The effects of opposite-directional static contraction of the muscles of the right upper extremity on the ipsilateral right soleus H-reflex

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Abstract

The objective of this study was to explore the neurophysiological remote after-effects of resistive static contraction (SC) of the muscles of the upper extremity, considering the resistant direction on the ipsilateral (right) soleus H-reflex.

The participants included 12 normal subjects with a mean (SD) age of 23.8 (2.8) years. The subjects were asked to maintain their upper extremity against the traction force, at a level of resistance that was 50% of the maximal SC strength. A 20-s SC of the muscles of the upper extremity utilizing contraction of the upper extremity muscles using a diagonal flexion (shoulder flexion-adduction-external rotation) or extension (shoulder extension-abduction-internal rotation), a proprioceptive neuromuscular facilitation (PNF) pattern was induced. The traction force line of the diagonal flexion or extension direction ran parallel to the diagonal line from the left acromion process to the right ASIS.

Three-way analysis of variance of the H/Mmax ratio with Scheffé's post-hoc tests revealed that the H/Mmacorrelatex ratio of SC via diagonal extension was significantly smaller than that via diagonal flexion and that the H/Mmax ratio during the 120–140 s phase after SC, as remote after-effect SC, was significantly smaller than that during SC. The induction of neurophysiological descending effects for inhibition requires consideration of the force direction

Keywords

- PNF;
- Remote after-effect;
- Range of motion;
- Resistive static contraction;
- H-reflex

Introduction

Proprioceptive neuromuscular facilitation (PNF) techniques are often used to induce muscle relaxation and increase the active range of motion (AROM) or the passive range of motion (PROM) in patients with neurological and/or orthopedic problems. Although the sustained stretching (SS) technique is a method in which the target muscle is elongated to tolerance (i.e., stretching of the hamstrings) at a relatively pain-free range and the muscle is held in position at its greatest tolerated length, a basic PNF technique for increasing hamstring flexibility is the hold-relax (HR) technique, which utilizes a shortening contraction of the hamstrings in a diagonal position (i.e., hip extension-abduction-internal rotation) followed by the maximal resistance of static contraction (SC) of the hip extensor-abductor-internal rotator (Voss and Inoka, 1985).

Both the HR and SS techniques are considered direct approaches.

Considering the contralateral effects of resistive exercise, Hellebrandt et al. (1957) demonstrated that the progressive resistance type exercise both increases the functional capacity of the contractile tissues subject to direct training and has a significant effect on the strength and endurance of homologous muscle groups of the contralateral unpracticed limb (Arai et al., 2001). Patients with fractures or arthritis can benefit from an indirect approach towards exercising the noninvolved limb in order to achieve contralateral muscle activity (Pink, 1981). This phenomenon has been referred to as cross-education (Arai et al., 2001). PNF movement, combined with hip internal rotation, has been found to be effective for inducing cross-education, which is defined as the muscle activity of the unexercised limb during contralateral exercise, by analyzing the force and electrical activity of the affected muscle in orthopedic patients (Arai et al., 2001).

With respect to the ascending remote after-effects, resistive SC of the pelvic depressors (RSCPD) using a PNF pattern in the mid-range of pelvic motion in side-lying, as an indirect approach, induces SC of the lower trunk muscles and increases the flexibility of remote body parts, such as the upper shoulders, as ascending remote after-effects (Arai and Shiratani, 2012a). Neurophysiological ascending effects induced by RSCPD on the flexor carpi radialis H-reflex depend on both the direction–strength combinations of RSCPD and the time course (Arai and Shiratani, 2012b).

With respect to the descending effects on remote parts, indirect approaches facilitated by resistive SC of the muscles of the upper extremity increase the flexibility of remote body parts, such as improvement of AROM or PROM of the knee joint, as descending effects (Nishiura et al., 2009; Shiratani et al., 2013); although the mechanism underlying the neurophysiological descending effects for improving AROM or PROM remains unknown.

Furthermore, the indirect descending neurophysiological effects of SC of the muscles of the upper extremity may also depend on the direction of movement, as well as the indirect ascending effects induced by RSCPD.

