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Observation of Muscle Activation in Relationship to Digit Force Production During a Precision Pinch Tracking Task

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Observation of Muscle Activation in Relationship to Digit Force Production During a Precision Pinch Tracking Task

by

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Abstract

Observation of Muscle Activation in Relationship to Digit Force Production During a Precision Pinch Tracking Task

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Abstract: The primary purpose of this study was to observe the relationship between muscle activation of the right hand with the force produced at the fingertips in an isometric precision pinch tracking task. Thirty right-handed subjects, 15 males and 15 females, with a mean age 23.5 (SD 3.5) years, free from any neurological disorder or physical ailment, had a pair of electromyography (EMG) electrodes placed over the first dorsal interosseous (FDI) muscle, which acts on the index finger, while performing a pinch force tracking task scaled to 20% maximum voluntary contraction (MVC). The tracking task was chosen because it created a continuously increasing force application to 20% MVC and then decreasing force release from 20% MVC at a prescribed rate in both cases of 6.66% MVC force per second. In addition to showing increases in EMG activation of the FDI with increases in force, the results revealed that muscle activation for a given force level was generally greater for force application than for force release. This may be due dynamics of muscle contraction or to patterns of multiple muscle coordination.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Hand movements such as reaching and grasping have long been an important area of interest for researchers. Choreographed hand movements in daily living have been studied in the biomechanical, neurophysiological, and ergonomic fields to understand the enormous variability in control mechanisms and requirements for movement. Through years of research, much work has been done to label movements and to differentiate between what is known as 'power gripping/grasping' and 'precision gripping.' This accepted nomenclature is based on the idea that the intended activity determines the type of grip being used; such that the grip used to pick up a pen differs greatly from that of a grip used to manipulate a shovel handle. These observations of grip patterns have been made in humans and non-human primates alike, utilizing various techniques in observation of neural mechanisms, movement, and force production.

The precision grip is often described as an isometric pinching motion in which the thumb opposes the index finger as a primary means of object control and manipulation for a task of daily function (Moerchen et al. 2007). As the hand lifts or holds an object by pinching or grasping, the isometric force produced by the combination of these two or more digits plays a critical role in exerting a vertical force to oppose the weight of the object and all forces which move the object. Chappell et al. (2006) described this isometric pinch force generation as being achieved by the stochastic recruitment of individual motor units, which sum together. Forces applied by the fingers have been measured during different dynamic and static work activities to assess and quantify performance patterns in order to improve hand tool design, showing that fingertip forces vary widely between occupational tasks (Kursa et al. 2005). As exertion of these forces on the object increases or decreases, muscle activation levels change, which can be observed through surface electromyography (EMG). EMG parameters such as amplitude or frequency are commonly used to assess the extent of activation by the central nervous system of a muscle (Kallenberg et al. 2008). The non-invasive measurement of muscle activation with surface EMG uses the electrical activity accompanying muscle contractions. Previous EMG studies have suggested that higher muscle activations are generated at higher loading rates during static and dynamic activities (Kursa et al. 2005).

The pinch mechanism is an accepted model for observing precision grip across various organizational strategies for force-shared digits. Attempts to observe or examine the organization of pinch force production have previously been limited by measurement of only single digit forces, often the index finger (Moerchen et al. 2007). This is problematic because the examination of hand function incorporating more than one digit suggests that force sharing and coordination of these digits reflect the mechanics of grip and pinch patterns as well as the force levels required. Observing only the index finger limits the functional observation of the pinch task. There are anatomical differences between the thumb and index finger, supporting the idea that each digit has the potential to adapt differently during pinch control (Moerchen et al. 2007). For example, during isometric pinch tasks, forces in the flexor digitorum profundus tendon are significantly higher than those found in the flexor digitorum superficialis tendon for the same externally applied fingertip force (Kursa et al. 2005). Also, with inter-digit differences there are large coefficients of variance among individuals, which are due to these intraand inter-individual differences. Thus, Kursa et al. (2005) suggested individual roles and contributions may vary with force, finger position, and force direction from task to task.

When attempting to understand force production at the fingertips in a precision grip task, it becomes necessary to make direct assessment of the muscles involved. This is often performed by observing the differences between intrinsic muscles, found in the hand, and extrinsic muscles, found in the forearm, as well as the synchronization and coupling effects in isometric force production. Research performed by McIsaac et al. (2008) has indicated the extrinsic muscles of the hand appear to have their activities tightly coupled together by descending pathways diverging to provide extensive common synaptic input across their respective motor nuclei. This differs from the intrinsic hand muscles, abductor pollicis and first dorsal interosseous, which were found to have little synchrony between motor unit pairs (McIsaac et al. 2008). These results suggest the descending pathways that control activities of intrinsic muscles provide more concentrated input to the individual motor nuclei than those innervating the extrinsic pathways. This suggestion carries the implication that the extrinsic muscles are for the higher-level force production while the intrinsic hand muscles are for controlling the precision fine control (McIsaac et al. 2008).

This implication is supported by previous research groups such as Maier et al. (1995a), who showed that intrinsic muscle activation is highly correlated with force production. They further stated that extrinsic muscle activation does not scale well with force production, primarily in the long flexors, extensors, and abductors. The intrinsic muscle amplitudes showed very widespread positive correlations of muscle combinations, or co-activations, with negative correlations being rare (Maier et al.

