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Original Article

Unilateral vibration stimulation decreases F-wave persistence and F/M amplitude ratio in contralateral homonymous muscle corresponding to the stimulated muscle during stimulation

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Abstract. [Purpose] This study aimed to examine the effects of unilateral vibratory stimulation on contralateral homonymous muscle. [Participants and Methods] The study included 14 participants without a history of any disease. Participants were tested under three separate conditions: vibratory stimulation, pressure stimulation, and rest. F-waves were measured at two time points for 15 seconds in the rest position under each of the testing conditions. [Results] The F/M amplitude ratio analysis showed interactions between the vibratory stimulation–pressure stimulation and vibratory stimulation–rest conditions. The F-wave persistence analysis demonstrated interactions between the vibratory and pressure stimulation conditions. Vibratory stimulation significantly decreased the F/M amplitude ratio and F-wave persistence at two time points, before and during the stimulation. [Conclusion] The vibratory stimulation used in this study could suppress the contralateral homonymous muscle tone.
Key words: Muscle vibration, F-wave, Muscle tonus

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INTRODUCTION

Spasticity is a typical clinical manifestation of cerebrovascular diseases, which significantly impacts activities of daily living[1)]. The effectiveness of vibratory stimulation[2)], functional electrical stimulation[3)], and thermotherapy[4)] in suppressing muscle tension has been investigated. Among these therapeutic modalities, vibratory stimulation is characterized by its simplicity and reproducibility; moreover, its effectiveness does not depend on proficiency in performing this technique.

Vibratory stimulation suppresses muscle tone by directly stimulating the muscles affected by spasticity, or by stimulating the antagonist muscles corresponding to the affected muscles[5, 6)]. However, the effect of vibratory stimulation on suppressing muscle tone persists only during the period of stimulation, and is impaired immediately when the stimulation is terminated[7)]. Exercise therapy after vibratory stimulation in rehabilitation can result in high muscle tone recurring.

One method of applying vibratory stimulation is to stimulate the contralateral homonymous muscle of the affected muscle. Applying unilateral vibratory stimulation decreases the muscle strength of the contralateral homonymous muscle[8)]. Furthermore, the central nervous system may be involved in this reduction in muscle strength, which can be viewed as being caused by reduced muscle tonus. This method may enable vibratory stimulation and other exercise therapies to be combined without interfering with the movement of the affected muscles.

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A close relationship exists between muscle tone and electrophysiological tests, demonstrating the interventional effects of vibratory stimulation. The F-wave is representative of such tests[9–11)]. The F-wave is a compound action potential obtained from the dominant muscle following retrograde electrical stimulation to the motor nerve through the axon and repeated firing in the anterior horn cells of the spinal cord. Such stimulation can be conducted from a variety of muscles. F-wave persistence is defined as the number of times an F-wave can be recorded for all stimuli; it is the average amplitude value of the F-wave divided by the maximum M-wave amplitude value expressed as a percentage value. The F/M ratio is a measure of the spinal cord anterior horn cell excitability, which indicates the degree of muscle tone. However, the effect of applying unilateral vibratory stimulation on the tonus of the contralateral muscle to the affected one is unclear. If unilateral vibratory stimulation affects muscle tonus contralateral to the affected area, it is expected that indices of excitability in the anterior horn cells of the spinal cord, such as the F/M ratio and F-wave persistence, would decrease during stimulation compared to the pre-stimulation baseline.

Therefore, in the present study, we examined the effect of unilateral vibratory stimulation on the tone of the contralateral homonymous muscle using the F-wave, a well-established index for evaluating muscle tone.

PARTICIPANTS AND METHODS

Fourteen healthy adults (age 26 ± 3.0 years) with no orthopedic or neurological history participated in this study. G Power (ver. 3.1.9.7) (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) was used to calculate the required sample, with F test as the test family and ANOVA as the statistical test: Fixed effects, special, main effects and interactions, Effect size as 0.4, α err prob as 0.05, Power as 0.8, Numerator dv as 1 and Number of groups as 3. The test family was F test, statistical test was ANOVA: fixed effects, special, main effects and interactions, Effect size was 0.4, α err prob was 0.05, Power was 0.8, Numerator dv was 1, and Number of groups was 3. All the participants received prior verbal and written explanations of the study content and ethical considerations to ensure adequate understanding, for example, of the risks and freedom to participate. We then asked them to cooperate in the study and obtained their written informed consent. The study conformed to the guidelines of the Declaration of Helsinki and the Research Ethics Review Committee of Kansai University of Health Sciences approved the study (approval number 21-25) before the experiments were conducted. All the participants sat at rest in a chair and underwent the three conditions of vibratory stimulation, pressure stimulation, and rest. We measured the F-wave at two time points before and during 15 seconds of stimulation in each condition. Each condition was performed on the same day, and the order in which they were performed was randomized so that participants did not feel familiarity or fatigue, which may have affected the results. In the vibratory stimulation condition, vibratory stimulation was applied to the muscle belly portion of the left short abductor pollicis brevis (APB) muscle (Fig. 1)[8, 12)]. The detailed settings for the condition were frequency 80 Hz, amplitude 0.4 mm, stimulation time 15 seconds, and pressure 400 g[13–16)]. We also checked the movement of the thumb that the tonic vibration reflex produced to confirm whether the muscles were stimulated during this condition[17)].