The objective of this study was to explore the neurophysiological effects of SC of the muscles of the upper extremity, considering the resistant direction, on the ipsilateral soleus H-reflex as a neurophysiological descending effect.

Relevance

The application of a specific resistance exercise of the upper extremity muscles may represent an effective approach for the indirect treatment of ipsilateral lower extremities that cannot be exercised directly. Inhibition or facilitation of the soleus H-reflex by a specific exercise of the upper extremity muscles, would provide neurophysiological evidence of the induction of remote effects on the ipsilateral lower extremity.

Methods

Participants

Nine female and three male subjects, aged 20–27 years (mean: 23.8 years; standard deviation (SD): 2.8 years) with no history of neurological or orthopedic illness volunteered to participate in this study.

All subjects signed informed consent forms approved by the Ethics Committee of Tokyo Metropolitan University, which approved this study.

This study was performed in compliance with the revised Declaration of Helsinki. The 4%–8%inant upper extremity of each subject was tested. Dominance was determined by asking the subjects which arms they preferred to use when writing their names. All subjects were right hand-dominant based on this criterion.

Experimental design

SC of the muscles of the upper extremity, utilizing contraction of the upper extremity muscles with diagonal flexion (shoulder flexion-adduction-external rotation) or diagonal extension (shoulder extension-abduction-internal rotation), a proprioceptive neuromuscular facilitation (PNF) pattern was induced by resistance generated by a traction force.

Each subject learned the SC methods sufficiently well before the start of the study so that they were able to perform the activity independently. After resting, the subjects performed each exercise for 20 s.

Two types of resistive SC exercises lasting 20 s were applied to each subject. The duration of each resistive exercise was 20 s.

1) Method of inducing the 20-s SC of diagonal flexion or extension

The subjects laid on a bed in the supine position and held their right upper extremity with the shoulder flexed at right angles in the sagittal plane [shoulder flexion (90°)-adduction (0°)-external rotation (0°)] (Fig. 1). The traction force line of the diagonal flexion or extension direction ran parallel to the diagonal line from the left acromion process to the right ASIS (Fig. 1). The potential effects of the order in which SCs were performed were controlled by randomizing the order of the SC for each subject.

PLACE FIGURE 1 HERE

The maximal SC strength of the force of each diagonal direction was measured using a hand-held dynamometer (Mobie MT-100, SAKAI Medical Co., Ltd., Tokyo, Japan).

Verbal exercise cues were limited to the following: (1) for measuring the maximal force, “Push the plate of the dynamometer as much as you can” and (2) for the SC exercise protocol, “Please keep your upper extremity steady against the resistance for 20 s”

During each exercise, the right soleus H-waves were measured in the supine position. Each subject aimed to maintain the upper extremity against the traction force as resistance, and the level of resistance was 50% of the maximal SC strength induced, using the pulley and weight system. The subjects maintained the right upper extremity against the traction force to induce SC for 20 s (Fig. 1). The distance between the axis of the pulley and the upper extremity was always checked for determining the static contraction of the upper extremities by an experimenter. After 20 s, the experimenter removed the traction force and then each subject relaxed by lowering the right upper extremity.

Each subject performed a trial (diagonal flexion or extension) under condition C2 (20 s), representing the phase of each resistive exercise (Fig. 2), followed by a rest period of 200 s. After 5 minutes, each subject performed another trial.

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H-reflex stimulation

The subject maintained a supine position in a quiet room. The right soleus H-reflex was measured at rest, during each resistive exercise, and after each resistive exercise. The soleus H-reflex was evoked by stimulating the posterior tibial nerve via a monopolar electrode (1-ms rectangular pulse) implanted in the popliteal fossa using a constant-current stimulator (Neuropack μ MEB9100, Nihon Kohden Corp., Tokyo, Japan).

H-reflexes were elicited with small M-waves below the cubital fossa over the belly of the soleus. The signal was amplified with a bandpass filter having a passband of 20 Hz to 3 kHz using an evoked potential measuring system. Skin care was employed to ensure that the impedance at the recording site was less than 2 k Ω.

