THE EFFECT OF INSTRUCTION AND HAND DOMINANCE ON GRIP FORCE COORDINATION IN MANIPULATION TASKS

by

Xin Jin

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Biomechanics and Movement Science

Spring 2011

THE EFFECT OF INSTRUCTION AND HAND DOMINANCE ON GRIP FORCE COORDINATION IN MANIPULATION TASKS

by
Xin Jin

Approved: ____
Slobodan Jaric, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: ____
Katherine S. Rudolph, PT, Ph.D.
Director of Biomechanics and Movement Science Program

Approved: ____
Kathleen S. Matt, Ph.D.
Dean of the College of Health Sciences

Approved: ____
Charles G. Riordan, Ph.D.
Vice Provost for Graduate and Professional Education

ACKNOWLEDGMENTS

Foremost, I would like to express my sincere gratitude to my advisor Dr. Slobodan Jaric for the continuous support of my study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me throughout my research and writing of this thesis. He is the best advisor a graduate student could wish for.

I would also like to express my thanks to my committee members: Dr. Susan Hall and Dr. Nancy Getchell, for their insightful comments which make my thesis better and better. And I am very grateful to all the professors who have taught me. The knowledge I learned was directly put to use in this thesis.

I need to thank all the graduate students in Human Performance Lab for helping me with my research and being my subjects. Among them I need to specially thank my lab mate and good friend Mehmet Uygur, for all the discussions we had and all the fun we had in the last two years.

Last but not least, I would like to thank my parents, Qingsu Jin and Rong Gao, for supporting me throughout my life, and also my girlfriend Xinyue Wang, for her encouragements, companionship and love.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

The ability to grasp and hold an object is not only one of the most common daily activities but also essential for living an independent life. According to a simple prehension model, the force applied upon a vertically oriented hand-held object could be decomposed into two distinctive but highly coordinated components: the grip force (GF; the component perpendicular to the hand-object contact area that provides friction) and the load force (LF; the component parallel to the hand-object contact area that can either move the object or support of the body). The GF-LF coordination could be affected by a number of factors that still remain underexplored. The aim of this study is to investigate the effect of instructions and hand dominance on the relationship of GF and LF. Sixteen right-handed participants were tested on a custom designed instrumented device. They performed bimanual manipulation tasks under different instructions and mechanical conditions. The exerted GF and LF were recorded and analyzed. Indices of GF scaling, GF-LG coupling and GF modulation were calculated separately for the dominant and non-dominant hand. The result showed that the instruction of "pull" leads to higher GF-LF coordination than the instruction of "hold", as seen by a lower GF/LF ratio, higher GF-LF coupling, and higher GF modulation. The only effect of hand dominance was a more prominent time-lag of GF of the non-dominant hand. Overall, the observed findings suggest that the instructions could play an important role in GF-LF coordination, and, therefore, they should be taken into account when either studying hand manipulation activities in healthy individuals or testing hand function in various patient populations.

Chapter 1

GENERAL INTRODUCTION

1.1 Hand function

Human hands are able to perform a wide variety of movements, most of which involve grasping or holding an object. Various studies have investigated different aspects of grasping and holding tasks. A kinetic approach is often used to study human hand motor control (Flanagan & Wing, 1993; Jaric, Russell, Collins, & Marwaha, 2005; Johansson & Westling, 1984) because it employs a fairly simple mechanical model, yet is able to reveal important mechanical and control characteristics of hand function. According to this mechanical model (Johansson & Westling, 1984; Westling & Johansson, 1984), the contact force applied at the hand object contact surface is decomposed into two distinct components: the grip force (GF) and the load force (LF) (Figure 1.1). GF is the normal force applied perpendicular to the hand-object contact surface to create friction. The harder the hand squeezes on the object, the higher GF will be. LF is the friction force applied parallel to the hand-object contact surface to work against the gravity and inertia of the object or to support the body.

From the mechanical aspect, the relationship between GF and LF is determined by the coefficient of friction (μ) of the hand-object contact surface. μ determines how much GF is minimally required when producing a certain amount of LF. According to the law of friction, the fingers and the thumb together have to produce GF that is at least equal to the ratio of LF and the coefficient of friction

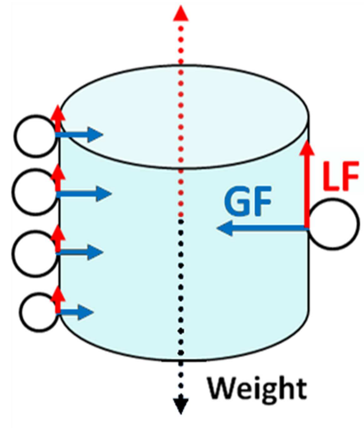

Figure 1.1 A simple mechanical model of hand grip

($GF_{min} = LF/\mu$) so that the grasped object will not slip out of the hand. In real grasping situations, individuals always produce GF higher than the minimum GF needed, and the amount of actual GF that exceeds GF_{min} is referred to as the "safety margin". Previous studies have shown that the safety margin in healthy individuals is generally low and stable (Johansson & Westling, 1984; Westling & Johansson, 1984).

1.2 General properties of GF-LF coordination in healthy people and individuals with impaired hand function

The LF and GF are partly produced by different muscle groups. The LF is produced not only by the muscles of the hand, but also by the muscles which are in charge of maintaining the position of upper limbs or moving them. The GF, however, is produced exclusively by the extrinsic and intrinsic forearm and hand muscles that associate with hand prehension. When holding or shaking an object, the magnitude of LF is consciously controlled based on the intended movement of the hand. When the

LF increases, the magnitude of GF also needs to be adjusted, so that it is sufficiently high to prevent dropping the object. However, GF also cannot be too high as well, because a high level of GF may cause fatigue and also the hand may crush the object (Johansson & Westling, 1984; Westling & Johansson, 1984). Previous studies have shown that when the mechanical characteristics of the manipulated object and expected changes of LF are known in advance, the exertion of GF is modulated by the central nervous system (CNS) in a predictive manner by the “feed-forward” control mechanism. The “feed-forward” control mechanism is able to provide anticipatory control over GF and LF and maintains a relatively stable relationship between them (Blakemore, Goodbody, & Wolpert, 1998; Flanagan & Wing, 1995; Johansson & Westling, 1984). When the CNS fails to anticipate the change of LF (e.g. when the weight of manipulated objects suddenly changes), an adaptation period is needed for the CNS to utilize the sensory feedback information provided by skin mechanoreceptors to produce the correct GF (Blakemore et al., 1998; Flanagan & Wing, 1997; Johansson & Westling, 1988).

Many studies have focused on task performance to evaluate the quality of hand grasp. The task performance is the measure of how accurately the participant performs compared to a prescribed standard, and in most situations it only concerns LF. Generally, task performance is assessed by variables including Root Mean Square Error (RMSE), absolute error and variable error. While these variables represent the participants’ motor control ability in certain aspects, a major deficiency is that they only take LF in to account and neglect the relationship between GF and LF, which is an important part of one’s hand function.

The relationship between GF and LF is a valid indication of the motor control ability of the CNS, and this relationship has been investigated in various static and dynamic manipulation tasks. The most often studied manipulation tasks include lifting, holding, shaking, and repositioning instrumented objects. Three different types of dependent variables have been often used to examine the relationship between GF and LF: GF scaling, GF coupling and GF modulation. GF scaling is the overall GF level relative to the LF level. It is assessed by the GF/LF ratio, which is calculated as either instantaneous GF over LF at a specific moment, or the average GF versus average LF throughout the entire trail. Note that the GF/LF ratio cannot be smaller than the inverse of the friction coefficient ($1/\mu$) in a steady grip. A low GF/LF ratio suggests that the participant is able to sense the contact surface friction condition and adjust GF accordingly in an efficient way, and therefore has been seen as an indication of high level GF-LF coordination (Flanagan & Wing, 1995; Jaric, Collins, Marwaha, & Russell, 2006; Jaric, Russell, et al., 2005; Zatsiorsky, Gao, & Latash, 2005). GF coupling reveals how much the change in GF and the change in LF relate to each other. GF-LF correlation coefficient, maximum GF-LF cross-correlation coefficient and the corresponding time-lags have been often used to assess GF coupling. High GF-LF coordination is usually accompanied with a correlation coefficient close to 1 and time-lag close to 0 (Flanagan & Wing, 1995; Gysin, Kaminski, & Gordon, 2003). GF modulation reveals how much GF changes when LF changes. The slope and intercept of the GF-LF regression line, which are often referred to as GF gain and offset respectively, have been used to evaluate GF modulation. High GF gain and low GF offset have been interpreted as an indication of a high GF-LF coordination. In previous studies, numerous manipulation tasks performed by healthy individuals have revealed that they are able to produce GF highly correlated with LF, which is revealed by low GF/LF ratio, high GF–LF correlation, and high GF gain (Flanagan & Wing, 1995; Jaric et al., 2006; Jaric, Russell, et al., 2005; Zatsiorsky et al., 2005).

