Somatosensory information in lifting objects while applying contralateral finger touch to the target arm

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THESIS

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BC

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CNS	Central Nervous system
COP	Center of Pressure
N	Newton
NT	No Touch
RMS	Root Mean Square
TW	Touch Wrist
TE	Touch Elbow
TS	Touch Shoulder

SUMMARY

Many daily actives involving lifting objects require producing, regulating, and maintaining grip force needed to perform the task. Successful manipulations of a hand-held object depend on the exertion of forces that should be large enough to prevent the slip but not too large to prevent a crash of the object, or cause unnecessary fatigue. A successful lifting of an object is based on the capability of regulating grip force parallel with load force. Also the property of the object needs to be taken into consideration when program grip force to produce a smooth and well coordinated force output.

A study conducted by Aruin A (2005) showed that by applying a light finger touch from the index finger of the contralateral hand to the wrist of the target hand while lifting and horizontally transporting a hand-held object, the exertion of grip force was significantly reduced in patient with stroke and healthy individuals. The effect of additional sensory cue in modulation of grip force is important in helping people to deal with many tasks used in their daily life. Several following experiments were conducted by a group of researchers in the same lab; the researchers found that the grip force modulation was maintained when velocity of the arm movement was varied and when the touch locations were differed along the forearm or when the finger touch was even applied to the hand-held object itself. Such a decrease in the grip force could be related to the use of the proprioceptive information that the central nervous system obtained from receptors located in muscles and joints of the contralateral arm

However, the mechanism of this modulation is not fully exposed. It is unknown if such a modulation will be present if the touch points were set on the upper arm. Also it is not known whether other types of somatosensory information can play a role in such reduction of grip force.

A study of the effect of different types of somatosensory information on grip force control was conducted using a pre and post-test design. A group of young healthy individuals were recruited and the data was collected from 9 right-handed subjects. Participants were asked to perform a functional task of lifting an instrumented object and putting it onto an elevated surface. A strain gauge and an accelerometer were attached to the object. The strain gauge was used to measure peak grip force and the accelerometer was used to measure peak acceleration within the experimental period. A Jamar dynamometer was used to measure the maximum grip force of each individual before the start of the experiment. The subjects were then asked to perform the task with or without a finger touch to the target by themselves. In the touch conditions, 3 touch points were set at wrist, elbow and shoulder. Outcome measure were maximum grip force, peak grip force and peak acceleration.

By measuring the magnitudes of the maximum grip force, we showed that the group of subjects was homogeneous (they were neither too strong nor too weak to perform the functional task).

Analysis of the peak acceleration confirmed that the subjects performed the task with similar acceleration.

We observed a significant reduction in peak grip force in the light touch conditions as compared to the no touch condition. No significant difference was seen within the three touch conditions of touching the wrist, elbow and shoulder. The results indicated that the healthy subjects positively utilized the somatosensory information from the contralateral arm in contact with the target arm: these resulted in reducing the peak grip force during the functional task of lifting and transporting a hand-held object.

Similar reduction of grip force observed when touching the shoulder joint compared to touching the wrist and elbow can be related to using cutaneous information obtained from the contralateral fingertip. In such a condition, there was a relative movement between contralateral fingertip and the touch location. Such explanations were also supported by the literature describing the effect of a light finger touch in reduction of the body sway and the literature describing thye effect of the plantar sensory input / cutaneous in maintenance of balance.

These results were in line with the outcomes of the previous studies and exposed a more developed mechanism of modulation of grip force that the CNS

SUMMARY (continued)

implements while using different types of somatosensory information. The ability to use different types of somatosensory information depends on the range of the movement of the contralateral arm and relative movements between the contralateral fingertip and target location.

The outcome of the studycan be used to formulate a rehabilitation protocol focused on helping optimizing grip force in performing activities of daily living

1. INTRODUCTION

Many daily actives involving lifting objects require producing, regulating, and maintaining grip force needed to perform the task. Successful manipulations of a hand-held object depend on the exertion of forces that should be large enough to prevent the slip but not too large to prevent a crash of the object, or cause fatigue. To solve a pure physical problem like this, the central nervous system (CNS) relies on visual, somatosensory or alternative information while planning the grip force output according to the properties of the object and the consequences of its manipulation (Gordon, Forssberg et al. 1991). We can easily obtain a general idea of how CNS regulating grip force from friction equation $f=\mu N$, where ‘f’, ‘μ’, ‘N’ is friction, coefficient and force that perpendicular to the surface, respectively. In program of grip force ‘f’, ‘N’ is grip force and load force. A possible lifting of a hand-held object relates to the capability of regulating grip force parallel with load force, also the physical property of the object, such as weight and surface friction, needs to be taken in to consideration to result in a smooth and well-coordinated force output at the grasping fingers (Hager-Ross and Johansson 1996).

A proper modulation of grip force is crucial for the performances of a number of work-related activities, such as lifting a glass or grasping a doorknob. It was shown that grip force applied to the hand-held object during its lifting and transporting could be significantly reduced when a light finger touch from the contralateral arm is provided to the target arm (Aruin 2005). It was suggested that auxiliary sensory cues delivered via a finger touch are the reason for the decrease of grip force. Moreover, several following studies, which were conducted by a group of researchers in the same lab, involving healthy individuals demonstrated that the finger touch-related decrease in the grip force was maintained when the velocity of lifting was varied (Iyengar, Santos et al. 2009), and when the finger touch was applied to different points on the forearm (Iyengar, Santos et al. 2007). Particularly, it was reported that within the same arm movement velocity, the reduction in grip force with an application of the touch from the contralateral finger is not associated with touch points located on the forearm. The explanation to this experimental finding was that the decrease of grip force is due to the information from muscles and joint receptors of the contralateral arm utilized together with the information from the receptors of the target arm thus allowing more efficient modulation of grip force (Iyengar, Santos et al. 2007).

