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# Decrements Encountered when Wearing Hazardous Materials Gloves

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**Abstract:** Hazardous materials gloves (HAZMAT) are frequently worn when performing clinical technical skills, but it is unclear how sensory and motor performance is affected in these circumstances. In Experiment 1, two timed standardized manual dexterity tests, and a test of sensory function were administered. Glove use resulted in a decreased ability to manipulate small objects and a decreased sensitivity to light touch. However, the ability to manipulate objects with a tool was unaffected by the glove. In Experiment 2, the objects were instrumented with a force/torque sensor and the coefficient of friction between the digits and the object was estimated. An elevation of grasping forces and an increased slipperiness between the digits and the object were observed. In Experiment 3, fingertip placement was quantified with pressure sensitive sheets and revealed a misalignment of the digits. Collectively these results suggest that impairments to motor performance when wearing a glove might be related to misalignment of the digits, associated with sensory decrement. These results can be used in the formulation of protocols for professionals wearing HAZMAT gloves and in the design of tools and HAZMAT garments.

**Keywords:** Sensory, motor, grasping, forces, torque, hand, touch perception.

## INTRODUCTION

In health-care settings, standard latex gloves play an important role in the protection of workers against contaminated body fluids [1-3]. Furthermore, recent terrorist attacks, increased military involvement, and the spread of communicable diseases such as Severe Acute Respiratory Syndrome (SARS) demand that health care workers may perform medical procedures while wearing heavy latex HAZMAT gloves (herein referred to as “HAZMAT gloves”). Emergency Medical Services (EMS) personnel, for example, may respond to incidents that may expose them to hazardous chemical or biological agents at petrochemical industry sites, clandestine drug laboratories, pharmaceutical manufacturing sites, and other locations where they may encounter chemical or biological agents. Responding to the approximately 18,000 accidents involving hazardous substances in the United States annually [4, 5] EMS agencies must be able to provide medical assistance without endangering the health and well- being of their personnel [6, 7]. Presently, however, the effects of HAZMAT gloves on sensory acuity, manipulative force generation, and motor performance with and without the use of medical instruments are unclear.

Many different types of gloves have been assessed in the literature that include cotton gloves [8], leather gloves [9], work gloves [10], surgical gloves [8, 11, 12], hazardous materials gloves [13], and extra-vehicular activity (space) gloves [14, 15]. On many occasions, gloves of differing types were compared with each other [8, 16-18]. As well, differences in performance between wearing one or more gloves of the same or differing types have been compared [19, 20]. While this literature provides insight into how performance when wearing these difference gloves differs, it does not directly address why one particular glove type has a different affect than another.

Nelson and Mital [11] compared the effects of various glove thicknesses on tactile sensitivity and dexterity when individuals picked up objects of different textures. Glove thickness, they found, had little effect on participants’ ability to identify and pick up various grades of sandpaper or on their ability to determine the size of the objects being touched. In addition, glove use did not affect the time needed for individuals to cut out various shapes with scissors. In another study conducted by Phillips *et al.* [21], performance results with either a bare hand, a single latex glove, or two latex glove layers were compared. This study showed that multiple gloves degraded sensory performance (texture matching, point discrimination, stereognosis); however, the performance on dexterity tasks (time to pick up marbles, and the use of forceps to transfer objects) was degraded to a much lesser degree than the sensory performance was. These findings suggest that the use of light gloves does not significantly affect dexterity. When Muralidhar and Bishu [22] examined how glove thickness and material (latex, cotton, and leather) affected performance on a subset of Jebsen’s tests of hand performance [23], they found significant motor impairments with the thicker gloves. That is, they found that performance with the latex gloves on tasks such as flipping cards, stacking checkers, picking up small objects and moving objects was similar to performance with the bare hand,

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but the heavier gloves impaired motor performance. However, it is unclear how motor function is affected in situations such as certain medical emergencies involving contagious agents and toxic waste handling where the use of thick gloves is mandatory and tasks are performed with hand-held tools such as forceps rather than with the fingers.

The degradation in motor performance as a result of wearing gloves can be quantified in two ways: first, by assessing the final product of the action or motor outcome, and second, by monitoring the actual manipulative forces applied to the surface of these objects. In most experiments focusing on the effects of gloves on motor performance, the *result* of a task was evaluated. For example, when the ability of participants to cut with scissors or flip cards was examined, attention was paid to whether they could or could not perform the task; and less attention was paid to the *process*, that is, how the movements were carried out. However, Bronkema *et al.* [24] have examined the movement process by using force measures to assess the influence of gloves on sensory and motor performance; specifically, they examined the amount of force generated on a handle when participants wearing the protective gloves used by astronauts lifted various masses. Results showed that the use of gloves had no influence on the amount of grip force produced. The authors proposed that this might have been due to the increased coefficient of friction between the gloved hand and the handle relative to that between the bare hand and the handle [25]. That is, any expected increases in force production due to the glove were offset by the decreased need for force due to the higher coefficient of friction in the glove condition. The lack of differences between the glove and no glove condition in the Bronkema *et al.* [24] study was also probably related to the nature of the task performed, that is, participants lifted a weighted bar across their fingers, much like carrying a suitcase. However, Shih *et al.* [12] demonstrated that when a precision grip is used to lift relatively light objects (in the range of 100 to 200 g) gloves do affect grip force production: in this study, results showed that participants lifting small objects with their bare index finger and thumb and then with their hands in a number of latex gloves did increase their grip force when wearing gloves.

