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Effect of gloves on prehensile forces during lifting and holding tasks

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Keywords: Gloves; Thickness; Grip; Force; Friction; Finger prehension.

The effect of gloves on the spatio-temporal characteristics of prehensile forces during lifting and holding tasks was investigated. Participants (n = 10) lifted a force transducer equipped object (weight = 0.29 N) with various types of gloves and barehanded using a two-fingered precision grip. Rubber surgical gloves of varied thicknesses (0.24, 0.61 and 1.02 mm) were worn to examine the effect of glove thickness on a rayon surface. It was found that grip force increased with thickness because the participants employed a higher safety margin above the minimum force required to hold the object. The safety margin for the barehanded condition was the smallest. The performance time for lifting the object was not influenced by the variation of glove thickness. The findings suggest that glove thickness, which presumably modifies the cutaneous sensation, influences grip force regulation. The effect of glove material (rubber and cotton) was also examined in relation to slippery (rayon) and non-slippery (sandpaper) surfaces. It was found that the participants used a larger grip force with the cotton glove than the rubber glove for the slippery surface, but not with the non-slippery surface. With use of the rubber glove, a relatively low grip force level was maintained for both slippery and non-slippery surfaces. The performance time for the cotton glove was longer than that for the rubber glove. The findings suggest that the rubber glove provides better efficiency of force and temporal control than the cotton glove in precision handling of small objects.

1. Introduction

Gloves protect the hands from toxic chemicals, infectious and pathogenic bacteria, extreme temperatures, sharp and abrasive surfaces, and colliding forces. However, they may hamper the efficiency of manipulative tasks. The effect of wearing gloves on the finger forces generated on a grasped object was studied by Lyman and Groth (1958). They found that the grip force while moving a small cylindrical object was smallest with the barehand, followed by a thin rubber surgical glove and a thick Army leather glove. Accordingly, they concluded that the thickness of the glove modifies the grip force output. One problem with this conclusion is that the surface friction between the skin and the gloves was not taken into account. Since frictional conditions at the interface of finger and object are a major factor by which individuals determine the magnitude of grip force necessary for holding an object (Westling and Johansson 1984, Kawai et al. 1995, Kinoshita et al. 1995, 1997), and could be varied largely among human skin, rubber and leather (Westling and Johansson 1984, Kinoshita et al. 1996), the observed grip force difference might have been to a large extent due to the effect of glove friction. It is, therefore, necessary to examine the effect of glove thickness on theprehension force under controlled frictional conditions. It is also necessary to examine the effect of glove material in
relation to varied frictional characteristics of the object manipulated under controlled glove thickness conditions.

Performance time has been used for testing the effect of gloves on the level of dexterity. Griffen (1944) first reported that time to move small pegs quickly from one hole to another on a board was prolonged with the use of gloves. Bradley (1969a, b), Plummer et al. (1985) and Robinette et al. (1986) found that the performance time for a wider variety of dexterity tasks was also prolonged by the use of gloves. Bensel (1993) reported that glove thickness and degree of adaptation to the glove were important factors determining time to complete a battery of manual dexterity tests. Although temporal efficiency may deteriorate with gloves when participants are requested to complete the tasks in the shortest performance time, it is still unknown if the same is true for an ordinary lifting task performed at a moderate and self-determined, natural speed.

The present study was therefore designed to investigate the effects of the thickness and material of gloves on the grip force and performance time during lifting and holding of a small object with the two-finger prehension grip.

2. Methods

2.1. Participants

Four females and six males, between 18 and 25 years of age, volunteered as participants. All participants were right-handed and healthy with no reported history of upper extremity dysfunction. None were involved in daily work that requires the use of gloves.

2.2. Test apparatus

The experimental set-up consisted of a free weight that was instrumented to monitor grip and lifting (load) forces and a force platform (figure 1). The design and construction of the object were based on those of the previous studies (Johansson and Westling 1984, Kinoshita et al. 1993). The object had a mass of 0.3 kg and was equipped with force transducers for measuring forces generated by gripping and lifting actions performed with the fingers. The grip forces of the index finger and thumb were measured independently by parallel metal discs and strain gauge force transducers (DC-490 Hz) located beneath the discs. The load force was measured by another strain gauge force transducer (DC-490 Hz) suspended on the grip force transducer system. The grip surfaces were two parallel vertical discs covered by varied surface materials, which were 30 mm apart and 30 mm in diameter. Two surface materials, finely textured rayon and rough sandpaper (no. 220) were used, which represented a relatively wide range between slippery and non-slippery surface conditions in relation to the skin (Kinoshita et al. 1997). The lighting of the room was adequate to find the object but not for visual discrimination of the touched surfaces. A force platform, which consisted of four strain gauge transducers (DC-350 Hz), provided data regarding the normal reaction force on the table in the vertical direction. This table reaction force was used to detect the instant the grip object was lifted off the supporting surface. All force data were amplified and digitized using an NEC personal computer via a 12-bit A-D converter sampling at 400 Hz for each channel.

