

Original Article

Cross-education effect of vibration foam rolling on eccentrically damaged muscles

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Abstract

Objectives: Previous studies showed that vibration foam rolling (VFR) on damaged muscles improves muscle soreness and range of motion (ROM). VFR intervention can also increase the ROM and pain pressure threshold (PPT) in the non-rolling side, known as a cross-education effect. However, this is not clear for the non-rolling side. Therefore, this study aimed to investigate the cross-education effects of VFR intervention on ROM, muscle soreness, and PPT in eccentrically damaged muscles. **Methods:** Participants were sedentary healthy male volunteers (n=14, 21.4±0.7 y) who performed eccentric exercise of the knee extensors with the dominant leg and received 90-s VFR intervention of the quadriceps at the nondamaged side 48 h after the eccentric exercise. The dependent variables were measured before the exercise (baseline), before (preintervention), and after VFR intervention (postintervention) 48 h after the eccentric exercise. The Bonferroni post hoc test was used to determine the differences between baseline, preintervention, and postintervention. **Results:** Results showed that the VFR intervention on the nondamaged side 48 h after the eccentric exercise improved significantly (p<0.05) the knee flexion ROM, muscle soreness at palpation, and PPT compared to baseline. **Conclusion:** VFR intervention on the nondamaged side can recover ROM and muscle soreness in eccentrically damaged muscles.

Keywords: Cross-Transfer Effect, Contralateral Effect, Range Of Motion, Countermovement Jump, Pain Pressure Threshold

Introduction

It is well studied that damaged onset muscle soreness (DOMS) is caused by muscle contractions, including eccentric contractions and intense exercise after a long sedentary period. DOMS causes muscle soreness at palpation, contraction, and stretching and decreases muscle strength and range of motion (ROM)¹⁻³. These impairments, in turn, can influence athletic performance, reduce training quality

and adherence to resistance training, and increase the prevalence of injury. Recent studies showed that foam rolling (FR) and vibration FR (VFR) interventions on the eccentrically damaged muscle could reduce muscle soreness and counteract the loss of ROM and muscle performance⁴⁻⁶, thereby effectively controlling the impairments caused by DOMS. However, FR and VFR interventions on the damaged muscle may lead to significant pain and discomfort.

Interestingly, a single FR intervention was reported to increase the ROM of the non-rolling contralateral leg^{7,8}. This phenomenon is called the “cross-education (transfer) effect.” Aboodarda et al. (2015) reported a non-local increase in the pressure pain threshold (PPT) in their study⁹. Nakamura et al. (2021) showed the same effect of FR intervention on ROM in both the intervention and nonintervention sides¹⁰. Similarly, García-Gutiérrez et al. (2018) showed that VFR intervention helped increase the ROM on the nonintervention side¹¹. Taken together, these studies indicate that VFR intervention on the nondamaged side can recover muscle

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soreness and decreased ROM due to muscle damage when the muscle damage is on only one side. The advantage of VFR intervention on the nondamaged side is that it can cause less pain and discomfort compared to VFR intervention on the damaged side. However, to the best of our knowledge, no study has thus far investigated the cross-education effect of VFR intervention for the nondamaged side on ROM, muscle soreness, and PPT in eccentrically damaged muscles. According to the findings of the previous studies¹¹, we hypothesized that VFR intervention on the nondamaged muscle could improve ROM, muscle soreness, PPT, muscle strength, and jump performance in the contralateral damaged muscle side. The results of this study suggest VFR as an effective treatment method for cases with unilaterally damaged muscles in athletes (e.g., in unilateral sports such as tennis and fencing) and older adults.