Wearing gloves can affect grip force production in at least three ways. First, gloves introduce sensory deficits by impairing direct contact between the sensory nerve endings and the objects being handled. There is strong evidence of sensory deficit when gloves are worn [11, 21]. Also, Johansson *et al.* [26] and Augurelle *et al.* [27] demonstrated that force production is impaired during complete anesthesia of the fingers. However, though wearing gloves may impair sensory function, it does not eliminate it. Thus, it is not clear if partial sensory impairment will also lead to decreased motor function in a manner similar to complete sensory loss. Second, gloves alter the frictional characteristics between the digits and the object and thus can influence grip force generation [12, 24, 28]. Third, the use of heavy gloves can impair the proprioceptive information coming from the digits (skin receptors, touch receptors, joint angles etc.) and this may lead to a misalignment of the digits on the objects. Such misalignment has been shown to cause an unstable grasp, which is overcome by increasing the grasping forces [29].

The first purpose of the present series of studies was to assess the effects of wearing heavy latex HAZMAT gloves on direct and tool-assisted manipulation of small objects and on basic sensory function. The second purpose was to examine if grasp force production (quantified as force production by the index finger and thumb) is influenced by the use of the HAZMAT gloves; in this phase of the project, also, the coefficient of friction between the HAZMAT glove and object was estimated. The third purpose of this series of studies was to test whether there is a significant misalignment of the digits on the object being lifted when the HAZMAT gloves are worn. The rationale between the progressions of these studies was to first examine sensory motor function using standardized clinical tests to quantify basic function. Following this, a more detailed kinetic analysis of hand function/grasping performance was conducted to gain insight into the mechanisms behind the performance observed in Experiment 1. Finally, the third study attempted to isolate a potentially confounding variable explaining the results of the first two experiments (see Fig. **1**).

## EXPERIMENT 1

As indicated above, studies conducted by Muralidhar and Bishu [22], Nelson and Mital [11], and Phillips *et al.* [21] collectively suggest that gloves affect fine manual movements performed with the hands to a greater extent than they affect similar movements performed with tools. It is hypothesized that when gloved hands use tools they achieve a stable grasp more easily because digit placement is no longer as critical.

## METHODS

### Participants

Twelve right-handed undergraduate students (mean age = 21.9 years; range = 19-26 years) participated in this study. This experiment received ethics approval by the local Office of Research and all participants gave informed written consent.

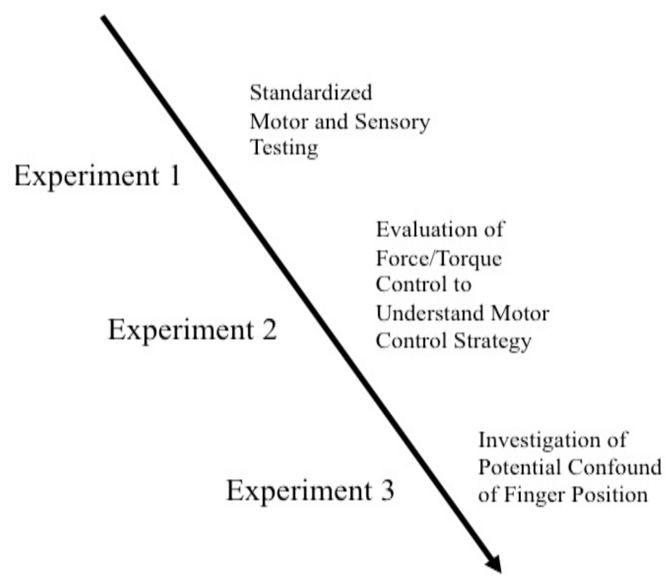


**Fig. (1).** A schematic representation of the progression of the three experiments.

### Apparatus and Procedures

Motor Testing: All participants were asked to perform two motor tasks - the Grooved Pegboard and O'Connor Tweezers Dexterity (Lafayette Instruments, Lafayette, IN) tests - with their right hand, first bare-handed and, then, wearing a HAZMAT glove. These gloves are part of a Saratoga Hammer Suit (TexShield, Charlotte, NC, USA), a lightweight, two-piece suit, approved by the US Department of Defense for battlefield and domestic preparedness use; this suit is the industry standard for public service agencies responding to incidents involving unknown chemical and biological agents [30]. The order of task presentation and HAZMAT glove condition was counterbalanced across all participants.

The Grooved Pegboard was placed on a table at each participant's midline, with the peg holder resting on the table, just above the board. The instructions suggested by the manufacturer (Instructions for the 32025 Grooved Pegboard Test 1989) were read to all participants. These instructions indicate that the pegs are grooved such that there is a round side and a square side matching the shapes of the holes in the board. The orientation of the grooves on the various holes is randomly arranged. Seated participants were required to fill all 25 peg holes on the board with pegs starting from the top row of holes in the board (moving from left to right) and working down, as fast as possible. Performance time, in seconds, was recorded, beginning when the participant started the task until the last peg was placed in the board. Performance was measured as the time elapsing between placement of the first and last pegs.

