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Kinematic Analysis in Reaching Depending on the Localized Vibration Duration in Persons With Hemiparetic Stroke

Yoo, Eun-Young*, Ph.D., O.T., Park, Ji-Hyuk*, Ph.D., O.T., Kwon, Jae-Sung**, Ph.D., O.T., Cho, Sang-Yoon***, Ph.D., O.T., Lee, Bo-Mi****, M.S., O.T., Kim, Yeong-Jo*****, M.S., O.T., Kim, Jae-Nam******, M.S., O.T., Kim, Sun-Ho*******, M.S., O.T.
*Dept. of Occupational Therapy, College of Health Science, Yonsei University, Wonju, Republic of Korea
**Dept. of Occupational Therapy, Cheongju University, Cheongju, Republic of Korea.
***Dept. of Occupational Therapy, Seoul Metropolitan Children's Hospital, Seoul, Republic of Korea.
****Dept. of Long term care, National Health Insurance Corporation, Seoul, Republic of Korea.
*****Jechon Danyang Branch, Daejeon Local Headquarter, National Health Insurance Corporation, Jechon, Republic of Korea.
*****Dept. of Rehabilitation Medicine, Seoul National University Hospital, Seoul, Republic of Korea.
*****Dept. of Occupational Therapy, Youngkwang Hospital, Wonju, Republic of Korea.

Abstract

Objective : Localized vibration has been shown to have a positive effect on recovery of upper-limb motor function in patients with hemiparetic stroke, but there has been little research on kinematic analysis for qualitative changes in movement. This study investigated kinematic changes in elbow motion during reaching after localized vibration in persons with hemiparetic stroke.

Methods : This study used a one-group, cross-over trial design. Ten chronic stroke patients randomly received localized vibrations on the affected biceps brachii for 5, 10, or 20 min, at 70 Hz. Kinematic analysis of reaching was measured using a 3-D motion analysis system. Variables included peak angular velocity, time to peak angular velocity, and movement units during elbow motion.

Result : Affected side elbow motion during reaching was faster, smoother, and more efficient after 20 min localized vibration. Peak angular velocity increased ($p<0.05$), and time to peak angular velocity ($p<0.05$) and the movement unit were significantly decreased ($p<0.05$) during elbow motion for reaching.

Conclusion : Localized vibration can improve kinematic components during reaching motion in persons with hemiparetic stroke.

Key words : Chronic stroke, Localized vibration, Motion analysis, Reaching

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Ⅰ. Introduction

Stroke is the loss of brain function due to disturbance in the blood supply to the brain, typically accompanied motor, sensory, cognitive, and perceptual disorders(Carr & Sherherd, 2003; Zwecker et al., 2002). The primary disorder in hemiparetic stroke is dysfunction of upper extremities, which also affects 85% of all stroke patients(Luke, Dodd & Brock, 2004). The upper extremity dysfunction is due to abnormal muscle tone and movement pattern(Heidi Mchugh & Winifred, 2011).

A variety of treatment methods have been employed in stroke patients to recover upper limb movement. Recently, localized vibration has been gaining traction as means to accelerate rehabilitation of upper extremity dysfunctions(Griffin, 2004). Localized vibration, which works by stimulating the somatosensory system, is regarded as an effective treatment to improve functional movement(Aziz et al., 2000). Vibration provides strong proprioceptive stimuli to muscles to positively affect both healthy individuals and patients with neurological disorders such as hemiparetic stroke and spinal cord injury. Specifically, stimulation of the tonic vibration reflex activates the muscle spindle, which is a more effective method of inducing muscle contraction(Roelants, Verschueren, Delecluse, Levin, & Stijnen, 2006). Thus far, this stimulus has been reported to aid muscle contraction, reduce muscle tone, and improve upper limb function(Griffin, 2004, Maldian, Gottschalk, Patel, Detre, & Alsop, 1999).

