Comparison of the effects of remote aftereffects of static contractions for different upper-extremity positions and pinch-force strengths in patients with restricted wrist flexion range of motion

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ABSTRACT

The objective of the study was to examine the aftereffects of static contractions of upper extremity muscles in different shoulder joint positions and at different pinch-force strengths on the maximal active range of motion (MAROM) and wrist agonist/antagonist IEMG activities for patients with restricted wrist flexion range of motion (ROM) due to upper limb pain and dysfunction. The subjects were 10 outpatients (3 males, 7 females) with restricted wrist joints. These subjects performed four static contractions of upper extremity muscles in neutral and diagonal shoulder joint positions and with weak and strong pinch-force strengths in random order. Two-way repeated measures analysis of variance showed that the change in MAROM was significantly larger ($P < 0.05$) after diagonal-strong static contractions than after neutral-weak static contractions. There were no significant correlations between changes in MAROM and IEMG activities. These results indicate that shoulder joint position and pinch-force strength should be considered for effective induction of remote aftereffects of static contractions for increasing MAROM for restricted wrist flexion ROM.

KEYWORDS: PNF Aftereffect; Active range of motion; Resistive static contraction; pinch-force; facilitation

INTRODUCTION

Aftereffects are observed in proximal muscles not involved in previous voluntary activity following a 30-60 s static contraction (SC) of distal muscles (Gurfinkel et al 1989). Muscle contractions are not restricted to the target muscle and activities occur in both ipsilateral and contralateral (non-target) muscles during strong unilateral contractions (Post et al 2008). In the cat, monosynaptic excitation by muscle spindle Ia afferents from a given muscle is not distributed exclusively to the α-motoneurons of this muscle (homonymous projections), but also reaches the pools of motoneurons of other muscles (heteronymous projections) acting synergistically at the same joint or at different joints (Marchand-Pauvert et al 2000). To date, the heteronymous connections described in the human upper limb are from wrist to elbow muscles (Cavallari & Katz 1989; Mazevet & Pierrot-Deseilligny 1994) and might provide proximal support for distal movements. Intrinsic stiffness or slackness of the intrafusal muscle fibers at any given time is highly dependent on the immediate history of movements and contractions (Hagbarth & Nordin, 1995). The mechanical contributions of various sources of stiffness vary under different functional conditions, such as joint position and voluntary contraction level (Mirbagheri et al 2001).

The improvement of maximal active range of motion (MAROM) was significantly larger after a static contraction combined with a diagonal shoulder joint position and a strong finger pinch (diagonal-strong SC) than that after a static contraction combined with a non-diagonal position and weak finger pinch (neutral-weak SC) in normal subjects (Arai et al 2012). The surface integrated electromyography (IEMG) activity of the flexor carpi radialis (FCR) was also greater after a diagonal-strong SC than after a neutral-weak SC, which may be explained by the observation that facilitation of FCR under strong pinch force is an aftereffect in normal subjects (Arai et al 2012). The increased flexibility mainly results from reduced passive stiffness of the muscle-tendon unit (Guissard & Duchateau 2004), an increasing muscular recruitment pattern, and the role of the central nervous system (Hashemirad et al 2009). This physiological phenomenon is explained by significant heteronymous monosynaptic Ia excitation from intrinsic hand muscles supplied by median and ulnar nerves, as found in human forearm motoneurons belonging to forearm motor nuclei of the FCR, flexor carpi ulnaris, flexor digitorum, superficialis, extensor carpi radialis (ECR), and extensor digitorum communis (Marchand-Pauvert et al 2000). Heteronymous connections from intrinsic hand to wrist muscles may facilitate remote after-effects of a specific SC (Arai et al 2012).

