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Muscle Latency Time and Activation Patterns for Upper Extremity During Reaching and Reach to Grasp Movement

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Abstract

Background: Despite muscle latency times and patterns were used as broad examination tools to diagnose disease and recovery, previous studies have not compared the dominant arm to the non-dominant arm in muscle latency time and muscle recruitment patterns during reaching and reach-to-grasp movements.

Objects: The present study aimed to investigate dominant and non-dominant hand differences in muscle latency time and recruitment pattern during reaching and reach-to-grasp movements. In addition, by manipulating the speed of movement, we examined the effect of movement speed on neuromuscular control of both right and left hands.

Methods: A total of 28 right-handed (measured by Edinburgh Handedness Inventory) healthy subjects were recruited. We recorded surface electromyography muscle latency time and muscle recruitment patterns of four upper extremity muscles (i.e., anterior deltoid, triceps brachii, flexor digitorum superficialis, and extensor digitorum) from each left and right arm. Mixed-effect linear regression was used to detect differences between hands, reaching and reach-to-grasp, and the fast and preferred speed conditions.

Results: There were no significant differences in muscle latency time between dominant and non-dominant hands or reaching and reach-to-grasp tasks ($p>.05$). However, there was a significantly longer muscle latency time in the preferred speed condition than the fast speed condition on both reaching and reach-to-grasp tasks ($p<.05$).

Conclusion: These findings showed similar muscle latency time and muscle activation patterns with respect to movement speeds and tasks. Our findings hope to provide normative muscle physiology data for both right and left hands, thus aiding the understanding of the abnormal movements from patients and to develop appropriate rehabilitation strategies specific to dominant and non-dominant hands.

Key Words: Handedness; Movement speed; Muscle latency times; Reach to grasp; Reaching.

Introduction

Almost 90% of people worldwide are right-handed and their dominant hand, the right hand, has different functional roles and movement control strategies compared to the non-dominant hand, the left hand (Carson et al, 1993a; Corballis, 1997; Coren et al, 1977; Sainburg et al, 2000). People who are right handed prefer to use their right hand for tasks requiring precision control, such as writing or hammering (Annett, 1992; Hammond, 2002). In contrast, the non-dominant left hand is used for stabilizing posture or holding objects (Duff and Sainburg, 2007; Kuhtz-Buschbeck et al, 2000; Schabowsky et al, 2007). According to the "dynamic dominance" hypothesis, this hand preference might be due to the different functional advantage of each hand, such that the dominant hand is specialized for coordinating intersegmental dynamics adapting to altered inertial conditions, whereas non-dominant hand is specialized for achieving stable final positions (Bagesteiro and Sainburg, 2000; Duff and Sainburg, 2007; Schaefer et al, 2009).

The discrepancy between right and left hands, their performance, and use is also shown in patients

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Corresponding author: Su-jin Kim sujink@jj.ac.kr with neurological disorders. Mani et al (2013) found that stroke patients with left hemisphere damage generated greater errors in the trajectory curvature and movement direction during reaching, whereas errors in movement extent were greatest in stroke patients with right hemisphere damage. In addition, patients with left hemisphere damage showed the increased use of their contralateral hand (right hand) compared to patients with right hemisphere damage, who used their contralateral hand (left hand), despite all patients being right handed. To investigate whether asymmetries in hand preference and motor control are associated with asymmetries in neural control by central and peripheral nervous systems, further research is needed.

Muscle latency time and muscle recruitment patterns using electromyograph (EMG) have been often used to understand neuromuscular mechanisms for upper extremity control in individuals with and without diseases (Cools et al, 2002; Cools et al, 2003; Peters et al, 2018; Sabatini, 2002; Wagner et al, 2007). Cools et al (2002) evaluated muscle latency times of anterior deltoid, upper, middle, and lower trapezius muscles in normal shoulders during unexpected arm movements. They found that muscle latency time of the anterior deltoid was shorter than all portions of the upper trapezius, and the muscle activation pattern was not altered with fatigue but delayed. More recently, Wagner et al (2007) studied muscle activation and recovery of upper extremities during reaching movements in acute and subacute stages of stroke patients, and age-matched control subjects. Findings were that muscle activations of upper extremity muscles in control subjects occurred prior to start of movement, whereas the hemiparetic group had delayed muscle onsets. After partial recovery in the subacute phase, muscle onsets were similar to normal subjects.