The soleus H- reflex was elicited by stimulating the tibial nerve using an AgCl cathode in the popliteal fossa and a 9-mm diameter anode, which was placed over the lateral malleolus. Electromyographic (EMG) signals were recorded from the soleus using standard nonpolarizable Ag-AgCl surface disk electrodes (outer diameter, 9 mm). An electrical stimulus with a rectangular pulse (1-ms duration) was delivered by the stimulator at a frequency of 1 Hz. The current was increased from 0 in 0.1-mA increments until the maximal amplitude of the H-reflex with a small M-wave was obtained. When the H-reflex increased markedly, demonstrating ankle plantar flexion with no pure eversion or eversion, it was considered to originate mainly from the soleus.

Reportedly, the number of additional motor neurons recruited by a constant excitatory conditioning stimulus in a monosynaptic test reflex is considered to be highly dependent on the size of the test reflex itself (Crone, 1990). The M-wave size [approximately 4%–8% of the maximal M wave amplitude (Mmax)] was maintained throughout the experiment to ensure that no displacement of the stimulation electrode occurred, and that the effects were not attributable to changes in reflex recruitment gain during the stimulus (Knikou, 2008; Crone, 1990). Repeated H-reflexes and M-waves (1 Hz) were elicited sequentially without interruption for a period of 300 s. The period of 300 s was divided into 13 conditions (condition C1, 60 s; conditions C2–C13, 20 s each. C1 represented the rest phase, C2 represented the phase of the resistive exercise, and C3–C13 represented the rest phase after each of the resistive exercises, as shown in Fig. 2. The intensity of the tibial nerve to induce H-reflexes with small M-waves was determined in C1. This initial stimulus intensity was held constant for each subject throughout all of the experimental trials.

The data were obtained from a randomized block experiment with two SC replications (direction factor: diagonal flexion or extension) for each subject (individual factor) over a period of 300 s (13 conditions (time course): condition C1-C3).

Parameter of excitability

For comparison, each H-reflex amplitude during and after each resistive exercise (C1–C13) was normalized to the corresponding Mmax H-reflex, as expressed by the ratio of

H/Mmax.

Statistical analyses

SPSS ver. 21.0 for Windows (IBM Corp., Somers, NY) was used for all statistical analyses.

The three-way analysis of variance (ANOVA) for the H/Mmax ratio was used with Scheffé's post-hoc tests to determine the effects of individuals, time course (13 conditions: conditions C1–C13), and direction (diagonal flexion or diagonal extension).

The level of significance was set at $P < 0.05$.

Results

To assess reliable measures for the soleus H- reflexes (peak-to-peak amplitude), three trials in C1, before each SC, were analyzed using ANOVA to derive the interclass coefficients (ICCs). The ICC (1,1) was 0.95 for the soleus H-reflexes, which indicated a high degree of consistency.

The mean and SD of the H/Mmax for each SC are shown in Table 1.

PLACE Table 1 HERE

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The mean and SD of the H/Mmax for each time course are shown in Table 2.

Three-way repeated-measures ANOVA [with individual, time-course (13 conditions: conditions: C1–C13), and direction (the diagonal flexion or diagonal extension)] of the H/Mmax ratio revealed significant main effects of individual [F (11,275) = 63.0, P = 0.00, partial eta squared = 0.72], direction [F (1,275) = 4.28 P = 0.04, partial eta squared = 0.02], time course [F (12,275) = 3.21, P = 0.00, partial eta squared = 0.12] and no significant interactions between direction and time course [F (12,275) = 0.73, P = 0.72, partial eta squared = 0.03].

The H/Mmax ratio of SC via diagonal extension was significantly smaller than that via diagonal flexion (Table 1, Fig. 3).

Post-hoc comparisons regarding the effects of time course indicated that H/Mmax under C9 was significantly smaller than that under C2 (Fig. 4).

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Discussion

The results of the three-way ANOVA suggest that the neurophysiological descending effects induced by SC of the upper extremity muscles on the soleus H-reflex depend on both the direction and time course; however, no significant relationship was observed between the direction and time course because of non-significant interactions.