Direct approaches to improve MAROM and strengthen the agonist muscles of restricted joints are difficult because of pain or weakness of the agonist muscles and/or antagonist muscles. In this context, therapy using after-effects may be useful to improve the restricted joint in an indirect neurorehabilitation procedure. However, effective methods that show a good correlation of static shoulder positions and SC strength on MAROM of wrist flexion with wrist agonist/antagonist IEMG activities for patients with restricted wrist flexion ROM due to upper limb pain and dysfunction have not been reported. Previous research has not focused on the effectiveness of the indirect effects of SC for intrinsic muscles in wrist MAROM. SCs with different shoulder positions and degrees of fingertip strength may show differences in the improvement of MAROM and these differences may be related to facilitation of the agonist (FCR) inhibition of the antagonist (ECR) as a remote aftereffect of SC. Therefore, the objective of this study was to compare the effects of aftereffects of SC of upper extremity muscles in different shoulder joint positions and at different pinch-force strengths on the change in MAROM and wrist agonist/antagonist IEMG activities for restricted wrist flexion ROM.

METHODS

Participants

The participants were 10 outpatients (3 males, 7 females) with restricted wrist joints and no history of upper motor neuron diseases who were referred by an orthopedist for improvement of ROM of the upper extremity, including the wrist joints. The patients were randomly selected from 25 outpatients. The mean age (standard deviation) was 60.8 (5.6) years (range, 34-81 years). Exclusion criteria included any other orthopedic disorders and any neurological disorder within the last year that required medical attention. All patients had pain during movement and restricted wrist motion relative to that of the unaffected side. MAROM may be restricted by upper limb pain and dysfunction. The time since onset of impairment varied from 9 weeks to 10 years. The patients had primary diagnoses of fracture of the radius and ulna, fracture of the radius, surgical neck fracture of the humerus, rheumatoid arthritis, carpal tunnel syndrome, and tenosynovitis of the flexor-tendon sheath of the index finger. MAROM of wrist flexion was measured on the more affected side (left, 9; right, 1). At the start of the study, all patients presented with stiff and mildly swollen wrists. No subject had knowledge of which exercise pattern might be more effective for improving MAROM of the wrist. The protocol was approved by the Hiroshima University Doctoral Degrees Committee. All patients gave written informed consent.

Experimental design

Each subject learned each SC method sufficiently well before the start of the study to allow performance of the activity alone. Because experienced therapists may have a bias toward certain therapeutic methods that may influence the outcome, the experiments were performed by two well-trained physical therapy students. The two students who performed the assessment had been in our program for 4 weeks and received training in the specific experiments for 2 weeks.

In preparation for data collection, the participants sat for 5 minutes to relax. After resting, the subjects performed each exercise for 2 s. The shoulder joint positions were the diagonal position [shoulder flexion (135°) and adduction (45°)] and the neutral position [shoulder flexion (90°) and adduction (0°)] (Fig. 1). The target strength of the pinch force was measured on a pinch meter and had ranges of 30-40% (weak pinch) and 70-80% (strong pinch) for maximal voluntary contractions. Subjects performed four different SCs of the upper extremity muscles in different shoulder joint positions (neutral and diagonal) and at different pinch-force strengths (weak and strong): neutral-weak, neutral-strong, diagonal-weak, and diagonal-strong. These actions were performed in a random order determined using a table of random numbers used for the order of SC combinations for each patient. MAROM of the wrist joint was measured before and after each SC.

The forearm attachment was supported by a researcher during each SC. Each SC condition was separated by a 60-s rest period. Verbal exercise cues were limited to: (1) for measuring the maximal pinch force, "Pinch the plate of the pinch meter as much as you can."; (2) for the SC exercise protocol, "Pinch the plate of the pinch meter to maintain the target force while looking at the pinch meter. Keep your fingers and wrist steady."

Measurement of MAROM

After each SC, MAROM for wrist flexion was maintained for >1 s with the arm at the side and neutrally rotated while the forearm and wrist were held in the neutral position. The forearm attachment was supported by a researcher.

Parameters

The change in MAROM of wrist flexion after each SC was calculated by subtracting MAROM before SC from MAROM after SC. This calculation was performed to normalize the change in MAROM to allow an examination of the change in ROM (Häkkinen et al 2010).