The O'Connor Tweezers Dexterity Test was administered in a similar manner. The test board was placed directly in front of the seated participants, with the pin tray resting on the table, at the right. The suggested instructions (Instructions for the 32022 O'Connor Tweezers Dexterity Test 1986) were read to the participants. These instructions indicated that participants, using tweezers held in their right hand, were required to pick up the pins (2.5 cm) and place them in one of the 100 holes (10 holes by 10 holes) on the board, starting from the furthest row on the left and moving to the right. Performance evaluation for the O'Connor Tweezer test was identical to that of the Grooved Pegboard test.

The data for each task were analyzed separately in a one way 2 condition (no glove, HAZMAT glove) analysis of variance (ANOVA).

Sensory testing: In this portion of the experiment, sensory deficits associated with wearing heavy latex HAZMAT gloves were tested. The Von Frey hair test (North Coast Medical, Inc. Morgan Hill, CA) was administered, using standardized procedures, on the index finger pads [31] of participants' bare hands and then on their hands in HAZMAT gloves. For this test, participants indicated whether they felt the application of hairs of various diameters to the skin [32]. The hairs were pressed into the skin until they started to bend. Larger hairs (labeled with larger numbers) required more force to bend than did smaller hairs; thus, this test was a measure of sensitivity to delicate force application. The force of application across the HAZMAT glove condition was consistent because a constant amount of force was required to bend a particular hair. The hair number of the smallest diameter hair that could be detected was then analyzed in a repeated measures 2 condition (no glove and HAZMAT glove) ANOVA.

## RESULTS AND DISCUSSION

Performance on the Grooved Pegboard test was slower when the participants were wearing the HAZMAT gloves, $F(1,11) = 82.92$, $p<.01$ (no glove M = 61.3 s, SE = 1.82, and HAZMAT glove M = 173.9 s, SE = 11.87), whereas performance on the O'Connor's Tweezers Dexterity test was not affected significantly by the wearing of the HAMZAT glove, $F(1,11) = 4.3$,$p > .05$ (no glove M = 389.0 s, SE = 24.5, and HAMAT glove M = 475.3 s, SE = 46.1). It is speculated that these two manipulative tasks (working with and without the tweezers) were performed using different motor control strategies. Aligning the configuration of the peg to fit the grooves on the pegboard required the participants to manipulate the pegs directly and align their fingers on them to avoid excessive torque production, whereas the use of the tweezers did not require such precise alignment of the fingers. It is believed the effects observed in Experiment 1 were due to the difficulties of controlling the grasping forces while manipulating the pegs with the gloved fingers.

Sensory testing: The analysis of the data for the Von Frey hair test showed that when participants were barehanded, they were more sensitive to light touch than when they wore the HAZMAT gloves, $F(1,11) = 53.63$, $p<.01$ (Hair number for no glove: M = 2.5, SE = .07, HAZMAT glove M = 3.8, SE = .16).

## EXPERIMENT 2

The purposes of Experiment 2 were twofold: first, to examine grip force generation when participants lifted small objects using a precision grip, initially with the gloved hand and then with the bare hand; and, second, to assess the frictional characteristics of the digit-object interface. Participants were required to use a pinch grasp to perform repeated lifts of three small objects with identical shapes and sizes but different masses. These objects were instrumented with a force sensor. In the present experiment, there was no advanced visual information about object size that could be used to predict object mass prior to digit contact [33]. The grip force produced should, therefore, be a consequence of force adjustments based on haptic feedback only. Thus, in this experiment, we tested whether there was sensory degradation associated with HAZMAT glove wear and whether this degradation influenced how the objects were grasped in terms of the force produced. We also estimated the frictional characteristics between the acting digits and object surface.

## METHODS

### Participants

The same 12 undergraduates who participated in the first experiment were asked to participate in the second experiment. The experiment received ethics approval by the local Office of Research and all participants gave informed written consent.

### Apparatus and Procedures

Lifting task: All participants were seated in front of a table with their index finger and thumb resting in a relaxed pinch grip directly in front of the midline according to previously described experimental details [34]. Figures depicting apparatus can be seen in Shih *et al.* [12]. Participants were instructed to reach toward and grasp a target object located 11 cm from the hand start position and to lift it approximately 5 cm above the tabletop. The object to be grasped was a six-axis force-torque sensor (Nano F/T transducer; ATI Industrial Automation, Garner, NC) with two exchangeable, polyethylene plastic, cylindrical mass containers with flat grasping surfaces, mounted on each side of the sensor. The resulting cylinder was 5.5 cm wide and 3 cm in diameter. A small, empty containment unit was attached to the transducer (2 by 2 by 6 cm). The experimenter was able to place small masses inside the containment unit in order to change the overall mass of the object to be lifted, but the participants were unable to identify the masses being changed. The total mass of the unit and the transducer could be 200, 300 or 400 g. Thus, since the objects appeared visually identical, participants could determine the mass of the objects only through haptic inputs after lifting the object.