Post-hoc comparisons of the effects of time course indicated that the H/Mmax ratio under C9 (the 120–140- s phase after SC) was significantly smaller than that under C2 (during SC with either diagonal flexion or extension), which indicates a temporary inhibitory effect following resistive exercise.

As a direct approach, after a vigorous bout (eight sets of 10 repetitions) of concentric-eccentric triceps surae exercise, the amplitudes of the soleus and lateral gastrocnemius H-reflexes were reported to be depressed for 10–60 s (Trimble and Harp, 1998). After voluntary contraction of the plantar flexors at 10% of the maximal level, the H/Mmax ratio also initially decreased significantly, and subsequently returned to baseline levels after 1 min (Xenofondos et al., 2015).

In contrast with the direct approach, the indirect approach implemented in this study revealed that significant inhibition occurred after 120 s compared with C2 (the SC phase) as a remote descending after-effect. In addition, the neurophysiological descending effects induced by voluntary SC via diagonal extension on the soleus H-reflex were smaller than those induced via diagonal flexion, reflecting involuntary inhibition of the reflex excitability of the motor neurons after 20-s SC via diagonal extension. Whereas the RSCPD-induced ascending remote rebound effects on the FCR H-reflex caused an initial reflexive inhibitory phase during RSCPD followed by a subsequent gradual facilitatory phase (Arai and Shiratani, 2012b), the effects of SC of the upper extremity muscles induced an initial reflexive facilitatory phase on the soleus H-reflex during SC followed by a subsequent inhibitory phase. In addition, the effective direction throughout SC of the muscles of the upper extremity, to induce descending inhibitory effects, was diagonal extension. Induction of neurophysiological descending effects for inhibition requires consideration of the force direction. The directional effects of an SC may be related to the information transmitted from Ib afferents to the motor neurons. With respect to the Ib inhibitory interneurons, many researchers have demonstrated that they have a wide convergence from the supraspinal area, which controls the gain and the direction of the action of the lb effects (Yanagawa et al., 1991).

In a clinical study, after SC via diagonal extension (shoulder extension-internal rotation), the improvement of the AROM of straight leg raising (SLR) was significantly larger than that of hip flexion with the knee flexed (Nishiura et al., 2009). SC of the lower extremity muscles utilizing a contraction of the target muscle without stretching in the middle range of motion (without stretch) using a PNF pattern (hip extension-abduction-internal rotation) could have immediate significant effects for increasing the AROM in knee extension compared with stretch in orthopedic patients (Masumoto et al., 2013). Ib afferents, which originate from Golgi tendon organs, have been reported to inhibit agonist (hamstrings) motor neurons (autogenetic inhibition) and at the same time as facilitating antagonistic (knee extensor) motor neurons (Laporte and Lloyd, 1952; Yanagawa et al., 1991). Conversely, a reduction in antagonist co-activation could allow increased expression of agonist muscle force (Gabriel and Kroll), which could lead to increasing the AROM or PROM after SC of the lower extremity muscles.

With respect to the remote descending effects, the potentiation of stretch reflexes by remote muscle contraction has subsequently become known as the Jendrássik maneuver (JM) (Zehr et al., 1999). It has also been reported that remote descending facilitation of the quadriceps motor nucleus was induced following voluntary contraction of the upper limb muscles (wrist extensors) as a JM (Delwaide et al., 1980; Toulouse et al., 1980). JM can selectively lead to inhibitory actions on the late component of the stretch reflex (mean latency; 79.8±7.2 ms) by gating a long-loop reflex pathway along its passage through supraspinal centers (Nardone and Schieppati, 2008). In contrast with the JM, the effects of a 20-s SC on the H/Mmax ratio under C9 (the 120–140- s phase after SC) indicate descending inhibitory after-effects of remote muscles in this study. The reason temporary inhibition occurred after 20-s SCs in this study was not obvious.