It is known that individual with unilateral impairment commonly use the help of a second hand for activities such as lifting a cup and feeding. Even for healthy individuals, when they try to lifting an object while they are already holding other objects in their hands, there is a tendency of involving contralateral arm. Hence the use of bimanual coordination in grip force manipulation is important (Aruin 2005).

In posture sway studies, it has been shown that a light finger touch, that is not adequate to offer mechanical support, significantly reduced body sway by providing additional sensory information to the CNS in healthy individuals(Jeka and Lackner 1994; Jeka, Schoner et al. 1997). The modulation of body sway was maintained even applied the light finger touch through a flexible filament(Lackner, Rabin et al. 2001). Moreover, contact of the index finger with a stationary surface, has been shown to decrease up by 50% of posture sway when vision is not available(Holden, Ventura et al. 1994).

It has been shown that plantar sensation is important in the maintenance of balance and the impact is expected to increase with the loss of additional sensory modalities(Meyer, Oddsson et al. 2004). Also there are reports that posture stability could be improved by enhancing cutaneous sensitivity (Palluel, Nougier et al. 2008; Palluel, Olivier et al. 2009).

Somtatosensory is comprised of the receptors of touch, proprioception, temperature and nociception. Based on the above-mentioned studies that have examined the effect of involving contralateral light finger touch which could be related to using proprioception and effect of cutaneous information in balance control, raises the question of whether and how somatosensory information from the contolateral side utilized with the information of the target arm could be used to regulate grip force.

1.1 Statement of the Research Problem

The investigation of the effect of sensory cues on grip force control is important in helping individuals to optimize force exertion and live in an economical manner while performing daily life activities. It is known that when a finger touch is applied along the forearm of the target arm or to the object itself, proprioceptive information from the receptors located in the muscles and joints of the contralateral arm is utilized together with the information obtained from the target arm to modulate grip force However, it is unknown if the modulation of grip force will be present when the finger touch is applied to the upper arm. Also the type of somatosensory information might play a role in such reduction of grip force needs to be investigated.

The purpose of this study is to further investigate the mechanism use to modulate grip force and to explain how a light touch from the contralateral arm allows optimizing grip force exerted by the target arm. It is important to find out whether a modulation of grip force will be present when the touch is applied to the upper arm. It is also important to find out if different types of somatosensory information play a role in the regulation of grip force.

1.2 Research Hypotheses

We hypothesized that the level of finger touch-related reduction of grip force will be affected by the availability and type of the somatosensory information from the contralateral arm.

This hypothesis will be tested in experimental tasks which will involve lifting an instrumented object and transporting it onto an elevated surface. There will be 4 conditions included in the experiment. The first condition will be no touch condition. The second, third and fourth condition will be light touch conditions with the touch points set on the wrist (TW), elbow (TE) and shoulder (TS), respectively. The touch sensory cue will be maintained throughout the duration of the movement. It is important to emphasize that changes within the touch conditions will be associated with different range of movement of the contralateral movement and different relative movement between finger tip and the touch location. The result of the observation will illustrate whether different type of somatosensory will play a role in the modulation of grip force.

1.3 Significance of the Study

Successful manipulation of hand-held objects is important in daily life activities. An explanation has been given to the observed modulation of grip force in conditions with the finger touch that relates to the use of proprioception that CNS obtains from the receptors located in the muscles and joints on the contralateral side. If a more developed mechanism of control of grip force is exposed, it will benefit further research. Moreover, the outcome of the study will provide a basis for the development of new rehabilitation protocols focused on optimization of grip force.

2. LITERATURE REVIEW

We are aware that upper extremity function plays an important role in our daily life, such as brushing teeth, buttoning clothes and drinking water. In addition, we may not consciously notice that upper extremities also have the ability to help keeping balance, and protecting our body from injury when balance recovery is not possible. 4 key elements were considered as components to accomplish the activities mentioned above: visual regard, approach, grasp (that also includes release), and manipulation of the object to be lifted. This literature review will focus on the grasp and manipulation components, as well as how human brain obtains extra information to optimize the lifting task.

2.1 Classification of Grasping Pattern

In 1956, Napier classified human grasping movements as power or precision grips (Napier 1956). It has been considered a prototype of grip of power grips when the object was grasped between palmar surfaces and the hand, while a prototype of grip of precision grip was considered while grasping an object between the pad of the thumb and the index finger. Both of the prototypes of grip play an important role in clinical routine, research and our daily life. Also both of the types have been subjected to the measurement of the grip force.

To obtain a measure of maximum grip force, power grip is primarily studied using various devices. The most widely used clinical device is the Jamar dynamometer that measures strength in a whole hand (Mathiowetz, Kashman et al. 1985). Maximum grip force can also be measured with a precision grip with an aim to examine the type of force that are used when manipulating common objects, like drinking water and lifting a cup. With the invention of strain gauges, isometric finger forces produced by a power grip and precision grip could be measured continuously, instead of using a Jamar dynamometer (that produces only one measurement), precisely and without major constrains to the motor task. For precision grip type, researches have been conducted looking at the maximum grip force, ability to maintain a constant force, tracking of dynamic task, and grip-load force ratio (Westling and Johansson 1984). Such studies were conducted to examine different aspects of fine motor control in healthy individuals and patients with peripheral neurological diseases or central nervous system diseases.