The main dependent variables of interest were peak load and grip force with their peak rates of production, and peak torque. The load force was defined as the vector sum of the two perpendicular forces acting in the orthogonal plane to the grip force axis. The grip force was measured along the grip axis defined by the line joining the centers of the object's two grasping surfaces. The forces were collected at 200 Hz with a resolution of 0.025 N. In addition, the absolute value of the torque (resolution of 0.05 N.mm) in the x-dimension (around the anterior-posterior axis) was measured since this was the torque that was created by potential misalignment of the digits along the y-axis. Raw force and torque data were filtered using a second-order dual-pass Butterworth filter with low pass cutoff frequency of 10 Hz. The load and grip force profiles were then differentiated in order to determine the rate of force production; this is believed to be the best estimate of the presence of an anticipatory strategy for grasp control [35].

The object was grasped both with bare hands and with hands in HAZMAT gloves. Ten trials were performed for each of the masses, resulting in a total of 60 experimental trials. The trials were performed in a blocked fashion with the order of the presentation of the masses being randomized across participants for each glove condition (no glove versus HAZMAT glove). The order of the presentation of the two glove conditions was counterbalanced across participants. The magnitudes of peak grip and load force, as well as their peak rates, and the resulting peak torque, were analyzed in separate 3 target mass (200 g, 300 g, 400 g) x 2 glove (no glove, HAZMAT glove) repeated measures ANOVAs.

After the completion of the experimental trials for each glove condition, three slip trials were performed in which the 300 g mass object was held between the finger and thumb and slowly released until it dropped. For all participants, the slip trials were performed first without gloves, and then while wearing HAZMAT gloves. The grip force at the moment the object began to slip between the fingers represented the minimum amount of force required to hold the object. The coefficient of friction was estimated by dividing the load force by the grip force at the moment of object slip [25] and was analyzed in a one-way ANOVA with glove as the only factor.

All ANOVA differences significant at $p< .05$ were further analyzed using the Tukey HSD method for post hoc comparison of means.

## RESULTS AND DISCUSSION

Lifting task: None of the participants dropped any of the presented objects in any of the experimental conditions. Therefore, for the range of small masses tested in the present study, HAZMAT glove use did not influence grasping and lifting success.

Fig. (**2**) shows example curves for one participant lifting the three masses, first wearing the HAZMAT glove and then barehanded. As evident from the curves, the grasping forces and their rates of generation increased when the HAZMAT glove was worn. In addition, the torque values were elevated when the HAZMAT glove was worn. These observations were supported by statistical analyses as outlined below.

The peak load force and its rate of generation were not influenced by either the mass of the object or whether the lift was performed either with the HAZMAT glove or with the bare hand. However, there was a trend towards higher peak load forces being associated with heavier objects ($p = 0.09$).

Load force generation is a function of lift acceleration and object mass. Therefore, the lack of scaling of load force rate to object mass is probably due to the lifts of the light objects being performed with higher velocities. That is, the lower load forces that should have been observed for the lighter objects were offset by the increases in force necessary due to higher lift velocities. However, since lifting velocity was not measured in this study, this hypothesis is only speculative.

The peak grip force, $F(1, 11) = 14.1$, $p< 0.01$, and the peak rate of grip force generation, $F (1, 11) = 10.0$, $p = 0.009$ were higher when HAZMAT gloves were worn (Figs. **2**, **3**). However, only the peak grip force was influenced by object mass when greater grip force was applied to the heavier objects and smaller force to the light one, $F(2, 22) = 62.6$, $p< .01$.

The lack of scaling of the peak rate of grip force production to object mass is consistent with previous research [35, 36] showing that the predictive or anticipatory scaling of grip force is based on the visual estimation of the object size and, in turn, the object mass. In the present study, all objects were visually identical; therefore, the participants could not make any predictions about the mass of the object based on its size, and thus, peak grip rate (which is a measure of anticipatory control strategies) was not affected. However, the participants did anticipate that wearing the HAZMAT gloves would result in a compromised grasp; this is reflected in the finding that the peak rate of grip force production was higher in this condition. Also, the finding that the final peak grip force was scaled to object mass indicates that at least some haptic information was being used to modulate grip force level.

Peak torque measure was used to estimate the stability of the grasped object. The torque values were higher when the participants lifted the objects with the gloved hand than when they did so with the bare hand, $F(1, 11) = 16.9$, $p<.01$ (Fig. **2**, no glove M = 46.9 N.mm, SE = 1.95, and HAZMAT glove M = 62.2 N.mm, SE = 2.78). This indicates that the objects were unstable when the HAZMAT gloves were worn, potentially leading to increased grip force.