Recent studies of vibration treatments on chronic stroke patients have found improvements in upper limb motor function. Caliandro, et al.(2012) reported upper extremity's functional improvement after 100 Hz, repetitive localized (0.2~0.5 mm) vibration stimulations on the affected pectoralis minor, biceps brachii, and flexor carpi muscles three times daily for 10 minutes for three days. Christova, Rafolt, Mayr, Wilfling, and Gallasch(2010) applied localized vibration (60 Hz, 0.5 mm) to a healthy individual for 10 minutes and found that transcranial magnetic stimulation (TMS) activated the individual's contralateral motor cortex. Marconi, et al.(2011) applied localized vibration (100 Hz, 0.2~0.5 mm) three times per day for three days and reported that TMS reduced the abnormal corticospinal excitatory state.

While such studies have set precedents and made strides in the use of localized vibrations for rehabilitation of upper limb function in stroke patients, they have largely been quantitative in nature. For example, precedent studies have focused on quantitative change of muscle tone, muscle contraction, and motor cortex activation. These research efforts have partially confirmed the positive effects of localized vibration on rehabilitation of stroke patients' upper limb functions. However, there is a lack of using kinematic analysis examining the qualitative changes. As a further limitation of previous studies, they have failed to provide qualitative changes in motor function and suggested optimal localized vibration conditions including duration, intensity, and frequency (Hz). Localized vibration application duration have been especially controversial, with recommended duration ranging from 5~60 minutes.

As such, objective application duration for use in clinical trials appear to be limited(Caliandro et al., 2012; Conrad, Scheidt, & Schmit, 2011; Forner-Cordero, Steyvers, Levin, Alaerts, & Swinnen, 2008; Marconi et al., 2011; Noma, Matsumoto, Etoh, Shimodozono, & Kawahira, 2009; Tavernese et al., 2013). Therefore, conventional research findings of quantitative changes in upper limb functions after localized vibration must be validated with respect to the effects on qualitative indicators of upper limb function such as movement coordination and velocity. Studies are also necessary to recommend effective localized vibration duration for clinical settings.

Consequently, the present study investigated two aspects of localized vibration treatment: qualitative kinematic changes in reaching of chronic stroke patients depending on the duration of locally applied vibration; and the optimal vibration duration that yields the maximum qualitative changes in reaching.

Ⅱ. Method

1. Design overview

The present study utilized a one-group cross-over trial design to investigate the optimal localized vibration duration to improve reaching in chronic stroke patients. Study participants were subjected to localized vibrations on their biceps brachii, and qualitative kinematic changes of the reaching were analyzed by using a 3-D motion analysis system. To determine the optimal localized vibration duration, patients were randomly assigned to one of three localized vibration duration groups (5 minutes, 10 minutes, and 20 minutes).

2. Participants

A total of 10 chronic stroke inpatients at the rehabilitation hospital in Korea participated in this study. The participant selection criteria were as follows: (a) hemiparetic stroke, (b) at least a 6 months post- stroke period, (c) ability to follow simple commands, (d) ability to reach towards a target object, (e) absence of unilateral neglect.

The present study (1041849-201310-BM-018-02) was approved by the Institutional Review Board of Yonsei University Wonju Campus; all participants were thoroughly briefed on the research purpose and methods before giving their voluntary consent.

General study participant characteristics are shown in Table 1. The study consisted of 6 males and 4 females. Of these 10 subjects, 6 had right hemiplegia and 4 had left hemiplegia. The average participant age and duration of illness were 58.4 years 53.10 months, respectively. Based on stages described in the Brunnstrom recovery stage, 4 participants were stage 5 and two participants each were stage 3, 4, and 6.

