Role of Movement Velocity on the Magnitude of Grip Force While Lifting an Object With Touch From the Contralateral Finger

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We investigated whether slower velocity of arm movement affects grip-force generation in conditions with the finger touch provided to the wrist of the target arm. Nine subjects performed the task of lifting and transporting an object at slow, intermediate, and fast velocities with a light finger touch from the contralateral arm and without it. There was an effect of velocity of arm movement on grip-force generation in both conditions. However, when the no touch and touch trials performed with similar velocity were matched, the effect of touch on grip-force reduction was statistically significant ($p < .001$). The observed decrease in grip force could not be explained by slower movement execution in the touch conditions and underlines the importance of using a contralateral touch in the performance of activities of daily living. It also points to a possibility of the development of therapeutic advances for the enhancement of grip-force control in patients with neurological impairments.

Keywords: grip force, finger touch, velocity, human

A prerequisite for the elaborate use of the human hand during manipulation of objects is the ability to produce, maintain, and regulate grip force. Appropriate modulation of grip force is essential when performing various activities of daily living, such as drinking, eating, buttoning a shirt, etc. Proper modulation of grip force is also crucial in carrying out a number of work-related activities by helping to avoid fatigue and injuries (Holewski, Stess, Graf, & Grunfeld, 1988; Bell-Krotoski, 1991; Gilles & Wing, 2003; Nowak & Hermsdorfer, 2004). It is well-documented that inability to produce adequate grip force is closely related to daily activity limitations in patients with neurological impairments (Bohannon, Warren, & Cogman, 1991; Boissy, Bourbonnais, Carlotti, Gravel, & Arsenault, 1999; Gordon, Quinn, Reilmann, & Marder, 2000; Brach & VanSwearingen, 2002; Videler, Beelen, Aufdemkampe, de Groot, & Van Leemputte, 2002) and the elderly (Brach & VanSwearingen, 2002; Danion, Descoins, & Bootsma, 2007).

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Many everyday tasks require skilled manipulations with two hands. In addition, individuals with weak hand muscles commonly use the help of a second hand for such activities as lifting a cup, using a towel, and eating. Involvement of a second hand makes it easier to perform a task by requiring a smaller application of grip force to the hand-held object. For example, it was demonstrated that if a supporting force from a second hand is provided to the object, the grip force is reduced (Scholz & Latash, 1998). It was also reported that sensory information from the nonaffected hand helps to optimize grip-force generation during subsequent lifts of the object with the affected hand (Gordon, Charles, & Duff, 1999).

Recent postural studies have shown that light finger touch, which is not adequate to offer mechanical support (<0.1 N), provides sensory information that reduces postural sway in standing individuals (Jeka & Lackner, 1994; Jeka, 1997; Lackner et al., 1999; Lackner, Rabin, & DiZio, 2001). Moreover, it was shown that grip force applied to the hand-held object during its lifting and transporting was significantly reduced when a light finger touch from the contralateral arm was provided to the wrist of the target arm (Aruin, 2005). The possible mechanisms, which could explain a decrease in grip force following application of light touch, include the availability of auxiliary sensory cues delivered via a finger touch, stabilization of the target arm finger touch-related information from the contralateral arm joint and muscle receptors becoming available, and attention drawn toward the target arm. Another possible explanation expressed recently is that a reduction of grip force could be associated with slower movement performance in the conditions with the application of a finger touch (Iyengar, Santos, & Aruin, 2007).

The effect of changes in the peak velocity across conditions with reaching and grasping an object using the arm only, the trunk only, and some combinations of both arm and trunk was reported in the literature (Wang & Stelmach, 1998). Modulation of grip force with the movement acceleration was also observed in experiments with subjects moving an instrumented object in the horizontal plane in various directions (Smith & Soechting, 2005). At the same time, no literature data are available on the effect of velocity in grip-force generation in conditions with a finger touch provided to the wrist of the target hand. Therefore, a purpose of the current study was to investigate whether possible changes in the velocity of the arm movement associated with provision of a light touch will affect grip-force generation during performance of a manipulative task. We hypothesized that velocity of arm movements will affect the magnitude of grip force needed to perform the tasks; however, the reduction of grip force in conditions with the finger touch will be observed irrespective of the velocity of the arm movement.

