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Neurophysiological study of remote rebound-effect of resistive static contraction of lower trunk on the flexor carpi radialis H-reflex.

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Abstract

We previously found a resistive static contraction of the pelvic depressors (RSCPD) using the proprioceptive neuromuscular facilitation pattern in the mid-range of pelvic motion in side-lying increase of the flexibility of remote body parts such as upper shoulder and elbow joints without stretching. However, a few studies have provided the evidence of ascending neurophysiological effects on remote parts induced by a static contraction of lower trunk muscles, such as RSCPD. The purpose of the present study was to find the neurophysiological the time-course of the remote effect of a resistive static contraction of the RSCPD as the lower trunk resistive exercise on the excitability of the relaxed flexor carpi radialis (FCR) H-reflex. Subjects were randomly assigned to (1) the handgrip group (n = 6), who participated in contralateral submaximal isometric handgrip exercises, or (2) the RSCPD group (n = 5), who participated in the RSCPD group. A post-hoc analysis and a first-order polynomial equation revealed that the contralateral effects of left handgrip exercises on the right FCR H-reflex caused gradual inhibition during and after the handgrip exercises. In contrast, a post-hoc analysis and a third-order polynomial equation suggested that the RSCPD induced ascending effects on the FCR H-reflex which initially caused a reflexive inhibition during RSCPD followed by a gradual excitation after the RSCPD. Remote rebound effects of the FCR H-reflex by RSCPD may provide neurophysiological evidence of the indirect approach for increasing flexibility of the treatment of extremities that cannot be exercised directly because of pain or weakness.

Keywords: FCR H-reflex, rebound remote-effect, resistive static contraction, facilitation, inhibition

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Introduction

To prevent a reduction in the number of functioning motor units and muscle atrophy, the indirect approach is often used by exercising the sound limb with resistance to stimulate muscle activity in the affected limb that cannot be directly approached [1]. It has already been shown that after a contraction of distal muscles, post-activation effects can appear in proximal muscles without the involvement in the previous voluntary activity as a remote post-activation effect on the upper extremity [2]. However, when direct approaches to improve the active range of motion (AROM) and/or passive range of motion (PROM) of severely restricted joints are difficult due to pain or weakness of the agonist muscles, indirect approaches are useful in clinical practice. A resistive static contraction of the pelvic depressors (RSCPD) is known as the indirect approach to improve the movements of the wrist joint. We previously reported that the resistive static contraction of the RSCPD using the proprioceptive neuromuscular facilitation pattern[3] in the mid-range of pelvic motion in side-lying increase of the flexibility of remote body parts such as upper shoulder and elbow joints without stretching [4,5]. With respect to the ascending neurophysiological effects of RSCPD, we also found the remote rebound effects induced by RSCPD on the extensor digitorum H-reflex initially caused reflexive inhibition during RSCPD, followed by a gradual excitation at rest [6]. However, few studies have provided the neurophysiological evidence of effects on remote parts induced by a static contraction of lower trunk muscles, such as RSCPD. To determine the excitability of remote effects, we measured the FCR H-reflex during and after RSCPD. We performed RSCPD as the resistive exercise of the lower trunk to detect the influence of the relaxed FCR H-reflex, which is considered a major probe for a non-invasive study of sensorimotor integration and plasticity of the central nervous system in humans [7]. When the amplitude of the H-reflex is high, it is assumed that there is an increase level of excitation of the motoneuronal pool and thus a greater contraction of the muscle can be generated.

Materials and Methods

Relevance

Application of RSCPD may be an effective approach for the indirect treatment of extremities that cannot be exercised directly. Inhibition or facilitation of the FCR H-reflex by RSCPD will provide physiological evidence of the remote effect of RSCPD.

Subjects

Seven female and five male neurologically intact volunteered subjects, aged 21–45 y (mean, 26.7 y; standard deviation (SD), 1.7 y). Exclusion criteria also included any injuries to the extremities or back within the last year that required medical attention. The protocol was approved by the Hiroshima University Higher Degrees Committee for Ph.D. Research Proposals and was performed according to the Declaration of Helsinki. The dominant upper extremity of each subject was tested. Dominance was determined by asking the subject which arm they preferred to use when writing his/her name. All the subjects were right-hand dominant based on this criterion. Subjects were randomly assigned to one of two groups: handgrip group (n = 6), which took part in the submaximal isometric handgrip exercise with the left hand, or the RSCPD group (n = 5), which took part in RSCPD (One subject in the RSCPD group was excluded because of failure to induce a FCR H-reflex).