3. Instruments

1) Vibrator

In this study, the vibrator used acoustic vibration was developed through a joint effort between Yonsei University’s Department of

Table 1. Clinical profile of 10 participants

No	Gender	Age	Duration (month)	Affected side	Type	MAS (elbow)	Brunnstrom stage
1	F	83	8	Right	Infarction	0	5
2	M	49	20	Left	Hemorrhage	0	5
3	M	36	38	Right	Hemorrhage	0	4
4	M	51	93	Left	Infarction	1+	3
5	F	52	120	Right	Hemorrhage	0	5
6	F	66	192	Right	Infarction	0	5
7	F	65	12	Right	Hemorrhage	0	6
8	M	63	18	Left	Hemorrhage	1+	4
9	M	61	24	Left	Hemorrhage	1	3
10	M	58	6	Right	Infarction	0	6

MAS: Modified Ashworth Scale.

Occupational Therapy and Evosonics. The head of the vibrator was circular and 4 cm in diameter for use on the biceps brachii. A strap was added to the vibrator so that participants could wear the apparatus on their arm. The apparatus was also equipped with a rechargeable battery to further facilitate its portability. An SD card slot was included in the design to take advantage of the precise intensity and frequency control provided by the acoustic vibration method.

2) 3-D motion analysis system

Kinematic changes in upper limb motions were measured by using a 3-D motion analysis system (Compact measuring system 10, Zebris Medical GmbH, Isny, Germany). This apparatus consists of a computer, a 1 cm marker that sends ultrasonic signals, a cable adapter that transmits data from the marker, and a measurement detector that detects the ultrasound signal. The 3-D space was defined as x-axis (front-back), y-axis (left-right), and z-axis (up-down). The sampling variation was set at 50 Hz. Data was converted from ultrasonic markers to a 3-D coordinate system by using WinArm software (Zebris Medical GmbH, Isny, Germany).

4. Procedure

The experiment started with each participant sitting at a table that allowed the participant to maintain a 90-degree angle with their knees and elbows. The affected arm was left on the table as a starting point and the unaffected arm was rested comfortably on the participant's knees. The experiment objective was for the participant to reach out to a target object by using the affected arm(Figure 1). Prior to evaluation, participants practiced the reaching motion twice to ensure that they understood the objective. A complete reaching motion consisted of reaching towards the target object and returning the arm to its

Figure 1. Position of the subject during the reaching task

original state. Each participant made 10 consecutive complete reaching motions.

Three markers were attached to each participant's arm to analyze kinematic component of reaching before and after localized vibration treatment. The first marker was attached to the ulnar styloid process; the second was attached to the lateral epicondyle of the humerus; the third marker was attached at the midpoint of the humerus so that the second and third markers formed a line parallel to the humerus.

All study participants received three localized vibration treatments. Each localized vibration treatment duration was decided randomly and indiscriminately among three options (5 minutes, 10 minutes, and 20 minutes). The frequency and intensity were set at 70 Hz and 0.2 mm, respectively. Localized vibrations were applied to the participants' biceps brachii.

5. Dependent variables

The present study evaluated peak angular velocity, time to peak angular velocity, and movement unit to measure kinematic changes of reaching after administration of localized vibrations. In other words, the reaching motion was faster when the peak angular velocity was higher and reduced time to peak angular velocity. Finally, the reaching motion was more smooth and efficient when the movement unit was decreased. One movement unit was defined as an instance where the angular acceleration moved beyond 0 and returned to 0 (Rice, Alaimo, & Cook, 1999).

6. Statistical analysis

Data gathered from the 3-D motion analysis system were analyzed by using 3DAwin 1.02. The reaching motion was set as the moment that the first marker exceeded a velocity of 0 to the moment that the velocity returned to 0. The reaching motion was executed 10 times and the average of three median values excluding outliers was used for analysis.

SPSS 21.0 was used for statistical analysis; a Wilcoxon signed-rank test investigated the changes before and after intervention. The statistical significance value was set as $p < 0.05$.

Ⅲ. Result

The changes in dependent variables after three conditions localized vibration are presented in Table 2. Localized vibration in 20-minute increased the peak angular velocity and decreased time to peak angular velocity and movement unit in the affected elbow reaching task. There were significant differences between the before and after treatment. However, 5-minute and 10-minute duration did not exhibit significant differences on the all dependent variables before and after localized vibration.