1995b). Thus Maier et al. reported that at low isometric loads the intrinsic muscles most likely provide the finely graded force while the extrinsic muscles are not strongly modulated to control objects at low forces. They did find synchronization in the intrinsic hand muscles with no synchronization being observed in the extrinsic muscles, contradicting McIsaac et al. (2008), but the authors suggested that the central nervous system does not rely, or quite rarely relies, on fixed synergies for precision grip force production. Maier et al. 1995b justify these synergistic outcomes as a result of anatomical structure and common goal.

The majority of the studies performed on this topic show that all hand muscles, intrinsic and extrinsic, are active in isometric finger force generation. This co-activation and co-contraction of these muscles has strong implications for neural control mechanisms. It has been reported that individual muscle contributions and roles vary with force, finger position, and force direction, thus creating a potentially different pattern for each task variation. It is realistic to expect subject independent muscle excitation patterns during these isometric precision grip force production tasks. Unique anatomical geometries occur, which create a mechanically different force production posture from person to person, making it reasonable to expect each person's central nervous system to converge on a mechanically unique and advantageous excitation pattern.

The intent of this study was to examine the relationship between muscle activation and applied force, through an isometric pinch task, by analyzing the individual digit forces (thumb and index finger) and activation of an intrinsic digit flexor used to produce a pinch of steadily changing force. This study examined how the activation level of the first dorsal interosseous (FDI) muscle, which can act as the thumb and index finger produce steadily changing isometric pinch forces, changes in both force application and force release. Factors examined were the effects of direction of force change, increasing (force application) vs. decreasing (force release), on this relationship as well as the general level of force production across the entire trial. The increasing or decreasing force production from both digits, reaching combined peak levels of 20% of combined maximum force, were expected to be linear in time if the task were executed perfectly, and it was expected that the muscle activation would increase or decrease in a related fashion. In order to ascertain whether the findings held true for a variety of force levels, isometric pinch performance was examined in a task which requires force production at steadily changing levels between 1% to 20% of combined maximal pinch force capacity.

The significance of this study was that it observed the isometric precision grip force production and muscle activation in a dynamic force production protocol of both the thumb and index finger. Previous research has been strongly based on the observation of static force production and muscle activation as a result of fatigue of one digit with little emphasis on dynamic isometric combined force production. By observing a dynamic level of force production, the task was more representative of daily tasks. As well, by utilizing both the index finger and the thumb in the task, we were able to examine how this muscle was related to how these digits work. With the understandings of the previous studies, it was hypothesized that the FDI muscle activation would increase as force increased. The muscle activation during steadily decreasing force was hypothesized to be less than during steadily increasing force.

Specifically, root mean square (RMS) amplitude (indicating motor unit recruitment) would increase with force application and decrease with force release.

Chapter 2: Methods

2.1 Participants

Fifteen male and fifteen female right-handed adult participants, with mean age 23.5 (SD 3.5) years, performed all experimental protocols. All participants gave written consent prior to experiment participation and reported no history of neurological disorder or musculoskeletal abnormalities as well as no pain associated with daily use of the right arm or hand.

2.2 Tasks and Procedures

The manual force quantification system (MFQS) apparatus employed in this study enabled the quantification of low-level isometric force control in a precision pinching task (Spirduso et al. 2005). The amount of force produced by each digit, the thumb and index finger, was displayed directly to the participant as the position of a cursor on a computer screen. The apparatus included a target-tracking template on the computer screen, a console that supported the force transducer and hand, and a software program that controlled the template, cursor, and the data-collection. The participants were instructed to sit at a desk facing the computer screen with their right arms flexed to 135 degrees about the elbow and stabilized with a strap about the forearm. Participants rested their forearms on the ulnar side and curled their last three fingers to the palm, to create a loosely held partial fist, leaving the index finger and thumb extended. The force transducer was adjusted, in height and orientation, so that the subjects' thumb and index finger tips touched the respective transducer pads. The force transducer support was secured so that no translational or rotational motion was possible. Thus, the instrument allowed for independent isometric force measurements of either digit, without any movement by the participant, see *Figure 1*.

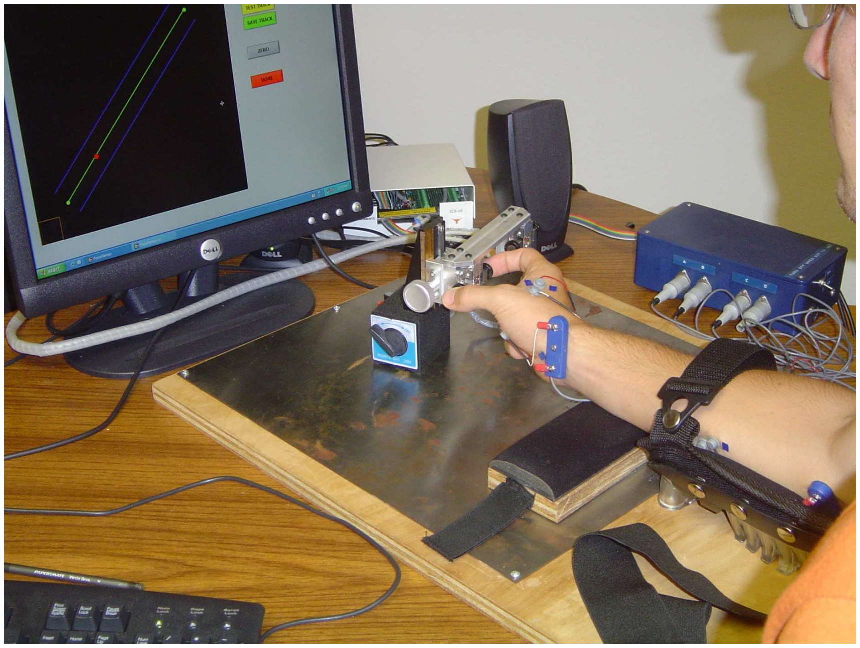


Figure 1: The manual force quantification system (MFQS) apparatus.