The associated IEMG activities during MAROM for wrist flexion maintained for >1 s (Fig. 3) were normalized by dividing the IEMG values by those obtained during maximum voluntary contraction performed before the start of each trial. This normalization allowed the level of IEMG activity for each muscle to be described using a value between 0 and 1.

Measurement instruments and apparatus

MAROM of wrist flexion was measured using an electrogoniometer (Penny & Giles, Blackwood, Gwent, UK) placed laterally across the affected wrist joint. Two pairs of disposable surface EMG electrodes (blue sensor, type N-10-F; Medicotest, Denmark) with a center separation of 15 mm were attached to the skin surface of the muscle bellies of the FCR and ECR muscles. All data collection devices were electronically synchronized via a BNC connector to the Noraxon Myosystem 2000 EMG system (Fig. 2). This facilitated synchronous collection of IEMG signals and goniometer voltage to determine the relationship between the IEMG amplitude and MAROM of wrist flexion during a 1-s static phase of flexion (Fig. 3). The skin was cleaned and shaved, and alcohol was used remove dirt, oil, and dead skin to lower the impedance to <1 kΩ at the recording site. The electrogoniometer was then calibrated for each patient’s wrist resting in an anatomically neutral position. A pinch meter (Yaesu Corp., Tokyo, Japan) was used to measure pinch strength.

Reliability of parameters

Prior to the study, a pilot study was conducted to determine the reliability of measurement of MAROM of wrist flexion and IEMG based on intraclass correlation coefficients (ICCs) for 5 patients. ICC (1,8) for MAROM was 0.995 (P = 0.000), reflecting high reproducibility. ICC (1,8) for IEMG was 0.98 (P = 0.000) for FCR and 0.98 (P = 0.000) for ECR during MAROM of flexion, indicating that the IEMG and MAROM measurements in this study were reliable.

Statistical analysis

SPSS ver. 21.0 for Windows (IBM Corp., Somers, NY) was used to perform all statistical analyses. Differences in the effects of types of shoulder position and pinch force on changes in MAROM and IEMG were tested by two-way repeated measures analysis of variance (ANOVA). Pearson correlation analysis was used to evaluate relationships between changes in MAROM and IEMG of FCR and ECR. Statistical significance was set at $P < 0.05$.

RESULTS

The means and standard deviations (SDs) of the change in MAROM and IEMG activities for the FCR and ECR muscles are shown in Table 1. Repeated measures two-way ANOVA for the change in MAROM showed significant main effects for shoulder position [$F (1,9) = 9.08$, $P =0.02$, $\eta^2 = 0.48$] and pinch force [$F (1,9) = 11.6$, $P = 0.01$, $\eta^2 = 0.56$], with a non-significant interaction between the main effects [$F (1,9) = 1.42$, $P=0.26$, $\eta^2 = 0.14$] (Table 2). The change in MAROM was significantly larger for the diagonal shoulder position compared to the neutral position. The best SC that produced a significant change in MAROM involved the diagonal-strong combination.

Repeated measures two-way ANOVA for the IEMG activities of the FCR and ECR muscles showed no significant main effects or interactions between the main effects (Table 2). There were also no significant correlations between IEMG activities and changes in MAROM for different position-strength combinations (Table 3). The Pearson correlation coefficient between changes in MAROM and IEMG activity for the ECR muscle in the diagonal-strong SC was −0.52 ($P = 0.89$), indicating a moderate, but non-significant, negative correlation. The Pearson correlation coefficient between changes in MAROM and IEMG activity for the ECR muscle in the diagonal-weak SC was 0.48 ($P = 0.16$), indicating a moderate, but non-significant, positive correlation.