Methods

Subjects

Nine healthy volunteers with no history of any neurological illness or musculoskeletal weakness (five women and four men, mean age 27 ± 4.9 years) were enrolled in the study. Before the commencement of the experiment, the subjects gave informed consent and the experiment was approved by the Institutional Review Board of the University of Illinois at Chicago.
Apparatus

A hand-held object (a plastic cylindrical cup, dimensions: 8 cm in diameter, 12 cm in height, and 305 g in weight) was used to perform the functional task of lifting and placing on an elevated surface. The cup was instrumented with a strain gauge that was placed on the side of the cup to measure the grip force applied by the thumb, and it was located at a distance of 8 cm from the bottom. Two unidirectional accelerometers (PCB model 333B42, PCB model 333B32) were attached to the cup close to its midpoint to measure the acceleration of the hand-held object in both vertical and horizontal planes.

Procedure

The subjects were asked to wash their hands before the experiment, and their fingertips were cleaned with an alcohol swab. They were seated upright in a chair with no back support, and the seat height was adjusted according to the subject’s comfort. Both of the subject’s feet were flat and supported on the floor, and their hands rested on their thighs before the start of the task. The experimental task included lifting the cup positioned on the table with a cylindrical grip that involved opposition of the thumb and the rest of fingers following an auditory signal (beep) and placing it on a shelf that was located at a height of 21 cm and a distance of 30 cm from the starting position. The initial and final positions were marked. Each subject was required to perform the just-mentioned task with no involvement of the contralateral arm and with application of a light touch from the index finger of the contralateral arm to the wrist before grasping the object. The point of application of the finger touch was marked with a pen for the convenience of the subjects.

In both experimental conditions (no touch, finger touch), the subjects were instructed to perform the task with three self-selected velocities. First, the subjects were instructed to perform the movement at their comfortable pace; this velocity was considered to be slow. Then, the subjects were instructed to perform the task as fast as possible. Finally, they were instructed to carry out the task with a velocity that was intermediate between the comfortable pace and the fast pace. Each subject performed five to six practice trials with and without a finger touch before the start of data collection. Then, the subjects completed three blocks of trials, five trials each, with each of the three velocities (slow, medium, and fast) in a randomized order. In each block, the subjects held the object with their thumb contacting the strain gauge and then lifted and placed it on the shelf with the required speed. They were instructed to return their hand back to the original starting position, leaving the cup on the shelf. The experimenter then placed the cup back to the starting position for the subsequent trial. The same set of trials (three blocks with different velocities) was repeated with no involvement of the contralateral arm and with the provision of light touch from the contralateral index finger. The subjects were instructed to apply a “zero” force to the wrist of the target arm and to avoid trunk movements while performing the task. Data were collected for 5 s, and a rest period of 3 s was provided between the trials.

To measure the actual force applied by the index finger to the wrist of the target arm during the experimental task performance, we conducted a pilot study involving four subjects. The subjects performed the task with application of the
light touch of the index finger of the contralateral hand to the wrist of the target hand via a miniature force sensor that was fixed to the wrist. We found this force to be $0.56 \pm 0.34$ N; this force is too small to provide a mechanical stabilization of the arm.