Assessment of muscle activation included the attachment of a pair of bipolar Ag/AgCl electrodes affixed to alcohol-cleaned skin on the right arm over the first dorsal interosseous (FDI) muscle belly. The recording electrodes were oriented parallel to the muscle fibers. The muscle belly was identified through palpation during anatomical action by abducting the index finger. Participants were then instructed to perform a series of hand movements to ensure proper EMG lead pair placement with repositioning performed when required. The forearm was then wrapped loosely in an Ace bandage to secure the wires.

Three maximal voluntary isometric pinch forces (MVCs) were recorded, in grams, using a 20-pound maximum pinch transducer. The largest force from these three trials was used to calculate 20% combined maximum force production. Tracking trials, using a 10 pound maximum transducer, consisted of a participant keeping the cursor on the track ball which moved up and down a 45 degree line from bottom left to top right on the screen (see *Figure 2*), with the range of forces required set at 1 to 20% combined maximum voluntary force production. Force measurements were collected with a two-paddle force transducer where the thumb controlled the cursor movement horizontally, or along the x direction, while the index finger controlled the vertical, or y direction, cursor movement. The goal of the task was to guide a participant-controlled cursor along a target line from the Start button to the Return button by applying steadily increasing pressure and then from the Return button back to the Start button by steadily releasing the pressure. The coordination of the two digit forces resulted in the ability to move the cursor along the specified diagonal line. A moving cursor target provided the participants with a goal rate of force change. Two practice trials without a moving target were given to familiarize the participant with manipulating the cursor along the diagonal line. Then two additional trials with the guiding indicator cursor were provided. Finally, data were collected during a set of 10 tracking trials performed to a maximum value of 20% of combined maximum voluntary force production, with 30 seconds rest between sets. The participants were informed that the tracking task would be at a prescribed duration of 6 seconds and they were to keep their cursor on the guide marker. This required fine motor control and maintenance of very similar force patterns over time for all trials and participants.

Tracking Template

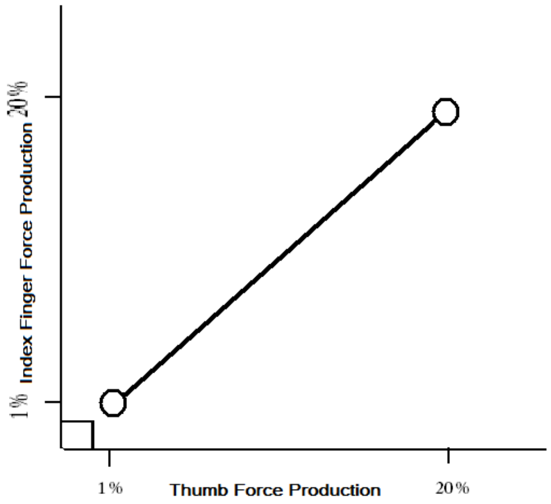


Figure 2: Tracking template in which the thumb controls the cursor in the *x* direction while the index finger controls the movement in the *y* direction. Combined use of the digits creates total control of the cursor.

2.3 Data acquisition

The MFQS apparatus used for data collection in this study included a Dell computer, custom-designed LabVIEW software, and A/D sampling of force records from a pair of force transducers as well as one channel of surface EMG. All data collection was controlled by a LabVIEW software application, which displayed instructions and task performance, sampled data, and stored the data for offline analysis. The pinch forces were recorded by two pairs of strain-gauge sensors. Maximal voluntary pinch force was measured using sensors that were calibrated up to 20 lb of force. Experimental task data were measured using sensors that were calibrated up to 10 lb of force, for greater precision. Force data were sampled at 1000 Hz with LabVIEW, averaging 5 samples for recording force data at 200Hz. Surface EMG data were collected with the use of preamplified electrode systems (Iomed 3000) with custom shaped bipolar Ag/AgCl surface electrodes (4 mm Beckman Surface Electrodes) affixed by adhesive tape (4 mm Biopac System Adhesive Discs) which created a gel-skin contact to alcohol-cleaned skin over each muscle of interest. The EMG signals were continuously visible to the experimenter using a Tektronix oscilloscope to verify signal quality. The EMG activity from the FDI muscle was collected to study muscle action contributing to the pinch action. All EMG data were sampled at 2000 Hz.

