RESEARCH ARTICLE

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Effect of Different Foam Rolling Sensitivities on the Amount of Change in Range of Motion: A Randomized Controlled Trial

Hiroto Kobune, Yoshiaki Kubo, Yasushi Fukuda, Yuto Matsuura, Takeyuki Kato, and Koji Koyama

ABSTRACT

Foam rolling (FR) is an easy-to-perform self-care activity to improve the range of motion in patients with injuries. However, even if FR is performed at the same intensity, the feeling differs depending on the patient. In addition, FR affects the contralateral side. This phenomenon is called cross education. Therefore, the main purpose of this study was to examine the relationship between FR sensitivities and FR efficacy. The secondary purpose was to determine how FR intensity perception influences cross education. In this study, FR sensitivity was calculated using the Visual Analogue Scale (VAS). The difference in the effect of FR sensitivity was evaluated using the correlation between the amount of change in PRE-test to POST- test ROM and VAS. The experimental procedure in this study first measures ankle dorsiflexion range of motion (ROM) on the left and right leg. Immediately after measurement, 3sets of FR were performed on one random leg. Participants wrote the VAS of FR for each set during the rest period of each FR intervention set. Immediately after 3 sets of FR, the ROM was measured in the left and right legs. Statistical analysis performed Two-way repeated measures ANOVA in group comparison. As a result, two-way ANOVA did not show a significant effect of group ($F = 0.003$, $P = 0.95$) or interaction effect ($F = 2.28$, $P = 0.14$). In contract, time had a significant effect ($F = 39.65$, $P = 0.001$). Post hoc result in [Dominant leg] PRE: 19.7 ± 7.6° POST: 22.2 ± 7.3° $P = 0.001$ $\Delta = 0.33$. [Non-dominant leg] PRE: 20.0 ± 7.8° POST: 21.6 ± 7.8° $P = 0.01$, $\Delta = 0.21$). On the other hand, Pearson's correlation coefficient was used for the correlation between the amount of change in ROM and VAS. As a result, a dominant leg significant negative correlation was observed between the 3dr set of FR VAS score and the amount of change in ROM ($r = -0.38$, $P = 0.04$). Non-dominant leg significant correlations were observed third set of FR VAS score and amount of change in ROM ($r = 0.41$, $P = 0.03$). The result of this study suggested that it is necessary to perform FR with a comfortable stimulus on the dominant leg to maximize the effect of FR.

Keywords: Ankle dorsiflexion, conditioning, foam rolling, self-care.

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I. INTRODUCTION

Injuries, such as fractures and dislocations, are often treated with immobilization using casts. In Japan, such treatment is performed not only by doctors but also by judo therapists (A Japanese traditional therapist). Long term immobilization can cause range of motion (ROM) restriction. ROM restriction also increases the risk of injury. Various studies reported that ankle dorsiflexion restriction can cause ankle sprains (de Noronha *et al.*, 2006; Fong *et al.*, 2011; Hoch & McKeon, 2010). Therefore, it is important to improve ROM restriction during rehabilitation. The ROM restriction involves ankle dorsiflexion of the triceps surae, knee flexion of the quadriceps, straight leg rising (SLR) of the hamstrings and elbow flexion of the triceps. Therefore, antagonist muscles influence ROM restriction.

Stretching has been proven effective in improving ROM restriction. Stretching was found more effective at high stimulation than at low stimulation (Kataura *et al.*, 2017; Nakamura *et al.*, 2021a). Foam rolling (FR) is a potential technique to improve ROM (Fig. 1). FR is a self-care tool that uses foam rollers and recently, it has gained popularity as it is easy to perform independently on a daily basis. Various effects of FR have been examined. For example, several researchers have reported improvements in ROM. These include ankle dorsiflexion, SLR, sit and reach, and heel-buttock distance (Grabow *et al.*, 2018; Hodgson *et al.*, 2018; Nakamura *et al.*, 2021b; Smith *et al.*, 2018; Yoshimura *et al.*, 2020). In these studies, FR was performed on the antagonist muscle. In addition, FR is effective not only on the intervening side but also on the non-intervening side. This phenomenon is called the crossover effect or cross-transfer (García-Gutiérrez *et al.*, 2018; Kelly & Beardsley, 2016; Killen *et al.*, 2019). However, it is not clear how much stimulus intensity can induce the crossover effect and cross transfer.

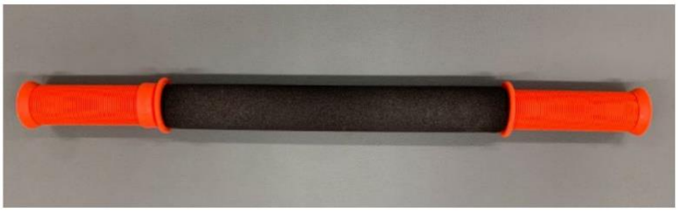

Fig. 1. Stick type foam roller.

Additionally, FR improves performance in countermovement jumps (Lin *et al.*, 2020; Richman *et al.*, 2019) and vertical jump heights (Peacock *et al.*, 2014; Smith *et al.*, 2018). In addition to the benefits of improving jump performance, previous studies suggested that athletes use FR for a variety of reasons including to increase ROM and flexibility, as a warm-up or cool-down activity enhances recovery and reduce muscle soreness and muscle stiffness during pre- and post- workout activities. However, FR exhibits a variety of stimulation intensities. Perceived pain of 7/10 on a visual analog Scale (VAS-10). Within the ranges of 15–25%, 32–52%, and 24.2% of their body weight, respectively. (Grabow *et al.*, 2018; Medeiros *et al.*, 2020; Nakamura *et al.*, 2021b; Okamoto *et al.*, 2014; Yoshimura *et al.*, 2021). Therefore, the stimulation intensity of the FR varied depending on the study. Despite this, the ROM improved in all cases.