While healthy individuals display a high level of GF-LF coordination, neurological patients known for impaired hand control consistently show low levels of GF-LF coordination. Many neurological diseases are known to cause hand dysfunction and limit manipulation ability, and, therefore, leads to deteriorated values of the aforementioned GF-LF coordination indices. For instance, multiple sclerosis (MS) patients, even those who are just mildly affected and have no difficulties in their daily activities, regularly apply higher GF than actually needed, which leads to a significantly higher GF/LF ratio than in healthy individuals (Iyengar, Santos, Ko, & Aruin, 2009; Krishnan, de Freitas, & Jaric, 2008; Krishnan & Jaric, 2008; Marwaha, Hall, Knight, & Jaric, 2006). In particular, the GF/LF ratio appears to be highly correlated with clinical evaluation tasks such as Expanded Disability Status Scale and the Jebsen–Taylor test (Krishnan & Jaric, 2008). The ability of MS patients to produce an accurate LF profile based on a predefined force level is also affected, which leads to lower task performance as compared to healthy individuals. This deterioration of the ability to accurately control LF has been observed in different types of static tasks, including the ramp-and-holding task and the oscillation task (Iyengar et al., 2009; Krishnan et al., 2008; Krishnan & Jaric, 2008; Marwaha et al., 2006). However, the GF coupling and modulation in mildly involved MS patients remained comparable with healthy individuals (Krishnan et al., 2008; Marwaha et al., 2006). Parkinson's disease patients also tend to produce higher GF than healthy people when lifting and holding an object (Fellows & Noth, 2004; Nowak & Hermsdorfer, 2006). They need longer time to initiate a lifting and the GF production of PD patients is also slow changing and unstable (Benice, Lou, Eaton, & Nutt, 2007; Ingvarsson, Gordon, & Forssberg, 1997). Likewise, individuals with Huntington's Disease take a longer time to lift the object and generate a higher amount of GF during lifting and holding tasks (Gordon, Quinn, Reilmann, & Marder, 2000; Schwarz, Fellows, Schaffrath, & Noth, 2001). Individuals with cerebellar dysfunction generate a large amount of GF during lifting and holding tasks, as well as during vertical point to point movements (Babin-Ratte, Sirigu, Gilles, & Wing, 1999; Nowak, Hermsdorfer, Marquardt, & Fuchs, 2002). Higher than normal GF production has also been observed in stroke patients (Hermsdorfer, Hagl, Nowak, & Marquardt, 2003). In total, these studies of individuals with neurological impairment suggests that the indices of GF-LF coordination could be valid indication of neural control ability and, therefore, used in routine clinical tests (Benice et al., 2007; Krishnan et al., 2008; Marwaha et al., 2006). However, before these tests can be developed, more research needs to be done on the general properties of GF-LF control in healthy individuals in order to better understand the typical range of these indices.

1.3 Factors that affect GF-LF coordination in healthy individuals

GF-LF coordination is affected by many other factors besides neurological diseases. Such factors involve the physical properties of the manipulated object and the characteristics of the manipulation task. The studies of these factors could be important for understanding the motor control mechanism of hands, as well as for developing clinical tests to evaluate hand functions.

The friction property of the hand-object contact surface apparently has a significant effect on GF/LF ratio. While more slippery contact surfaces require higher

GF scaling, the relative safety margin also increases (de Freitas & Jaric, 2009; de Freitas, Uygur, & Jaric, 2009). Different grasping skills using different areas of skin have an effect on the GF/LF ratio and GF-LF correlation as well (de Freitas & Jaric, 2009; de Freitas et al., 2009). Jaric and collaborators showed that switching from a uni-directional task to a bi-directional task leads to a significant deterioration in GF-LF coordination, which is represented by a higher GF/LF ratio, lower GF-LF correlation and higher GF gain (Jaric, Russell, et al., 2005). Their subsequent studies revealed that there might be two different control mechanisms for uni-directional and bi-directional tasks which are triggered by different cutaneous input (de Freitas, Krishnan, & Jaric, 2007a; de Freitas, Markovic, Krishnan, & Jaric, 2008). Increasing the frequency of repetitive manipulative actions leads to deteriorated GF-LF coordination (Flanagan & Wing, 1993, 1995; Zatsiorsky et al., 2005); however, while both frequency and magnitude will affect the rate of change in LF, increase in magnitude does not affect the GF-LF coordination as much as an increase in frequency does (Uygur, de Freitas, & Jaric, 2010).

The effect of instruction has been widely discussed in motor control studies, especially in the field of motor learning (see review by Landin, 1994). Instruction is an important part of motor learning procedures and plays a significant role in the selection of movement patterns. Instructions are often used to convey general information about the fundamental aspect of skill to the recipient, and different instructions may have different effects. Instruction can influence attentional focus and instructions that direct the participant to external focus will result in greater force production and lower muscular activity during isokinetic elbow flexions when compared with an internal focus (Marchant, Greig, & Scott, 2009). Avoidant instruction is well known to have the effect of increasing the chance of movement error (Russell & Grealy, 2010). Instructions can also be used to make participants perform different tasks similarly or perform the same task differently and therefore serve as a method to control independent variables in motor control experiments. Brown and Cooke (1981) conducted experiments on elbow flexion-extension movement with the instruction of moving “accurately” and “fast”, which revealed that the EMG pattern of antagonist muscles varies when different instructions are given to the participant. Sometimes the experimenter can make the participants believe that they are doing different tasks by giving them different instructions, although they are actually doing the same thing. Latash and Jaric (1998) performed an experiment in which they asked the participants to put their right elbow on the table, keep the forearm and hand straight and push a fixed metal frame with their hand. The participants were asked to keep a constant force production under two different instructions. One instruction asked the participant to produce the force primarily by their wrist muscle and relax the elbow, while the other instruction asked the participant to produce the force primarily by their elbow muscle and relax the wrist. Note that no matter which instruction they receive, the participants had to produce the same joint torque in the wrist and elbow joint in order to keep the same force output at the hand and, therefore, these were essentially the same task. However, the change in instruction led to a significant change in myoelectric activities in most muscles. Specifically, the muscles over the instructed joint had higher activities than the uninstructed joint. These findings suggest that movement control is also instruction specific, and different instructions may lead to different motor performance. In the study of hand force coordination, we have been using various instructions without paying attention to their specific meanings, and it has yet to be determined whether different instruction would lead to a different pattern of the GF-LF coordination.

Hand dominance could be another factor that affects GF-LF coordination. A traditional understanding of hand dominance suggested that the dominant and non-dominant arms are predominantly controlled by open- and closed-loop neural mechanisms, repectively. However, this idea has been challenged by the model of motor lateralization (Sainburg, 2002, 2005). The model states that the dominant limb is specialized for dynamics tasks, such as controlling limb trajectory using torque-efficient strategies (Bagesteiro & Sainburg, 2002), and the non-dominant limb is specialized in static tasks, such as controlling the limb position due to more effective load compensation (Bagesteiro & Sainburg, 2003). The advantage of the dominant hand in dynamic tasks has been studied extensively (Bagesteiro & Sainburg, 2002). However, the advantage of the non-dominant hand in static tasks has not been well documented, especially for coordination of GF and LF in grasping, which can be generalized to a variety of manipulation tasks (de Freitas, Krishnan, & Jaric, 2007b). Two studies on the GF-LF coordination have explored the difference in coordination between dominant and non-dominant hands. The first study revealed a somewhat lower GF/LF ratio of the non-dominant hand in static bimanual tasks, which suggests that the non-dominant hand is able to adjust to the grasping condition and works more efficiently in static manipulation than the dominant hand, and, therefore, this result speaks in favor of the motor lateralization (Ferrand & Jaric, 2006). The second study did not detect a significant difference in the GF/LF ratio, but revealed a difference in LF direction deviation between hands (de Freitas, Krishnan, & Jaric, 2007b). The results specifically suggest that the non-dominant hand has better control of the force direction under the static condition. However, both studies failed to find any difference in GF coupling and GF modulation between hands, as well as in the tested task performance. Therefore, the effect of hand dominance on GF-LF coordination still remains inconclusive, and further research is needed to address the discussed issue.