Resistive exercise protocol

Resistive exercises and all experiments were conducted with the subjects in the side-lying position. For the handgrip group, we used a handgrip dynamometer to measure the maximal grip strength of the left hand before the static isometric grip was performed. Each subject was positioned in side lying and supported by cushions or solid pillows to prevent movements of the trunk and extremities as shown in Fig.1. The exercise was then performed by squeezing the handgrip dynamometer in the left hand for 20 s at a 75% maximum voluntary contraction. In the RSCPD group, resistance was applied by a experimenter. The experimenter stood behind the subject with his elbows locked in extension and placed his hands over the subject’s upper ischial tuberosity. The experimenter applied manual resistance over the upper ischial tuberosity in the direction of the medial sacral crest. The duration of each resistive exercise was 20 s. The amount of resistance provided by the experimenter was between 2–3 kg, measured by a pinch meter over the subject’s ischial tuberosity. Intrarater reliability was established for the force of the RSCPD by intraclass correlation coefficients (ICCs) for 20 s at random points before the experiment. The reliability of resistance from 4 trials measured during the RSCPD was ensured by using a two-way analysis of variance (ANOVA) to derive the ICCs. The ICC of the value of the force during the RSCPD was 0.95, which reflects a high reproducibility of resistance.

H-reflex stimulation

While in the side-lying position, each subject was instructed to keep the arm completely relaxed with his/her right shoulder at an angle of 90 degrees and his/her right forearm immobilized in a cuff in a pronated position with wrist and fingers extended as shown in Fig.1. We measured the FCR H-reflex of the right upper extremity during each resistive exercise and at rest before and after each resistive exercise. During data collection, the intensity of stimulation was constant in each subject. H-reflex was measured with a Neuropackμ evoked potential measuring system (model MEB9100, Nihon Kohden Corporation, Tokyo, Japan). We elicited H-reflexes in FCR muscle using electrical stimulation of the median nerve in the cubital fossa. The signal was amplified with a bandpass filter having a passband of 20 Hz to 3 kHz using an electromyμ evoked potential measuring system (model MEB9100, Nihon Kohden Corporation, Tokyo, Japan). The skin was cleaned with alcohol, and the area was rubbed gently using skin preparation gel (Skinpure; Nihon Kohden Corporation, Tokyo, Japan) for removal of dirt, oil and dead skin to lower the impedance at the recording site was below 0.5 kΩ. Test stimuli were administered using a 1-ms pulse delivered through a pair of surface electrodes placed 1.5 cm apart over the belly of the FCR, with the cathode located proximal to the anode. EMG signals were recorded from the FCR with standard nonpolarizable Ag-AgCl surface disk electrodes. An electrical stimulus with a rectangular pulse (1-ms duration) was delivered by a stimulator at a frequency of 1 Hz. When the FCR H-reflex increased markedly, demonstrating wrist flexion with no pure pronation or pure flexion of the fingers, it was considered to originate mainly from the FCR.

Experimental design

A small M-wave size was maintained throughout the experiment to ensure that no displacement of the stimulation electrode occurred and that the effects were not due to changes in a reflex recruitment gain during the stimulus gain. M-wave and H-reflex were obtained using 20 sweeps (20 repeated reflex responses) every 20 s in all conditions (condition-C2~-C8) while stimulation current was concurrently measured for all experimental trials. For each reflex recorded in this study, repeated H-reflexes and M-waves (1 Hz) were sequentially elicited in a row without interval for a period of 220 s. The period of 220 s was divided into 8 conditions (condition-C1～condition-C8). Condition-C1 (four trials; 80 s) represented the phase of rest; condition-C2 (20 s) the phase of each resistive exercise; conditions-C3 (20 s) ,-C4 (20 s) ,-C5 (20 s) ,-C6 (20 s) ,-C7 (20 s) and -C8 (20 s) represented the rest phase after each resistive exercise as shown in Fig. 2. The intensity of median nerve to induce H-reflexes with small M-waves was determined in condition-C1, and this initial stimulus intensity was held constant for each subject during all of the experimental trials [8]. By repeating the experimental at several stimulus intensities and using the M-wave as a measure of the effective stimulus strength, H-reflexes occurring at various phases could be compared at equal stimulus intensities [8]. We determined the steady intensity of stimuli necessary to elicit a large H-reflex with a small M-wave in each subject prior to resistive exercise.