Despite that muscle latency times and patterns are used as broad examination tools for monitoring recovery, there is a lack of studies that compare dominant to non-dominant arms in muscle latency time and recruitment patterns. To our knowledge, there are no muscle physiological studies that have been conducted to understand the difference between reaching and reach-to-grasp movements as movement speed changes. Grosskopf et al (2006) reported no significant effects of hand for reaction time during the reach-to-grasp task in both the fast and preferred conditions, while others found that left-handed participants showed shorter reaction times than right-handed (van Doorn, 2008). A basic feature such as muscle latency time and patterns of the right and left hands are inadequate.

Therefore, the purpose of this study was to investigate dominant and non-dominant arm differences in muscle latency time and recruitment patterns during reaching and reach-to-grasp movements. In addition, by manipulating the speed of movement, we examined the effect of movement speed on neuromuscular control of both right and left hands.

Methods

Subjects

The demographic characteristics and information of the 28 subjects, which include gender, age, height, weight, and edinburgh handedness inventory (EHI) score are shown in Table 1. Healthy, young adults (n=28; 14 men, 14 women) were recruited from the J University. Inclusion criteria were right handedness as measured by Edinburgh Handedness Inventory (Oldfield, 1971) and the ability to move upper extremities without problems and understand experimental instructions. Exclusion criteria were pres-

Table 1. Participant's characteristics (N=28)

Variable	Right handed
Gender (male/female)	14/14
Age (years)	22.1±2.3[a]
Height (㎝)	166.3±8.1
Weight (㎏)	64.3±13.1
EHI[b] (%)	83.3±13.4

[a]mean±standard deviation, [b]Edinburgh Handedness Inventory.

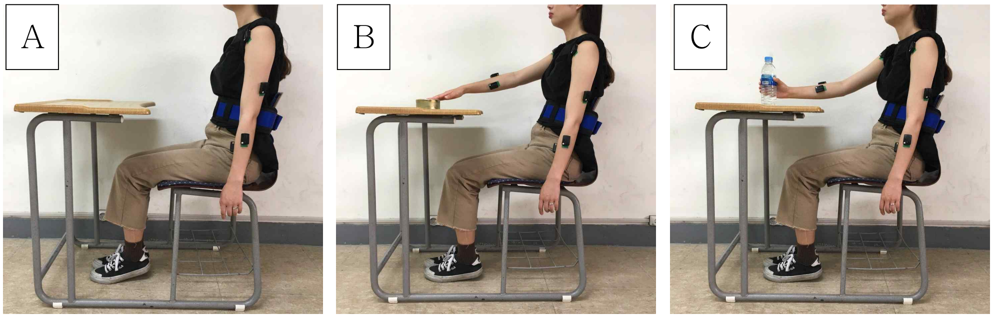

Figure 1. A: starting position, B: reaching, C: reach-to-grasp.

ence of neurological or musculoskeletal diseases and previous upper extremity surgery six months prior to the start of the experiment. All subjects understood the purpose of this experiment and agreed to consent information.

Instrumentation

Surface EMG (wireless Trigno EMG system, Delsys Inc., MA, USA) was used to measure muscle latency time and recruitment patterns in both right and left upper extremities. After removing excessive hair, skin was abrasively wiped with an alcohol pad. The electrodes were attached to the prepared skin using double-sided tape. Once the electrode signal quality was assessed, the electrodes were secured with a light wrap of CobanTM or tape to minimize changes in the electrode locations. Surface EMG data were collected on each arm from four upper extremity muscles: anterior deltoid (AD), triceps brachii (TB), flexor digitorum superficialis (FDS), and extensor digitorum communis (ED). These muscles are the primary muscles for reaching and grasping, as shown in previous studies (Peters et al, 2018; Wagner et al, 2007). Electrodes were placed parallel to each muscle based on the recommendations from the surface EMG for a non-invasive assessment of muscles (SENIAM). The AD electrode was placed at one finger width distal and anterior to the acromion. The TB electrode was placed at 50% on the line between the posterior acromion and the olecranon at two finger widths medial to the line, as recommended by the SENIAM (Hermens et al, 2000). The FDS electrode was placed at the distance along the forearm from the medial epicondyle of the elbow and the distance from the medial border of the forearm (Butler et al, 2005). The ED electrode was placed in the middle of the forearm, approximately half the distance between the radial and ulnar borders (Mogk et al, 2003). Our EMG system contained the accelerometer, thus, during movement, we obtained both the raw EMG signals sampled at 1,920 ㎐ and the raw accelerometer signals sampled at 148 ㎐.