Chapter 2

SPECIFIC AIMS

The ability of our hands to grasp and hold an object is a prerequisite for a number of common daily activities and also essential for living an independent life. According to a simple prehension model, the force applied upon a vertically oriented hand-held object could be decomposed into two distinctive components: the grip force (GF, the force component that is perpendicular to the hand-object contact area and provides friction) and the load force (LF, the force component that is parallel to the hand-object contact area that can either move the object vertically or provides externals support of the body). Previous studies have shown that these two forces are mutually highly correlated. This elaborate coordination could be affected by a number of factors that still remain underexplored. For example, although it is generally known that the neural control of voluntary movements is both task and instruction specific, it remains unknown whether some of the most frequent instructions, such as “hold” and “pull”, differently affect the GF-LF coordination. The effect of hand dominance could be another factor that affects GF-LF coordination because the model of motor lateralization implicitly suggests lateral differences in passive (e.g., hold) and active (e.g., pull) tasks. Therefore *the aim of this study was to explore the effect of instructions and hand dominance on the participants’ ability to coordinate their GF and LF in static manipulation tasks.*

Hypothesis #1: The instruction of “pull” will lead to higher force coordination than the instruction of “hold”, even when the hands are performing mechanically identical tasks.

Hypothesis #2: The non-dominant hand will provide relatively higher force coordination in the holding tasks, while the dominant hand will perform relatively better in pulling tasks.

The hypothesized results will not only reveal the effect of instructions on manipulation task performance, but also stress the importance of instructions and laterality in both the studies and the routine testing of hand function.

Chapter 3

MANUSCRIPT

3.1 Introduction

The ability to manipulate objects is crucial for living an independent and active life. Many studies have investigated hand manipulation tasks. Force analysis in manipulation tasks has been usually based on a simple mechanical model of holding a vertically oriented object (Flanagan & Wing, 1995; Jaric, Russell, et al., 2005; Johansson & Westling, 1984). The load force (LF) is the friction force applied in parallel to the hand-object contact surface to overcome the object's weight and inertia. The grip force (GF) is the normal force applied perpendicularly against the object and provides friction and controls the object position. According to the model, GF needs to be scaled high enough to prevent slippage, but also not excessively to crush the object or cause fatigue. Studies performed on healthy individuals have consistently shown a high level of GF-LF coordination through several properties of GF control (Flanagan & Wing, 1995; Jaric, Russell, et al., 2005; Johansson & Westling, 1984; Westling & Johansson, 1984). First, GF is scaled to provide a relatively low and stable GF-LF ratio which is, however, still high enough to prevent slippage. Second, a continuous coupling of GF with the ongoing changes in LF has been observed. This coupling has been revealed through high GF-LF correlation and low time-lag between them (Flanagan & Wing, 1995; Jaric et al., 2006; Johansson & Westling, 1984), which suggests involvement of anticipatory 'feed-forward' neural control mechanisms (Johansson & Westling, 1984, 1988). Third, to provide the aforementioned coupling and a stable GF-LF ratio, GF is highly modulated with respect to the changes in LF caused by ongoing manipulative actions (Flanagan & Wing, 1995; Jaric et al., 2006; Johansson & Westling, 1984; Westling & Johansson, 1984). However, this fine coordination between GF and LF could be affected by a number of factors, which include underlying neurological diseases (Benice et al., 2007; Krishnan et al., 2008; Marwaha et al., 2006; Nowak & Hermsdorfer, 2006), switching from uni-directional to bi-direction tasks (de Freitas et al., 2008; Jaric, Russell, et al., 2005), or increased complexity of the tasks performed (Krishnan & Jaric, 2010). Therefore, GF-LF coordination has been seen both as a window for studying some basic neural control mechanisms of movement control and as a basis for development of routine quantitative tests of hand function in various patient populations (Krishnan & Jaric, 2008; Nowak & Hermsdorfer, 2006).

Although these phenomena have been studied extensively over previous decades, some factors that can affect GF-LF coordination still remain underexplored. For example, instruction plays a significant role in the selection of movement patterns (Glaser & Bassok, 1989; Landin, 1994). Distinctive effects of instructions to move “fast”, “fast and accurate” and “accurate” on the subsequent task performance are probably the best known example in motor control literature (Brown & Cooke, 1981; Fitts, 1954). It has been shown in a mechanically constrained task that emphasizing the action on only one muscle group within a limb leads to a profoundly different activation pattern of individual muscles while the limb is producing mechanically identical tasks (Latash & Jaric, 1998). Therefore, it remains possible that switching the instructional emphasis in the same manipulation task (e.g., “pull” instead of “hold”) could affect the GF-LF coordination pattern. Another factor that could play a role in

GF-LF coordination is the hand dominance. The model of motor lateralization suggests that the dominant limb is specialized for dynamic, feed-forward controlled tasks (Bagesteiro & Sainburg, 2002; Sainburg, 2002), while the non-dominant limb could be specialized for feedback mediated error correction mechanisms (Bagesteiro & Sainburg, 2003). In the very few studies that explored the effect of hand dominance on GF-LF coordination, results have been inconsistent (Ferrand & Jaric, 2006; de Freitas, Krishnan, & Jaric, 2007b).

We designed an experimental protocol based on the manipulation tasks that required a bimanual holding of free moving or externally fixed instrumented handles, and exerting prescribed LF profiles against them. We hypothesized that the studied GF-LF coordination would be higher under the instruction to "pull" than to "hold", as well as that the non-dominant hand would perform relatively better in static feedback controlled task than the dominant hand. The expected findings could be of importance for the understanding of some important aspects of force coordination, as well as for refining the testing protocols of both future research studies and routine testing of hand function.

3.2 Methods

Healthy right-handed participants (as assessed by the Edinburgh Inventory Questionnaire; (Oldfield, 1971)) were recruited (8 males and 8 females, 20 to 30 years old). The experiment was approved by IRB of the University of Delaware and conducted in accordance with the declaration of Helsinki.

A custom designed device similar to the device used in our previous experiments (Jaric, Knight, Collins, & Marwaha, 2005) was used to record GF and LF produced by the participants (Figure 3.1A). Two handles were mounted on two ends of a metal stick which was detachable from an external support frame. The handles consisted of two parallel plates covered with high friction rubber with a single-axis force sensor (WMC-50, Interface Inc., USA) installed in between to record the compression force exerted against them (F_n). Multi-axis force transducers (Mini40, ATI, USA) were positioned at the handle-stick junctions to record the total force applied against the handle in all three directions (F_x, F_y and F_z). Similar to previous studies, GF and LF were calculated as $GF = \| F_n \| + \| F_n - F_y \|$ and $LF = \sqrt{F_x^2 + F_z^2}$ (de Freitas et al., 2008). A custom designed LabVIEW program was used to display the real-time LF on a screen placed in front of the participant during the experiment in order to record the data for analysis.

Prior to the testing, participants were asked to wash and dry their hands. They were sitting on a chair with their elbows supported by a table and holding the device with both hands (Ferrand & Jaric, 2006). The height of the device was individually adjusted so that the participant could hold the device comfortably. To familiarize them with the tested tasks, each participant first completed 5 practice trials of each task. The tested tasks included the *ramp-and-holding task* that required the participants to pull the handles away and therefore produce a tension force gradually increasing from 0 N to 10 N at a constant rate over 6 s and thereafter continue keeping a constant force (i.e. 10 N) for another 6 s. The *oscillation task* is the other tested task, which required the participant to produce an oscillating sinusoidal force in the direction of tension within the range of 2 N and 10 N for 8 s at the frequency of 1.33 Hz paced by a metronome. Prior the familiarization, both tasks were demonstrated and thereafter the specific instructions were given.