Parameter of excitability

For comparison, each H-reflex amplitude during and after each resistive exercise (conditions-C2～-C8) were normalized to the corresponding H-reflexes recorded in condition-C1 to reduce inter-subject variability. This ratio, indicating the relative size of the H-reflex amplitude, was used as a parameter of motoneuron excitability. The M-ratio was also calculated in the same manner as the H-ratio. The M-ratio was used as a parameter of change in reflex recruitment gain across the experiments. The peak-to-peak amplitude of each H-reflex in condition-C1 served to determine the remote effect during each resistive exercise and remote after-effects after each resistive exercise. SPSS for Windows (version 12.0) was used in all analyses. A probability level of P < 0.05 was used to determine statistical significance.

Results

The mean (±SD) stimulus intensity was 4.1 (±1.5) mA (range, 2.0–6.3 mA) for all subjects, 3.8 (±1.6) mA (range, 2.0–6.3 mA) for the RSCPD group, and 4.5 (±1.4) mA (range, 2.1–5.4 mA) for the handgrip group. No significant difference in the mean strength of stimulus required to induce the H-reflex and M-wave was observed between the two groups by using the unpaired t-test.

Both H-reflex and M-wave latency were consistent within subjects in this study. The mean H-reflex latency (±SD) was 22.7 (±0.4) ms (range, 20.5–-27.0 ms) for all subjects, 22.1 (±0.8) ms (range, 20.5–-22.8 ms) for the RSCPD group, and 23.3 (±2.4) ms (range, 20.7–27.0 ms) for the handgrip group. The mean M-wave latency(±SD) was 5.1 (±2.2) ms (range, 2.8–8.6 ms) for all subjects, 4.6 (±2.0) ms (range, 2.8–8.5 ms) for the RSCPD group, and 5.5 (±2.4) ms (range, 3.6–8.6 ms) for the handgrip group. Subjects exhibited remarkable consistency over trials.

The non-significant differences between the two groups for the mean stimulus intensity and the high reproducibility of the M-waves across the experiments suggest that H-reflexes were elicited with stable M-waves, and therefore that a constant number of motor nerve fibers, and thus Ia afferents, were excited by the test stimuli. These results suggested that no change in reflex recruitment gain across the experiment was observe

***Table 1.**. Means ± standard deviations of both the M-ratio and H-ratio*

			Mean Standard Deviation of the M-ratio				
	C2	C3	C4	C5	C6	C7	C8
Handgrip	*0.96±0.09*	*0.92±0.07*	*0.96±0.06*	*1.00±0.08*	*0.84±0.07*	*0.96±0.09*	*0.94±0.05*
RSCPD	*0.93±0.12*	*1.07±0.13*	*0.98±0.12*	*0.98 ±0.08*	*1.02±0.06*	*1.13±0.12*	*1.18±0.13*
			Mean Standard Deviation of H-ratio				
Handgrip	*1.07±0.11*	*0.96±0.04*	*.93±0.06*	*0.92±0.08*	*1.07±0.11*	*0.90±0.08*	*..94±0.10*
RSCPD	*0.57±0.13*	*1.17±0.13*	*1.43±0.18*	*0.96±0.025*	*1.58±0.25*	*1.58±0.25*	*1.64±0.23*

The unpaired t-test revealed that no significant differences between the two groups in the mean stimulus intensity, latency of H-reflexes and M-waves for all conditions, and amplitude of H-reflexes and M-waves in condition-C1.