2.2 Grip Force During Lifting an Object

Measuring a parameter such as grip-load force ratio has inspired a large amount of scientist to investigate fine motor control in healthy people and patient populations. Evaluation of behaviors such as timing and grip-load coupling may provide more insight into the sensory mechanisms behind the behavioral changes.

In 1984, Johansson and Westling conducted an experiment to study the control of grip force under natural conditions, including grasp and lifting a small object between the tips of the index finger and thumb and held stationary in space (Westling and Johansson 1984). The researchers concluded that possible lifting related to the capability of regulating grip force parallel with load force (Johansson and Westling 1984). In the grasping and lifting study, it reveals that the response of the central nervous system to the physical constraints defined by the task is important. Contrary to the assumption that the grip force can be exerted in any value as long as it is higher than the slip force to prevent slipping, the grip is always has to be a little higher than the slip force (load force) in order to perform the task. The central nervous system works highly economically and anticipates precisely the demand of the motor task. Johansson's study demonstrated the characteristics of grip force that at time zero the finger contact the object and grip force increases. Load force starts to increase after a small grip force increases until the object is lifted off and reached the final height with a relatively constant load force (weight of the object). The grip-load force ratio was adjusted to different weight of the object, but the ratio itself was relatively constant if the acceleration was not taken in the consideration. Also grip force was higher when the force was applied to a more slippery surface with lower friction (Johansson and Westling 1984). it is reported in the literature that individual with stroke, cerebellar disorders, multiple sclerosis and the elderly commonly produce inefficiently elevated grip forces while performing simple daily tasks (Aruin 2005; Iyengar, Santos et al. 2009) and that even healthy individuals exert unnecessarily large forces which are in this sense uneconomical (Gao, Latash et al. 2005).

2.3 Regulation of Grip Force by Cutaneous Feedback

Cutaneous sensibility of the grasping digits plays an important role in successful regulation of grip force (Nowak and Hermsdorfer 2003). Several studies showed that sensory cues which reflected object weight and surface texture (friction) were obtained to regulate grip force economically during dynamic manipulation of a hand held object.

Novak and Hermsdorfer investigated whether cooling the grasping digits could affect scaling of the grip force magnitude in relation to load force generated during the continuous vertical arm movements performed with a grasped instrumented object (Nowak and Hermsdorfer 2003). Extremum values of load force were set at the lower and upper turning point of the arm movement cycle. Digits cooling were achieved by application of ethyl chloride to the palmar surface of the hand and fingers. As such digits cooling did not influence the ability of anticipation of the movement induced fluctuations mentioned above. Grip-load ratio was calculated to evaluate the scaling of grip force. The authors found that a 10-70% higher ratio between grip and load force was generated when manipulated the hand held object with cooling digits than normal unimpaired fingers.

Following experiment was conducted by the same group of researchers involving patients with reduced sensibility of the grasping digits (Nowak and Hermsdorfer 2003). The researchers investigated grip force control in nine patients with moderately impaired tactile sensibility of the grasping digits and in nine gender and age matched healthy controls lifting and holding an instrumented object. The research team have observed the outcome obtained from healthy individuals that was a similar with the results described by Johansson and Westling (Westling and Johansson 1984). However, they found that the patients employed greater maximum grip force and greater grip force to hold the object. Both of the experiments provided support evidence to the suggestion that cutaneous information from the grasping fingers plays an important role in scaling the grip force.

There are other primary components of the two controls processes that determine grip force. Anticipatory force control (the other one is feedback sensory information from the grasping digits) specifies the motor command based on prediction about the physical property of the object and demand of motor task

(Nowak and Hermsdorfer 2003). The regulation of grip force to unpredictable load changes during the manipulation of a hand held object more rely on the sensory feedback from the grasping digits. A series of experiments done by Johansson and colleagues (Johansson, Hager et al. 1992; Johansson, Hger et al. 1992; Johansson, Riso et al. 1992) investigated the regulation of grip force to unpredictable load changes during manipulation of the hand held object. It have been found that the reactive grip force adjustment was absent during the anesthesia of the finger digits when a sudden change of the weight of the hand held object was induced. It is also reported that when participants wore a thicker pair of gloves, the grip force increased, suggesting that the gloves' thickness probably affected the cutaneous sensation leading to change of grip force control (Kinoshita 1999).

In summary, the cutaneous sensory feedback is necessary for economically scaling of grip force as well as for the anticipation of changing the load of the hand held object in order to exert force large enough to prevent slipping and application of the unnecessary large grip force that might crash the hand held object or causing fatigue.