2.3. Experimental procedure

Each participant washed their hands with soap and water to normalize skin conditions about 5 min prior to the experiment. During the experiment, the
participant, seated in a height-adjustable chair, faced a testing table. The participant’s right upper arm was parallel with the torso, and the forearm extended anteriorly. The hand was held in a half-prone position, and rested on the table ~10 cm away from the object. For each of the experimental trials, three computer-generated beeps were given to cue specific events in the sequence of the experimental task. The first sound cued the participant to initiate a sequence of reach, grip and lift of the object to match a pointer to a 1-cm wide target (figure 1). The height of the lift was $3 \pm 0.5$ cm above the platform surface, and lifting speed was self-determined. The object was then held still until the participant heard a second beep, which came $8 - 11$ s after the first. With this sound, the participant moved the object slowly and laterally to the space above a 2-cm thick sponge cushion located on the right side of the force platform (figure 1). A third beep, $3 - 4$ s after the second, informed the participant to drop the object on the cushion by slowly moving the finger and thumb apart.

Four glove types (table 1) were selected for the present study. All are commonly used for precision handling of materials in numerous working situations. Three different sizes (small, medium and large) were prepared for each type of glove allowing for appropriate fit to the participants’ hand. For the surgical #2 and chemical gloves, a cotton inner glove (0.39 mm thick) was used to aid in the absorption of sweat, a relatively common activity in the workplace. A barehanded condition was also examined as control. Prior to the experiment, a practice trial session (10 min) was given for each participant to experience and become accustomed to the gloves as well as to the experimental task. All participants underwent three
successive experimental sessions. In the first session, they performed a block of six trials under each of the five glove and barehanded conditions with the rayon surface after several practice trials. In the second session, a block of six trials was performed for the surgical #2 glove, cotton glove and the barehanded conditions with the sandpaper surface after several practice trials with the sandpaper surface. In the third session, a block of seven trials was performed for the surgical #2 glove, cotton glove and the barehanded conditions while the rayon and sandpaper surfaces were presented in a random order. The time between successive lifts was about 8 s. Presentation of the order of experimental conditions was determined randomly for each participant.

2.4. Data analysis
All trial records were processed for data analysis except for the first trial with the random surface variation. For each record, three temporal and four force parameters were evaluated. Some are shown in figure 2. Temporal parameters were used for the evaluation of performance time were ‘preload’, ‘loading’ (figure 2) and ‘total’ phases. The preload and loading phases corresponded to the two phases defined earlier by Johansson and Westling (1984). The preload phase started with the initial touch of the grip surface by the finger and ended when the positive load force was detected. The loading phase began with the onset of the load force and ended when the object was lifted off its support. The total phase was a sum of the preload and loading phases.

The force parameters, defined below, were the peak, static and slip forces and safety margin (figure 2). In this study, only the index finger grip force was used for analysis because the difference between the thumb and index finger grip forces was quite small in all cases. The peak force was the peak value of the index finger grip force which commonly occurred immediately after the event of object lift-off. The static force was the average for the index finger grip force between 1 and 3 s prior to the second beep. The slip force, representing a minimum grip force required to hold the object, was obtained from the index finger grip force at the onset of slippage when the object was slowly released at the end of the trial. There was, predictably, a sudden decrease in load force corresponding to the onset of slippage. The safety margin was defined as that part of the exerted static grip force that the participants employed to prevent the inadvertent or accidental slippage of the objects held. In this study, the safety margin was computed as the difference between the static grip force

Table 1. Characteristics of gloves tested.