The pressure stimulation condition was then set to eliminate this confounding factor since the pressure stimulation was provided at the same time as the vibratory stimulation. As in the vibratory stimulation condition, we set the pressure to 400 g and applied it continuously to the APB muscle for 15 seconds. A muscle–tendon vibratory stimulation device, MGV-1000-F (Uchida Electron Co., Ltd., Tokyo, Japan; Fig. 2) was used to apply vibratory and pressure stimulations. We recorded the F-waves at two time points during rest.

We recorded the F-waves with a Neuropack S3 (Nihon Kohden Co., Ltd., Tokyo, Japan). For stimulating electrodes, the cathode was placed 3 cm proximal to the most distal wrist crease, and the anode was placed 2 cm proximal to the wrist crease. For F-wave recordings, the APB, a purely median innervated muscle on the psoas muscle and known as the most common

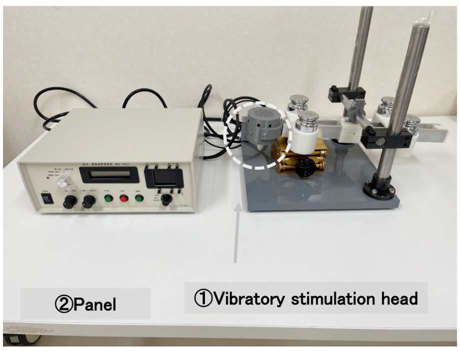

Fig. 1. Muscle-tendon vibratory stimulation device, MGV-1000-F (Uchida electron Co., Ltd., Tokyo, Japan)

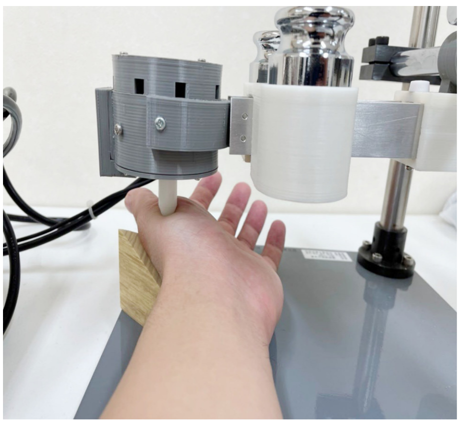

Fig. 2. Stimulation of the abductor pollicis brevis muscle

recording muscle, was selected, and a pair of round disks were attached with collodion to the skin and muscle belly of the APB. The recording conditions for the F-wave were as follows: stimulation site, median nerve; stimulation frequency, 2 Hz; and stimulation duration, 0.2 ms. The minimum amplitude standard for the F-wave was 30 µV or higher[10], and the waveform analysis items were F/M ratio and F-wave persistence. To ensure that the measurement environment did not affect the F-wave results, the measurement time period was set between 17:00 and 19:00, and the room temperature was set at 25°C[18]. Three factors (vibration stimulus, compression stimulus, and rest) and two levels before and during stimulation were treated as fixed effects[19]. However, the Shapiro–Wilk test, normality was rejected. Therefore, we performed a generalized linear mixed model analysis, which can generally be used even when normality is rejected. Interpretation of the results confirmed the interaction between the intervention method and time, and the main effect was confirmed by conducting the Bonferroni corrected Wilcoxon signed-rank test. Effect sizes were also calculated together to compensate for the insufficient number of participants. We performed the statistical analyses using IBM SPSS Statistics for Windows version 28.0 (IBM Corp., Armonk, NY, USA) and set statistical significance at $p<0.05$.

RESULTS

The F/M amplitude ratio of each condition was 1.3% ± 0.4% before and 1.4% ± 0.5% during the pressure stimulation condition, and 1.4% ± 0.5% before and 0.9% ± 0.3% during the vibration stimulation condition. The ratios for the rest condition were 1.3% ± 0.5% before and 1.1% ± 0.5% during stimulation (rest).