The experimental session followed the practice session after a 10 minute rest. It included testing both tasks under different conditions. First, the device was arranged in two different physical conditions: fixed to the external support (device *fixed*) and detached from it (device *free*). Note that for the device fixed, the actions of two hands were mechanically separated, while for the device free, LF produced by two hands were inevitably equal to mechanically compensate for each other. Second, the instructions were manipulated. Under the device *free* condition, the instructions were: (1) “pull the handle EQUALLY with both of your hands”, (2) “pull ONLY with your left hand while using your right hand just for holding”, and (3) “pull ONLY with your right hand while using your left hand just for holding.” As a result, for the free device each hand was tested under the conditions when both hands were pulling (Free B/Pull), when pulling while the other hand was holding (Free Pull), and when holding while the other hand was pulling (Free Hold). The only difference for the device fixed was regarding the instructions (2) and (3), where the other hand was instructed “to relax”, instead of “to hold”. Therefore, since the forces of the relaxed hand were not recorded, each hand for the device fixed was tested when both hands were pulling (Fixed B/Pull) and when only one hand was pulling (Fixed Pull).

The experimenter repeated the instructions prior to each trial and also stressed that the real time feedback regarding LF shown on the computer monitor originated only from the pulling hand. The sequence of the tasks (ramp-and-holding and oscillation), physical conditions (device fixed and free), and instructions were randomized. Under each of their combinations, the practice and, thereafter, the experimental trial were performed.

Raw signals from the force transducers were sampled at 200Hz and low-pass filtered at 10 Hz with a fourth order Butterworth filter. In the ramp-and-holding task the data from the first and last 1 s of each phase were discarded, and as well as the first 3 s and the last second in the oscillation task, since they might be affected by the preceding and anticipated transitions (de Freitas, Krishnan, & Jaric, 2007b). ANOVA and MANOVA were used on ramp-and-holding task and oscillation task respectively to analyze the main effect of *condition* (Fixed B/Pull, Fixed Pull, Free B/Pull, Free Pull, and Free Hold), *hand* (dominant and non-dominant, i.e. right and left), and, only for the ramp-and-holding task, *phase* (ramp and holding). In line with previous studies, we expected to observe high GF-LF coordination through low GF scaling, high GF coupling, and high GF modulation (Blakemore et al., 1998; Blank et al., 2001; Flanagan & Tresilian, 1994; Jaric, Russell, et al., 2005; Zatsiorsky et al., 2005). The level of significance was set to 0.05 and pairwise comparisons were adjusted by Bonferroni corrections.

3.3 Results

Figure 3.1 shows force profiles obtained from a representative participant under the instruction to pull the free-moving device with the right hand and hold with the left hand. Note that the hand instructed to pull revealed higher force level than the hand instructed to hold in the oscillation task (panel C), but not in the ramp-and-holding task (B). As a consequence, the GF-LF diagram (panel D) shows higher overall GF/LF ratio and GF modulation for the hand instructed to pull than the hand instructed to hold.

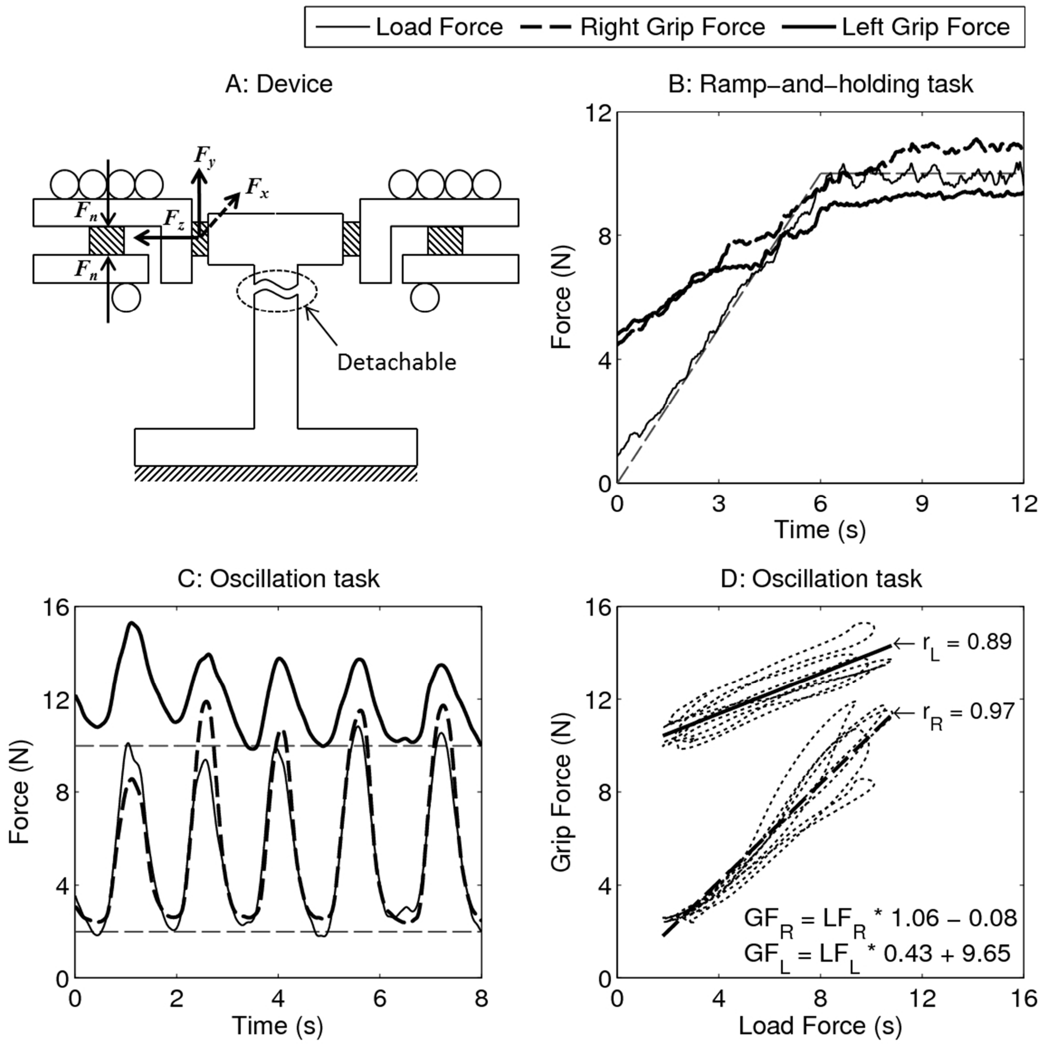

Figure 3.1 **(A) The experimental device and the forces exerted (transducers represented by shaded blocks) by the tips of the digits (circles). Force profiles recorded in a representative subject during ramp-and-hold (B) and oscillation task (C) are shown, together with the GF-LF diagram (D) obtained from the depicted oscillation trial. The correlations (r) reveal GF-LF coupling, while the slopes of the regression lines show GF modulation.**

We also evaluated the errors to assess the overall task performance. The RMSE of the ramp and holding phase of the ramp-and-holding task were 0.44±0.04 and 0.34±0.04 N (mean±SD), respectively (data averaged across the participants, conditions and instructions). The absolute error of the oscillation task (averaged for the prescribed minima and maxima of the sinusoidal profiles) was 0.80±0.32 N (see Appendix 1 for details). Therefore, we could conclude that the obtained LF profiles were accurate enough to allow for the testing of the hypothesized effects.