<table>
<thead>
<tr>
<th>Glove type</th>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Common usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical #1</td>
<td>rubber</td>
<td>0.24</td>
<td>Dental work, medical testing and surgery, chemical material handling, food packing, etc.</td>
</tr>
<tr>
<td>Surgical #2</td>
<td>rubber + thin cotton</td>
<td>0.61</td>
<td>Dental work, medical testing, surgery, chemical material handling, food packing, etc.</td>
</tr>
<tr>
<td>Chemical</td>
<td>rubber + thin cotton</td>
<td>1.02</td>
<td>Industrial and laboratory material handling, toxic chemical material handling, etc.</td>
</tr>
<tr>
<td>Cotton</td>
<td>cotton</td>
<td>0.60</td>
<td>Industrial and laboratory material handling, glass and precious material handling, etc.</td>
</tr>
</tbody>
</table>
and the slip force (figure 2). Coefficients of static friction between the skin of the hand or gloves and each of the two surfaces were generated as measures of the degree of slipperiness encountered in gripping and lifting. It was assumed that the index finger and thumb were each supporting nearly half of the load of the bilaterally symmetrical object, and thus for the purposes of calculating the coefficient of static friction between the glove or skin and surface, the slip force on the index finger was divided by half of the load force measured at the onset of slippage.

2.5. Statistical analysis

For each of the response parameters, the mean of all trials for each set of experimental conditions was computed for each participant. For the determination of the effect of glove thickness, a one-way repeated measures analysis of variance (ANOVA) was performed on each response parameter using data for the three levels of 0.24, 0.61 and 1.02 mm rubber gloves (table 1 - surgical #1 and #2, and chemical gloves, respectively) with the rayon surface. The data obtained from the first experimental session (see §2.3) were therefore used for this purpose. A post-hoc analysis using Tukey’s multiple comparison was also performed to assess statistical differences between selected pairs of these means.

The effect of glove material was further examined using data for the rubber (surgical #2) and cotton gloves in relation to the rayon and sandpaper surfaces. These gloves had a similar thickness (0.60 – 0.61 mm). The material effect was tested in two steps. In the first, the data obtained from the first and second experimental sessions in which each of the two surfaces was unchanged were used. In the second, the data from the third experimental session in which the two surfaces were varied in a random
order were used. In each step we used a two-way repeated measures ANOVA on each response parameter. Statistical significance was accepted at $p < 0.05$.

3. Results

3.1. Fundamental data for the barehanded trials

Table 2 shows the means of the force and temporal parameters, as defined in §2.4., for all participants in the barehanded condition. The results for a statistical comparison between the two surfaces for each parameter are also shown in Table 2. A highly significant difference was found for the peak, static and slip forces and coefficient of static friction. The rayon surface was more than twice as slippery as the sandpaper surface. There was no surface difference for the safety margin and all temporal parameters.

3.2. Effect of glove thickness

Figure 3A shows the mean peak, static and slip forces for rubber gloves of varied thicknesses. ANOVA revealed that the peak and static forces significantly increased with thickness of the glove ($F(2,18) = 7.02$ and $F(2,18) = 7.33$, respectively, $p < 0.01$), and the difference between all pairs of the means was statistically significant ($p < 0.05$). The peak and static forces increased by 34 and 37% from 0.24 to 1.02 mm-thick gloves. There was no significant effect of thickness for the slip force. As compared with the small variability in the slip force, those for the peak and static forces were apparently larger (see SD bars in figure 3A), reflecting intersubject variation of voluntary force output.

The coefficients of static friction for the 0.24, 0.61 and 1.02 mm-thick gloves used were $1.41 \pm 0.08$ (SD), $1.40 \pm 0.08$, and $1.37 \pm 0.04$ respectively. Though the 1.02 mm-thick chemical glove had a slightly lower coefficient of friction, it was not statistically different from the 0.24 and 0.61 mm-thick surgical gloves. Compared with the friction of human skin in relation to the rayon surface (table 2), skin properties of these rubber gloves were more than twice less slippery, and its intersubject variability (SDs for the coefficient of friction) was three time less. The mean safety margin for each glove thickness is plotted in figure 3B. The safety margin increased nearly linearly ($r = 0.537$, d.f. = 28, $p < 0.01$). As information concerning the safety margin for a zero thickness condition, the data for the barehanded condition against the rayon surface were used. In each step we used a two-way repeated measures ANOVA on each response parameter. Statistical significance was accepted at $p < 0.05$.

Table 2. Mean (SD) values of the force and temporal parameters for the barehanded, and ANOVA $F$-values.