The F-wave persistence of each condition was 46.6% ± 11.3% before and 53.1% ± 14.0% during stimulation in the pressure stimulation condition, 53.2% ± 12.7% before and 43.9% ± 12.3% during the vibration stimulation condition, and 53.2% ± 12.7% before and 43.9% ± 12.3% during the rest condition. In the rest condition, we rested 53.0% ± 15.4% and 54.0% ± 14.0% of the participants before and during the stimulation, respectively. Interaction was observed in the F/M ratio ($F[2, 65]=7.055$, $p=0.002$, Table 1). Furthermore, an interaction was observed in the vibratory stimulation–pressure stimulation ($F[3, 39]=8.409$, $p=0.002$, Table 1) and vibratory stimulation–rest ($F[3, 38]=12.535$, $p=0.017$, Table 1) conditions. No interaction was observed in the pressure stimulation–rest conditions ($F[3, 38]=1.504$, $p=0.167$, Table 1).

Interaction was also observed in F-wave persistence ($F[2, 65]=4.980$, $p=0.010$ and $F[3, 39]=4.182$, $p=0.002$, Table 2). No interactions were observed between the vibratory stimulation–rest conditions ($F[3, 39]=3.400$, $p=0.054$, Table 2) and the pressure stimulation–rest conditions ($F[3, 39]=1.582$, $p=0.314$, Table 2).

Table 1. F/M amplitude interaction between each condition

	df (between)	df (within)	F	p-value
Vibratory stimulation condition -Pressure stimulation condition -Rest condition	2	65	7.055	0.002*
Vibratory stimulation condition -Pressure stimulation condition	3	39	8.409	0.002*
Vibratory stimulation condition -Rest condition	3	38	12.535	0.017*
Pressure stimulation condition -Rest condition	3	39	1.504	0.167

*Statistically significant, p<0.05.

Table 2. F-wave persistence Interaction between each condition

	df (between)	df (within)	F	p-value
Vibratory stimulation condition -Pressure stimulation condition -Rest condition	2	65	4.98	0.010*
Vibratory stimulation condition -Pressure stimulation condition	3	39	4.182	0.002*
Vibratory stimulation condition -Rest condition	3	39	1.582	0.054
Pressure stimulation condition -Rest condition	3	39	1.504	0.314

*Statistically significant, p<0.05.

The main effect of the F/M ratio was significantly decreased during stimulation in the vibratory stimulation condition (p=0.001, r=−0.89). However, we found no significant difference in the pressure stimulation (p=0.705, r=−0.42) or rest (p=0.102, r=−0.23) conditions (Table 3). The main effect of F-wave persistence was also significantly reduced during stimulation in the vibratory stimulation condition (p=0.016, r=−0.64), with no significant differences observed in the pressure stimulation (p=0.096, r=0.45) and rest (p=0.688, r=−0.11) conditions (Table 4).

DISCUSSION

In the current study, healthy adults were subjected to the following conditions: a vibratory stimulation condition, in which vibratory stimulation was applied to the left APB muscle for 15 seconds at a frequency of 80 Hz, an amplitude of 0.4 mm, and a pressure of 400 g; a pressure stimulation condition in which pressure stimulation of 400 g was applied to the left APB muscle for 15 seconds, and a rest condition in which rest was maintained for 15 seconds. For the pressure stimulation condition, we applied 400 g of pressure to the left APB muscle for 15 seconds, and for the rest condition, the left APB muscle was held in a state of rest for 15 seconds. The F/M amplitude ratio showed that the pressure and vibratory stimulation conditions were more frequent than the pressure stimulation condition. The F/M amplitude ratio showed a different trend between the pressure and the vibratory stimulation conditions, and between the rest and the vibratory stimulation conditions. Additionally, the F-wave persistence and F/M amplitude ratio obtained from the right APB muscle decreased during stimulation compared with those obtained before stimulation.

The F-wave test used in this study is a typical electrophysiological test for evaluating muscle tonus. The most important feature of this test is that it can be easily derived from the hand muscles, especially the APB muscle. The H-reflex test is another well-known electrophysiological test for testing muscle tonus. However, the H-reflex is generally derived from the flexor carpi radialis and extensor carpi radialis as deriving it from the hand muscles is difficult. Therefore, in the present study, we focused on the muscles of the hand, where spasticity can easily limit activities of daily living, and used the F-wave as an evaluation index. A discussion regarding the fact that pressure stimulation did not decrease the excitability of contralateral spinal cord anterior horn cells follows. Sustained pressure stimulation excites Merkel cells and Ruffini endings, which are classified as slow-adapting receptors on the stimulating side, and gets transmitted to the stimulating side of the spinal cord via Aβ fibers[20, 21]. Stimulation of sensory nerves on one side does not involve commissural interneurons in the spinal cord and does not affect the excitability of the contralateral spinal anterior horn cells[22]. In the present results, pressure stimulation of the unilateral APB muscle did not significantly alter the F/M ratio and F-wave duration obtained from the contralateral APB muscle, suggesting that the pressure stimulation used had no inhibitory effect on the excitability of the contralateral spinal cord anterior horn cells, as in previous studies[22].