Table 1 shows the mean M-ratios ± SD. Two-way repeated ANOVA showed no effect of time or group on M-ratio. To ascertain the consistency of the peak-to-peak M-wave amplitudes across the 12 trials measured in each subject over the course of the experiment, reliability was tested by assessing the ICCs. ICC (1,7) analysis of the FCR M-wave amplitude indicated a high degree of consistency across experimental conditions (all subjects, ICC (1,7) = 0.98; handgrip group, ICC (1,7)= 0.94; and RSCPD group, ICC = 0.99). The two-way repeated-measures ANOVA showed no effect of time or group on the M-ratio (group; F (1,4)=1.83; time course; F (6,54)= 0.93).

Table 1 shows the mean H-ratios ± SD. To assess reliable measures for the FCR H-reflexes (peak-to-peak amplitude), 4 trials in condition-C1 were analyzed using a two-way analysis of variance (ANOVA) to derive the ICCs. The ICC (1,4) was 0.99 for the FCR H-reflexes, which indicated a high degree of consistency in condition-C1.

A two-way repeated ANOVA for the H-ratio showed that the time-course produced a main effect, but not so for the group (group: F (1,4) =0.23: F (6,24) = 13.52, $p < 0.001$). The interaction between group and time course was also significant for the H-ratios (F (6,24) =8.13, $p < 0.001$). Post-hoc tests using a Bonferroni analysis revealed significant differences in the RSCPD group over time. The H-ratio in condition-C2 during the RSCPD was significantly reduced compared with the H-ratio in condition-C4 as shown in Fig. 3.

The relationship between the H-ratio and the time course in the handgrip group was best fitted by a single-order polynomial equation ($y = -0.03x + 1.08$, $p < 0.05$). The M-wave showed a significant but very weak negative trend. In contrast, the relationship between the H-ratio and the time course was best fitted by a third-order polynomial equation ($y = 1.71x3 - 0.30x2 + 0.02x - 1.80$, $p < 0.01$).

Figure 1. *FCR H-reflexes measured in the dominant hand. The elastic bandage held the wrist in the neutral position with forearm pronation to induce the right FCR H-reflexes and M-waves without voluntary contractions of the right FCR while in the side-lying position*

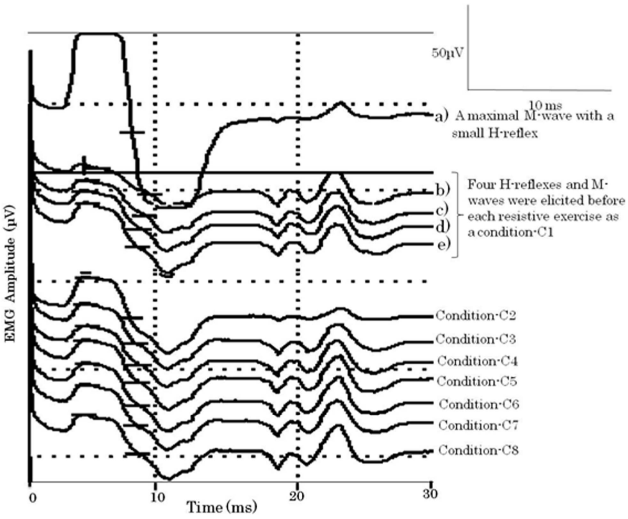

Figure 2. *A maximal M-wave with a small H-reflex was obtained (a). The amplitude of the FCR H-reflex was maintained between 5-20% of the maximum direct motor response (Mmax) in condition-C1. For each reflex recorded in this study, repeated H-reflexes and M-waves (1 Hz) were sequentially elicited in a row without interval for a period of 220 s. The period of 220 s was divided into 8 conditions (condition-C1 ～condition-C8). Condition-C1 (four trials; 80 s) represented the phase of rest; condition-C2 the phase of each resistive exercise; conditions-C3,-C4,-C5,-C6,-C7 and -C8 (20 s each) represented the rest phase after each resistive exercise*