<table>
<thead>
<tr>
<th>Surface</th>
<th>Force parameters</th>
<th></th>
<th></th>
<th>Temporal parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak force (N)</td>
<td>Static force (N)</td>
<td>Slip force (N)</td>
<td>Coefficient of friction</td>
<td>Safety margin (N)</td>
</tr>
<tr>
<td>Rayon</td>
<td>6.11 (2.08)</td>
<td>4.54 (1.53)</td>
<td>2.88 (1.18)</td>
<td>0.59 (0.22)</td>
<td>1.66 (0.55)</td>
</tr>
<tr>
<td>Sandpaper</td>
<td>4.05 (1.19)</td>
<td>2.55 (0.75)</td>
<td>1.13 (0.22)</td>
<td>1.35 (0.24)</td>
<td>1.42 (0.61)</td>
</tr>
</tbody>
</table>

| $F$-value    | 21.23***         | 36.32***                  | 30.35***                | 193.71***           | 3.88                   | 4.18               | 0.01             | 4.65             |

***$p < 0.001$. 

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Figure 3. Effect of glove thickness. (A) Mean peak, static and slip forces. Only the rubber gloves on the rayon surface were tested. The vertical bars describe ± 1SD; (B) mean safety margin. The filled circles represent the rubber glove conditions on a rayon surface. The zero thickness condition (open circle) is represented by the barehanded condition on the sandpaper surface, which had a coefficient of friction similar to that for the rubber glove on the rayon surface. The vertical bar describes ± 1 SD.
sandpaper surface (empty circle in figure 3B) are included, since this frictional condition happened to be similar to that between the rubber gloves and the rayon surface. A stronger linear relationship was attained with the inclusion of the barehanded data \((r = 0.67, \text{ d.f.} = 38, p < 0.001)\). A comparison using one-way ANOVA with repeated measures was performed to compare the differences between the barehanded condition and each glove thickness condition. It was found that the safety margins for the 0.61 and 1.02 mm-thick gloves were significantly larger than that for the barehanded condition \((p < 0.05)\).

The preload and loading phases for the 0.24 mm-thick glove were 101 ± 38 and 180 ± 57 ms, respectively. For the 1.02 mm-thick glove, these increased to 124 ± 51 and 204 ± 53 ms, respectively. ANOVA revealed that neither of these increases in phases was significant. The total phase, therefore, increased by 47 ms from 0.24 to 1.02 mm-thick; however, this was also statistically insignificant.

3.3. Effect of glove material

3.3.1. Trials with a constant surface: Figure 4A shows the effect of rubber and cotton gloves on the peak, static and slip forces for the repeated trials with rayon and sandpaper surfaces. ANOVA revealed a highly significant interaction effect of glove × surface in the peak force \(\{F(1,9) = 120.8, p < 0.000\}\), static force \(\{F(1,9) = 156.1, p < 0.000\}\) and slip force \(\{F(1,9) = 1411.9, p < 0.000\}\). The interaction effect indicated that there was no surface difference when the rubber glove was used, while with the cotton glove there were larger peak and static grip forces with the rayon surface than the sandpaper surface. The main effects of material and surface for all of these forces were also significant \((p < 0.001)\). The mean coefficients of friction for the rubber glove against the rayon and sandpaper surfaces were 1.40 ± 0.08 (SD) and 1.37 ± 0.09, respectively, and those for the cotton glove were 0.32 ± 0.02 and 1.50 ± 0.14, respectively. Hence, the rubber glove provided nearly four times greater friction against the rayon surface than the cotton glove, but against the sandpaper surface it gave 10% less friction. Compared with the barehand (see coefficient of friction in table 2), the cotton glove provided less friction against the rayon surface and greater friction against the sandpaper surface.

The mean safety margin ranged from 2.11 to 2.46 N (see constant surface condition data in figure 4B), and neither the interaction effect of glove × surface nor the main effects of material and surface were significant. Using a separate one-way ANOVA with repeated measures, these safety margin values were compared with those of the barehanded values against the corresponding surfaces (see safety margin values in table 2). It was found that they were significantly higher than those of the barehand \((p < 0.05)\).