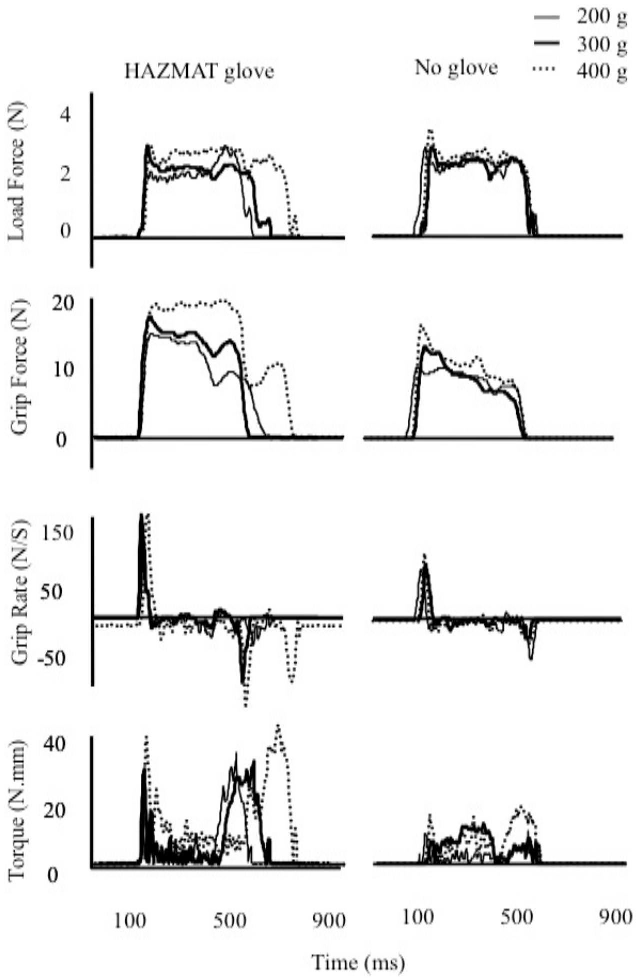


**Fig. (2).** Load force, grip force and the rate of production and associated torque profiles for a single participant in Experiment 2. These trajectories represent a single lift in each experimental condition.

Estimated coefficient of friction, derived from the ratio of the minimal load and grip forces employed in order to prevent the object from slipping was used as an estimation of the coefficient of friction between the digit and the object. The estimated coefficient of friction was lower when the objects were held with the gloved hand, $F(1,11) = 27.8$, $p<0.01$ (no glove, M = 1.95, SE = .09, and HAZMAT glove M = 1.45, SE = .07). This indicates that the digit-object interface was more slippery when the HAZMAT gloves were worn, contributing to higher peak grip forces in this condition.

In summary, when the HAZMAT gloves were worn, grip forces were elevated; the digit-object interface was more slippery; and torques were elevated, suggesting that the objects were unstable.

## EXPERIMENT 3

The purpose of Experiment 3 was to address the possibility that wearing HAZMAT gloves affected the stability of grasp formation through the misalignment of the digits. According to Monzee *et al*. [29] when the digits are misaligned (due to sensory deficit), elevated torques are produced [37]. Experiment 3 was designed to measure the spatial positioning of the digits on the object surface during grasp formation, thus addressing the hypothesis that the elevated torques observed in Experiment 2 were at least partially due to a misalignment of the digits when participants wore HAZMAT gloves.

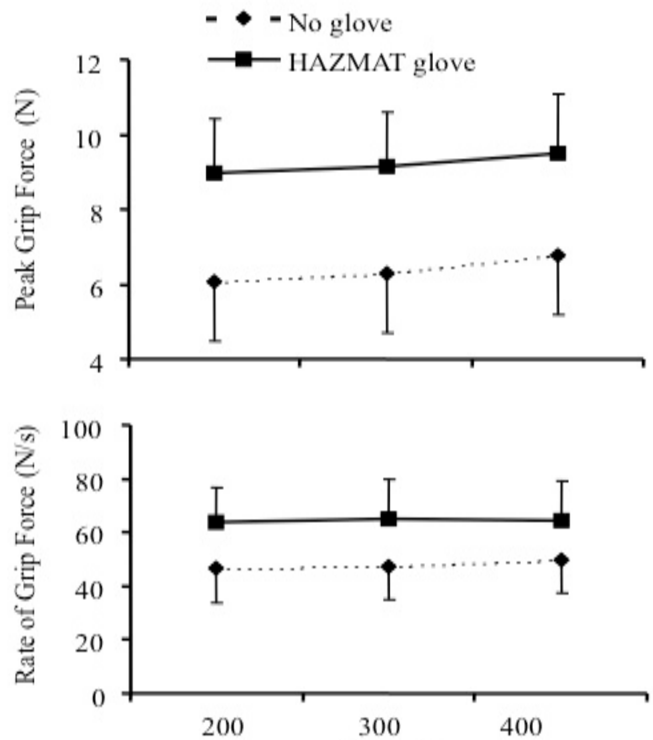


**Fig. (3).** Peak grip forces (GF) and the associated rates of grip force generation as a function of object mass and glove condition, in Experiment 2. Grip forces were influenced by both object mass and wearing gloves. The grip force rates, however, were affected only by HAZMAT glove wear.

## METHODS

### Participants

Eight (6 males and 2 females) right-handed, undergraduate students (mean age = 22.3 years; range = 21-25 years) who did not participate in the first two experiments participated in this experiment. All participants gave informed written consent and the project was given ethics approval by the local Office of Research.

### Apparatus and Procedures

The apparatus consisted of a Tekscan Pressure Sensitive Sheet (Tekscan, Inc. Boston, MA). The Tekscan Sheet was wrapped over the top of 2 metal plates that were attached to a containment unit able to hold various masses (Fig. **4**). The total mass of the apparatus could be either 200 g, 300 g, or 400 g, and the various masses were presented randomly. Tekscan data were collected with a sampling rate of 127 Hz.