Materials and Methods

Experimental Design

The outcome measurements consisted of knee flexion ROM, maximal voluntary isometric contraction (MVC-ISO), maximal voluntary concentric contraction (MVC-CON) torque of knee extensor, countermovement jump (CMJ) height, pain pressure threshold (PPT), tissue hardness, muscle soreness at MVC-ISO, MVC-CON, and stretching. All participants completed a bout of eccentric exercise of the knee extensors and received 90 s VFR intervention (30 s * 3 sets) of the nondamaged side at 48-h after the eccentric exercise⁴⁻⁶. These outcomes were measured before the maximal ECC task (baseline) and before (preintervention), and after VFR intervention (postintervention) by the same investigator. The postintervention measurements were performed immediately after the VFR intervention. All measurements were taken at the same time of the day for each participant. Our previous study confirmed the high reliability of the outcome variables¹².

Participants

Fourteen sedentary healthy young male volunteers participated in this study (age, 21.4±0.7 years; height, 171.0±5.8 cm; body mass, 65.3±8.2 kg). All participants had not performed habitual exercise activities and had not been involved in any regular resistance training or flexibility training for at least 6 months prior to participating in this study. We excluded participants who had a history of neuromuscular disease or musculoskeletal injury on the lower extremities. All subjects were fully informed of the procedures and purpose of the study and provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee at the Niigata University of Health and Welfare, Niigata, Japan.

The sample size required for a one-way repeated analysis of variance (ANOVA) according to previous studies with a similar design⁴⁻⁶ (effect size=0.50, α error=0.05, and

power=0.80) using G* power 3.1 software (Heinrich Heine University, Düsseldorf, Germany) was 14 participants.

MVC-ISO and MVC-CON

Using an isokinetic dynamometer (Biodex System 3.0, Biodex Medical Systems Inc., MVC-ISO was measured at two different angles, namely, 20° and 70° knee angles¹². The participants were instructed to perform a maximal contraction of the knee extensors for 3 s at each angle two times with a 60 s rest between trials. The average value was adopted for further analysis. MVC-CON was measured at an angular velocity of 60°/s for an ROM of 70° (20°–90° knee angles) for three continuous MVC-CONs for the extension. The highest value among the three trials was adopted for further analysis. Verbal encouragement was provided consistently during all trials.

Knee Flexion ROM

Each participant was placed in a side-lying position on a massage bed, and the hip and knee of the nonexercised leg were flexed at 90° to prevent pelvis movement during ROM measurements⁴. Next, the investigator brought the dominant leg to full knee flexion with the hip joint in a neutral position to the maximum pain the subject could tolerate⁴⁻⁶. Finally, a goniometer (MMI universal goniometer Todai 300 mm, Muranaka Medical Instruments, Co., Ltd., Osaka, Japan) was used to measure the knee flexion ROM three times, and the average value was used for further analysis.

Muscle Soreness

Using a visual analog scale that had a continuous 100-mm line with “not sore at all” on one side (0 mm) and “very, very sore” on the other side (100 mm), the magnitude of knee extensor muscle soreness was assessed by muscle contraction, stretching, and palpation^{4-6,13}. Both MVC-ISO and MVC-CON were measured to assess muscle soreness on contraction, and the average value was adopted for further analysis. For muscle soreness during palpation, the participants lay supine on a massage bed, and the investigator palpated the proximal, middle, and distal points of the vastus medialis, vastus lateralis, and rectus femoris^{4-6,12}. Again, the average value of the knee extensor palpation points was used for further analysis. The ROM measurement was taken three times to determine muscle soreness during stretching, and the average value was used for further analysis.

PPT

An algometer measured PPT measurements (NEUTONE TAM-22 (BT10); TRY ALL, Chiba, Japan) in the supine position. The measurement position was set at the midpoint between the anterior superior iliac spine and the upper end of the patella of the dominant side for the rectus femoris muscle. With a continuously increasing pressure, the metal rod of the algometer was used to compress the

Table 1. Changes (mean±SD) in knee flexion range of motion (ROM), maximal voluntary isometric contraction torque of knee extensor (MVC-ISO), maximal voluntary concentric contraction torque (MVC-CON) at 60°/s, countermovement jump (CMJ) height before maximal eccentric contraction task (baseline), pre- and post-vibration foam rolling for non-damaged side. The one-way repeated analysis of variance (ANOVA) results (p, and F-values and partial η^2 (η_p^2)) are shown in the bottom column.