DISCUSSION

This study shows that the amount of resistance and shoulder position influence the increase in MAROM of the wrist joint as an aftereffect of SCs of upper extremity muscles. The sample size was small, but the effect size was large (η^2 value is 0.56). Effect sizes are resistant to sample size influence, and thus provide a truer measure of the magnitude of an effect between variables (Ferguson et al, 2009). However, the hypothesis that facilitation of the agonist for improving MAROM of the wrist joint by a SC was not supported. IEMG activities of the FCR muscle after diagonal-strong SCs showed a non-significant change compared to those for other SC methods used in the study. In contrast, the IEMG activity of the FCR muscle is greater after a diagonal-strong SC than after a neutral-weak SC in normal subjects (Arai et al 2012). IEMG activity may be useful for measuring the voltage associated with recruitment of motor units, which may be used to estimate the number of motor units firing and the firing frequency (Schmitz & Westwood 2001). However, IEMG activity failed to explain the cause of the significant increases in MAROM of the wrist joints in this study.

Disuse atrophy from immobilization also decreases muscle strength, which may be due to impaired central neural activation of the wrist flexors and changes in the functional properties of the central nervous system (Sale 1988; Lundbye-Jensen et al 2008; Clark et al 2010). Pain caused by orthopedic diseases or upper limb immobilization also induces extensive neuroplastic reorganization (Tinazzi et al 2000; Zanette et al 2004). However, we could not prove this hypothesis in the current study, because deficits in MAROM may reflect peripheral factors, including stiffness and muscle atrophy; as well as central factors, including impairments in central neural activation and pain. The central nervous system has a prominent role in muscle stiffness (Milner et al 1995) and pain (Tinazzi et al 2000; Zanette et al 2004). For strong pinch, muscle activity is not restricted to the target muscle and is observed in both ipsilateral and contralateral (non-target) muscles during strong unilateral contractions (Post et al 2008).

Ginanneschi et al (2006) provided evidence that different static shoulder positions influence the recruitment efficiency (gain) of corticospinal volleys to motoneurons of forearm muscles as remote aftereffects. Differences in the shoulder joint may influence impairments in central neural activation and/or pain~~ in orthopedic patients~~. The physiological effects of a diagonal-strong SC may be correlated with a specific mechanism as a remote aftereffect, which may be due to supraspinal mechanisms, rather than spinal mechanisms, ~~orthopedic patients~~. The diagonal-strong SC may induce improvement in the wrist MAROM by minimizing symptoms such as muscle stiffness and/or pain. However, we were unable to identify the cause of remote aftereffects in this study. Further research is needed to compare brain activity induced by different SCs with that induced by other methods, such as functional magnetic resonance imaging and motor evoked potential.

CONCLUSION

Effective induction of remote aftereffects for increasing MAROM of wrist flexion requires consideration of the SC shoulder joint position and pinch-force strength. The use of SCs that do not stretch target muscles and that involve variations in joint position and voluntary contraction level to achieve optimal improvement in MAROM of the wrist is an effective and safe method for~~ orthopedic ~~patients who may feel pain and/or incur muscle damage when other methods are used. If direct approaches to improve MAROM and strengthen the agonist muscles of restricted joints are difficult because of pain or weakness of the agonist or antagonist muscles, indirect neurorehabilitation therapy, such as the use of specific SCs to obtain the benefits of remote aftereffects, may be useful for improving restricted joints.

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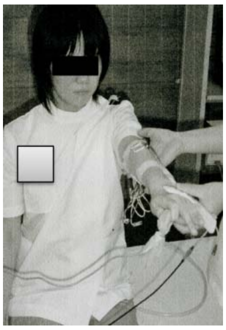

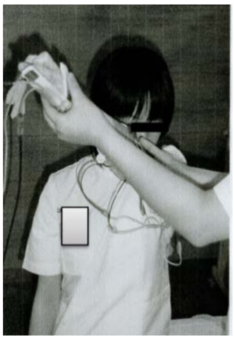

(a) neutral position (b) diagonal position

Fig. 1. Shoulder joint positions during static contractions (SCs). *Potential effects of the order in which SCs were performed were controlled by randomizing the order of the SC combinations (neutral-weak, neutral-strong, diagonal-weak, diagonal-strong) for each patient.