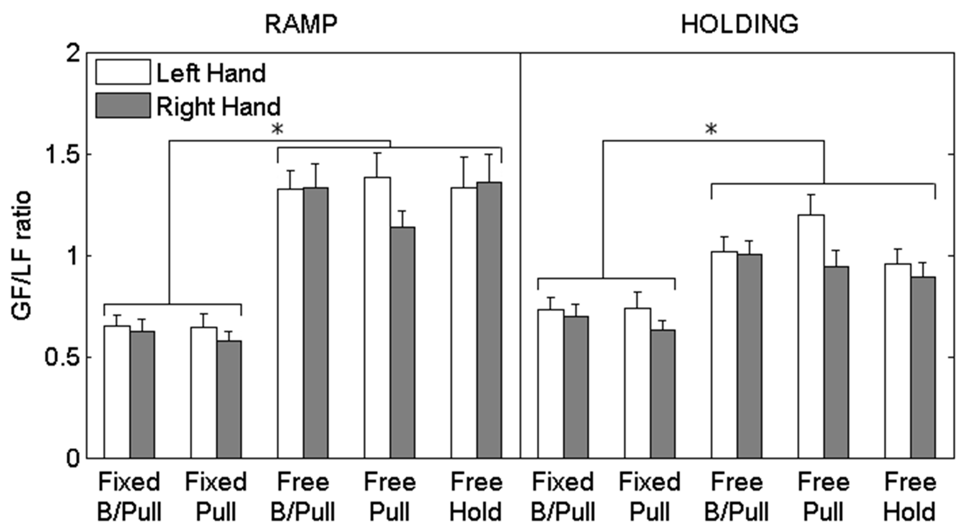

Figure 3.2 GF scaling observed through the GF/LF ratio in the ramp-and-holding task for two hands under different conditions (data averaged across participants with standard error bars; *: $p < 0.05$).

In the ramp-and-holding task, a 3-way mixed design ANOVA (*hand* as between subject factor, *phase* and *condition* as within subject factor) was used to test the GF scaling through GF/LF ratio (Figure 3.2). The results revealed the significant main effect of phase (F (1, 30) = 46.10, $p < 0.001$, $\eta^2 = 0.606$; these and further data were Greenhouse-Geisser corrected if Mauchly's test of sphericity was significant) and condition (F (2.53, 75.77) = 39.74, $p < 0.001$, $\eta^2 = 0.570$). The significant phase × condition interaction (F (2.56, 76.92) = 36.27, $p < 0.001$, $\eta^2 = 0.547$) suggested that the difference between the free and fixed conditions was higher during the ramp than during the holding phase. Pairwise comparison showed that within each phase, the free conditions lead to significant higher GF/LF ratio than the fixed conditions. Neither the main effect of hand nor its interactions was significant.

For the oscillation task, the main effect of *hand* (between subject factor) and *condition* (within subject factor) on GF-LF coordination was assessed by a 2-way mixed design MANOVA on GF scaling (through GF/LF ratio), GF-LF coupling (through Z-transformed correlation coefficient and the corresponding time-lags), and GF modulation (through GF gain observed from GF-LF diagrams; see Figure 3.1D for illustration). The MANOVA applied on these four GF-LF coordination variables revealed the significant main effect of condition (Wilks' Lambda = 0.21, F (16, 358.08) = 14.70, $p < 0.001$, $\eta^2 = 0.320$) and hand × condition interaction (Wilks' Lambda = 0.80, F (16, 358.08) = 1.73, $p < 0.05$, $\eta^2 = 0.055$), while the main effect of hand (Wilks' Lambda = 0.87, F (4, 27) = 1.04, $p > 0.05$, , $\eta^2 = 0.133$) was not significant. However, the univariate test revealed no significant hand × condition interaction on all dependent variables. Univariate analyses on each dependent variable revealed significant main effect of condition on GF/LF ratio (F (1.67, 50.10) = 39.24, $p < 0.001$, $\eta^2 = 0.567$), Z-transformed correlation coefficient (F (2.75, 82.50) = 20.94, $p < 0.001$, $\eta^2 = 0.411$) and GF gain (F (2.69, 80.75) = 20.56, $p < 0.001$, $\eta^2 = 0.407$),

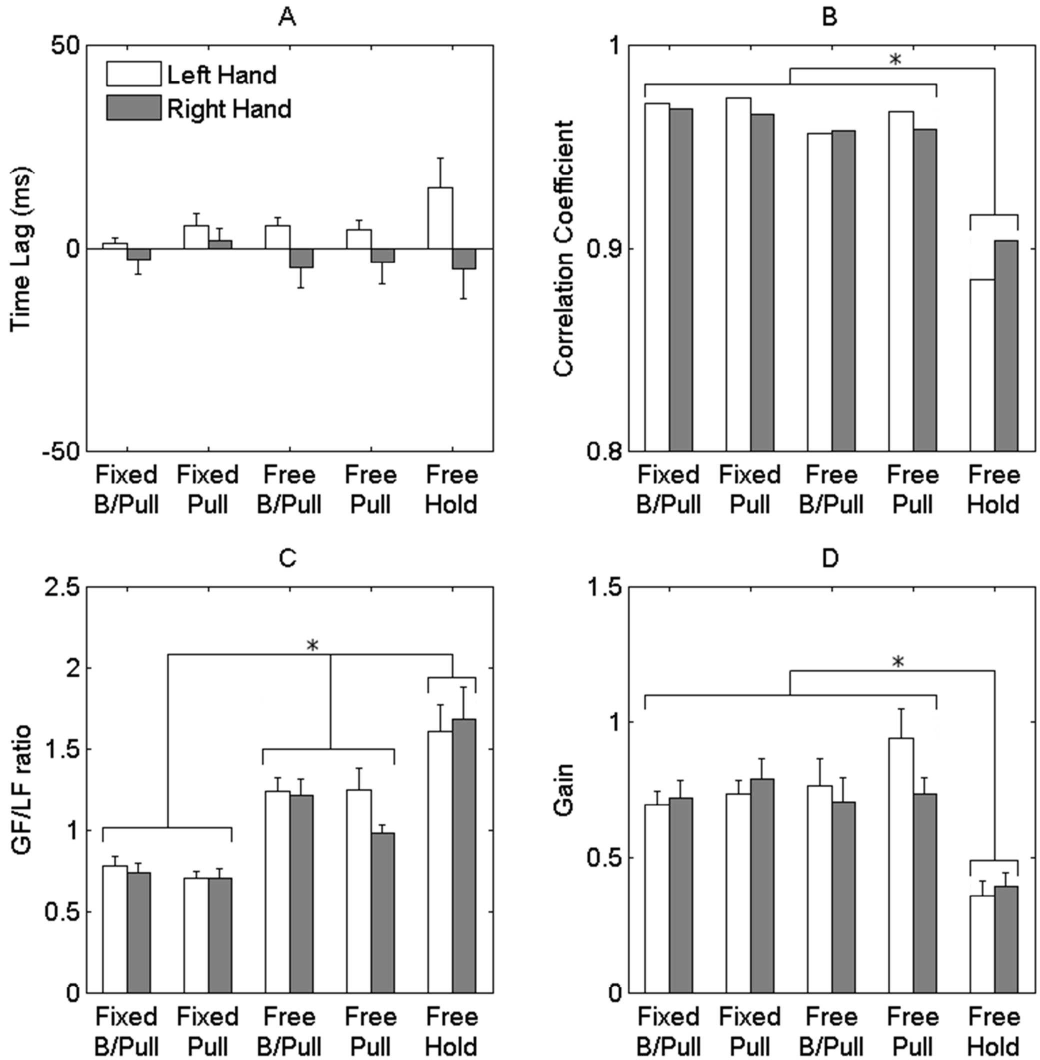

Figure 3.3 GF-LF coordination indices observed in oscillation tasks (data averaged across subjects with standard error bars). Panel A and B depicts GF coupling through the time-lag and median of correlation coefficient, respectively. Panel C depicts GF scaling assessed by GF/LF ratio, while panel D depicts GF modulation through GF gain. (*: $p < 0.05$).

but not on time-lag (F (1.66, 49.95) = 1.09, $p > 0.05$, $\eta^2 = 0.035$). Pairwise comparison revealed that the Free Hold condition resulted in significant higher GF/LF ratio, lower GF- LF correlation and lower GF gain than the other 4 conditions. Similar to the ramp-and-holding task, the free conditions suggested higher GF/LF ratios than the fixed conditions, while the Fixed B/Pull condition revealed higher correlation coefficient than the Free Pull condition. The univariate analyses also revealed that although the main effect of the hand was not significant in multivariate analyses, it was significant regarding the univariate analysis of time-lag (F (1, 30) = 4.35, $p < 0.05$, $\eta^2 = 0.127$). Pairwise comparison showed that the time-lag was significantly higher in the left hand than in the right hand.

