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Characteristics of Finger Muscle Activity Due to Differences in Wrist Joint Alignment: A Study Using Surface Electromyography

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Abstract

Background: In 2017, Tanabe *et al.* developed a technique to activate the extensor digitorum communis in hemiplegic stroke patients. However, there has not yet been sufficient analysis of this technique for activating the extensor muscles. Therefore, this study aimed to apply this method to healthy subjects and clarify the activity of the flexor and extensor muscles using surface electromyography. **Method:** This study included 17 healthy subjects. Surface electromyography was measured for the extensor digitorum communis and flexor digitorum superficialis muscles while participants pushed forward under three conditions: condition 1 (wrist dorsiflexion), condition 2 (wrist neutral), and condition 3 (wrist palmar flexion). The data obtained from surface electromyography was digitally processed and divided by maximum muscle output to calculate the % maximal voluntary contraction (%MVC). Additionally, the simultaneous co-contraction index (%CCI) was calculated. The %MVC and %CCI for each condition were analyzed using a Friedman test, with a Dunn test conducted as a post-hoc analysis. **Results:** Significant differences ($P < 0.001$) were observed between conditions for both %MVC and %CCI. In terms of %MVC, the flexor digitorum superficialis was significantly ($P < 0.001$) greater than the extensor digitorum communis in condition 1. In conditions 2 and 3, the extensor digitorum communis was significantly ($P < 0.02$) greater than the flexor digitorum superficialis. Furthermore, the activity of the extensor digitorum communis was significantly ($P < 0.001$) greater in conditions 2 and 3 than in condition 1. For %CCI, condition 2 was significantly ($P < 0.001$) greater than conditions 1 and 3. **Conclusion:** The muscles acting on the fingers were selectively affected by the positional relationship of the wrist. This confirms that the method developed by Tanabe *et al.* for activating the extensor digitorum communis can effectively promote its activation.

Keywords

Surface Electromyography, Extensor Digitorum, Co-Contraction, Wrist Joint Alignment

1. Introduction

Chronic upper limb dysfunction due to hemiplegia after a stroke is a major factor that reduces independence in activities of daily living (ADL) and quality of life (QOL) [1]. One significant challenge in utilizing the paralyzed upper limb is the inability to automatically extend the fingers [2].

In clinical practice, methods have been reported to induce finger extension by controlling abnormal muscle tone through electromyography-triggered neuromuscular stimulation and botulinum toxin type A administration [3] [4]. However, these methods require expensive equipment or are highly invasive, making them difficult for physical and occupational therapists to implement in clinical settings.

Figure 1. The wrist is flexed and the second to fifth fingers are held in a fully extended position, and the elbow is extended while applying optimal resistance to the fingertips.

In this context, Tanabe *et al.* developed a technique to facilitate the extensor digitorum communis muscle in the paralyzed hand due to central nervous system disease, successfully restoring finger movement in severely hemiplegic hands [5] [6]. This facilitation method involves the following: 1) fixing the wrist on the affected side in a palmar flexion position while keeping the fingers fully extended and applying resistance to the fingertips and 2) performing an extension movement of the elbow joint. These two factors increase the muscle output of the extensor digitorum communis (**Figure 1**). Tanabe *et al.* hypothesize that in this method, the threshold of the tendon spindles in the stretched finger flexor muscles is higher than that of the muscle spindles, and that excessive stretching inhibits the flexor muscles, thereby increasing output in favor of the extensor muscles. However, since Tanabe *et al.* focused solely on the paralyzed upper limb of hemiplegic patients, their analysis may not be comprehensive. Therefore, the purpose of this study is to use surface electromyography to enhance our biomechanical and neurophysiological understanding of how the balance between flexor and extensor muscle activity is affected when an environment simulating this facilitation method is created in healthy individuals.