Participants sat in front of a table with their hand resting 25 cm away from the target object. They then reached for the

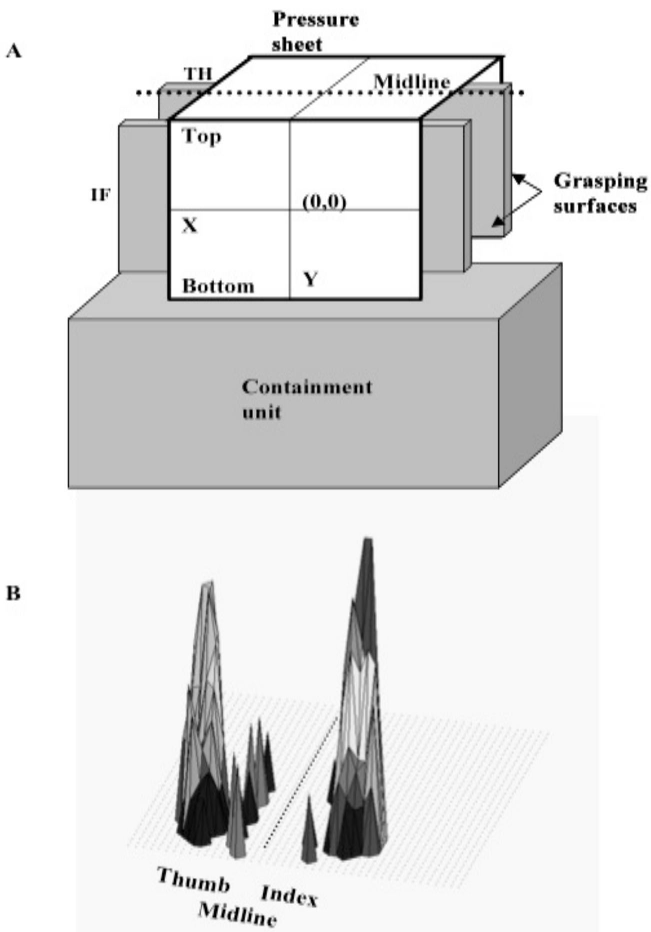


**Fig. (4).** Experimental apparatus used in Experiment 3. Panel **A**: TH and IF represent the two gripping surfaces, one for the thumb and the other for the index finger respectively. The surfaces were wrapped with a single TEXSCAN pressure sensitive sheet. The central points of origin for each grasping surface were identified and used for comparisons. The positive X direction was to the right of the origin and the negative X was to the left of the origin. Positive Y was above the origin and negative Y was below the origin. Panel **B**: An "unwrapped" sheet that was rotated by $90^o$ to the right for easier interpretation of the results.

object with their right hand, grasped it using a pinch grasp between their index finger and thumb, lifted it 10 cm above the table surface, held it for 5 s and replaced it onto the table. Each object mass was presented 5 times in a random order resulting in 30 lifts in total: 15 with the gloved hand and 15 with the bare hand. The order of the presentation of the glove condition was counterbalanced across participants.

The variables of interest included initial and holding grip forces for both the index finger and thumb, initial and holding contact areas for both digits, and initial and holding finger placement accuracy (see Fig. **5a**). The contact areas were calculated by the number of active pressure sensitive cells (resolution = 1 $mm^2$) under each digit at the moment of peak grip force. The initial digit placement accuracy was calculated by identifying the coordinates of a maximum pressure cell (corresponding to the initial peak force) of each of the interacting digits in the vertical (Y) and horizontal (X) directions (Fig. **5b**). These locations were then normalized to the center point of the two grasping plates. Holding peak grip force, contact area, and finger placement accuracy were determined in the same fashion 3 s after the initial contact with the object and represent the steady state holding phase. Pilot work showed that a period of 3 seconds duration was long enough for all variables to reach steady levels.

All variables were analyzed in separate 3 target mass (200 g, 300 g, 400 g) x 2 glove (no glove, HAZMAT glove) x 2 sampling times (initial, holding) x 2 digit (index finger, thumb) repeated measures ANOVAs. All ANOVA differences significant at $p < .05$ were further analyzed using the Tukey HSD method for post hoc comparison of means.

## RESULTS AND DISCUSSION

The initial and holding grip forces were higher when participants grasped with the HAZMAT glove than when they grasped with the bare hand, $F(1,7) = 8.59$, $p<.05$ (Fig. **6**). In addition, grip force increased as a function of object mass, $F(2,14) = 23.4$, $P < .01$ (200 g = 10.49 N, SE = .76, 300 g = 12.3 N, SE = .65, 400 g = 14.1 N, SE = .62).

There was a digit-by-time interaction such that the initial grip force produced by the thumb was greater than the initial force produced by the index finger; however, the forces at each of the digits were not statistically different during the holding phase, $F(1,7) = 11.30$, $p<.05$ (Fig. **6**). This indicates that the grasp generation starts by an uneven application of grip forces to the grasping surfaces; however, during the stable holding phase, both digits produce the same amount of force in order to hold the object against gravity and keep it stable.

When the contact area was examined, there was a significant condition-by-digit interaction that showed that. That is, when participants grasped with the bare hand, the contact area for index finger and thumb did not differ; but when they wore the HAZMAT glove, the contact area of the thumb was larger than that of the index finger, $F(1,7) = 15.06$, $p<.01$ (Fig. **6**). In addition, contact area increased as object mass increased, $F(2,14) = 10.65$, $p < .01$ (200 g = 2.02 mm, SE = .10, 300 g = 2.26, mm, SE = .10, 400 g = 2.35 mm, SE = .09).