Next, a discussion on the fact that vibratory stimulation decreased the excitability of contralateral spinal anterior horn cells is presented below. When the left APB muscle was stimulated using the vibratory stimulation conditions, the excitability of the spinal cord anterior horn cells corresponding to the contralateral APB muscle was decreased. A study by De Gail et al. demonstrated that vibratory stimulation to one side excites the muscle spindles on that side and that sensory information is transmitted into the spinal cord via the Ia fibers[23]. Furthermore, sensory information conveyed via the unilateral Ia fibers inhibits the muscle tone in contralateral homonymous muscles via commissural interneurons in the spinal cord[24, 25]. Therefore, when the contralateral muscle tone is suppressed through unilateral vibratory stimulation, exciting the muscle spindles on the side of the vibratory stimulation is necessary to transmit sensation into the spinal cord via the Ia fibers.

Table 3. Post-hoc test results for F/M amplitude

	Before stimulation Mean (SD)	During stimulation Mean (SD)	p-value	r
Pressure stimulation condition	1.3 ± 0.4%	1.4 ± 0.5%	0.705	−0.42
Vibratory stimulation condition	1.4 ± 0.5%	0.9 ± 0.3%	0.001*	−0.89
Rest condition	1.3 ± 0.5%	1.1 ± 0.5%	0.102	−0.23

*Statistically significant, p<0.05. SD: standard deviation.

Table 4. Post-hoc test results for F-wave persistence

	Before stimulation Mean (SD)	During stimulation Mean (SD)	p-value	r
Pressure stimulation condition	46.6 ± 11.3%	53.1 ± 14.0%	0.096	−0.45
Vibratory stimulation condition	53.2 ± 12.7%	43.9 ± 12.3%	0.016*	−0.64
Rest condition	53.0 ± 15.4%	54.0 ± 14.0%	0.688	−0.11

*Statistically significant, p<0.05. SD: standard deviation.

Moreover, in the present study, we applied vibratory stimuli of an 80 Hz frequency, 0.4 mm amplitude, and 400 g pressure to the muscle belly of the left APB muscle for 15 seconds. These vibration stimulation conditions are different from those used in other studies[23]. In the present study, we employed a perceivable vibration condition so that more Ia fibers were excited by the vibratory stimulus[8, 12–16]. As a result, we succeeded in conditioning the muscle spindles on the side to which the vibration was applied to show increased excitability. Similar to the results reported by De Gail et al.[23], when the intervention was applied, the muscle spindles on the vibratory stimulation side were stimulated as the movement of the thumb produced by the tonic vibration reflex was checked.

In conclusion, stimulation of the unilateral APB muscle using the vibratory stimulation condition set up in this study reduced the excitability of the spinal cord anterior horn cells corresponding to the contralateral APB muscle. This stimulation may have resulted in the F/M ratio and F-wave persistence derived from the contralateral APB muscle being reduced significantly.

Finally, the clinical implications are described below. The results of our study show that vibratory stimulation of the contralateral homonymous muscle corresponding to the affected muscle does not interfere with the movement of the affected muscle. In other words, vibratory stimulation can be easily combined with other exercise therapies used in clinical settings. Previous studies have only clarified the effectiveness of the stretching technique, which requires at least 50 s of stretching[26, 27]. The present results indicate that unilateral vibration stimulation is an effective intervention that uses inhibition of the muscle tonus of the contralateral APB muscle; therefore, inhibiting the muscle tonus earlier than the stimulation time shown in previous studies may be possible. Our results suggest that vibration stimulation may suppress the muscle tonus faster than the stimulation time used in previous studies. Furthermore, vibration stimulation can provide machine-set stimulation and is unlikely to be affected by the skill level of a therapist.

In addition to applying vibratory stimulation to the homonymous muscles corresponding to the affected muscles, the results of the present study suggest that more effective rehabilitation therapy may be provided by combining a technique that promotes exercise therapy for the affected muscles. This aspect is worth further investigation.

In summary, 15 seconds of vibratory stimulation on the left APB muscle, using 80 Hz frequency, 0.4 mm amplitude, and 400 g pressure, reduced F-wave persistence and F/M ratio values in the right APB muscle.

We only examined results for a 15 seconds stimulation time, so determining the most effective stimulation duration is Additionally, as the vibratory stimulation conditions in our study differed from those produced by commonly used vibration stimulation devices in rehabilitation situations, further research is recommended to understand the effective stimulation duration.

Author contributions

Conceptualization, all authors; Methodology, all authors; Investigation, Kenta Kunoh; Writing−Original Draft, Kenta Kunoh; Writing−Review & Editing, all authors; Funding acquisition, None; Resources, None; Supervision, Toshiaki Suzuki.

Conflict of interest

The authors declare that there are no conflicts of interest.

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