2.4 Effect of Spike Insole and Light Touch on Postural Stability

Among influence and reference conditions of interactions between sensory cues, aging and pathologies, tactile plantar sensory plays a role in improving stance stability by simply stimulate plantar-surface cutaneous sensory receptors. There are evidence shows that sensation from the feet and ankles are important for standing balance control. Experiments were conducted to explore the role of plantar cutaneous sensation in quasi-static balance control (Meyer, Oddsson et al. 2004). Iontophoretic delivery of anesthesia was used to reduce the sensitivity of the forefoot soles in procedure one, and in the follow-up experiment, subjects received intradermal injections in to the entire surface of the foot soles. The author found that forefoot anesthesia mainly influenced mediolateral posture control, whereas complete foot-sole anesthesia had effect on anteroposterior posture control. The effect of anesthesia of foot-sole on COP displacement was only present under eyes closed conditions, including increase in COP velocity and shear force RMS. This effect was observed when standing in both bipedal and unipedal stance. By isolating plantar cutaneous sensation from foot and ankle proprioception, Meyer found that reduced plantar sensation had no effect on bipedal balance when vision was available; when the postural control system was challenged by unipedal stance or eyes closed, the loss of plantar sensation caused an increase in the velocity of postural sway. The author concluded that feedback from plantar cutaneous receptors is important for maintenance of balance when vision is not available, mainly because sensory information from the foot soles is used to set a relevant background muscle activity for a given posture and properties of the support surface.

Bernard D. L and colleagues recruited 30 subjects to explore whether tactile plantar stimulation improves postural control of persons with superficial plantar sensory deficit (Bernard-Demanze, Vuillerme et al. 2009). All of the subjects were tested in eyes closed condition. Before the tactile plantar stimulation, the sway area and mean root mean square (RMS) were greater in older adults and older adults with plantar sensory deficit. After stimulation, a decrease in the mean RMS was observed in older subjects with plantar sensory deficit, indicating that application of tactile plantar stimulation may compensate for a loss of superficial plantar sensitivity. Estelle and colleagues used spike insoles to enhance plantar surface cutaneous sensitivity (Palluel, Nougier et al. 2008;

Palluel, Olivier et al. 2009). The results of the study showed that walking while equipped with spike insoles led to a significant improvement of quiet standing in the elderly, indicated that at least temporarily, wearing sandals with spike insoles can contribute to the improvement of unperturbed stance in elderly people with relatively intact plantar cutaneous sensation, and the elderly were particularly perturbed when the tactile sensitivity enhancement device was removed.

Attentions have been drawn to the use of light touch in the stabilization of upright posture. Several experiments showed that postural sway decrease by up to 50% when the index finger contacts a stationary surface at mechanically inefficient level (Jeka and Lackner 1994; Jeka, Schoner et al. 1997). The reason behind that is that the external contact can provide an additional sensory cue that helps posture to stabilize.

2.5 Bimanual Manipulation on Grip Force Modulation

Several studies involved bimanual motor tasks while exerting grip force to test the applicability of the notion of synergy (Scholz and Latash 1998). The participants were asked to sit with their dominant hand holding a cup between thumb and opposite fingers. Force transducer recorded the grip force exerted by the thumb and opposing fingers to the surface of the cup. In different conditions, a supporting force was added to and release from the bottom of the cup by the subject's non-dominant hand or by the experimenter. The results showed the existence of feedforward adjustments of the grip force with a voluntary movement done by the subject. A significant correlation between the grip force and supporting force was also established. The observed findings were diminished when the supporting force was applied and released by the experimenter. It was suggested that the grip force adjustments represented peripheral patterns of a single synergy rather than being isolated focal from postural components of the action.

2.6 Effect of Light Touch on Grip Force

It was shown in a series of experiments 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 target arm (Aruin 2005; Iyengar, Santos et al. 2007; Iyengar, Santos et al. 2009; Iyengar, Santos et al. 2009; Iyengar, Santos et al. 2009). The possible mechanisms that explain a decrease in grip force could be auxiliary sensors most likely providing proprioceptive information. In other words, when application of a light touch by a contralateral finger is provided, information from the joint and muscle receptors in the contralateral arm become available. This finding is in line with the report that sensory information from the non-affected hand helps to optimize grip-force generation during subsequent lifts of the object with the affected hand (Gordon and Duff 1999). To interpret the mechanism behind the change of behavior, the series of experiments were designed in such a way that the participants were required to perform similar motor task, i.e. grasping and lifting a cup, with or without application of a light finger touch from the contralateral arm to the forearm and the task was performed within different velocities. Results showed that compared to no touch conditions, grip force was significantly reduced in touch conditions, but there was no significant difference in the grip force magnitudes between different points of application of the finger touch along the forearm as well as within similar velocity. However, grip force increased with the increasing of velocity. As such, the authors explained that the decrease of grip force in the conditions with the application of a light touch by a contralateral finge could be due to the availability of proprioceptive information from the contralateral arm joint and muscle receptors and that information, was utilized to optimize grip force (Aruin 2005; Iyengar, Santos et al. 2007; Iyengar, Santos et al. 2009).

3. METHODOLOGY

3.1 Participants

Nine healthy right-handed young volunteers (4 males, 5 females, mean age 28±4.24) participated in the experiment. The experimental protocol was approved by the University of Illinois at Chicago Institutional Review Board and all participants provided written informed consent before taking part in the experimental procedures.

The inclusion criteria for the participants were as follows: a) Individual lacing any medical and neurological illness; b) Individual which are right-handed; c) individual that had the capability to perform the experimental task.

Demographic data of the nine healthy subjects with age, sex, height and weight is summarized in Table I.

TABLE I: DEMOGRAPHIC CHARACTERISTICS OF HEALTHY SUBJECTS

Subjects	Age (year)	Sex	Height (cm)	Weight (kg)
1	25	F	165	54
2	23	F	171	68
3	38	M	176	69
4	28	F	158	50
5	28	M	180	93
6	25	M	178	126
7	31	F	167	60
8	25	F	160	62
9	28	M	178	80
Average	29	F/M=5/4	170	73

3.2 Experimental Set-up

3.2.1 Design

The study consisted of a single session design for each participant, that include no touch, touch conditions.