One possible reason underlying the temporary inhibition may be considered in relation to the long propriospinal neurons. The remote effects of a 20-s SC (diagonal extension) on the soleus H-reflex in this study may also correlate with the long propriospinal neurons, as well as the SC of the lower trunk muscles (RSCPD). Directional SC of the upper extremity extensor muscles may also produce specific descending effects and change the motor strategies through the propriospinal pathways between the cervical and lumbo-sacral segments. Long propriospinal neurons originating from the forelimb segments with axons descending in the dorsal half of the lateral funicle have monosynaptic connections with interneurons of inhibitory and excitatory reflex pathways from Ib afferents to motor neurons in the cat (Jankowska et al., 1983). In humans, ascending propriospinal pathways between the lumbo-sacral and cervical segments may also exert inhibitory and excitatory actions on muscles of the forearm (Arai and Shiratani, 2012b). In this study, a temporary inhibition could occur by descending propriospinal pathways between the cervical and lumbo-sacral segments and may also exert inhibitory actions on muscles of the lower extremity.

Generalized arousal of the reticular formation probably occurs during the JM (Delwaide et al., 1980, Toulouse et al., 1980), and commissural interneurons may activate motor neurons via reticulospinal neurons both directly and indirectly by enhancing or weakening the activation of premotor interneurons in pathways from group Ib and group II afferents (Cabaj et al., 2006). The effects of 20-s SCs in this study may correlate with brain activities. Further investigations are needed to identify the brain activities underlying the effects of temporary inhibition using fMRI. In addition, the mechanism by which the magnitude and direction of force to the SC of the upper extremity might facilitate or inhibit the neurophysiological remote after-effects most efficiently and whether SC via diagonal extension or flexion is effective for increasing AROM remains unclear. Further research is needed to identify the neurophysiological remote after-effects of the SC of muscles of the upper extremity.

Conclusion

The effective force direction during SC of the muscles of the upper extremity to induce descending inhibitory effects was diagonal extension opposed to diagonal flexion.

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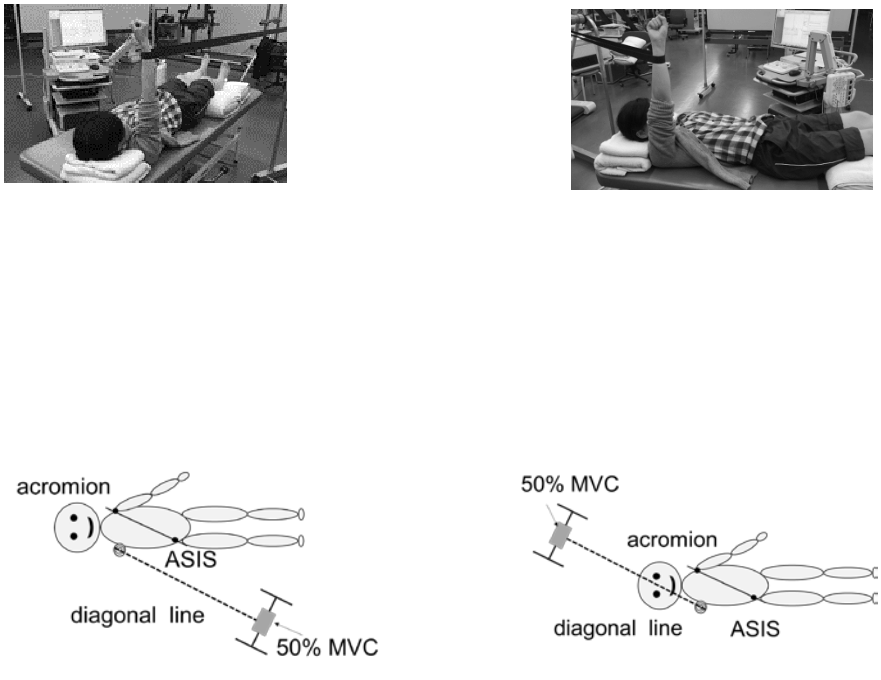
Table 1. Right soleus H/Mmax ratio for each type of static contraction

	Mean	SD
Diagonal flexion direction	0.25	0.12
Diagonal extension direction	0.24	0.13