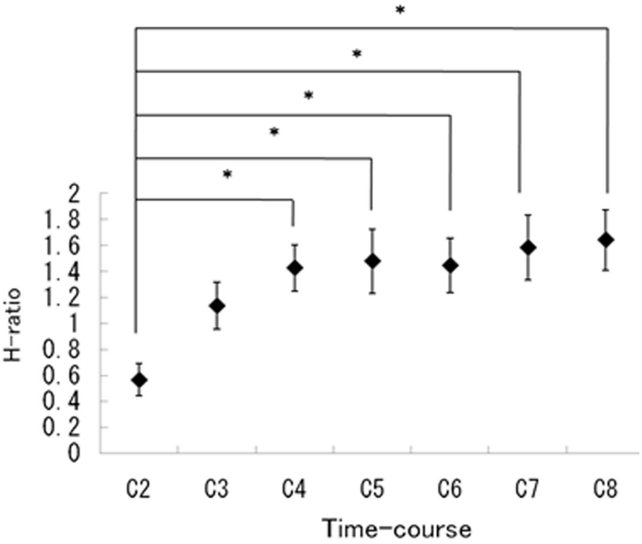

Figure 3.*Time course of the H-ratio. Remote ascending effects of a resistive static contraction of the pelvic depressors (RSCPD) on the FCR H-reflex which initially caused a reflexive inhibition during RSCPD followed by a gradual excitation after the RSCPD. Data are given means±the standard error; p < 0.05 (indicated by *).*

Discussion

While the results of the repeated ANOVA suggested that the effect of a preceding submaximal voluntary contraction of the contralateral handgrip did not cause a significant change, a gradual weak inhibitory remote effect on the contralateral FCR H-reflex in the present study was noted by the single-order equation as well as by the soleus H-reflex [9]. On the other hand, the post-hoc analysis and a significant third-order polynomial equation suggest that the RSCPD-induced ascending remote effects on the FCR H-reflex cause an initial reflexive inhibition phase during the RSCPD and a subsequent gradual facilitatory phase after the RSCPD (remote rebound-effect) as shown in Fig.3. The modulation of the FCR H-reflex suggests a generalization beyond the spinal segmental level. The inhibitory effect on the FCR H-reflex during the RSCPD may be interpreted as a "tranquilizing" effect controlled by the central nervous system, which may develop upon FCR relaxation. After the inhibitory effect, the facilitatory effect on the FCR H-reflex occurred and lasted over 80 s as shown in Fig.3. A remote rebound-effect after a RSCPD suggests an enhancement of the central nervous system, which develops upon enhancement of FCR motor unit discharge synchronization. A RSCPD may facilitate the linkages between the arm and trunk. To the best of our knowledge, the present study is the first to demonstrate an ascending remote rebound-effect during and after a resistive exercise of the lower trunk, such as a RSCPD, on the upper extremity in human. In the spinal cord in cats, ascending propriospinal pathways between lumbo-sacral and cervical segments exert excitatory and inhibitory actions upon motoneurones innervating muscles of the shoulder girdle, and mainly inhibitory actions on muscles of the forearm [12]. The coupling between the lumbar and sacral networks can be modified by sensory inputs, suggesting that the spinal machinery can modulate and adapt the coupling of these two spinal networks [4]. In humans, ascending propriospinal pathways between lumbo-sacral and cervical segments may also exert the inhibitory and excitatory actions upon muscles of the forearm. However, how magnitude and direction of force to the lower trunk facilitate rebound-effects most efficiently still remains unclear. Further research is needed to identify the mechanism of this phenomenon.

We observed that a remote rebound-effect induced by RSCPD on the FCR H-reflex initially caused a large degree of reflex inhibition during the RSCPD, and subsequently a gradual excitation occurred after the RSCPD as an after-effect. Temporary profound inhibition of the FCR H-reflex occurred during RSCPD in the reduction of FCR H-reflex, which may decrease muscle stiffness, allow enhanced more muscle compliance, and subsequently improve upper extremity PROM. In the second phase of the remote rebound effect, the gradual facilitation observed in the remote upper extremityies after following RSCPD may reflect increased motor unit recruitment and subsequently improve upper extremity AROM. Remote rebound effects of the FCR H-reflex by RSCPD may provide the neurophysiological evidence of the indirect treatment of extremities that cannot be exercised directly in patients with severely restricted joint or painful movements.

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