3.2.2 Setting

All the experiments were performed at the Harry G Knecht Laboratory in the Department of Physical Therapy at the University of Illinois at Chicago

3.2.3 Instrumentation

An instrumented object made as a cylindrical plastic cup (16.5 cm high, 6 cm diameter, total weight 435g) was used to perform the task of lifting and transporting it. A strain gauge (PCB model-208c03) was located at the center of the object (10.5 cm from the bottom) and extended out from both sides of the cup by aluminum projections of 9.5 x2.5 cm each. The strain gauge measured grip force applied by the thumb and four opposing fingers. A 3-dimentional accelerometer (PCB model-356a16) was attached to the instrumented object to measure the acceleration in three orthogonal directions.

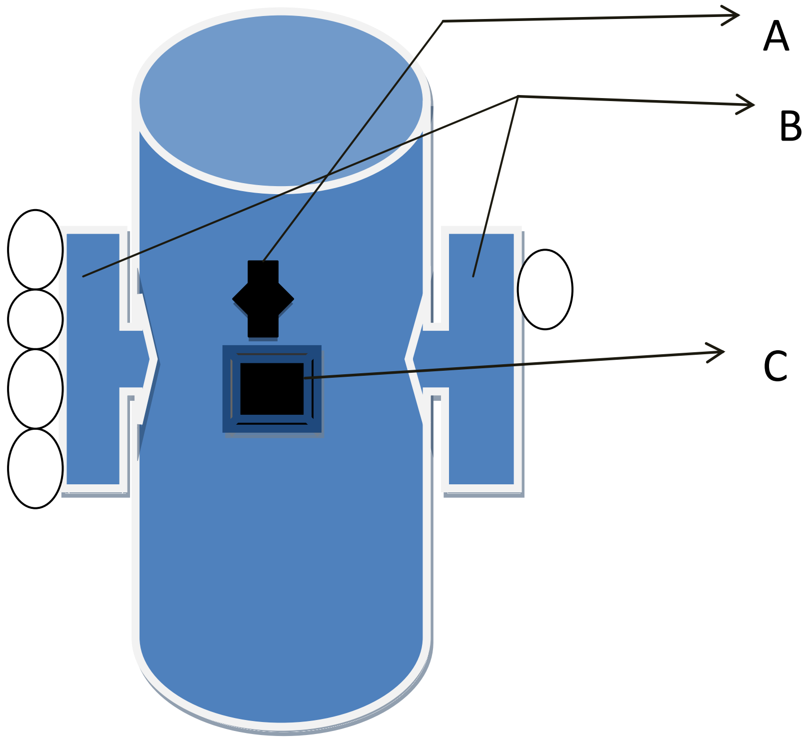


Figure 1: Instrumented object that was used during the experiment. A shows the strain gauge instrumented inside the cup. B shows the extended handle that connected to the strain gauge. C shows the accelerometer.

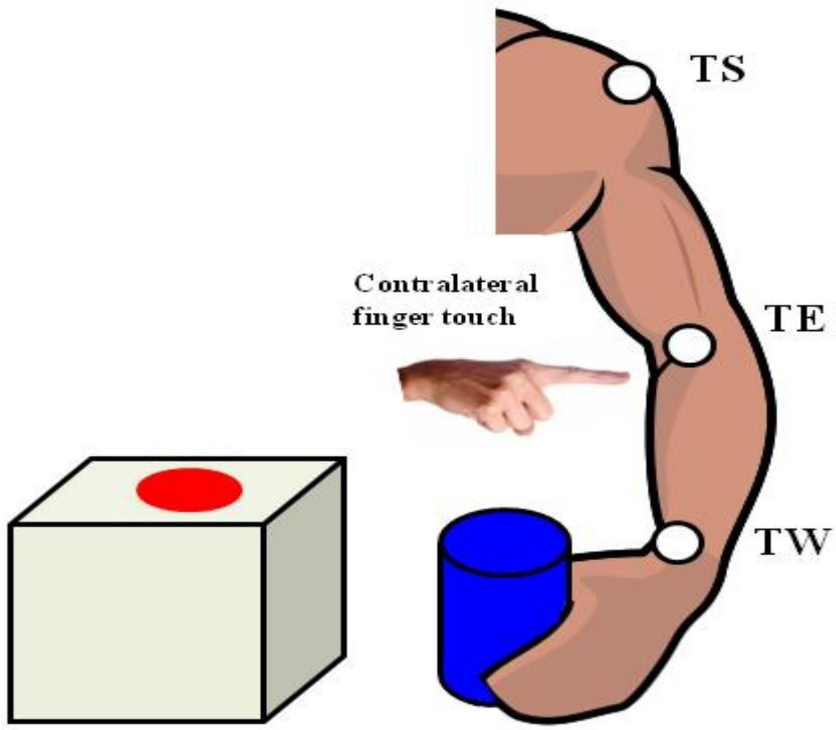
3.2.4 Experimental Procedure

The participants were asked to sit on an adjustable chair in front of an adjustable table with their trunk upright (no back support) and feet flat on the floor. Jamar dynamometer was used for measuring maximum static grip force while the subjects were in the sitting position mentioned above; keeping their arm close to the body, when elbow was flexed to 90 degrees and wrist was in mid pronation.