3.4 Discussion

In this study, we explored the GF pattern when the participants' two hands were receiving two different instructions (i.e., "pull" and "hold") but were performing identical pulling tasks. Due to the tasks' bimanual nature, we were also able to assess the effect of hand dominance on the GF pattern. We hypothesized a higher GF-LF coordination under the instruction of "pull" than "hold", as well as a relatively higher coordination of the non-dominant hand in the static feedback controlled task than the dominant hand. Overall, the results supported the first hypothesis. Specifically, we found significant differences in all of the GF-LF coordination indices between the pulling condition and the holding condition in the oscillation task, which suggested that the instruction of "pull" resulted in higher GF-LF coordination than the instruction of "hold". Regarding the second hypothesis, we failed to find any significant differences between the dominant hand and the non-dominant hand except for the time-lags obtained from the oscillation tasks.

The most important finding of this study was that the two distinctive instructions of “pull” and “hold” could have a significant effect on GF-LF coordination. Specifically, the results suggested that the instruction of “pull” could lead to a better GF-LF coordination than the instruction of “hold”, as seen through a lower GF/LF ratio, higher GF-LF correlation, and higher GF gain. This could be seen as an extension of the finding that focusing effort on different arm joints while performing the mechanically identical act could lead to distinctive activation patterns of involved muscles (Latash & Jaric, 1998). Here, one could speculate that the instruction of “pull” could be implicitly understood by participants as a command to actively exert and modulate the forces, while the instruction of “hold” could lead them to employ a more passive and low modulation strategy of force control. Note that the previous studies have shown that the GF/LF ratio is generally higher and GF-LF correlation is lower when passively holding an object than actively pulling it (Johansson, Riso, Hager, & Backstrom, 1992). From the practical aspect, when asking our participants to perform a particular manipulation task, we often routinely instruct them either to “pull” or to “hold” or something else, without paying particular attention to specific wording. Here we see a prominent instruction associated differences in the motor behavior even in mechanically identical acts, which clearly speaks in favor of standardizing instructions either in future research or in routine testing of hand function.

Regarding hand dominance, several studies have been conducted in our lab to investigate its effect on GF-LF coordination. However, these studies have provided inconsistent results. The first study found a significantly lower GF/LF ratio in the non-dominant hand in both ramp-and-holding task and oscillation task performed under static conditions, although the effect *per se* was relatively small (Ferrand & Jaric, 2006). However, the second study failed to reveal a significant difference in GF/LF ratio, but found an advantage of the non-dominant hand when accurately controlling LF direction under static conditions (de Freitas, Krishnan, & Jaric, 2007b). Nevertheless, the results were implicitly in line with the model of motor lateralization (Sainburg, 2002), suggesting that the non-dominant limb is specialized for controlling limb position under static conditions (Sainburg, 2005). However, this study mainly failed to detect any significant differences in GF-LF coordination variables between the dominant and non-dominant hands in either of the tested tasks. The only exception was the time-lags observed from the oscillation task, which suggest that GF slightly lags LF in the left (i.e., non-dominant) hand, but not in the right hand. Although the observed difference between two hands was smaller than the delays of the anticipated GF reactions to sudden LF changes (Ohki, Edin, & Johansson, 2002), it could originate from a partial involvement of feedback control mechanisms. Although somewhat below the significant level, the observed difference between two hands was particularly prominent under the holding instruction, which also supports the hypothesized instruction specific patterns of the control mechanisms. Nevertheless, further research is needed on the role of hand dominance in GF-LF coordination and, in particular, on the possible differences in neural control mechanisms between two hands.

Since all of our previous experiments were performed on fixed device and this experiment requires a free moving device, we tested our subjects on both conditions in this experiment. The result revealed similar level of GF-LF coordination indices except for a significant higher GF/LF ratio on free device than fixed device. We interpret this increased GF/LF ratio when holding a free device as an action to reduce the risk of dropping. Similar findings were observed when decreasing the coefficient of friction on the hand-object contact surface (de Freitas et al., 2009), as the GF/LF ratio would increase in order to prevent dropping when holding a more slippery object.

In summary, our result suggests that GF control is instruction specific and therefore different instructions could lead to different force patterns in manipulative tasks. Although not novel in the general field of motor control (Brown & Cooke, 1981; Latash & Jaric, 1998; Sahaly, Vandewalle, Driss, & Monod, 2001), the revealed instruction specific control patterns are novel in the area of force control in manipulation tasks. In addition to its general importance, the present findings need to be taken into account when designing either experimental procedures or routine protocols for testing hand functions through force coordination. However, the effect of hand dominance still remains unclear; although the observed differences in time-lags suggest that the feedback neural mechanisms could be partly involved in the anticipatory control of the GF of the non-dominant hand but not the dominant hand.

Chapter 4

GENERAL CONCLUSIONS

Object manipulations are among the most important motor actions performed in our daily lives. Therefore, the understanding of the force control in manipulative actions is vital not only because it contributes to understanding the involved neural mechanisms, but also because it could contribute to further development and refinement of the procedures routinely used in rehabilitation of neurological and other patients, as well as in developing routine protocols for testing hand functions.

In this study we explored the effect of instruction and hand dominance on the GF-LF coordination in various static manipulation tasks. In general, we found that the GF-LF coordination can be considerably affected by instructions. Specifically, instruction “to pull” could lead to lower GF scaling, higher GF coupling, higher GF modulation, and therefore better overall GF-LF coordination than the instruction “to hold”. However, we did not find significant differences in GF-LF coordination indices between the dominant hand and the non-dominant hand, except for a higher time-lag in the non-dominant hand during oscillation task. In addition, we also found that the GF scaling would increase significantly when manipulating a free object compared with manipulating a fixed object.

Overall, the observed findings suggest that the instructions could play an important role in GF-LF coordination and, therefore, they should be taken into account when studying hand manipulation activities. Therefore, experimenters should be cautious regarding instructions and, particularly, specific wording throughout both the experimental and routine testing procedures. It is plausible to assume that the specific instructions could also lead to distinctive results when applied during the various rehabilitation protocols aimed towards improvement of hand function. The selective effect of instructions still remains to be explored in various populations of individuals with neurological and other diseases.

Regarding the role of hand dominance, both the present and previous studies generally suggest that although the effect may exist, it could be relatively weak. Therefore, it is possible that the effects of motor lateralization are more prominent both at other levels (e.g., movement kinematics, myoelectric patterns) and in other tasks (e.g., reaching movements, reactions to perturbations) than in the studied GF-LF coordination. Nevertheless, the observed difference in time-lags between the dominant and non-dominant hand certainly deserves further attention since it could reveal a fundamental distinction in motor function between the two hands/brain hemispheres.

REFERENCES

Babin-Ratte, S., Sirigu, A., Gilles, M., & Wing, A. (1999). Impaired anticipatory finger grip-force adjustments in a case of cerebellar degeneration. *Experimental Brain Research*, *128*(1-2), 81-85.

Bagesteiro, L., & Sainburg, R. (2002). Handedness: Dominant arm advantages in control of limb dynamics. *Journal of Neurophysiology*, *88*(5), 2408-2421.

Bagesteiro, L., & Sainburg, R. (2003). Nondominant arm advantages in load compensation during rapid elbow joint movements. *Journal of Neurophysiology*, *90*(3), 1503-1513.

Benice, T. S., Lou, J.-S., Eaton, R., & Nutt, J. (2007). Hand coordination as a quantitative measure of motor abnormality and therapeutic response in Parkinson's disease. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *118*(8), 1776-1784.

Blakemore, S., Goodbody, S., & Wolpert, D. (1998). Predicting the consequences of our own actions: The role of sensorimotor context estimation. *Journal of Neuroscience*, *18*(18), 7511-7518.

Blank, R., Breitenbach, A., Nitschke, M., Heizer, W., Letzgus, S., & Hermsdorfer, J. (2001). Human development of grip force modulation relating to cyclic movement-induced inertial loads. *Experimental Brain Research*, *138*(2), 193-199.

Brown, S., & Cooke, J. (1981). Amplitude-dependent and instruction-dependent modulation of movement-related electromyogram activity in humans. *Journal of Physiology-London*, *316*(JUL), 97-107.