2. Methods

2.1. Subjects

Study subjects were recruited by distributing a recruitment notice to students and staff of a vocational school. A total of 17 out of 18 applicants participated in the study (mean age, 30.8 ± 11.9). The exclusion criteria included a lack of history of surgery or injury to the upper limbs or fingers and no functional impairments that would interfere with daily life. One subject was excluded due to a fingertip injury that caused pain during task performance. The purpose of the study was explained to participants both in writing and verbally, and they were informed that they could withdraw their consent at any time. The study was conducted with the approval of the Reiwa Health Science University Ethics Committee (approval number: 23-038).

2.2. Experimental Environment

As shown in **Figure 2**, subjects sat on a chair (45 cm above the floor) with their shoulder joint bent at 90˚. An intravenous injection table was provided to support the upper arm, adjusted so that the fingertips were just touching the chair. An isometric dynamometer (μTas F-1, ANIMA) was positioned on a pillar, and the subjects maintained a basic position (**Figure 2**). A surface electromyograph (Clinical DTS NORAXON) was used to measure two muscles: the extensor digitorum communis and flexor digitorum superficialis. To minimize electrical resistance, cotton wool soaked in alcohol was used to prepare the skin, and disposable electrodes (Blue Sensor N-00-S, Ambu) were attached to the extensor digitorum communis and flexor digitorum superficialis of the measurement limb. The electrodes were positioned where muscle contraction was most easily palpable during resistance exercises of the middle finger, and the experiment proceeded after confirming that the electromyographic waveform could be recorded during automatic exercise (**Figure 3**).

Figure 2. Experimental environment.

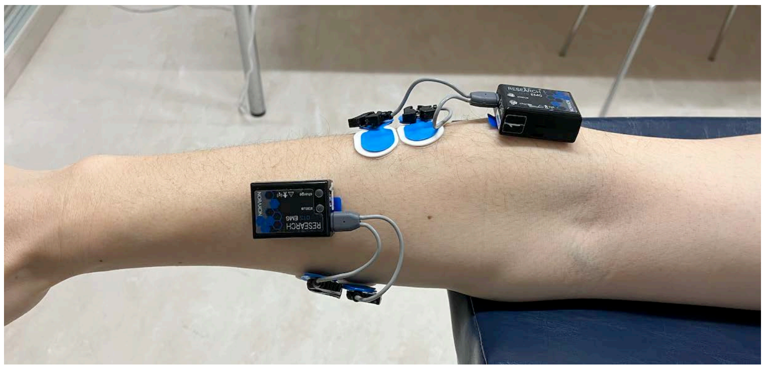

Figure 3. FDS and EDC electrode placement positions.

2.3. Experimental Procedure

To examine the effect of wrist position, subjects performed forward pushing three times under the following conditions. To control pushing strength, subjects were instructed to push until the isometric dynamometer indicated a force of 3 kg, with several practice attempts prior to the experiment.

Condition 1: Elbow extended, wrist dorsiflexed, fingers extended.

Condition 2: Elbow extended, wrist in a neutral position, fingers extended.

Condition 3: Elbow extended, wrist palm flexed, fingers extended.

Conditions 1 to 3 were performed in random order for each subject (**Figure 4**).

Figure 4. Wrist position for each condition.

2.4. EMG Measurement and Waveform Processing

The sampling frequency was set to 1500 Hz, with the bandpass filter frequency band adjusted to 20 - 450 Hz to remove artifacts. For quantitative analysis of the EMG, smoothing digital waveform processing was performed using the root mean square in the MYO MUSCLE system (VerMR3,14,28. NORAXON Co.), followed by calculation of the % maximum voluntary contraction (%MVC) by dividing by the maximum muscle output. Maximum muscle output was measured through isometric contraction against maximum resistance from the examiner for 3 seconds, with the peak value used for analysis.

2.5. Calculation of the Co-Contraction Index

To assess the degree of simultaneous contraction of the flexor and extensor muscles during movements in conditions 1 to 3, the co-contraction index (CCI) of the extensor digitorum communis and flexor digitorum superficialis during the pushing movement was calculated.