2.4 Data analysis

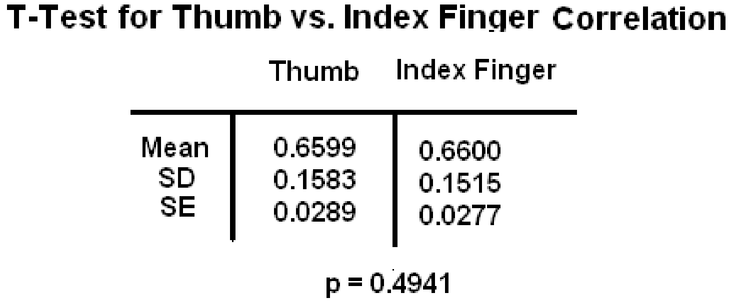
The target path was divided into 30 equal segments of time, .2 seconds per segment, with 15 segments for ascent (increasing force) and 15 segments for descent (decreasing force). For each segment the average force for each digit was calculated, and the EMG average amplitude for that segment from was also calculated. The root mean square (RMS) EMG amplitude was calculated as a percentage of maximal amplitude, obtained from the maximal force production trials, using a custom Matlab program.

In order to normalize the force and EMG records, for comparisons between participants, each person initially was asked to produce a few trials of maximal pinch force. During the actual experimental trials, participants produced steadily changing force levels up to 20% of their combined digit maximal capacity in order to produce specified patterns of force level over time. From these basic measurements, the following dependent measures were calculated for use in statistical analysis: individual average digit normalized force and EMG RMS normalized amplitude.

Separate statistical analyses were performed for each digit force record, for each direction of force change, and for the EMG activation level. The 10 trial scatterplots were created for individual participants to determine the relationship between muscle activation and force. From these plots, the slopes and extrapolated zero-line intercepts were calculated, according to participant, for both the thumb and index finger in force application and force release. Correlation coefficients were calculated using Microsoft Excel for observations in first dorsal interosseous muscle activation and force production resultant from the both thumb and index finger. One-tailed paired t-tests were then performed to examine statistical significance between digits, slopes, extrapolated zero-line intercepts, and differences between force application and force release. A one-tailed t-test rather than a two-tailed t-test was used because the hypothesis being evaluated involved a directional relationship and greater power to detect direction of effect was desired

Chapter 3: Results

As hypothesized, a strong positive correlation was found between the first dorsal interosseous EMG activation level and force. This was true for both the thumb and index finger with mean correlations of approximately 0.66, see *table 1 and Appendix A*. With the correlation coefficients being so close for the thumb and index finger, it was concluded that there was no significant difference between the two digits in respect to the relationship between first dorsal interosseous EMG activity and force.



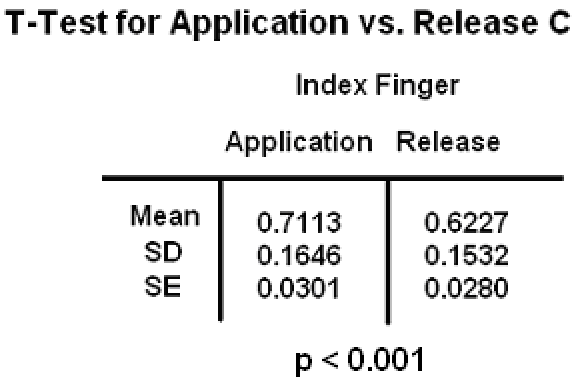
T-Test for Thumb vs. Index Finger Correlation

	Thumb	Index Finger
Mean	0.6599	0.6600
SD	0.1583	0.1515
SE	0.0289	0.0277

p = 0.4941

Table 1. t-test of differences in correlation coefficients between the FDI activation level and the forces produced by the thumb or index finger. (Significance set at p=0.05)

Comparing the correlations for the thirty participants between force application and force release, it was found that there was a higher correlation between FDI muscle activation and force production than in force release, see *table 2*. In force application the mean correlation coefficient was found to be 0.7113 while the mean correlation coefficient for force release was found to be 0.6227, which is significantly different with a p-value of 0.0000035.



T-Test for Application vs. Release Correlation

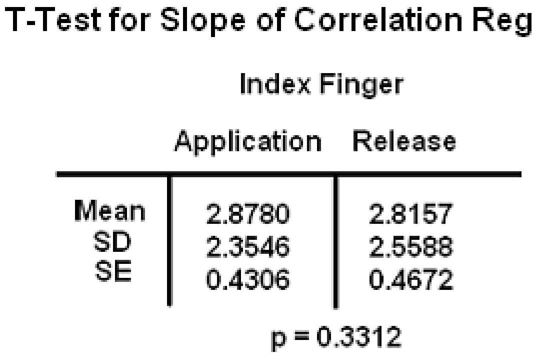
Index Finger

	Application	Release
Mean	0.7113	0.6227
SD	0.1646	0.1532
SE	0.0301	0.0280

$p < 0.001$

Table 2. t-test observation of the correlation between first dorsal interosseous RMS amplitude and index finger force application and release. (Significance set at p=0.05)

No significant difference was found between the slopes of the linear regression lines for the correlation of index finger force and FDI activation level in force application and release, see *table 3*. Even though the force application mean slope 2.8780 was higher than the mean force release slope 2.8157, these slopes were not significantly different as found by the p-value 0.3312. This showed that the rate of FDI activation change was extremely similar during force application and force release, see *Appendix B*.