Table II ANTROPOMETRIC CHARACTERISTICS OF HEALTHY SUBJECTS INCLUDING ARM LENGTH AND MAXIMUM GRIP FORCE

Subjects	Forearm length (L) (cm)	Forearm length (R) (cm)	Individual max grip force (L) (kgF)	Individual max grip force (R) (kgF)
1	25	25	19	19
2	25	25	10	19
3	24	24	35	41
4	22	22	26	30
5	29	29	35	30
6	29	29	30	30
7	25	25	18	19
8	25	25	10	12
9	28	28	32	36
Average	26	26	24	26

The experimental task involved lifting the instrumented object positioned on the top of the table and transporting it onto a shelf, by grasping the out extended aluminum projections with the thumb and the four opposing fingers. The table and chair were adjusted in such a way that when a subject fully extended the arm in the anterior direction along the middle line, he/she would be able to reach the object (positioned on the surface of the table in the initial position) and put it on the shelf. The shelf, 21 cm height, was positioned 23 cm in front of the initial position of the instrumented object. The initial position and the final positions were marked with red spot stickers 7 cm in diameter. The subjects were instructed to grasp and transport the cup onto the shelf with the same maximal acceleration. This acceleration magnitude was selected based on the results of a pilot experiment and the outcome of a previous study.(Iyengar, Santos et al. 2007)



b

Figure 2: A schematic presentation of the experimental task. A is a side view of the subject performing the lifting and transporting task. B is where the touch points were set when perform a touch experimental task.

Maximal acceleration was recorded during the task performance and the subjects were provided with feedback by the experimenter after each trial; a trial was repeated if the recorded acceleration was below 4 m/s^2 or above 6 m/s^2.

The experimenter provided the subjects with two instructions, first ‘ready’ and then ‘go’. In response to the ‘ready’ command the subjects were required to put the fingers of the target hand around the instrumented object. However, the subjects were asked not to exert force to the aluminum projectors until he/she heard the second command ‘go’. After the ‘go’ signal the subjects lifted the object and put it on the shelf. After completion of the trial, the experimenter put the instrumented cup back to the initiatial position for the subsequent trial.

The subjects were instructed not to use the trunk movements while performing the experimental tasks. The accuracy of positioning the cup on the shelf was not taken in consideration however, if the cup was completely out of the spot, the subject was asked to repeat the trial again.

Each subject was required to perform the experimental task with no involvement of the contralateral arm and with a light touch from the index finger of the contralateral arm. A light touch of the index finger was provided to the three points on the target arm: (1) ventral aspect of the wrist (TW), (2) ventral aspect of the elbow (TE), and (3) on the top of the shoulder (TS). The light finger touch was applied immediately before the lift of the instrumented object and maintained during the whole duration of the task till the object was released.

The subjects were required to perform all the tasks with eyes open. 2-3 practice trials were provided to the subjects before collecting data, and five trials were collected in each experiment condition. The order of conditions was randomized for each participant.

3.2.5 Data Collection and Processing

The signals from the strain gauge and the accelerometer were digitized with a 16-bit resolution at 1,000 Hz by means of customized LabVIEW 8.6.1 software (National Instruments, Austin TX, USA). The data was then processed and analyzed in MATLAB program (MathWorks, Natick, MA, USA).

Peak value was set the maximum value during 5 seconds of experimental period. Peak grip force was measured as the maximum grip force applied to the strain gauge by the thumb and opposing four fingers during the task performance (N). The mean of the peak grip force for 5 trials in each condition was then calculated. Peak acceleration was also measured as the maximum acceleration during the task performance (m/s^2).

One way ANOVAs with 4 groups (NT, TW, TE, and TS) was performed for peak grip force and peak acceleration respectively. Statistical significance was set at $p<0.05$.

4. RESULTS

The grip force measured with Jamar dynamometer was 26.22±9.46 kgF for the group. The peak of acceleration recorded during the task of lifting and transporting the instrumented object in the no touch condition was 5.60±1.85 m/s2. When the task was performed with the contralateral finger touch to the wrist, elbow and shoulder joint, the peaks of acceleration were 5.15±0.99 m/s2, 5.624±1.84 m/s2, and 5.07±0.63 m/s2, respectively (Figure 3). There was no significant difference between the peaks of acceleration in different conditions ($F=0.23$, $P=0.87$).