The CCI was calculated using the following formula [7] based on data processed during electromyography measurement to determine the CCI (%) of the flexor digitorum superficialis and extensor digitorum communis.

2.6. Statistical Processing

An assessment of the normality of the obtained %MVC and %CCI data indicated that normality could not be guaranteed (**Table 1**). Because repeated measurements were performed on three paired groups, a nonparametric Friedman test was conducted on the %MVC and %CCI for each condition, followed by a Dunn test as a post-hoc analysis.

Table 1. %MVC Normality test results for each condition and muscle.

	Ave.	SD	Shapiro-Wilk W	P value
FDS				
Condition① Dorsiflexion	24.64	14.06	0.83	0.0048
Condition② Middle	13.05	9.12	0.835	0.0051
Condition③ Palmarflexion	7.55	4.52	0.931	0.207
EDC				
Condition① Dorsiflexion	7.6	5.62	0.711	0.0001
Condition② Middle	22.4	11.78	0.938	0.275
Condition③ Palmarflexion	26.84	8.79	0.955	0.509

3. Results

The Friedman test revealed significant differences between conditions for both %MVC and %CCI. Consequently, a Dunn test was conducted as a post-hoc analysis to identify which specific data points exhibited significant differences. In condition

1, the %MVC of the flexor digitorum superficialis was significantly greater ($P < 0.001$) than that of the extensor digitorum communis, and in condition 2, it was significantly greater ($P < 0.05$) than that of the flexor digitorum superficialis. In condition 3, the %MVC of the extensor digitorum communis was significantly greater ($P < 0.001$) than that of the flexor digitorum superficialis (**Table 2**). Additionally, when comparing each muscle across conditions, the %MVC value of the flexor digitorum superficialis was significantly higher in condition 1 (dorsiflexion) than in condition 2 (intermediate position) ($P < 0.01$) and condition 3 (palmar flexion) ($P < 0.001$). Conversely, the %MVC value of the extensor digitorum communis was significantly higher in condition 2 (intermediate position) ($P < 0.001$) and condition 3 (palmar flexion) ($P < 0.01$) than in condition 1 (dorsiflexion) (**Table 3**). No significant difference was found between condition 2 (intermediate position) and condition 3 (palmar flexion). Regarding %CCI, condition 2 was significantly greater than both conditions 1 and 3 (both $P < 0.001$) (**Table 4**).

Table 2. Comparison of %MVC between FDS and EDC in each condition.

	FDS	EDC	FDS vs EDC
Condition① Dorsiflexion	24.64 ± 14.06	7.6 ± 5.62	***
Condition② Middle	13.05 ± 9.12	22.4 ± 11.78	*
Condition③ Palmar flexion	7.55 ± 4.52	26.84 ± 8.79	***

Dunn's test for multiple comparisons * P<0.05 *** P<0.001

Table 3. Comparison of %MVC between conditions for each muscle.

	Condition① Dorsiflexion	Condition② Middle	Condition③ Palmar flexion
FDS	24.64 ± 14.06	13.05 ± 9.12	7.55 ± 4.52
FDS: ① vs ② / ② vs ③ / ① vs ③	*	ns	***
EDC	7.6 ± 5.62	22.4 ± 11.78	26.84 ± 8.79
EDC: ① vs ② / ② vs ③ / ① vs ③	***	ns	***

Dunn's test for multiple comparisons * P<0.05 *** P<0.01

Table 4. Comparison of %CCI between conditions.

Condition① Dorsiflexion	Condition② Middle	Condition③ Palmar flexion
40.84 ± 15.69	60.35 ± 20.86	44.00 ± 21.25
① vs ②: ***	② vs ③: **	① vs ③: ns

Dunn's test for multiple comparisons ** P<0.01 *** P<0.001

4. Discussion

In this study, surface electromyography was performed to assess the facilitation method for the extensor digitorum communis, a finger extensor muscle, as presented by Tanabe *et al.* The aim was to confirm muscle activity in terms of %MVC and simultaneous contraction activity with the antagonist muscle measured in %CCI. The activities of the extensor digitorum communis and the flexor digitorum superficialis, identified as the antagonist muscle, were measured and compared by altering the wrist position. The results indicated that in condition 1, when pressing in the dorsiflexed position, the activity of the flexor digitorum superficialis selectively increased. In condition 3, pressing in the palmar flexed position, the activity of the extensor digitorum communis selectively increased. In condition 2, when in a neutral position, both the flexor digitorum superficialis and the extensor digitorum communis exhibited simultaneous contraction.