T-Test for Slope of Correlation Regression

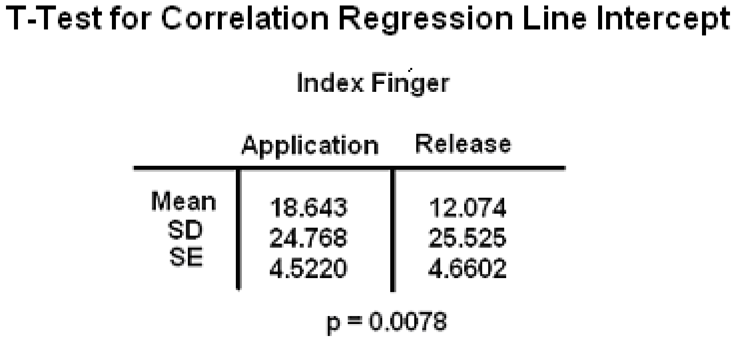
Index Finger

	Application	Release
Mean	2.8780	2.8157
SD	2.3546	2.5588
SE	0.4306	0.4672

$p = 0.3312$

Table 3. t-test of linear regression slope for application and release of force. (Significance set at p=0.05)

Even though no difference was found between the slopes for the linear regression for application and release, these two conditions did not share the same FDI activation levels at each force level. It was found that during force application the extrapolated zero-line intercept was significantly higher than that for force release, see table 4. The mean intercept for application was 18.643 % muscle activation and the mean intercept for release at 12.074 % muscle activation. Thus, the FDI had greater muscle activation at the extrapolated zero-line intercept for force application than for force release. Combining this result with the lack of difference in regression line slope, it can be concluded that muscle activation for each force application level was higher than for the same level in force release.



T-Test for Correlation Regression Line Intercept

Index Finger

	Application	Release
Mean	18.643	12.074
SD	24.768	25.525
SE	4.5220	4.6602

p = 0.0078

Table 4. t-test observation for extrapolated zero-line intercept % muscle activation in force application vs. force release. (Significance set at p=0.05)

Chapter 4: Discussion

The present study was designed to observe the relationship between muscle activation of the FDI on force production in a precision pinch task ranging from 1-20% of MVC. Analysis of the data showed a strong correlation between RMS amplitude and force for both the thumb and index finger, with no statistical difference found between digits. These results were comparable to the study performed by Moerchen and Gruben (2006) who utilized a dynamic isometric pinch, increasing and decreasing force, to show a high cross-correlation between the thumb and index finger. As a result of this high cross-correlation, subsequent results in this study were examined with respect to the index finger forces. This was deemed acceptable due to the anatomical definition of the first dorsal interosseous being an index finger flexor and abductor.

Although differences were not observed between digits, they were observed between force application and force release. The correlation coefficients for force application and muscle activation were higher than for force release and muscle activation. This finding was also supported by Moerchen and Gruben (2006), who found lower force coupling at lower force levels with decreased force production. This lower coupling between force production and muscle activation may have resulted from an underlying neuromechanical mechanism, an increased difficulty in releasing force compared to increasing force, or a more nonlinear trajectory of activation changes during release.

The current study found that the extrapolated zero-line intercepts from linear regressions derived from the relationship between force and muscle activation were greater for force application than for force release. However, the slopes of these lines did not significantly differ, resulting in the muscle activation being higher for a given force in application than in release, see *figure 3*. This decreased muscle activation for a given force level may have resulted in greater variance in force release. In general observance of a single tracking trial, it was seen that the path was generally much smoother and direct in force application than in force release, see *figure 4*. As well, this less smooth descending path with greater variance in force required more corrective maneuvers to finish the task. These corrective maneuvers along with lower muscle activation in force release than in force application may also have led to the lower correlation coefficients in force release.

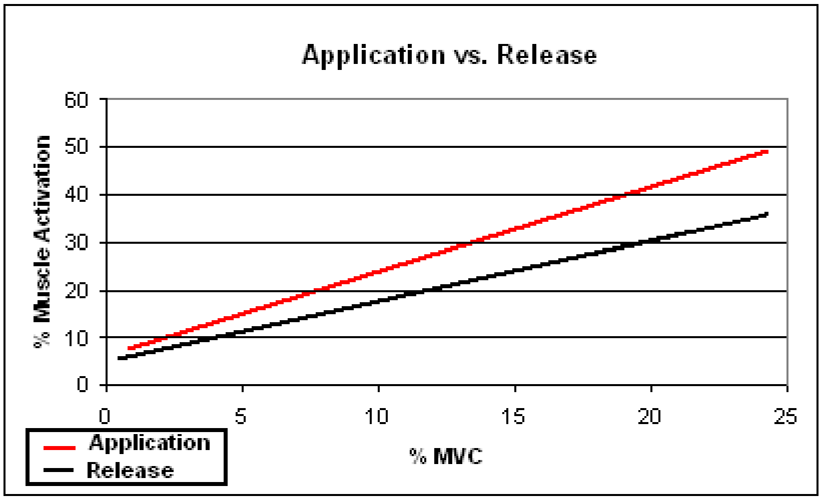


Figure 3. An individual participant, 4.1, representation of the linear regression for force application vs. force release. Force application is represented by the (RED) line with the equation y=1.7909x+5.854. Force release is represented by the (BLACK) line with the equation y=1.2801x+4.802.