Fellows, S., & Noth, J. (2004). Grip force abnormalities in de novo Parkinson's disease. *Movement Disorders*, *19*(5), 560-565.

Ferrand, L., & Jaric, S. (2006). Force coordination in static bimanual manipulation: Effect of handedness. *Motor Control*, *10*(4), 359-370.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, *47*(6), 381-391.

Flanagan, J., & Tresilian, J. (1994). Grip load force coupling - a general control strategy for transporting objects. *Journal of Experimental Psychology-Human Perception and Performance*, *20*(5), 944-957.

Flanagan, J., & Wing, A. (1993). Modulation of grip force with load force during point-to-point arm movements. *Experimental Brain Research*, *95*(1), 131-143.

Flanagan, J., & Wing, A. (1995). The stability of precision grip forces during cyclic arm movements with a hand-held load. *Experimental Brain Research*, *105*(3), 455-464.

Flanagan, J., & Wing, A. (1997). The role of internal models in motion planning and control: Evidence from grip force adjustments during movements of hand-held loads. *Journal of Neuroscience*, *17*(4), 1519-1528.

de Freitas, P., & Jaric, S. (2009). Force coordination in static manipulation tasks performed using standard and non-standard grasping techniques. *Experimental Brain Research*, *194*(4), 605-618.

de Freitas, P., Krishnan, V., & Jaric, S. (2007a). Elaborate force coordination of precision grip could be generalized to bimanual grasping techniques. *Neuroscience Letters*, *412*(2), 179-184.

de Freitas, P., Krishnan, V., & Jaric, S. (2007b). Force coordination in static manipulation tasks: effects of the change in direction and handedness. *Experimental Brain Research*, *183*(4), 487-497.

de Freitas, P., Markovic, G., Krishnan, V., & Jaric, S. (2008). Force coordination in static manipulation: Discerning the contribution of muscle synergies and cutaneous afferents. *Neuroscience Letters*, *434*(2), 234-239.

de Freitas, P., Uygur, M., & Jaric, S. (2009). Grip force adaptation in manipulation activities performed under different coating and grasping conditions. *Neuroscience Letters*, *457*(1), 16-20.

Glaser, R., & Bassok, M. (1989). Learning-theory and the study of instruction. *Annual Review of Psychology*, *40*, 631-666.

Gordon, A., Quinn, L., Reilmann, R., & Marder, K. (2000). Coordination of prehensile forces during precision grip in Huntington's disease. *Experimental Neurology, 163*(1), 136-148.

Gysin, P., Kaminski, T., & Gordon, A. (2003). Coordination of fingertip forces in object transport during locomotion. *Experimental Brain Research, 149*(3), 371-379.

Hermsdorfer, J., Hagl, E., Nowak, D., & Marquardt, C. (2003). Grip force control during object manipulation in cerebral stroke. *Clinical Neurophysiology, 114*(5), 915-929.

Ingvarsson, P. E., Gordon, A., & Forssberg, H. (1997). Coordination of Manipulative Forces in Parkinson's Disease. *Experimental Neurology, 145*(2), 489-501.

Iyengar, V., Santos, M., Ko, M., & Aruin, A. (2009). Grip Force Control in Individuals With Multiple Sclerosis. *Neurorehabilitation and Neural Repair, 23*(8), 855-861.

Jaric, S., Collins, J., Marwaha, R., & Russell, E. (2006). Interlimb and within limb force coordination in static bimanual manipulation task. *Experimental Brain Research, 168*(1-2), 88-97.

Jaric, S., Knight, C., Collins, J., & Marwaha, R. (2005). Evaluation of a method for bimanual testing coordination of hand grip and load forces under isometric conditions. *Journal of Electromyography and Kinesiology, 15*(6), 556-563.

Jaric, S., Russell, E., Collins, J., & Marwaha, R. (2005). Coordination of hand grip and load forces in uni- and bidirectional static force production tasks. *Neuroscience Letters, 381*(1-2), 51-56.

Johansson, R., Riso, R., Hager, C., & Backstrom, L. (1992). Somatosensory control of precision grip during unpredictable pulling loads .1. Changes in load force amplitude. *Experimental Brain Research, 89*(1), 181-191.

Johansson, R., & Westling, G. (1984). Roles of glabrous skin receptors and sensorimotor memory in automatic-control of precision grip when lifting rougher or more slippery objects. *Experimental Brain Research, 56*(3), 550-564.

Johansson, R., & Westling, G. (1988). Programmed and triggered actions to rapid load changes during precision grip. *Experimental Brain Research, 71*(1), 72-86.

Krishnan, V., de Freitas, P., & Jaric, S. (2008). Impaired object manipulation in mildly involved individuals with multiple sclerosis. *Motor Control*, *12*(1), 3-20.

Krishnan, V., & Jaric, S. (2008). Hand function in multiple sclerosis: Force coordination in manipulation tasks. *Clinical Neurophysiology*, *119*(10), 2274-2281.

Krishnan, V., & Jaric, S. (2010). Effects of Task Complexity on Coordination of Inter-Limb and Within-Limb Forces in Static Bimanual Manipulation. *Motor Control*, *14*(4), 528-544.

Landin, D. (1994). The role of verbal cues in skill learning. *Quest*, *46*(3), 299-313.

Latash, M., & Jaric, S. (1998). Instruction-dependent muscle activation patterns within a two-joint synergy: Separating mechanics from neurophysiology. *Journal of Motor Behavior*, *30*(3), 194-198.

Marchant, D., Greig, M., & Scott, C. (2009). Attentional focusing instructions influence force production and muscular activity during isokinetic elbow flexions. *Journal of Strength and Conditioning Research*, *23*(8), 2358-2366.

Marwaha, R., Hall, S., Knight, C., & Jaric, S. (2006). Load and grip force coordination in static bimanual manipulation tasks in multiple sclerosis. *Motor Control*, *10*(2), 160-177.

Nowak, D., & Hermsdorfer, J. (2006). Objective evaluation of manual performance deficits in neurological movement disorders. *Brain Research Reviews*, *51*(1), 108-124.

Nowak, D., Hermsdorfer, J., Marquardt, C., & Fuchs, H. (2002). Grip and load force coupling during discrete vertical arm movements with a grasped object in cerebellar atrophy. *Experimental Brain Research*, *145*(1), 28-39.

Ohki, Y., Edin, B., & Johansson, R. (2002). Predictions specify reactive control of individual digits in manipulation. *Journal of Neuroscience*, *22*(2), 600-610.

Oldfield, R. (1971). Assessment and analysis of handedness - Edinburgh Inventory. *Neuropsychologia*, *9*(1), 97-113.

Russell, C., & Grealy, M. (2010). Avoidant instructions induce ironic and overcompensatory movement errors differently between and within individuals. *Quarterly Journal of Experimental Psychology*, *63*(9), 1671-1682.

Sahaly, R., Vandewalle, H., Driss, T., & Monod, H. (2001). Maximal voluntary force and rate of force development in humans - importance of instruction. *European Journal of Applied Physiology*, *85*(3-4), 345-350.

Sainburg, R. (2002). Evidence for a dynamic-dominance hypothesis of handedness. *Experimental Brain Research*, *142*(2), 241-258.

Sainburg, R. (2005). Handedness: Differential specializations for control of trajectory and position. *Exercise and Sport Sciences Reviews*, *33*(4), 206-213.

Schwarz, M., Fellows, S., Schaffrath, C., & Noth, J. (2001). Deficits in sensorimotor control during precise hand movements in Huntington's disease. *Clinical Neurophysiology*, *112*(1), 95-106.

Uygur, M., de Freitas, P., & Jaric, S. (2010). Effects of varying the load force range and frequency on force coordination in static manipulation. *Neuroscience Letters*, *475*(2), 115-119.

Westling, G., & Johansson, R. (1984). Factors influencing the force control during precision grip. *Experimental Brain Research*, *53*(2), 277-284.

Zatsiorsky, V., Gao, F., & Latash, M. (2005). Motor control goes beyond physics: differential effects of gravity and inertia on finger forces during manipulation of hand-held objects. *Experimental Brain Research*, *162*(3), 300-308.