The preload phases for the rubber glove against the rayon and sandpaper surfaces were 103 ± 41 and 99 ± 39 ms, respectively, while those for the cotton glove were 137 ± 41 and 133 ± 40 ms, respectively. ANOVA revealed that this phase was significantly longer with the cotton glove than the rubber glove \(\{F(1,9) = 8.23, p < 0.05\}\). There was no interaction effect of material × surface and no main effect of surface. The loading phases for both gloves with the two surfaces ranged between 180 and 190 ms, and there was no significant difference due to glove material. The total phase was on average 26 ms longer for the cotton glove than the rubber glove; however this difference was statistically insignificant.
Figure 4. Effect of glove material. (A) Mean peak, static and slip forces for the trials with a constant surface; (B) mean safety margin for the trials with a constant surface and with a random variation of the two surfaces. The vertical bars describe +1SD.
3.3.2. Trials with a random variation of surfaces: Since the object slipped and dropped from the fingers in every trial, the participants were undoubtedly able to judge the current frictional conditions of the surface and glove skin in repeated trials with a constant surface. Trials with a random variation of the surface then can provide additional information about responses without the knowledge of surface conditions. Figure 5 shows the mean peak, static and slip forces for the rubber and cotton gloves while the rayon and sandpaper surfaces are presented randomly. ANOVA revealed that for the peak force the main effects of glove {F(1,9) = 89.71, p < 0.000} and surface {F(1,9) = 9.42, p < 0.05} were significant, but the glove × surface interaction was insignificant. For the static force, the glove × surface interaction effect {F(1,9) = 20.07, p < 0.001}, and the main effects of glove {F(1,9) = 55.05, p < 0.000} and surface {F(1,9) = 15.66, p < 0.01} were all significant. Similarly, for the slip force there was a highly significant interaction {F(1,9) = 980.03, p < 0.000}, and main effect of glove {F(1,9) = 1366.21, p < 0.000} and surface {F(1,9) = 975.74, p < 0.000}.

Compared with the results for the constant surface (figure 4A), the peak and static forces for the combination of cotton glove and sandpaper surface were much larger in these random surface variation trials. The corresponding safety margin was therefore significantly higher than that of the repeated trials with the constant sandpaper surface {F(1,9) = 13.95, p < 0.000} (figure 4B).

4. Discussion

4.1. Effect of glove thickness
To achieve better protection against various virus and toxic chemical agents, as well as to increase higher puncture resistance, the use of thicker gloves is commonly recommended in medical and industrial professions (Serrano et al. 1990, Godin et al. 1991). Thinner gloves are, on the other hand, suggested to provide a better
The present study demonstrated that the grip forces for lifting and holding of a small object in a natural and ordinary lifting task increased with thicker gloves. Both the peak and static forces were increased >30% by the selection of 1 mm-thick compared with 0.24 mm-thick gloves, and thus possibly lowering physiological efficiency by a similar magnitude for the 1 mm-thick glove. It was further shown in the present study that the force increase was due to the fact that the safety margin was raised as the glove thickness increased. The safety margin with the barehanded condition was therefore the smallest, and that for the 1 mm-thick glove was about twice that of the barehand. These findings indicate that the thickness of the hand covering influences the grip force regulated voluntarily. Johansson and Westling (1984, 1987, Westling and Johansson 1984) and Macefield et al. (1996) investigated responses of the mechno-receptors in the finger-tips during lifting and holding tasks, and reported that tactile sensors played a major role in the maintenance of a small safety margin above various slip force levels. With an application of local anaesthesia to block the tactile sensation of the fingers completely or partially (Cole 1990), the safety margin employed increased, and adaptation of the grip force to varied surface conditions was lost (Johansson and Westling 1984) or degraded (Cole 1990). An increase of the safety margin in relation to degeneration of the sensory function of the fingers with ageing has also been demonstrated by Cole (1991) and Kinoshita and Francis (1996). The findings of the present study therefore seem to indicate that the normal activity of the mechno-receptors to adapt to the surface is disturbed by the use of gloves, and that the level of this disturbance is associated with the thickness of the covering material.

It was noted in the present study that performance time as evaluated by the preload and total phases was prolonged slightly (<35 ms) by wearing gloves. However, among the rubber gloves of varied thicknesses, there was no difference in these phases. Nelson and Mital (1995) studied the effect of surgical gloves of varied thickness on the time to sense the difference in the varied grits of sandpaper surface as well as that of the varied diameters of pipes. According to their data, the mean time to pick up a specified surface for the barehanded condition, 0.21 and 0.51 mm-thick gloves was 3 s, and this increased to 6 s for the thicker gloves. Detection time for the varied pipe diameters, however, changed only slightly in relation to glove thickness. Other researchers (Griffen 1944, Bradley 1969a, Plummer et al. 1985, Bensel 1993) reported that there was prolongation of the performance time with use of thicker gloves when their participants were requested to perform various manipulative tasks at their fastest speed. Results of this study therefore seem to indicate that for the execution of fundamental daily manipulative tasks where fast movement speed is not a prime concern, the use of rubber gloves up to 1 mm-thick has almost no practical influence on temporal efficiency.