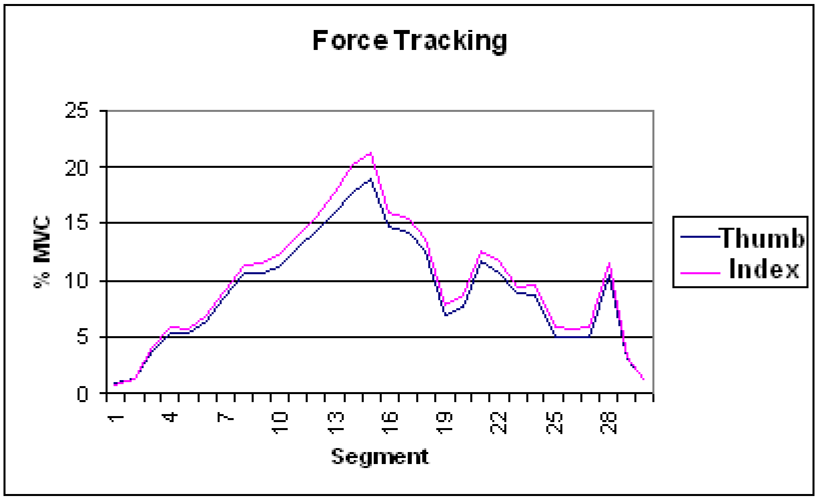


Figure 4. A single trial force tracking path for participant 4.1 representing a general trend in force application and release.

One limitation of this study was that only one muscle was studied, as this was an initial attempt to examine muscle activation in this task. Another limitation was that no comparison was made across genders. While no differences were expected or observed, future work might examine similar data more carefully for possible differences in mechanisms. Other limitations of the study include that individual participants may have not held a uniform hand geometry throughout all trials. All participants were instructed to perform the task with a given hand orientation, which was a uniform description to all participants, but repositioning of the hand between trials did occur. This possibility of a shift in hand position may have created different muscle orientations under the skin surface resulting in different EMG source signals. As well, there was a potential for skin artifact to occur with the movement of muscle from relaxation to contraction, but this movement was limited by the isometric nature of the task. There were also varying levels of tissue conductivities across participants. Muscle biopsies were not performed to test potential differing fiber types, but this was not expected to be very problematic because muscle activation and force levels were scaled across subjects to maximal levels. However, potential limitations in the maximum value collection did occur. While producing their maximum force levels, the maximum muscle activations were not always observed. It is possible some participants changed activation patterns significantly while trying to create maximal forces. All individuals were normalized in the same scaling manner but this may have distorted the normalization scale.

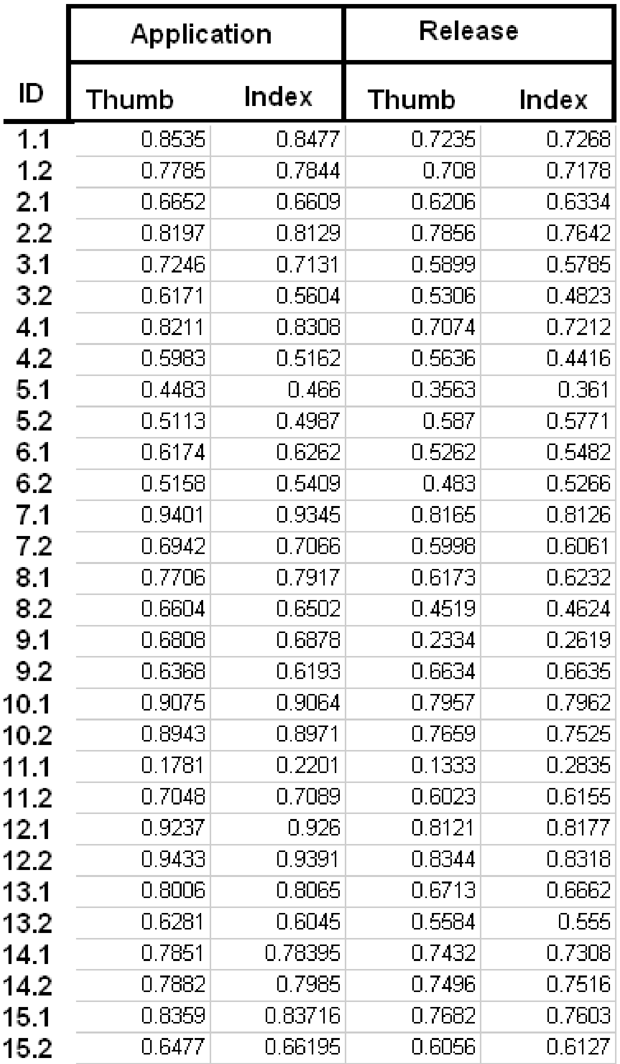
The results of this study only apply to healthy right-handed young adults between the ages 18-35 performing a dynamic force change in precision grip. Other individual differences such as handedness, injury or disease might be expected to alter these individual roles and contributions as well. Chappell and Taylor (2006) stated that a better understanding of injuries and disabilities from the perspective of normal musculoskeletal systems of the upper limb could lead to improvements in the functional ability in the injured or disabled. Research performed by Schreuders et al. (2003) found that non-injured hands have higher maximal force production capabilities but produced no significant differences in force production error for intra-examiner and inter-examiner measurements of pinch force when scaled with non-injured participants. This may not be true if the task is dynamic in nature. Just as gender and size differences were not found in force matching but were present in dynamic isometric tasks, this may be the case for injured or diseased individuals as well. Also, many natural processes such as aging result in muscle strength declines (Lindeberg et al. 2008). This is generally thought to occur as a result of spinal motor neuron loss, which in turn alters the functional properties of the retained motor units, causing the size of the motor unit innervations to get larger with decreases in contractile speed. Further research utilizing dynamic isometric precision pinch needs to be performed on the injured and aged so that a better understanding of the mechanisms can be observed and used to improve functional ability.