Experimental procedures

The subject sat down with their back to a chair and their trunk was fixed with a belt to prevent compensational movements during experiments (Carr et al, 2004). At the starting position, subjects placed their shoulder and elbow joints at 0°, and hip and knee joints at 90° flexion with eyes closed (Figure 1A). The subjects were instructed to either reach or reach-to-grasp the objects presented at 50 ㎝ straight from each person's navel on their belt. For the reaching task, a cylinder (10 ㎝ in diameter and 4 ㎝ in height), while a water bottle (5.5 ㎝ in width and 15 ㎝ in height) was used for the reach-to-grasp task (Figure 1B, 1C). There were two movement speed conditions; a fast condition where the subjects moved as fast as they could, and a preferred condition, where subjects moved at their preferred speed. Two experimenters conducted all test procedures. One experimenter operated the EMG system and gave a start signal by saying “start”. The other experimenter wore an accelerometer on their right arm and moved it with start cue. This accelerometer data was used as a stimulus signal during signal processing (see

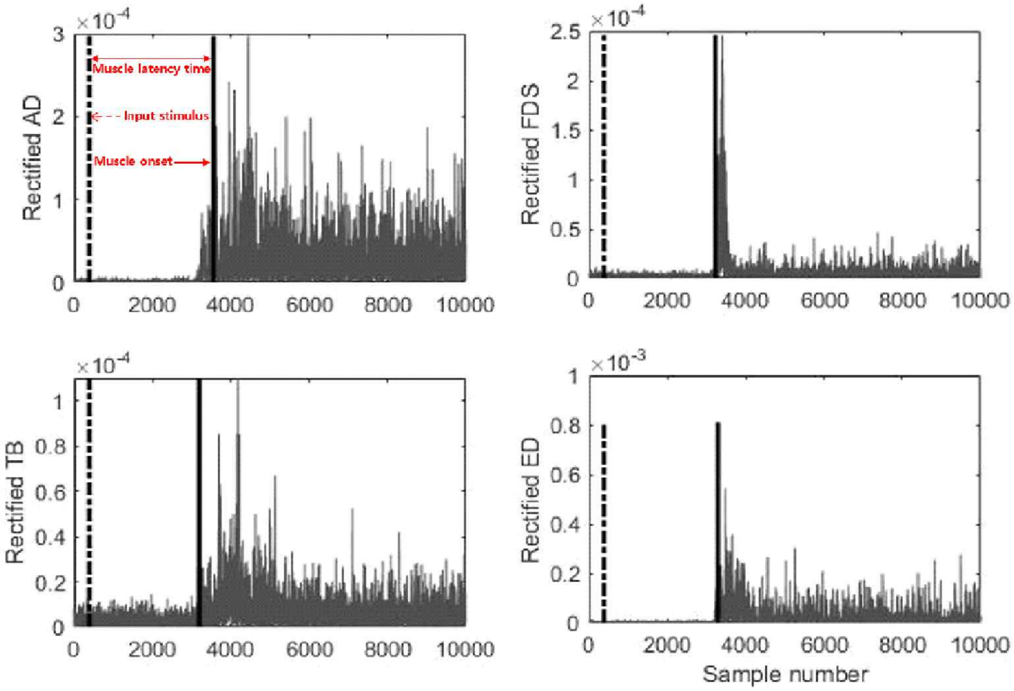

Figure 2. The example of defining muscle latency time from one representative. Dashed line: the accelerator on the experimenter's hand was used as a stimulus input. Thick line: muscle onset, which was a first point exceed three SD of baseline activity. Muscle latency time is defined as a period between stimulus input (dashed line) and muscle onset (thick line).

below). When given the start signal, the subject reached or reached-to-grasp toward the target object after opening their eyes. Once the subject reached toward or held the object, they maintained that position for 5 seconds and returned to the starting position. The experimental order for two tasks (reaching and reach-to-grasp), two conditions (fast and preferred speed conditions), and two hands (right and left hands) were randomized using the Latin square method. The subjects repeated each movement three times and first movement was used for the further data analysis.

Signal processing and data analysis

All raw EMG signals were full-wave rectified and band-pass filtered (single pass, Butterworth, 10-500 ㎐ bandpass filter of the fifth order) with a notch filter for rejection of 60 ㎐. After rectifying, filtering, and normalizing, data were processed into the root mean square with a window of 150 ㎳. Muscle latency response was determined by the period between the input stimulus from the accelerometer on the experimenter and muscle onset. To define muscle onset, the mean and standard deviation (SD) of baseline activity 200 ㎳ prior to stimulus input were calculated. The first time point that the EMG signal was above three SD of baseline activity and maintained for at least 50 ㎳ was described as the muscle onset time. If the baseline activity was too high or low, 50% of the peak EMG activity was defined as the muscle onset time (Suehiro et al, 2018; Cowan et al, 2001; Gilleard et al, 1998). Custom software was written in MATLAB (Mathworks, Massachusetts, MA, USA) for signal processing and muscle latency time. The example for calculating muscle latency time for one representative is shown in Figure 2.