4.2. Effect of glove material

For precision manual tasks in laboratories and industries, both rubber and cotton gloves are commonly used. The present study demonstrated clearly a difference in glove materials for the control of grip force against different surfaces. It was found that the rubber surgical glove could lower the slip force against an ordinary slippery surface, and it equalized the frictional state between the glove and the surface under varied frictional conditions. The cotton glove, on the other hand, had high and low slip forces for the slippery and non-slippery surfaces, respectively, providing fairly
low and high frictional conditions, respectively. The cotton glove produced an even wider frictional range than the skin. With use of the rubber glove, the participants did not have to modify the static force to maintain a similar safety margin for slippery and non-slippery surfaces. This was not the case for the cotton glove: to maintain a similar safety margin, the participants had to adjust the peak and static forces depending on the slip force for each of the surfaces despite a decline in tactile accuracy. Moreover, if the surface was varied such that the participants could not predict its slipperiness, this force adaptation was nearly lost (figure 5). For the cotton glove the participants then had to use an unnecessarily excessive safety margin against the non-slippery surface (figure 4B).

The findings indicated that adaptation to the surfaces took place when the same frictional condition was repeated. It is natural to assume that the participants gained information about the frictional conditions between the glove and object surface through the experience of dropping the object, and this information seems important for the adjustment of grip force. The sensory experience of dropping an object prior to manipulative work then should help in the reduction of unnecessary muscular effort for grasping forces even with use of relatively slippery gloves.

The slightly longer performance time with the use of cotton compared with rubber gloves suggests better temporal efficiency of the rubber glove. A post-experiment interview revealed that all the participants felt that the task was easier with rubber than cotton gloves, and some even felt that the task was easier with the rubber glove than barehanded. The findings suggest overall that rubber gloves provide better control and thus a higher performance efficiency than cotton gloves in the precision handling of objects.

Further study is needed to examine the interactive nature of other types of gloves against a wider variety of surface materials and surface conditions (wetness, oiled, etc.). The effects of object weight, shapes and sizes, and more complex tasks should also be examined.

4.3. Implications of the findings

Practical applications of the present findings may merit further discussion. The results indicated that the thicker the glove, the greater the extra grip force employed. Thick gloves are, however, indispensable in cold climates, and for handling hot, cold, toxic or sometimes extremely heavy items. In such cases, caution must be exercised to prevent the accidental dropping of grasped objects due to not only the lowered tactile sensory information but also to muscular fatigue of the hand resulting from the greater grip force exertion during continuous holding or a repetitive lifting task. To this end, we recommend that workers use gloves in which the finger-tip areas are coated with rubber or any other non-slippery material. The surface of the objects handled should also be covered better by a non-slippery material, and a sufficient resting period between the tasks should also be allocated.

Although cotton gloves are commonly used in the workplace, they may be unsuitable for the handling of slippery objects, due to their fairly low friction against such objects. The required muscular effort associated with the use of cotton gloves was much higher compared with the rubber gloves or barehanded. More importantly, when the surface property is unexpectedly changed from a non-slippery to slippery surface, a high risk of accidental drop of objects is present. This is probably minimized even with the use of cotton gloves if the glove finger-tips are covered with non-slippery material.
Our findings suggest that in some cases rubber gloves may provide better manipulability than the barehanded situation because of their more stable frictional condition on various surfaces of the objects grasped. In the barehanded condition, sweating of the fingers modifies the frictional condition and requires a moment-by-moment adjustment of grip force-load force ratio (Johansson and Westling 1984). The use of thin rubber gloves with an inner cotton glove or gloves with rubber fingertips and vapour-permeable materials at other parts provides a more stable frictional condition, which may lead to higher productivity than the barehanded condition for some tasks that require dexterity.

5. Conclusions

In conclusion, the thickness of the gloves worn influenced the magnitude of the finger force safety margin. The thicker the glove, the higher the safety margin and therefore the greater the grip force. Thickness of the gloves did not influence performance time when the task was performed at a self-determined moderate speed. The material of the gloves and surface of the objects manipulated were important factors in determining the magnitude of exerted grip force and performance time. Rubber was superior to cotton in both force and temporal efficiency.

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