Chapter 6: Conclusion

A strong positive correlation was found between the digits involved in a precision grip tracking task ranging from 1-20% MVC in relationship to the first dorsal interosseous muscle activation. The digits involved, the thumb and index finger, were not found to be significantly different in this muscle activation/force production relationship. However, force application (steadily increasing force) was found more greatly related to RMS amplitude muscle activation than for force release (steadily decreasing force). The linear representations of these conditional observations were found to have similar slopes in force application and force release. What did differ was the extrapolated zero-line intercepts for the percent muscle activation. In force application the intercept was greater than that for force release. Thus when looking at both the intercept and slope, it was found that the first dorsal interosseous was more active for a given force level in force application than in force release.

Appendix (Correlation Coefficients)

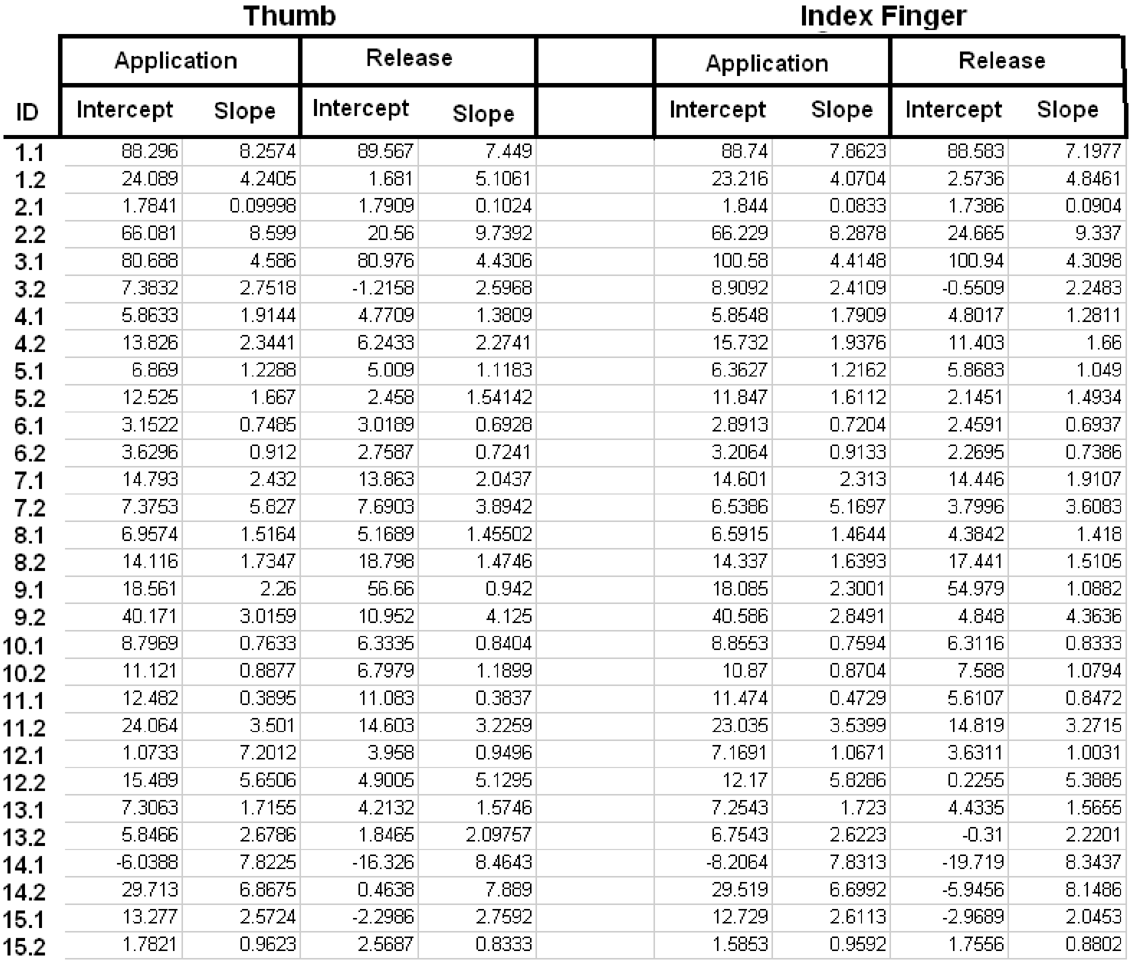
Correlation Coefficient for RMS Amplitude and Force