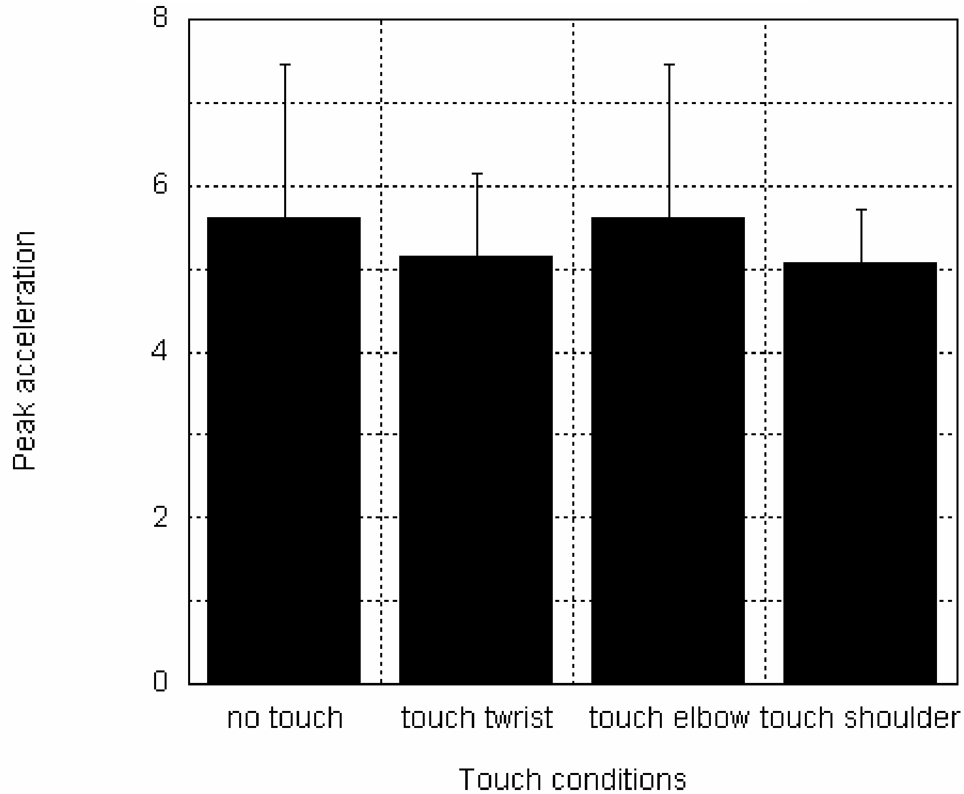


Figure 3: Changes of peak acceleration in 4 conditions (NT, TW, TE, TS)

The peak grip force during the no touch condition was 22.28±4.77 N. The peak grip force decreased reaching 16.86±3.94 N, 16.11±4.05 N, and 13.59±2.93 N, in the conditions with the light finger touch provided to the wrist, elbow and shoulder joint, respectively (Fig. 5). The differences between different conditions were significant (F=7.60, P=0.001). Further post hoc analysis revealed there was no statistically significant difference across the touch conditions (F=1.96, P=0.16).

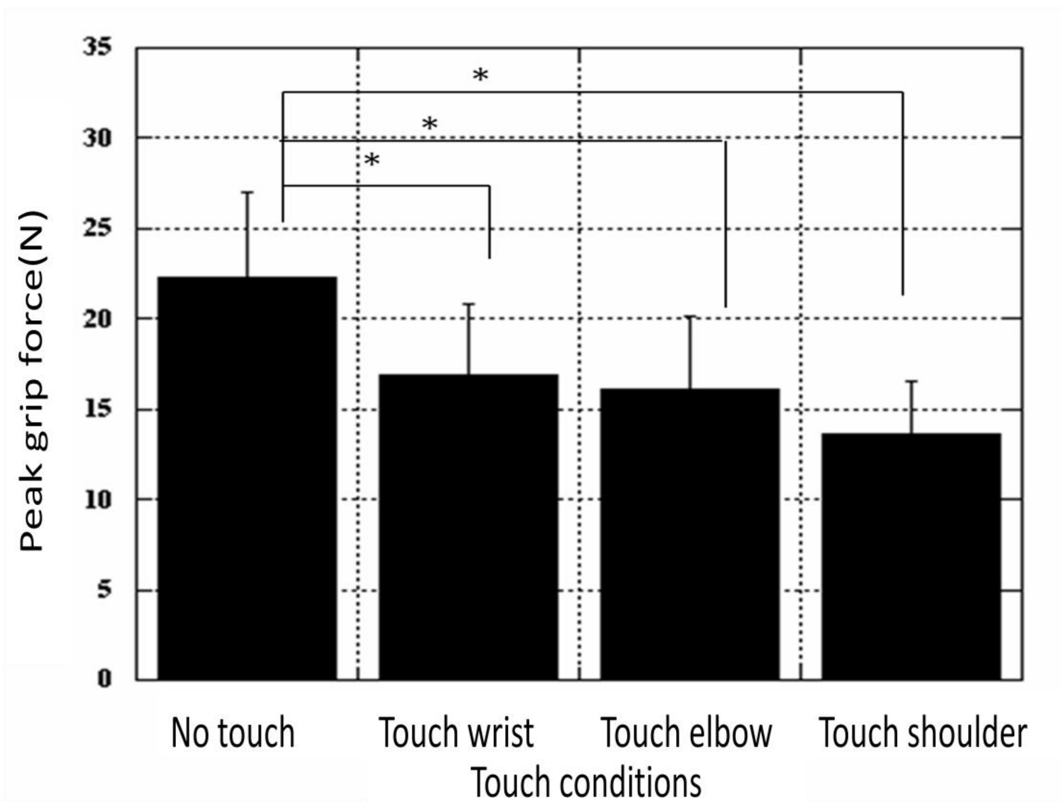


Figure 4: Changes in the peak grip force with no finger touch (NT) and with application of a contralateral finger touch to the wrist (TW), elbow (TE), and shoulder (TS). Grip force is in (N). * shows statistical significance (P<0.05).

5. DISCUSSION

The main outcome of the study is that grip force applied to the hand-held object was significantly reduced during lifting and transporting it in conditions when a light contralateral finger touch was provided to the target arm.