**Data Processing**

The signals from the force sensor and two accelerometers were sampled at 100 Hz with a 16-bit resolution using LabView software and stored for off-line processing on a computer. The data processing included trial alignments using the first deflection of the accelerometer signal from its baseline, which reflected the moment of liftoff of the object. The data were then analyzed in the MATLAB program. The following outcome measures were obtained: peak grip force (PGF) was the maximum grip force applied by the thumb during the task performance (N), peak total acceleration ($A_p$) was the maximum acceleration during the task performance (m/s$^2$), maximal load force ($LF_{max}$) was calculated as the product of the mass of the object (m) and the vector sum of the horizontal and vertical acceleration ($A$; N), force ratio (PGF/$LF_{max}$) was calculated by dividing the peak grip force by the maximal load force, and the latency of grip force was measured as the time taken to reach the peak grip force from the time of liftoff. The time difference between the time of peak grip force ($T_{PGF}$) and time of peak of load force ($T_{LF_{max}}$) was measured (s) and called the time lag. For each subject, aligned trials performed with light touch were matched with the trials without light touch based on the velocity of the movement. Matching of the trials resulted in a decrease of the number of trials: two trials for each condition for each subject (touch, no touch, and three velocities of movements) were used in the statistical analysis.

**Statistical Analysis**

A repeated-measures analysis of variance (ANOVA) was performed with within-subjects factors of condition (no touch and light touch) and velocity of movement (slow, intermediate, and fast). The dependent variables were peak grip force, force ratio, time lag, and latency of grip force. A post hoc comparison was done using the $t$ test ($p < .05$).

**Results**

On average, movement velocity during performance of the no touch tasks was $71.54 \pm 4.63$ m/s, $95.71 \pm 7.51$ m/s, and $127.69 \pm 7.43$ m/s for the slow, intermediate, and fast movements, respectively. The velocity in conditions with the finger touch was $69.51 \pm 4.38$ m/s, $96.31 \pm 7.51$ m/s, and $128.32 \pm 8.49$ m/s for slow, intermediate, and fast movements, respectively. There was no difference in velocity magnitudes between the no touch and touch conditions for the slow ($p = .11$), medium ($p = .56$), and fast ($p = .68$) movements.

The PGF in the no touch conditions when performing the task with slow velocity was $7.49 \pm 0.89$ N, and it was reduced to $6.13 \pm 0.74$ N in the series with the light touch. When the task was performed with intermediate velocity, the PGF in the series with no finger touch was $10.62 \pm 1.44$ N, and it was reduced to $9.51$
± 1.3 N in the touch conditions. Finally, the PGF in the no touch trials performed fast reached 18.30 ± 4.35 N, and it decreased with provision of a finger touch to 16.29 ± 3.88 N (Figure 1). The results of the ANOVA revealed that the effect of touch was statistically significant across all the conditions ($F = 7.28, p < .001$). Post hoc analysis showed significant differences for the slow ($p < .001$), intermediate ($p = .043$), and fast ($p = .017$) conditions. There was a linear relationship between the PGF and peak velocity across all conditions (Figure 2).

The magnitude of the ratio between the PGF and load force ($\text{PGF}/L\text{F}_{\text{max}}$) was smaller in the touch conditions compared with no touch trials across different velocities of the task. Thus, the $\text{PGF}/L\text{F}_{\text{max}}$ ratios for slow, intermediate, and fast velocities without light touch were 1.49 ± 0.13, 1.81 ± 0.22, and 2.23 ± 0.38, respectively. With the application of a light finger touch, they reduced to 1.23 ± 0.1, 1.68 ± 0.17, and 2.11 ± 0.34 in the slow, intermediate, and fast velocity

![Grip force across conditions](image)

**Figure 1** — Peak grip force when performing the task of lifting and transporting an object with and without a contralateral finger touch at three different velocities. Smaller grip force could be seen in the three series of lifts performed with small, medium, and fast velocities in conditions with a finger touch provided. Mean and $SE$ are shown.
conditions ($F = 6.011, p < .001$). The difference in the PGF/LF_{max} ratios between no touch and touch conditions in the series with either a slow, medium, or fast velocity was statistically significant ($F = 11.19, p = .004$).