Table 2. Right soleus H/Mmax ratio over time

Time course	Mean	SD
C1	0.28	0.16
C2	0.32	0.20
C3	0.24	0.14
C4	0.25	0.12
C5	0.24	0.13
C6	0.24	0.11
C7	0.24	0.10
C8	0.23	0.10
C9	0.21	0.12
C10	0.23	0.11
C11	0.23	0.10
C12	0.23	0.11
C13	0.22	0.11

Condition C1 represents the rest phase, condition C2 represents the phase of each resistive exercise, and conditions C3–C13 represent the rest phase after each resistive exercise.



(a) (b)

Fig. 1 Two different traction force lines

The traction force lines of diagonal flexion or extension run parallel to the diagonal line from the left acromion process to the right ASIS. The subjects maintained their upper extremity against the traction force [(a) Diagonal flexion and (b) Diagonal extension].

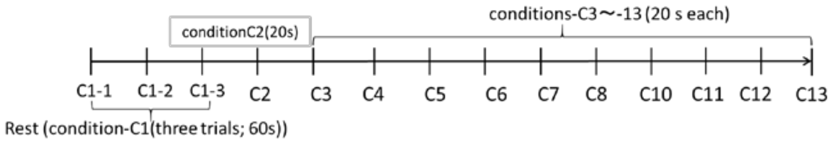


Fig. 2 Time-course (thirteen conditions: conditions C1–C13)

Condition C1 represents the rest phase; condition C2 represents the phase of each resistive exercise, and conditions C3–C13 represent the resting phase after each resistive exercise.

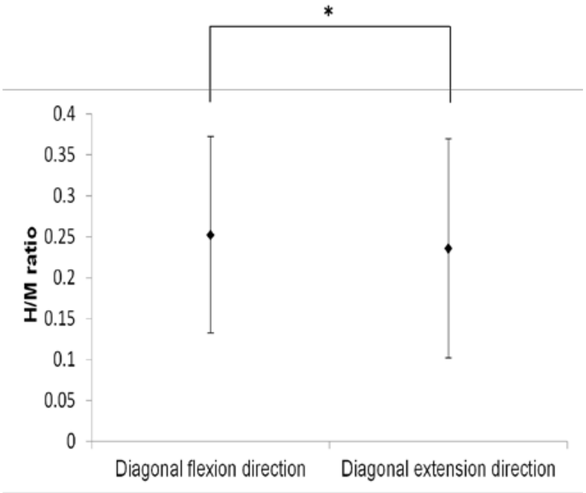


Fig. 3 H/Mmax ratio for Diagonal flexion vs. diagonal extension

The H/Mmax ratio for static contraction (SC) via diagonal extension was smaller than that via diagonal flexion.

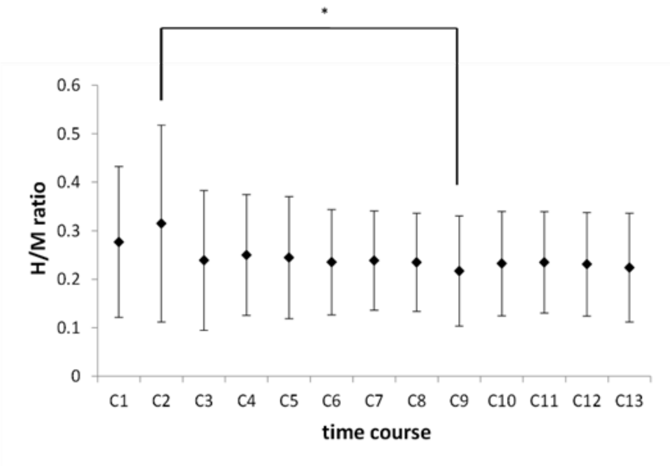


Fig. 4 Time course of the H/Mmax ratio under contraction and during the resting phase.

(thirteen 13 conditions: conditions C1–C13)

Post-hoc comparison of the effects of time course indicated that the H/Mmax before C2 was significantly larger than those conditions before C9.