	Application		Release	
ID	Thumb	Index	Thumb	Index
1.1	0.8535	0.8477	0.7235	0.7268
1.2	0.7785	0.7844	0.708	0.7178
2.1	0.6652	0.6609	0.6206	0.6334
2.2	0.8197	0.8129	0.7856	0.7642
3.1	0.7246	0.7131	0.5899	0.5785
3.2	0.6171	0.5604	0.5306	0.4823
4.1	0.8211	0.8308	0.7074	0.7212
4.2	0.5983	0.5162	0.5636	0.4416
5.1	0.4483	0.466	0.3563	0.361
5.2	0.5113	0.4987	0.587	0.5771
6.1	0.6174	0.6262	0.5262	0.5482
6.2	0.5158	0.5409	0.483	0.5266
7.1	0.9401	0.9345	0.8165	0.8126
7.2	0.6942	0.7066	0.5998	0.6061
8.1	0.7706	0.7917	0.6173	0.6232
8.2	0.6604	0.6502	0.4519	0.4624
9.1	0.6808	0.6878	0.2334	0.2619
9.2	0.6368	0.6193	0.6634	0.6635
10.1	0.9075	0.9064	0.7957	0.7962
10.2	0.8943	0.8971	0.7659	0.7525
11.1	0.1781	0.2201	0.1333	0.2835
11.2	0.7048	0.7089	0.6023	0.6155
12.1	0.9237	0.926	0.8121	0.8177
12.2	0.9433	0.9391	0.8344	0.8318
13.1	0.8006	0.8065	0.6713	0.6662
13.2	0.6281	0.6045	0.5584	0.555
14.1	0.7851	0.78395	0.7432	0.7308
14.2	0.7882	0.7985	0.7496	0.7516
15.1	0.8359	0.83716	0.7682	0.7603
15.2	0.6477	0.66195	0.6056	0.6127

Appendix A. List of correlation coefficients for force in relationship with first dorsal interosseous RMS activation for the thumb and index finger. ID represents the participant ID in which the second number represents gender, with 1 indicating a male and 2 indicating a female.

Intercepts and Slopes for Linear Regressions



	Thumb					Index Finger			
	Application		Release			Application		Release	
ID	Intercept	Slope	Intercept	Slope		Intercept	Slope	Intercept	Slope
1.1	88.296	8.2574	89.567	7.449		88.74	7.8623	88.583	7.1977
1.2	24.089	4.2405	1.681	5.1061		23.216	4.0704	2.5736	4.8461
2.1	1.7841	0.09998	1.7909	0.1024		1.844	0.0833	1.7386	0.0904
2.2	66.081	8.599	20.56	9.7392		66.229	8.2878	24.665	9.337
3.1	80.688	4.586	80.976	4.4306		100.58	4.4148	100.94	4.3098
3.2	7.3832	2.7518	-1.2158	2.5968		8.9092	2.4109	-0.5509	2.2483
4.1	5.8633	1.9144	4.7709	1.3809		5.8548	1.7909	4.8017	1.2811
4.2	13.826	2.3441	6.2433	2.2741		15.732	1.9376	11.403	1.66
5.1	6.869	1.2288	5.009	1.1183		6.3627	1.2162	5.8683	1.049
5.2	12.525	1.667	2.458	1.54142		11.847	1.6112	2.1451	1.4934
6.1	3.1522	0.7485	3.0189	0.6928		2.8913	0.7204	2.4591	0.6937
6.2	3.6296	0.912	2.7587	0.7241		3.2064	0.9133	2.2695	0.7386
7.1	14.793	2.432	13.863	2.0437		14.601	2.313	14.446	1.9107
7.2	7.3753	5.827	7.6903	3.8942		6.5386	5.1697	3.7996	3.6083
8.1	6.9574	1.5164	5.1689	1.45502		6.5915	1.4644	4.3842	1.418
8.2	14.116	1.7347	18.798	1.4746		14.337	1.6393	17.441	1.5105
9.1	18.561	2.26	56.66	0.942		18.085	2.3001	54.979	1.0882
9.2	40.171	3.0159	10.952	4.125		40.586	2.8491	4.848	4.3636
10.1	8.7969	0.7633	6.3335	0.8404		8.8553	0.7594	6.3116	0.8333
10.2	11.121	0.8877	6.7979	1.1899		10.87	0.8704	7.588	1.0794
11.1	12.482	0.3895	11.083	0.3837		11.474	0.4729	5.6107	0.8472
11.2	24.064	3.501	14.603	3.2259		23.035	3.5399	14.819	3.2715
12.1	1.0733	7.2012	3.958	0.9496		7.1691	1.0671	3.6311	1.0031
12.2	15.489	5.6506	4.9005	5.1295		12.17	5.8286	0.2255	5.3885
13.1	7.3063	1.7155	4.2132	1.5746		7.2543	1.723	4.4335	1.5655
13.2	5.8466	2.6786	1.8465	2.09757		6.7543	2.6223	-0.31	2.2201
14.1	-6.0388	7.8225	-16.326	8.4643		-8.2064	7.8313	-19.719	8.3437
14.2	29.713	6.8675	0.4638	7.889		29.519	6.6992	-5.9456	8.1486
15.1	13.277	2.5724	-2.2986	2.7592		12.729	2.6113	-2.9689	2.0453
15.2	1.7821	0.9623	2.5687	0.8333		1.5853	0.9592	1.7556	0.8802

Appendix B. List of linear regression intercepts and slopes for the first dorsal interosseous. ID represents the participant ID in which the second number represents gender, with 1 indicating a male and 2 indicating a female.

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Vita

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