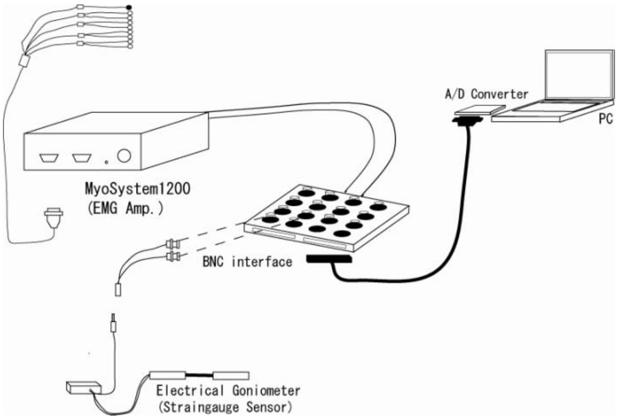

Fig. 2. Electromyograph (EMG) and goniometer system. All data collection devices were electronically synchronized via a BNC connector to the Noraxon Myosystem 2000 EMG systems (EMG system).

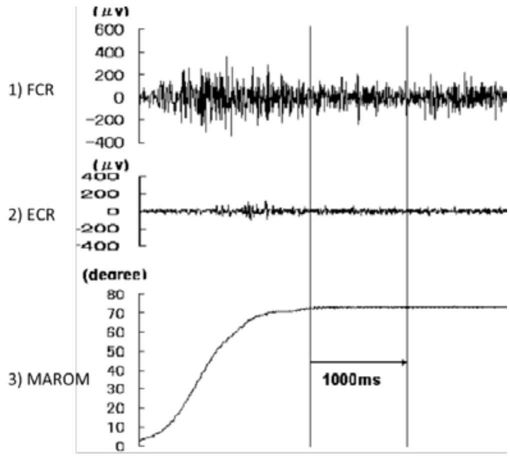

Fig. 3. Relationship between IEMG amplitude and MAROM of wrist flexion during a 1-s (1000 ms) static phase of flexion.

Table 1. Mean values, standard deviations (SDs), and ranges for different static contraction combinations

	diagonal-weak			straight-weak			diagonal-strong			straight-strong		
Variable	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
CR-MAROM	2.83	9.50	0.37 to 0.67	−1.36	11.43	0.39 to 0.73	11.94	6.28	0.41 to 0.81	1.28	13.92	0.36 to 0.79
IEMG ratio of FCR	0.48	0.11	0.08 to 0.25	0.51	0.11	0.05 to 0.23	0.51	0.12	0.06 to 0.26	0.50	0.13	0.04 to 0.24
IEMG ratio of ECR	0.14	0.07	−14.24 to 14.89	0.14	0.06	−19.09 to 20.50	0.14	0.06	3.33 to 24.10	0.14	0.06	−28.85 to 21.28

Table 2. Repeated measures two-way ANOVA summary table for each factor

	shoulder position			pinch force			interaction		
Factor	F(1,9)	P	η^2	F(1,9)	P	η^2	F(1,9)	P	η^2
CR-MAROM	9.08	0.02*	0.48	11.6	0.01*	0.56	1.42	0.26	0.14
EMG ratio of FCR	0.23	0.64	0.03	0.04	0.84	0.01	0.91	0.37	0.09
EMG ratio of ECR	1.11	0.32	0.11	1.11	0.32	0.11	0.69	0.43	0.07

(*: P < 0.05)

Table 3. Pearson correlations between changes in MAROM and IEMG activities for different position-strength combinations

	IEMG ratio of FCR		IEMG ratio of ECR	
CR-MAROM for strength-position	r	P	r	P
diagonal-weak	0.00	1.00	0.48	0.16
straight-weak	0.00	0.93	−0.04	0.92
diagonal-strong	0.09	0.80	−0.52	0.89
straight-strong	0.03	0.92	−0.19	0.59