The increase in muscle activity of the extensor digitorum communis in condition 3 (palmar flexion) supports the notion that the method presented by Tanabe *et al.* is an effective, evidence-based, non-invasive treatment technique routinely used by occupational therapists.

From a biomechanical perspective, the results suggest that the wrist joint angle significantly influences muscle exertion. Yamamoto *et al.* reported that antagonistic muscle activity counteracts the ground reaction force vector's action relative to joint position [8]. Murray *et al.* also noted that the rotational moment increases as the moment arm radius grows [9]. Consequently, during pushing in condition 1 (dorsiflexion) or condition 2 (palmar flexion), the moment arm is extended relative to the axis of each finger joint compared to the neutral position. This suggests that in condition 1, the contraction of the flexor digitorum superficialis (a finger flexor) is enhanced, while in condition 3 (palmar flexion), the contraction of the extensor digitorum communis (a finger extensor) is increased. Additionally, the increased muscle tension in both the extensor digitorum communis and the flexor digitorum superficialis may improve contraction efficiency due to mechanical stretching from the change in wrist joint angle, consistent with the "length-tension relationship" [10] [11]. In condition 2, %CCI was significantly higher than in conditions 1 (dorsiflexion) and 3 (palmar flexion), suggesting simultaneous contraction of the flexor digitorum superficialis and extensor digitorum communis, interpreted as a joint stabilization strategy through the concurrent contraction of antagonistic muscles. Smith identified three scenarios where simultaneous contraction is likely to occur: 1) when precisely controlling tension and joint angle, 2) when decelerating at high speed or under load, and 3) when grasping an object [12]. Furthermore, multiple studies have reported that simultaneous contraction of agonist and antagonist muscles increases joint stability [13] [14]. These findings suggest that pushing in condition 2 (intermediate position) is essential for maintaining and stabilizing the MP and IP joints of the fingers.

The changes in finger muscle activity due to the wrist joint angle observed in this study suggest not only biomechanical factors, but also the involvement of the central nervous system, such as reciprocal inhibition, co-contraction control, and even the "posture-dependent motor facilitation" reported by Bizzi *et al.* (2000) [15]. For example, in condition 3, palmar flexion, the stretching stimulus to the extensor digitorum communis increases the activity of Ia afferent fibers, suggesting the possibility that it functions as a "preparatory posture" that influences the selection of motor modules at the spinal cord level and increases the output of EDC. In addition, the %CCI was significantly higher in condition 2, intermediate position, as Nielsen *et al.* (1993) [16]. Reported that reciprocal inhibition is suppressed during co-contraction, and that it is regulated by higher central nerves such as spinal interneurons and the cerebral cortex.

One limitation of this study is that, due to the use of surface electromyography, it was not possible to measure the electromyograms of all muscles related to finger movement, limiting the analysis to the flexor digitorum superficialis and extensor digitorum communis. Consequently, it is not feasible to determine the activity of other finger-related muscles due to wrist joint angle changes. Additionally, since measurements were conducted on healthy subjects, there is uncertainty regarding the direct applicability of the results to patients with central nervous system disorders, such as those with cerebrovascular disease. However, Tanabe *et al.* reported outcomes like reduced spasticity and improved voluntary finger extension. Thus, conducting similar measurements in patients with cerebrovascular disease in the future could provide valuable insights into high-clinical-value interventions aimed at restoring voluntary movement in individuals with chronic hemiplegia in a landscape increasingly focused on evidence-based practices.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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