The latency (time delay between the grip force at liftoff and the time taken to reach the maximum grip force) in the no touch condition was $1.40 \pm 0.05$ ms, $1.16 \pm 0.05$ ms, and $0.97 \pm 0.04$ ms for the slow, intermediate, and fast velocities, respectively. When a light touch was available, latency in the slow, intermediate, and fast velocity conditions was $1.41 \pm 0.06$ ms, $1.14 \pm 0.07$ ms, and $0.98 \pm 0.04$ ms, respectively. The latency decrease with increase of the velocity of the arm movement was statistically significant ($F = 15.51, p < .001$). However, there was no effect of touch on the latency between the liftoff and the time taken to reach the maximum grip force.

$T_{PGF}$ and $T_{LF_{max}}$ are presented in Table 1. The time difference between $T_{PGF}$ and $T_{LF_{max}}$ was called time lag; this parameter represents the temporal coupling between the grip force and the load force. Time lag in no touch conditions was $27.22 \pm 4.83$ ms, $27.22 \pm 9.28$ ms, and $34.44 \pm 6.62$ ms in the series performed with slow, intermediate, and fast velocities, respectively. When finger touch was

![Figure 2](image)

**Figure 2** — Relationship between the peak grip force and the velocity of the task. The task was performed with and without a finger touch from the contralateral finger provided to the wrist of the target arm. Regression lines and regression equations are shown.
provided, the time lag was 32.77 ± 7.22 ms, 35.0 ± 8.25 ms, and 32.77 ± 7.70 ms with movements performed with slow, intermediate, and fast velocities, respectively. The difference between no touch and touch conditions was statistically insignificant ($F = 0.38$, $p = .54$). The relationship between $T_{\text{PGF}}$ and $T_{\text{LFmax}}$ was linear between finger touch and no touch conditions for the three velocities (Figures 3 and 4).

### Discussion

Uneconomically elevated grip forces during manipulation of hand-held objects performed by individuals with pathological conditions have been described in the literature. Thus, it was shown that individuals with cerebellar dysfunction (Fellows, Ernst, Schwarz, Topper, & Noth, 2001), basal ganglia disorders (Fellows, Noth, & Schwarz, 1998; Serrien, Burgunder, & Wiesendanger, 2001), stroke (Nowak, Hermsdorfer, & Topka, 2003), and motor neuron disease (Nowak & Hermsdorfer, 2002) all apply higher-than-needed grip force. It was also shown that healthy individuals apply elevated grip force during vertical movements of a grasped object when the task is performed after digital anesthesia (Nowak et al., 2001).

One possible way to reduce excessive application of grip force is to use a lifting approach that involves a finger touch from the contralateral arm (Aruin, 2005). However, application of a finger touch could slow down the arm movement and, as a consequence, result in a smaller grip force applied to the object. Thus, the current study was designed to investigate whether decreased grip force in the finger touch conditions could be attributed to a slower movement performance. Matching the trials with the same velocity made it possible to isolate the effect of touch on grip force control from the effect of the velocity of the movement.

A major result of the study was that grip force in conditions with provision of the contralateral finger touch to the wrist of the target arm was always smaller compared with the no touch conditions. This decreased grip force seen across all task velocities suggests that the minimization of grip force when a finger touch is provided is not associated with possible slowness of the movement of the target arm. It also suggests that the finger touch–related decrease in grip force is quite a general phenomenon, which should be studied further.

At the same time, a strong positive linear correlation between the velocity of movement and the PGF was observed in both no touch and touch conditions. One possible explanation for such a linear relationship is that lifting and transporting an object with increased velocity induces additional constraints on task performance. To comply with the consequences of the actions in progress, the individual has to apply larger grip force. Indeed, modulation of grip force with acceleration was observed in experiments with subjects moving an instrumented object in the horizontal plane in various directions (Smith & Soechting, 2005). Moreover, it was demonstrated experimentally that load forces increased during point-to-point movements performed with high acceleration (Flanagan, Tresilian, & Wing, 1993; Flanagan & Wing, 1993; Flanagan & Tresilian, 1994). It was suggested that the central nervous system increases grip force before the initiation of movement by changing activation commands to the finger flexors proportionally to the velocity.
Table 1  Peak Grip Force (PGF), Ratio Between Peak of Grip Force and Peak of Load Force (PGF/LFmax), Time of Peak Load Force (TLFmax), and Time of Peak Grip Force (TPGF) During Performance of the Lifting Task With No Touch and Touch at 3 Velocities