	Knee flexion ROM (deg)	MVC-ISO (Nm)	MVC-CON (Nm)	CMJ height (cm)
Baseline	136.3±5.5	155.2±26.3	161.6±25.1	19.0±2.9
Pre-intervention	125.9±9.9*	104.6±22.5*	111.7±28.8*	15.7±2.9*
Post-intervention	130.4±7.6*#	104.8±24.6*	115.4±29.7*	16.7±3.1*
One-way repeated ANOVA	p<0.01, F=19.2, $\eta_p^2=0.596$	p<0.01, F=96.3, $\eta_p^2=0.881$	p<0.01, F=60.0, $\eta_p^2=0.822$	p<0.01, F=14.6, $\eta_p^2=0.529$

*: A significantly ($P<0.05$) different from the baseline value; #: A significantly ($P<0.05$) different from the pre-intervention value.

soft tissue in the measurement area. The participants were instructed to immediately press a trigger when they felt pain rather than just pressure. The value read from the device at this time point (kilograms per square centimeter) corresponded to the PPT. Based on previous studies^{14,15}, the mean value (kilograms per square centimeter) of the three repeated measurements were taken with a 30-s interval for data analysis.

Countermovement Jump

The CMJ height was calculated from flight time using the jump mat system (4Assist Inc., Tokyo, Japan). The participants started with the foot of the dominant leg on the mat with their hands in front of their chest. From this position, the participants were instructed to dip quickly (eccentric phase), reaching a self-selected depth to jump as high as possible in the next concentric phase. The landing phase was performed on both feet. The knee of the uninvolved leg was held at approximately 90° of the flexion¹⁶. Immediately after three familiarization repetitions, three sets of CMJ were performed and measured, and the maximal vertical jump height was used for further analysis.

ECC Exercise Task

All participants performed six sets out of ten maximal ECCs of the unilateral knee extensors (dominant leg) on the isokinetic dynamometer^{4,12}. The participants sat on the dynamometer chair at an 80° hip flexion angle, with adjustable Velcro straps fixed over the trunk, pelvis, and thigh of the exercised limb. The participants were instructed to perform the maximal ECC from a slightly flexed position (20°) to a flexed position (110°) at an angular velocity of 60°/s^{4,12}. After each ECC, the lever arm passively returned the knee joint to the starting position at 10°/s, which gave a 9 s rest between contractions. Each set was repeated ten times, and a 100-s rest period was allotted between the six sets. The participants received verbal encouragement during each ECC to generate maximum force.

Vibration Foam Rolling Intervention

A foam roller (Stretch Roll SR-002, Dream Factory, Umeda, Japan) was used for the VFR intervention. Before the VFR intervention, a physical therapist instructed the participants on how to use the foam roller. The VFR intervention was performed in three 30-s bouts with a 30-s rest between each set at 35 Hz. The participants were instructed lie the plank position with the foam roller at the most proximal portion of the quadriceps of the nondamaged leg only. Here we defined one cycle of VFR intervention as one distal rolling plus one subsequent proximal rolling movement, whereas the frequency was defined as 15 cycles per 30 s (for a total of 45 cycles in three sets) and measured using a metronome (Smart Metronome; Tomohiro Ihara, Japan). One cycle of VFR intervention was defined as the point between the top of the patella and the anterior superior iliac spine under the direct supervision of investigators. The participants were asked to place as much of their body mass on the roller as tolerable.

Statistical Analysis

SPSS (version 24.0; SPSS Japan Inc., Tokyo, Japan) was used for statistical analysis. The data distribution was assessed using the Shapiro–Wilk test, and we confirmed that the data followed a normal distribution. Significant differences in all variables were assessed using a one-way repeated ANOVA. When a significant effect was found, the Bonferroni post hoc test was used to determine the differences between measurements taken at baseline, preintervention, and postintervention. Additionally, we calculated the effect size (Cohen's d) as differences in the mean value divided by the pooled standard deviation (SD) between the pre- and postintervention in each group, in which a d of 0.00–0.19 was considered as trivial, 0.20–0.49 as small, 0.50–0.79 as moderate, and ≥ 0.80 as large^{17,18}. Differences were considered statistically significant at an alpha of $P<0.05$. The data are presented as mean ± SD.