The analyses of the initial horizontal positions (i.e., along the x-axis) showed only a main effect of time, $F(1,7) = 22.29$, $p<.01$ (Fig. **6**). The digits initially grasped the plate past the center and the digits shifted toward the center as the object was held. This pattern was present with the HAZMAT glove and with the bare hand. In the vertical direction (i.e., along the y-axis), there was a three-way interaction of digit, condition and time, $F(1,7) = 5.1$, $p<.05$. The bare thumb was initially positioned below the center of the grasping plate and the bare index finger above the center. When the HAZMAT glove was worn, the thumb was placed in the same position below the center; however, the index finger was positioned significantly higher than when the HAZMAT glove was not worn. With time, only the gloved index finger was repositioned towards the center of the grasping surfaces.

Together, these analyses indicate that when the HAZMAT glove was worn the index finger was positioned inaccurately above the center of the grasped surfaces and above the thumb. In response, the forces produced on the grasping surface by the thumb were elevated, leading to an unstable object. This finding supports the hypothesis that the increases in the grip force production related to wearing the HAZMAT glove was due in part to the instability of the object caused by digit misalignment.

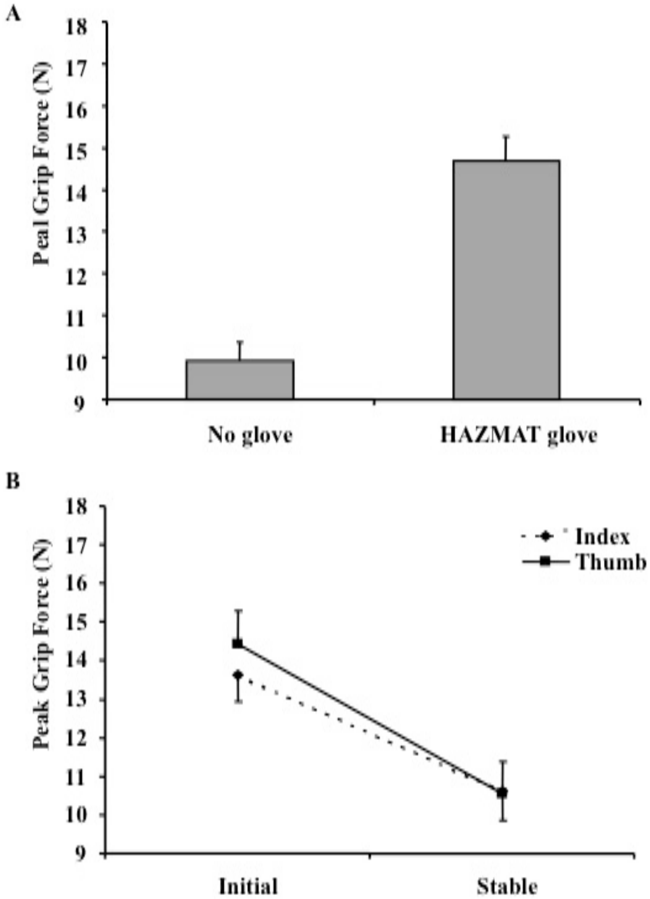


**Fig. (5).** This figure represents all factors influencing grip force generation in Experiment 3. The effects of glove wear on overall grip force are indicated in panel **A**. The forces were elevated when the HAZMAT gloves were worn. In addition, panel **B** shows that higher initial grip forces were produced, especially by the thumb, immediately altering the contact with the object, and they decreased and became equal during the stable grasp phase.

## CONCLUSIONS

The purpose of these three studies was to examine the effects of wearing heavy latex HAZMAT gloves on manual and tool performance. Sensory and motor deficits in terms of force were examined, as well as control and finger placement. It was found that manual performance on a precision dexterity task was adversely affected by HAZMAT glove wear; however, when a similar task was performed with tweezers, these effects were no longer present. It was hypothesized that the observed performance deficits were largely due to inefficient object manipulation control strategies when HAZMAT gloves were worn. More specifically, it was found that the HAZMAT gloves caused decreased fingertip sensitivity. It was also found that HAZMAT glove use resulted in a lower estimated coefficient of friction between the object and the grasping surface (glove) - the glove was more slippery than the bare digits. As well, a misalignment of the digits on the object also led to changes in manipulative force production. Specifically, it was found that the gloved index finger was misaligned in the vertical position, thus creating a potentially unstable object. Collectively, these factors contributed to the deficits in fine motor control.