Statistical analysis

Differences in muscle latency time between hands, conditions, and tasks were analyzed using mixed models with individuals taken as random effects. In this statistical model, hand (two levels), condition (two levels), and task (two levels) were fixed factors and categorical variables. As a sub-analysis, in each reaching or reach-to-grasp task conditions, muscle activation patterns were studied using mixed models. Post-hoc analyses were performed using the Tukey Test to correct for multiple comparisons. Statistical significance levels were set to .05 and all results are reported as average ± SD. The statistical analyses were carried out using R Statistical Software (R statistical software, R Core Team, Vienna, Austria).

Results

The descriptive statistics for the muscle latency times are summarized in Table 2. There were no significant differences in muscle latency time between dominant and non-dominant hands, or between reaching and reach-to-grasp tasks (p>.05). However, there was a significantly longer muscle latency time in the preferred speed condition than the fast speed condition on both reaching and reach-to-grasp tasks (p<.05) (Figure 3). For muscle activation patterns, the FDS muscle latency time was significantly longer than for AD, TB, and ED muscles during the reaching task, but this longer latency time become similar to other muscles during the reach-to-grasp task, where all muscles were activated simultaneously (p<.05).

Discussion

In this study, we examined interlimb differences in muscle latency time and recruitment patterns of anterior deltoid, triceps brachii, flexor digitorum superficialis, and extensor digitorum communis muscles. Subjects made reaching and reach-to-grasp movements with preferred and fast speeds. When given the start signal, the subject reached toward or held the object after opening their eyes, they maintained that position for 5 seconds and returned to the starting position. Both arms performed the task equally well, as there were no significant differences in muscle latency time and activation patterns. However, the fast condition had shorter muscle latency time than those of the preferred condition for both arms.

Muscle latency times for right and left hands were not significantly different, regardless of task conditions and movement speed. In an analogous task to that studied here, van Doorn (2008) revealed that the reaction time for the left hand was 30 ms faster the right hand during a frontal reaching movement using a hand-held stylus. In addition, the left hand took longer to execute movements than the right hand, suggesting that the left hand increases movement accuracy by reducing reaction time, but increases movement execution time required for overcoming the left hand's inherent noise and less-accurate

Table 2. Muscle latency times (Unit : ms)

		Reaching		Reach-to-grasp	
	Hand side	Preferred speed	Fast speed	Preferred speed	Fast speed
AD[a]	Dominant	1284.98±880.08	896.40±621.62[b]*	1229.47±866.45	1030.39±729.47*
	Non dominant	1388.82±887.21	962.01±678.84*	1245.07±917.57	1293.01±780.22*
TB[c]	Dominant	1326.10±678.72	1121.20±679.32*	1785.74±1702.39	1056.99±648.64*
	Non dominant	1223.71±850.63	1073.34±587.37*	1472.08±863.98	909.01±569.99*
FDS[d]	Dominant	1383.16±698.23†	1111.39±555.21*†	1464.55±822.35†	1057.63±605.29*†
	Non dominant	1630.11±921.87†	1180.75±757.21*†	1541.06±1805.01†	930.17±648.25*†
ED[e]	Dominant	1289.22±754.57	1015.31±572.62*	1450.24±747.20	1243.94±585.69*
	Non dominant	1265.60±767.32	948.59±567.66*	1408.88±817.33	1192.26±508.67*

[a] anterior deltoid, [b] mean±standard deviation, [c] triceps brachii, [d] flexor digitorum superficialis, [e] extensor digitorum communis, *significant difference between preferred speed and fast speed (p<.05), † significant difference of FDS from other muscles (p<.05).