There are several possible explanations to the observed diminished grip force in conditions with the light finger touch. The decrease of grip force could be due to the auxiliary sensory cues provided to the target arm via a light finger touch(Aruin 2005). Indeed, it has been shown that light finger touch could physically counteract body sway in healthy individuals and patients with peripheral neuropathy (Jeka and Lackner 1994; Dickstein, Shupert et al. 2001; Lackner, Rabin et al. 2001). As such, it is possible that similarly to the described improvement of the body stability (Jeka, Schoner et al. 1997; Dickstein, Shupert et al. 2001), a finger touch provides additional spatial cues allowing to enhance generation of grip force. Another explanation to the effect of the finger touch relates to the use of the information from muscles and joint receptors of the contralateral arm combined together with the information from the target arm (Iyengar, Santos et al. 2007).

Several other factors could potentially explain the observed decrease of the grip force in conditions with the contralateral finger touch. For one, differences in the velocity of the movements performed with and without a finger touch could affect the magnitude of the grip force. It is known that manipulative tasks performed with higher velocity are associated with higher grip forces (Pilon, De Serres et al. 2007). 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 and Soechting 2005). However, all the tasks in the current study were performed with a similar acceleration suggesting that the observed finger touch-related decline in the magnitudes of grip force could not be due to the effect of changes in the velocity of the movements. This conclusion is in line with the outcome of a previous study investigating the effect of velocity of the arm movements on the ability to generate smaller grip forces when a finger touch to the wrist was available (Iyengar, Santos et al. 2009). Second, the location of the point of contact along the target arm could be responsible for the decline of the grip force as the range of the contralateral arm movements will vary depending on the location of the point of contact. However, it was shown previously that when the finger touch is provided to the wrist or mid forearm, the decline in the magnitude of grip force (compared to no touch conditions) was similar (Iyengar, Santos et al. 2007). Since the position and the range of movements of the contralateral arm with a finger touching the wrist and forearm was similar, the contribution from the receptors of the contralateral arm most likely was similar in the two experimental conditions which resulted in a similar decline in the grip force while lifting and transporting an instrumented object.

In the current experiment, the location of a finger touch along the target arm (to the wrist, elbow and shoulder) affected the movements of the contralateral arm. Indeed, such movements are limited when touch is provided to the elbow and there almost are no movements of the contralateral arm when the finger touching the shoulder. As such one should expect to see differences in the level of available information from the contralateral arm joint and muscles receptors and associated changes in the grip force.

It is known that information about the target arm movement performance could be obtained through the mechanoreceptors located in the musulotendonous junctions of the contralateral arm and forearm muscles as well as the capsuloligamentous structures of the shoulder (Proske 2006) and as such be used in optimizing grip force magnitude (Iyengar, Santos et al. 2009). As such, when the task is performed with the application of light finger touch to the wrist and partially to the elbow but not to the shoulder, the decrease of grip force could be explained by the role of additional proprioceptive information obtained from these structures in the contralateral arm On the other hand, the range of movements of contralateral arm is reduced when a finger touch is applied to the elbow of the target arm and there is almost none when the finger touch is provided to the shoulder joint. As such, the amount of auxiliary sensory information obtained from the contralateral arm should vary between the three experimental conditions resulting in differences in the magnitude of grip force. Quite the opposite, the grip force was equally reduced in all the experimental conditions with the contralateral finger touch.

A possible explanation to the observed decrease in the grip force while touching the shoulder relates to the effect of movements between the contralateral finger tip and the target arm. It is known that plantar sensation is important in the maintenance of balance (Meyer, Oddsson et al. 2004) and there are reports that posture stability could be improved by enhancing cutaneous sensitivity (Palluel, Nougier et al. 2008; Palluel, Olivier et al. 2009). Moreover, sensory information from cutaneous feedback plays a role in adjusting grip force (Hager-Ross and Johansson 1996). In addition, it was reported that the cutaneous afferent information is used in prediction of temporal regulation of the grip force profile as it was shown in experiments involving cooling of finger digits (Nowak and Hermsdorfer 2003). As such, one can suggest that the CNS uses different types of somatosensory information depending on the range of movement of contralateral arm and relative movements between the contralateral finger tip and target location. Thus, in the experiments with the finger touching the wrist (TW), grip force generation was enhanced primarily by the utilization of auxiliary sensory information from the muscles and joint receptors of the contralateral arm as there was no cutaneous input (no relative movement between fingertip and the target location). When the finger touch was provided to the shoulder, (TS), no proprioceptive information from the contralateral arm was utilized, instead cutaneous afferent input was used to optimize grip force control. Indeed, in the experiments with the finger touching the shoulder, the subjects reported that they could feel the movement of the shoulder joint when performing the task. So it looks like when subjects performed the experimental task with application of a contralateral finger touch to the shoulder joint tactile sensory receptors of the finger helped reading the information about the task performance in anticipation of the movement-induced load fluctuation and updating the relevant internal models. Most likely information from the capsuloligamentous structures of the shoulder (that provide sense of position and movement of the arm in space (Nowak and Hermsdorfer 2003; Proske 2006)) was obtained via the nfinger tip cutaneous receptors.

This suggestion is supported by the literature on the high sensitivity of the cutaneous receptors that could even stabilize postural sway (Lackner, Rabin et al. 2001) as well as be the fact that the pathways of both cutanteous sensory and proprioceptive information share the same neurological circuit and projected to the same area of the brain (Mima, Ikeda et al. 1997).

6. CONCLUSION

This study results demonstrate that grip force was decreased during lifting and transporting an instrumented object with application of a light finger touch from contralateral arm compared to no touch conditions. There was no effect of location of the touch along the target arm, suggesting that both proprioception and cutaneous sensory information from the contralateral arm was utilized to optimize grip force control.

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