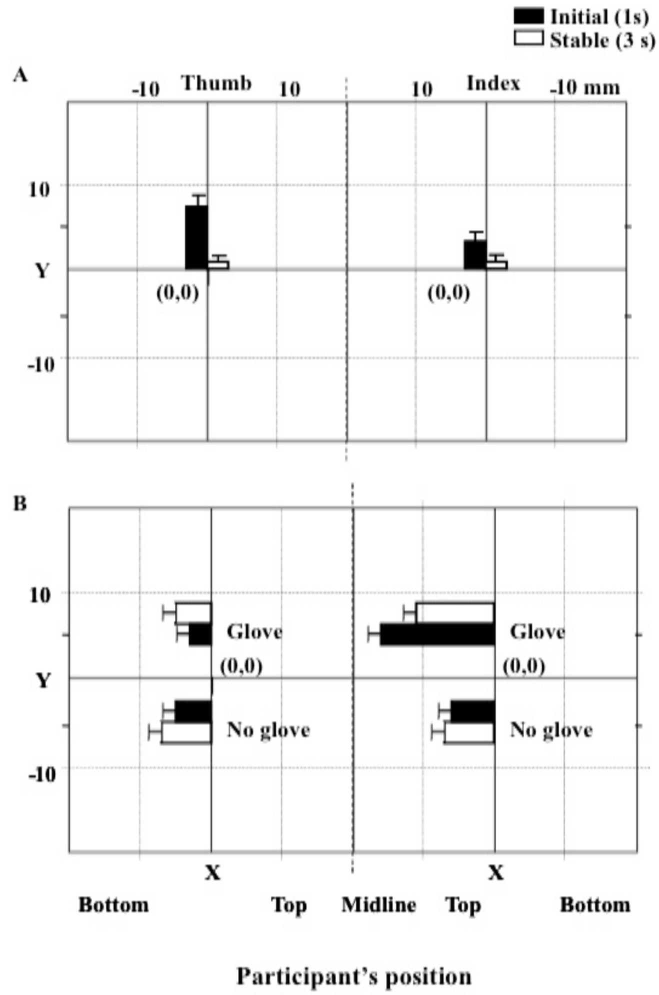


**Fig. (6).** This figure depicts the bird's eye view of the unfolded pressure sheet. Each bar represents the horizontal (**A**) and vertical (**B**) positions, relative to the participant's position in the initial and stable phases of the grasp for each digit. Note that in the horizontal (**A**) direction, the participants initially overshot the central grasping point; however, their grasp was repositioned towards this point with time. Note that there were no differences between the glove and no glove conditions. In the vertical direction (**B**), the participants placed the index finger above the central point, and the thumb below it; with time, only the index finger's position was adjusted.

Previous research has demonstrated that manual performance time on pegboard tasks increases when gloves are worn [38]. However, the effects of glove wear on the performance of tasks that involve tools have not been well addressed. There are many procedures that are performed using precision tools when thick gloves are worn. For example, specific life-saving resuscitation procedures performed by EMS personnel are time-sensitive, requiring effective, unimpaired performance. These procedures include both skills that involve gross motor coordination such as electrical defibrillation and administration of subcutaneous epinephrine and skills that require a high degree of fine motor and hand-eye coordination such as intravenous cannulation and tracheal intubation. The present results suggest that the effects of HAZMAT glove wear are more pronounced when there is direct contact between the gloved hand and the object to be manipulated, as compared to the situation in which a tool, such as a pair of tweezers, is used to complete a similar precision task. Our findings suggest that this should be attributed to the HAZMAT glove material impairing the sensory contributions from the finger pads, changes in the frictional characteristics of the object/finger interface, as well as the inaccurate placement of digits on the object, causing the object to be unstable and difficult to manipulate. Because there were no decrements in the performance observed when participants were asked to perform a similar task using tweezers, it is hypothesized that the action of the tweezers was still effective even if the digits were not precisely aligned on the instrument.

Though functionally there was no impairment (none of the participants dropped the objects in Experiment 2), the increased force production observed may create long term problems of fatigue and potential repetitive strain injury. Studies of ergonomic factors in the workplace (such as repetition, force, static muscle loading and extreme joint position) have found a strong causal relationship between jobs involving highly repetitive, forceful work and disorders of the neck and upper limbs [39, 40]. However, recently the findings that even non-forceful but highly repetitive tasks requiring people to use fewer and smaller muscles have greatly contributed to the surge in reported muscle, tendon or nerve entrapment disorders in the neck and upper limbs [39]. Thus, for even highly repetitive, non-forceful tasks, a reduction of any unnecessary force production could directly reduce the incidence of repetitive strain injuries. One relatively simple solution would be to make the HAZMAT glove surfaces "stickier," that is, with a higher coefficient of friction; thus, less force would be required when grasping with a HAZMAT glove than when using a bare hand.

It is not clear what the role of learning or expertise is in the present findings. That is, the participants in the present experiments were not experienced at wearing HAZMAT gloves. However, there were quite experienced at performing the types of simple grasping movements they were required to generate. It is quite possible that simple repeated exposure to performing in these gloves would help ameliorate some of the deficits observed. Future work will address this issue.

In summary, the present series of studies showed that HAZMAT gloves cause haptic sensory degradation; they change the frictional characteristics between the digits and the object being lifted, and they change the stability of the grasp. Collectively, these effects translate into elevated grip force levels with a potential for a work-related injury. Also, these sensorimotor changes adversely affect manual performance, but only when there is a direct contact between the gloved hand and the object. No such effect was present when tools (tweezers, for instance) were used to complete the motor task. The extrapolation of these findings to other tasks in which heavier objects are manipulated and other tools are used needs to be addressed in future research.

## ACKNOWLEDGEMENTS

This research was supported by separate Natural Science and Engineering Research Council of Canada Discovery grants awarded to H. Carnahan and A. Dubrowski.

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Received: November 22, 2008 Revised: February 2, 2009 Accepted: February 4, 2009