Table 2. Changes (mean±SD) in pain pressure threshold (PPT), muscle soreness at maximal voluntary isometric contraction (MVC-ISO), maximal voluntary concentric contraction (MVC-CON), stretching, and palpation before maximal eccentric contraction task (baseline), pre- and post-vibration foam rolling for the non-damaged side. The one-way repeated analysis of variance (ANOVA) results (p, and F-values and partial η^2 (η_p^2)) are shown in the bottom column.

	Ppt (kg)	Muscle soreness at mvc-iso (mm)	Muscle soreness at mvc-con (mm)	Muscle soreness at stretching (mm)	Muscle soreness at palpation (mm)
Baseline	2.8±1.0	10.2±11.6	8.3±9.6	2.3±3.9	7.4±5.2
Pre-intervention	1.8±1.2*	30.6±16.9*	28.6±21.2*	34.4±14.7*	41.6±19.9*
Post-intervention	2.4±1.1#	24.8±16.2*.#	23.4±19.5*.#	29.1±13.3*	34.6±18.6*.#
One-way repeated ANOVA	p<0.01, F=12.6, $\eta_p^2=0.492$	p<0.01, F=16.7, $\eta_p^2=0.562$	p<0.01, F=13.5, $\eta_p^2=0.51$	p<0.01, F=49.9, $\eta_p^2=0.793$	p<0.01, F=39.9, $\eta_p^2=0.754$

*: A significantly (P<0.05) different from the baseline value; #: A significantly (P<0.05) different from the pre-intervention value.

Results

Table 1 shows the knee flexion ROM, MVC-ISO, MVC-CON, and CMJ at baseline, pre-, and post-VFR for the nondamaged side. The one-way ANOVA indicated the main effects for all variables. As a result of the post hoc test, all variables were significantly decreased after the ECC task. The knee flexion ROM was improved after VFR intervention on the nondamaged side (p<0.01, d=0.51). However, the postintervention value of the knee flexion ROM was significantly lower than the baseline value (p=0.01). On the other hand, the VFR intervention on the nondamaged side did not induce significant changes in MVC-ISO (p=1.00, d=0.01), MVC-CON (p=0.23, d=0.12) and CMJ height (p=0.16, d=0.32).

Table 2 shows PPT and muscle soreness at MVC-ISO, MVC-CON, stretching, and palpation at baseline, pre-, and post-VFR for the nondamaged side. The one-way ANOVA indicated the main effects for all variables. As a result of the post hoc test, all variables in the preintervention were changed significantly compared to the baseline measurement. However, VFR intervention on the nondamaged side significantly recovered PPT (p=0.048, d=0.56), muscle soreness at MVC-ISO (p=0.024, d=-0.35), MVC-CON (p=0.02, d=-0.26), and palpation (p=0.02, d=-0.37), except for muscle soreness at stretching (p=0.15, d=-0.38). Moreover, the postintervention value of muscle soreness at MVC-ISO, MVC-CON, and palpation was significantly higher than the baseline value.

Discussion

This study investigated the cross-education effect of VFR intervention on the eccentrically damaged muscles of fourteen healthy male subjects. Our results showed that the VFR intervention of the nondamaged side was able to recover the knee flexion ROM, PPT, and muscle soreness. Thus, it could be an effective treatment for DOMS via VFR intervention on the nondamaged side in athletes (e.g., in unilateral sports such as tennis and fencing) and older adults.