Ⅳ. Discussion

This study investigated the instantaneous qualitative changes in arm reaching motions in chronic stroke patients after 3 conditions (5 minutes, 10 minutes, and 20 minutes) localized vibration. Furthermore, the study investigated the optimal localized vibration duration. The results showed that a single localized vibration of 20 minutes to the biceps brachii of chronic stroke patients led to significant improvements in reaching peak angular velocity (p=0.028), time to peak angular velocity (p=0.032), and movement unit (p=0.041). Consequently, the study results confirmed qualitative improvement in upper limb function as exemplified by the arm reaching motion, and especially, localized vibrations of 70 Hz and 0.2 mm for a 20-minute duration were shown to be the most effective.

Bosco, et al.(1999) stated that mechanical vibration stimulation frequencies between 10~200

Table 2. Pre-post comparison of the change in during reaching task

		Pre Mean ± SD	Post Mean ± SD	Z	p
Peak angular velocity (°/s)	5 min	107.50 ± 36.99	104.18 ± 21.03	-0.153	0.878
	10 min	106.37 ± 31.72	105.81 ± 28.05	-0.051	0.959
	20 min	104.54 ± 25.52	112.18 ± 27.54	-2.191	0.028*
Time to peak angular velocity (ms)	5 min	457.33 ± 172.97	430.67 ± 142.44	-1.275	0.202
	10 min	452.00 ± 184.80	429.33 ± 108.78	-0.178	0.859
	20 min	460.00 ± 114.61	418.00 ± 107.27	-2.145	0.032*
Movement unit (unit)	5 min	7.26 ± 3.76	7.83 ± 3.36	-0.889	0.374
	10 min	7.80 ± 4.12	6.97 ± 3.14	-0.890	0.373
	20 min	7.90 ± 3.83	6.80 ± 3.54	-2.043	0.041*

*Significant at $p < 0.05$.

Hz applied to muscle belly or tendon can cause tonic vibration reflex. Conrad et al.(2011) reported improvements in affected arm motions after administering 70 Hz localized vibrations to the wrist flexor tendon. Kwon(2013) showed improved upper limb motor function after administering 72 Hz localized vibrations to the wrist tendon of the subject. Localized vibration previous studies on each applied varying vibration frequencies but generally similar intensities (0.2~0.5 mm) (Albert, Bergenheim, Ribot-Ciscar, & Roll, 2006; Caliandro et al., 2012; Celik, O'Malley, Gillespie, Shewokis, & Contreras-Vidal, 2009; Marconi et al., 2011; Roll et al., 2009). Roll, Vedel, and Ribot(1989) reported that lower intensity muscle vibration stimulation led to better stimulation of the motor cortex. Consequently, the present study set the experimental vibration frequency and intensity at 70 Hz and 0.2 mm, respectively, based on the results of the precedent studies. The results of this study showed that chronic stroke patients exhibited a significant improvement in arm reaching motion velocity and smoothness after 20 minutes of localized vibration on their affected biceps brachii. Such results indicate that 70 Hz localized vibrations stimulate not only tendons but also muscles.

The present study used a 3-D motion analysis system to examine the qualitative kinematic changes in arm reaching motion. The precedent studies that used motion analysis systems to investigate arm reaching motions used peak angular velocity, time to peak angular velocity, angular acceleration, and the sum of angular movements (Gasser-Wieland & Rice, 2002; Maitra et al., 2003; Rice et al., 1999). The present study used variables based on Kamper, Georage Hornby, and Rymer(2002) and Park, Yoo, Chung, and Jung(2009), which included peak angular velocity, time to peak angular velocity, and movement unit. In other words, the motion velocity increased as the peak angular velocity increased and time to peak angular velocity decreased; and the movement smoothness and efficiency increased as the movement unit values decreased (Gasser-Wieland & Rice, 2002; Maitra et al., 2003). As such, variables including peak angular velocity, time to peak angular velocity, and changes in angular acceleration were successfully used to make qualitative measurements of chronic stroke patient movements.

