single layer of thin material in the above-mentioned key prehensile areas. One other oil/gas heavy-duty glove performed well, along with the knit and leather gloves. One possible explanation is that this task uses the lateral side of the pointer finger that is adjacent to the thumb for part of the prehension, and the material properties of each glove in this area influences sensation and prehension. In the heavy-duty glove category, most gloves have extra gusseting in this area, which may result in diminished sensation and prehension for this task, which would explain why as a group, task completion times were longer.

5. Conclusion

The hand is a complex structure that integrates tactile sensory-motor function with functional task performance. Glove fit and comfort each have a profound influence on the ability of the hand to feel objects being manipulated, which determines the movements of the hand, the amount of muscular force needed for the task, the position in space of the object, and its orientation to other objects in the environment. The sensory receptor sensitivity of the hand varies, and is most concentrated at the tips of the fingers and on the palmar surface. Therefore, glove fit, comfort, materials, and design that lessen sensory information loss through the glove will improve dexterity, task performance, and user acceptance.

Gloves with higher dexterity, fit, and comfort user experience ratings had faster functional task completion times. Worker use of PPE is essential to improving safety, and workers are more likely to use PPE that is comfortable and does not interfere with their tasks. For impact gloves, fit, comfort, and dexterity were correlated, suggesting that consideration of fit and comfort in impact protective glove selection will increase their use on the job. Future studies can further investigate the junction of user experience and functional task to drive improvements in glove materials and design.

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