Our results showed that the VFR intervention of the

nondamaged side was able to significantly recover PPT and muscle soreness at MVC-ISO, MVC-CON, and palpation. VFR was able to selectively activate, through pressure and vibration, rapid muscle contractions that improved the pain sensation¹⁹. A previous study also showed reduced pain perception after FR intervention, as follows: 1) ascending pain inhibitory system (gate theory of pain), 2) the descending anti-nociceptive pathway (diffuse noxious inhibitory control [DNIC]), and 3) the autonomic nervous system⁹. Although the detailed mechanism of the analgesic effect of VFR intervention on the nondamaged muscle was unclear in this study, the mechanism described above was able to reduce muscle soreness in the damaged muscle side without direct intervention. However, muscle soreness at stretching could not significantly change after VFR intervention on the nondamaged side. This study measured knee flexion ROM to the maximum angle that the participants could tolerate. Therefore, muscle soreness at stretching did not change significantly. Thus, the decreased muscle soreness at stretching after the VFR intervention on the nondamaged side could have increased knee flexion ROM.

Interestingly, our results showed that ROM was recovered but not in muscle strength or CMJ height after VFR intervention on the nondamaged side. Our previous study showed that FR intervention on the damaged muscle side could recover muscle strength⁴, but VFR intervention could not⁶. However, VFR intervention could recover the CMJ height⁶. The reason for the discrepancy between the current study and the previous studies^{4,6} is unclear. However, it is possible that direct FR or VFR intervention on a damaged muscle might affect can strength and jump performance. Hence, if the goal of an athlete is to fully regain strength after muscle damage, a combination of FR and VFR on the damaged muscle is recommended. Further studies are needed to investigate the discrepancy between the direct effect and the cross-education effect of FR and/or VFR intervention on muscle strength and jump performance.

Kasahara et al. (2022) investigated the effect of direct VFR intervention on the damaged muscle side using the same protocol as this study. In our study, the changes from

pre- to post-VFR intervention for the nondamaged side were $3.8\pm 3.7\%$ ($d=0.51$) in the knee flexion ROM, 0.72 ± 0.8 kg ($d=0.56$) in PPT, and -7.0 ± 7.6 mm ($d=-0.37$) at muscle soreness at palpation. On the other hand, the previous study showed that the changes from pre- to post-VFR intervention for the damaged side were $6.1\pm 4.4\%$ ($d = 0.68$) in knee flexion ROM, 1.1 ± 0.9 kg ($d=0.93$) in PPT, and -15.2 ± 10.4 mm ($d=-1.27$) at muscle soreness at palpation. These differences could be related to the magnitude of pain or discomfort during the VFR intervention. VFR intervention on the damaged muscle side caused greater pain and discomfort than VFR interventions on the nondamaged side, resulting in greater ROM and muscle soreness changes. Therefore, if an individual can tolerate the pain or discomfort brought on by VFR intervention on the damaged muscle side, then direct VFR intervention on the damaged muscle side will be more effective than intervention on the nondamaged side. However, if the pain and discomfort are too severe for VFR intervention on the damaged muscle side. In that case, it may be more effective to first intervene on the nondamaged muscle side and then carry out VFR intervention on the damaged muscle side after the pain is relieved. Future studies should investigate VFR intervention's effect on the damaged side after VFR intervention on the nondamaged side on changes in these variables.

There were some limitations in this study. First, although we followed the suggestions of the a priori sample size calculation and recruited 14 participants, the sample might have been at the lower border (i.e., small post-hoc power). Second, the participants in this study were not athletes but sedentary healthy young males. Thus, future studies should investigate the effects of VFR on nondamaged muscle in athletes participants in a larger sample size.

In conclusion, VFR intervention on the nondamaged side was able to induce a cross-education effect, i.e., recover ROM and muscle soreness but not muscle strength and jump performance. These findings indicate that if it is too painful to intervene directly on the damaged muscle side, it may be a practical course of treatment to intervene on the nondamaged muscle side.

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Ethical Approval

This study was approved by the Ethics Committee of the Niigata University of Health and Welfare, Niigata, Japan (Procedure #18220), and has complied with the requirements of the Declaration of Helsinki.

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