<table>
<thead>
<tr>
<th>Condition</th>
<th>PGF (N)</th>
<th>PGF/LF(_{max})</th>
<th>T(_{LFmax}) (s)</th>
<th>T(_{PGF}) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>I</td>
<td>F</td>
<td>S</td>
</tr>
<tr>
<td>No touch</td>
<td>7.49</td>
<td>10.62</td>
<td>18.30</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>(0.89)</td>
<td>(1.44)</td>
<td>(4.35)</td>
<td>(0.13)</td>
</tr>
<tr>
<td>Touch</td>
<td>6.13</td>
<td>9.50</td>
<td>16.29</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>(0.74)</td>
<td>(1.3)</td>
<td>(3.88)</td>
<td>(0.1)</td>
</tr>
</tbody>
</table>

*Note.* Mean and SE (in parentheses) are shown. S = Slow. I = Intermediate. F = Fast.
properties of the forthcoming movements (Flanagan & Wing, 1997; Weeks, Sherwood, & Noteboom, 2002). It is noteworthy that a comparable velocity–grip force relationship with similar $R$ values and a line slope is observed in the no touch and finger touch conditions (Figure 2), suggesting that the coupling between the grip and load forces was not influenced by provision of the finger touch.

The ratio between maximum grip and load force, which provides information about the efficiency of the produced grip force magnitude in relation to the actual load, increased with the rise in the velocity of the movement in both no touch and touch conditions. Elevated force ratios were previously described in the cases of dysfunction of sensorimotor performance due to anesthesia (Nowak et al., 2001), pathological conditions such as Parkinson’s disease (Fellows et al., 1998), Down syndrome (Cole, Abbs, & Turner, 1988), and stroke (Nowak et al., 2003). The force ratios in the current study were smaller in the conditions with provision of a contralateral finger touch compared with no touch conditions. From these findings, we argue that although the ratio increases with the increase in velocity of the movement, it seems that, for a given velocity of the movement, the application of

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**Figure 3** — Relationship between the time of peak grip force ($T_{\text{PCF}}$) and the time of load force ($T_{\text{Lmax}}$) for the task performed with no touch of the finger. Regression lines and regression equations are shown.
grip force in the task performed with the provision of a light finger touch from the contralateral hand is achieved more efficiently.

In the current study, the latency (the time taken to reach PGF in relation to the grip force at liftoff) decreased with the increase of the velocity of the arm movement (i.e., it was shorter for fast velocities and longer for slow velocities). In addition, the results of the current study suggest that, for a determined velocity of the arm movement (slow, intermediate, or fast), the latency will not be affected by the provision of the finger touch, and thus, the finger touch approach could be used by patients who apply excessive grip force to improve their ability to grasp and lift objects. On the other hand, it was shown that the elderly (Cole, Rotella, & Harper, 1999), individuals with Parkinson’s disease (Fellows et al., 1998), and individuals with stroke (Aruin, 2005) demonstrate longer latency while lifting the objects. It is quite possible that differences in the latencies between the healthy individuals and individuals with neurological impairments are due to the tendency of the patients to perform movement slower than their healthy counterparts. Therefore,
special attention to the movement velocity should be given in studies of grip force control involving neurological patients.

**Conclusion**

The results of the study suggest that reduction in grip force observed while lifting an object using an application of the touch from the contralateral finger is not associated with changes in the velocity of the arm movement. Instead, it underlines the existence of another mechanism that allows application of a more economical grip force while lifting and transporting the objects. It also suggests a need for future studies focused on achieving a better understanding of the finger touch phenomena. In addition, it points to a possibility of developing therapeutic advances for the enhancement of grip-force control in patients with neurological impairments such as stroke and individuals with multiple sclerosis.

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**References**