APPENDIX I

TASK PERFORMANCE

The task performance of the ramp-and-holding task was measured by the root mean square error (RMSE) of the participant's force pattern compared with the prescribed force profile. Since the force profile displayed on the screen in front of the participants during the experiments was recorded for both the left and right hand whose profiles could have been slightly different due to inertia and other factors, we used the averaged force to measure task performance. Based on the order of the experiments, these data were grouped regarding 6 conditions: both hands pulling the fixed and free device (Fixed BP and Free BP), left pulling right holding the fixed and free device (Fixed LPRH and Free LPRH) and right pulling left holding the fixed and free device (Fixed RPLH and Free RPLH). The average RMSE for all participants during the ramp phase was 0.34±0.04 (Mean±SD), and during the holding phase is 0.44±0.04. A two way ANOVA (6 conditions × 2 phases) is applied on the data, and the result showed significant main effect of both the condition (F (2.61, 39.23) = 8.19, $p < 0.001$) and phase (F (1, 15) = 8.83, $p < 0.01$), but not their interaction. Pairwise comparison showed that RMSE of the ramp phase was higher than that of the holding phase ($p < 0.001$), as well as the RMSE recorded under Free LPRH condition was higher than under the Fixed LPRH, Fixed RPLH and Free BP condition ($p < 0.001$).

The task performance of the oscillation task was measured by the absolute error (AE) and variable error (VE). The AE averaged across the participants and conditions was 0.80±0.32, while VE was 0.68±0.33. Two one-way ANOVA (6 conditions similar to RMSE in ramp-and-holding task) was performed on both AE and VE. The result revealed significant main effect of condition on AE ($F(3.15, 47.35) = 3.47$, $P < 0.01$). Pairwise comparison suggested a significantly lower AE under Fixed BP condition than under Fixed LPRH condition. No significance effect of conditions was found regarding VE.

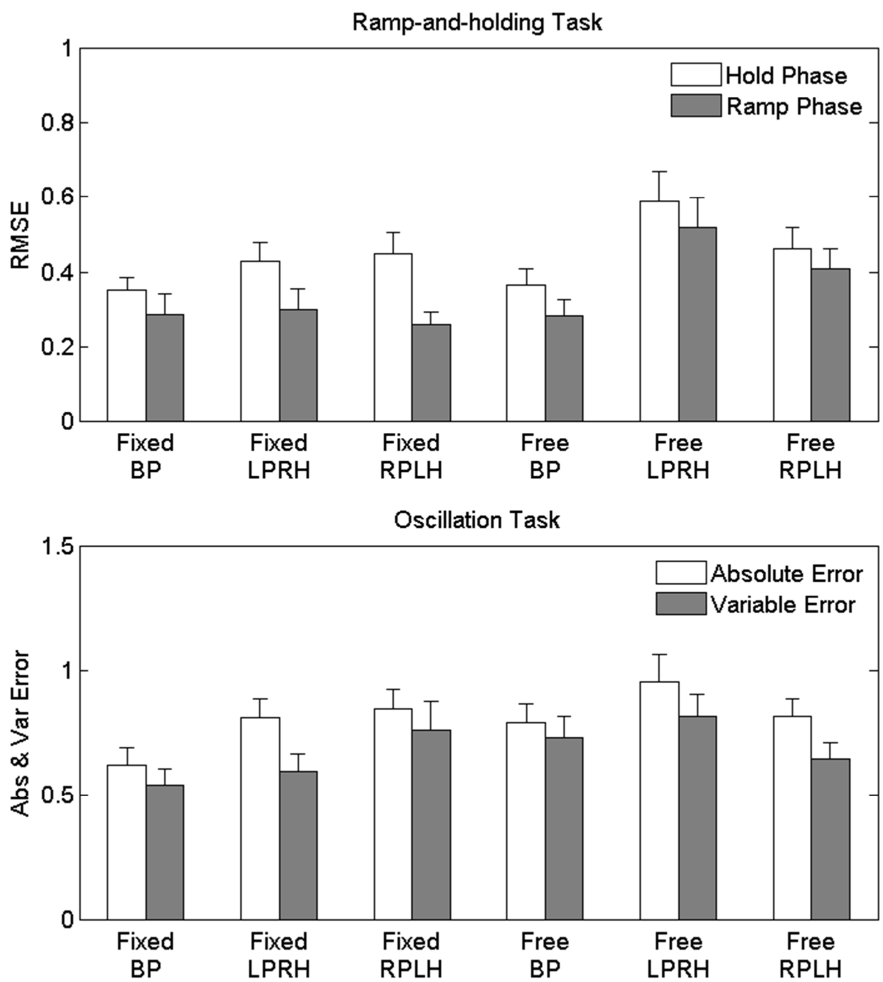

Figure A.1 The task performance variables (data averaged across subjects with standard error bars) for ramp-and-holding task and oscillation task.

APPENDIX II

INFORMED CONSENT FORM

INFORMED CONSENT FORM

Research Study: ASSESSMENT OF HAND FUNCTION THROUGH FORCE COORDINATION IN MANIPULATION TASKS

Investigators: Slobodan Jaric, PhD (Health and Exercise Sciences)

1. PURPOSE/DESCRIPTION OF THE RESEARCH
Slobodan Jaric has requested your participation in this research study. The purpose of this research is to examine how people exert different patterns of forces along a hand-held device. You are one of approximately 30 individuals who are recreationally active adults without a neurological disorder between the ages of 18 and 60 who will participate in this study. You will be asked to attend either one or two testing sessions lasting between 1 and 1.5 hours each.

At each session, you will sit in a chair or stand still and comfortably hold a lightweight device in front of you with tips of your fingers. At the beginning of the session, there will be a handedness test to make sure you are right handed. Then you will grip that the device with as much force as you can exert with each of your hands. Next, you will be given instructions on how to hold the device and what kind of forces to produce with your hands while holding it. The most applied force you will be asked to use during this part of the testing will not be greater than the forces produced while doing such things as eating with fork and knife, or lifting a glass of water.

2. CONDITIONS OF SUBJECT PARTICIPATION
Your participation is totally voluntary. The experimental results will be reported in aggregate form only. You will not be individually identified, except possibly by a subject number known only to the researchers. The results of the research study may be published but your name or identity will not be revealed. All data and records will remain confidential, securely stored as computer files or paper documents in a locked cabinet in the investigator's office indefinitely, and will only be accessed by the investigator. In the unlikely event of physical injury during laboratory testing procedures, you will receive first aid. If you require additional medical treatment, you will be responsible for the cost. Testing will be stopped if you cannot adequately perform the tasks. You may withdraw your consent and discontinue participation in this study at any time without penalty.

3. RISKS AND BENEFITS
There is a small risk of some transient muscle fatigue, however the task is not more strenuous than ordinary tasks of manipulating lightweight objects or using external supports we regularly perform during daily living. You will be given opportunity to rest during the testing session, if necessary.
There are no direct benefits to you for participation. However, this study should provide new information about the neural control of patterns of unimanual and bimanual forces in various manipulative tasks.

5. CONTACTS
If you have questions about the research study, you may call Dr. Slobodan Jaric (302/831-6174), Associate Professor, Department of Health and Exercise Sciences. If you have questions

Subject's initials: _________

regarding the rights of individuals who agree to participate in this research you may call the Chair of the University of Delaware IRB (302/831-2137).

6. SUBJECT'S ASSURANCES
I have read the above informed consent. The nature, demands, risks and benefits of the project have been explained to me. I understand that I may withdraw my consent and discontinue my participation in this study at any time without penalty or loss of benefit to myself. My participation in this research study is not related to any course grade associated with the University of Delaware. A copy of this consent form has been given to me.

7. CONSENT SIGNATURES

Subject's Signature: ________________________________ Date:__________

Subject's Name (printed): ____________________________ Date:__________

I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. I have provided the subject with a copy of this informed consent document.

Signature of the Investigator: ___________________________ Date:_________

APPENDIX III

EDINBURGH INVENTORY QUESTIONNAIRE

APPENDIX II

Medical Research Council Speech & Communication Unit

EDINBURGH HANDEDNESS INVENTORY

Surname.................................... Given Names....................................

Date of Birth.................................... Sex....................

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column.* Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put ++.* If in any case you are really indifferent *put + in both columns.*

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	DECILE	

MARCH 1970