The present study randomly applied one of three localized vibration duration to each subject. A localized vibration of 5 minutes and 10 minutes, did not exhibit significant reaching motion differences. These results contradict Noma, et al.(2009), who reported that 91 Hz, 1 mm localized vibration at 5 minute administered to stroke patients' upper limb flexor muscles resulted in decreased of muscle tone and increased motor functions. These contradictory results despite the same treatment duration may be explained by differences in vibration frequency and intensity.

The results of the present study differed from that of Caliandro, et al.(2012) and Marconi, et al.(2011) which both reported improved upper limb motor functions, neurological changes, and decreased spasticity after administration of 10 minutes of localized vibrations three times per day for three days to stroke patients. As such, a single administration of 10 minutes of localized vibration may be insufficient to observe qualitative changes in motion.

This study demonstrated that, while kinematic changes in reaching motion velocity, and smoothness differ based on treatment duration, a single administration of localized vibration resulted in instantaneous qualitative improvement in the arm reaching motion of chronic stroke patients. At least 20 minutes of localized vibration treatment at 70 Hz was necessary to qualitatively improve motor function in chronic stroke patients. As such, localized vibrations may contribute to upper limb motor function rehabilitation efforts in stroke patients by qualitatively improving the patients' motions.

However, one limitation of this study was the low number of study subjects. Furthermore, the study only investigated instantaneous effect after localized vibration and did not provide evidence for the long term effect of these improvements. Consequently, future studies should include more participants and investigate not only the instantaneous, but also the long-term effects of localized vibrations on motor functions in chronic stroke patients.

Declaration of Interest

Following are results of a study on the "Leaders Industry-university Cooperation" Project, supported by the Ministry of Education.

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국문초록

국소 진동자극이 편마비 뇌졸중 환자의 팔 뻗기 수행에 미치는 영향에 대한 운동학적 분석

유은영*, 박지혁*, 권재성, 조상윤***, 이보미****, 김영조****, 김재남*****, 김선호********

*연세대학교 보건과학대학 작업치료학과

**청주대학교 보건의료대학 작업치료학과

***서울특별시 어린이병원 작업치료실

****국민건강보험공단

*****서울대학교병원 재활의학과

******영광병원 작업치료실

목적 : 본 연구의 목적은 뇌졸중 환자를 대상으로 환측 상지에 진동자극을 적용했을 때, 팔 뻗기 수행에서 나타나는 팔꿈치 움직임의 운동학적 변화를 관찰하기 위함이다.

연구방법 : 연구 설계는 단일집단 교차실험설계(one-group cross-over trial design)를 사용하였으며, 10명의 만성 뇌졸중 환자를 대상으로 하였다. 대상자의 환측 위팔두갈래근(biceps brachii)에 국소 진동자극을 5분, 10분, 20분 동안 무작위로 70Hz로 적용한 후, 3차원 동작분석 시스템을 통해 팔 뻗기 수행의 운동학적 움직임을 분석하였다. 종속변수에는 팔꿈치 움직임에서 나타나는 최대 각속도, 최대 각속도까지의 시간, 움직임 단위를 포함하였다.

결과 : 팔 뻗기를 수행함에 있어서 팔꿈치의 움직임은 20분 동안 국소 진동자극을 적용하였을 때 보다 빠르고 부드러워졌으며, 효율적으로 나타났다. 팔꿈치 움직임의 최대 각속도는 증가하였고($p<0.05$), 최대 각속도까지의 시간과 운동단위는 유의하게 감소하였다($p<0.05$).

결론 : 국소 진동자극은 편마비 뇌졸중 환자가 팔 뻗기 움직임을 수행함에 있어 발생하는 운동학적 구성요소를 향상시킬 수 있는 효과적인 방법일 될 수 있다.

주제어 : 국소 진동자극, 동작분석, 만성 뇌졸중, 팔 뻗기