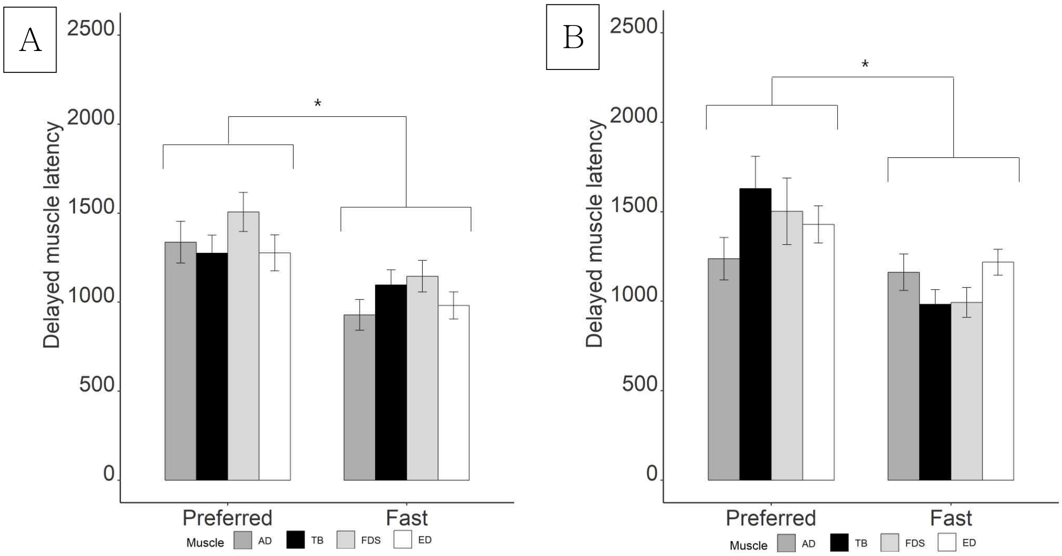

Figure 3. The average muscle latency times for all muscles during reaching and reach-to-grasp movements across all subjects. Each bar indicates each upper extremity muscle (A: reaching, B: reach-to-grasp).

movements (Annett et al, 1979; Carson, 1992; Carson et al, 1993b). Contrarily, other studies have reported that reaction time for left and right hands were similar in both the fast and preferred conditions (Grosskopf et al, 2006).

Although muscle latency time in our study can be viewed as a proxy of the movement preparation, similar to reaction time, it does not necessarily indicate that the actual movement starts from the muscle onset point. It is possible that the initial muscle activation for the left and right hands occurs simultaneously, but that the left hand requires less time for starting movements it relies on online feedback control. Alternatively, the right hand uses the 'feedforward' strategy; thus, it may require more time from muscle onset to movement start to prepare the proceeding movement (Yadav et al, 2014). Further research is needed to support this idea.

Upper and forearm muscles in this study demonstrated distinct task-related activation patterns. During the reaching task, muscle latency time of the FDS was longer than those of the AD, TB, and ED (Tukey's honest significant difference, p<.03 for all). In contrast, the FDS activated simultaneously with other muscles during the reach-to-grasp task. This is a similar result of the previous studies showing that wrist flexors and extensors were activated later than those of the AD, posterior during simple reaching movements (Wagner et al, 2007). This task-specific muscle activation might be due to specific circuits performing a sensorimotor transformation of the object's visual properties and task environment into a set of motor commands that will result in the appropriate preparation of upper extremity muscles for completing the task efficiently (Jeannerod et al, 1995). This transformation involves a parieto-frontal circuit, where the posterior parietal cortex reconstructs and interprets properties of the object, and the ventral premotor area selects the type of movement to be performed (Stark et al, 2007; Murata et al, 1997; Luppino et al, 2000). These areas are also involved in motor planning and the preparation for both stimulus-triggered and voluntary movements (Cisek et al, 2010; Shenoy et al, 2013); thus, the short muscle latency time in the fast condition in this study might be due to programmed controls from these areas.

The limitations of this study were that subjects initiated the reaching movement when they heard the "go" cue with their eyes closed. After the "go" cue, they opened their eyes and found the target location.

This experimental design led to longer muscle latency time compared to other studies. Also, the fact that each subjects developed the individual strategies to avoid hitting the desk may act as a confounding factor in this study. In addition, since the accelerator on the experimenter's hand was used as a stimulus input for muscle latency calculation, our data might be less accurate than other devices, such as the electrical switch to indicate stimulation. Although subjects were instructed to relax their arm at the starting position, they could not completely rest their upper extremities due to the effect of gravity. This might lead to early activation of the TB muscles, among others. Future investigations should emphasize muscle recruitment patterns and muscle latency time combined with a kinematic variable, such as reaction time or velocity, to better understand the anticipatory control of upper extremity movements for the right and left hands.

Conclusion

This study revealed that left and right hands are similar in muscle latency time and muscle recruitment patterns during reaching and reach-to-grasp tasks in young healthy adults. Both arms showed similar muscle latency time and muscle activation patterns with respect to movement speeds and tasks. Our findings provide normative muscle physiology data for both right and left hands. Therefore, it will be helpful to understand abnormal movements from patients and can be the basic information to investigate the neurological, physiological, and biomechanical differences between dominant and non-dominant hands.

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