Therefore, we believe that participants' sensitivity was more important than the intensity of the stimulus. We hypothesized that the stronger the participants' perceived FR stimulation, the greater the improvement in ROM after FR. Second, cross-education appeared more prominent as participants experienced a high stimulation of FR. The main purpose of this study was to examine the effect of the difference in the perception of FR on the amount of change in ankle dorsiflexion ROM from PRE-test to POST-test, that is, before and after FR. The secondary purpose was to determine how FR intensity perception influences the crossover effect. In addition, in most previous studies, the foam roller was used with body weight (Fig. 2); there have been few reports on the effectiveness of stick-type foam rollers (Fig. 1). Therefore, in this study, the effects of a stick-type foam roller were examined.

Fig. 2. Put body weight on the foam roller.

II. Method

A. Study Design

In this randomized controlled trial, ankle dorsiflexion before and after foam rolling was compared using the following procedure: (1) The left and right ankle dorsiflexion was measured; (2) three sets of foam rolling intervention were performed; (3) the participant completed a VAS during the rest period after each FR intervention set; and (4) immediately after (1)–(3), ankle dorsiflexion was measured again on the left and right sides (Fig. 3).

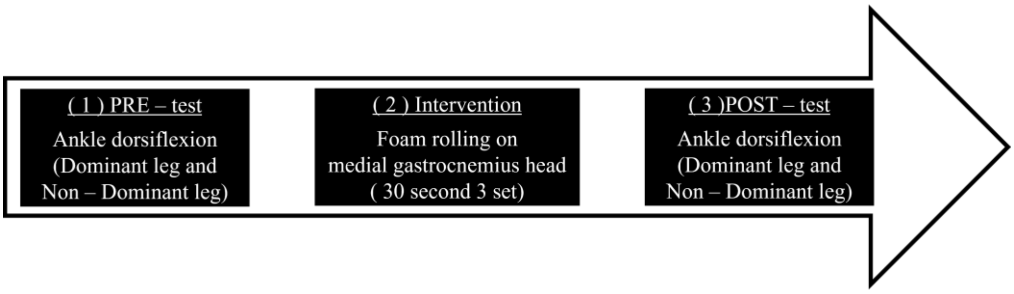

Fig. 3. The experimental procedure.

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B. Participants

Thirty healthy university students including 14 males (20.1 ± 1.4 years, 172.3 ± 3.9 cm, 65.3 ± 4.8 kg) and 16 females (20.1 ± 1.9 years, 158.1 ± 4.7 cm, 52.9 ± 6.3 kg) were recruited. The purpose of the experiment was explained orally to all participants, and they were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. All the participants provided written informed consent. This study was approved by the Tokyo Ariake University of Medical and Health Sciences (Ethics approval number: 370). None of the participants performed routine strenuous exercise. Inclusion criteria were no injuries to the ankle and triceps surae in the previous year (i.e., ankle sprain and pulled muscle). Patients who had undergone surgery on their lower limbs were excluded.

C. Measurement

1) Ankle Dorsiflexion

To measure the ankle dorsiflexion of the dominant and non-dominant legs, participants were positioned supine with their hips and knees flexed at 90° on a bed. The stationary arm of the goniometer was placed parallel to the long axis of the lower leg between the fibular head and the lateral malleolus, and the moving arm was placed at the fifth metatarsal. The ankle dorsiflexion was measured using the goniometer, before and after the FR intervention. The median values of three measurements were calculated. All measurements were performed by an individual who was not involved in the study design.

2) Visual Analogue Scale (VAS)

The VAS was used to evaluate the sensitivity of each foam roller set. The score ranges from 0 mm (painless) to 100 mm (the greatest conceivable pain) (Fig. 4) and is marked by the participants during rest between the FR sessions. During each measurement, the mark of the previous set is hidden to avoid bias. After the intervention, the written paper was placed in an envelope so that it could not be viewed by the interventionist. Later, it was measured using a digital caliper of length t marked on a 100 mm line by the participant, and the average of three measurements was taken. All measurements were performed by an individual who was not involved in the study design.

Fig. 4. VAS: 0 mm (painless) ~ 100 m (Conceivable the greatest pain)

D. Intervention

1) Foam Rolling

Immediately following the PRE-test, a stick-type foam roller (Tiger Tail, USA) was used for the intervention. It has plastic handles on both ends and has a length of 45.5 cm, a diameter 3.5 cm, and a circumference 11 cm. The intervention side was determined using an allocation table created from a random number table generated in Latin 390 (Block Size 4×2 and Block Size 2×2) by a person who had no contact with the participant. The order of allocation is shown in Fig. 5. The intervention side was blinded by the investigator. In this study, the examiner applied the same amount of force to the participants while they were in a prone position on the bed; the amount of force used was consistent with the force applied by the participants. The target area was the medial gastrocnemius head (Calucaneus ridge popliteal fossa). The foam rolling was applied in 3 sets of 30 seconds each with 30 seconds rest between each set. The foam roller is rolled over the muscle within 2 seconds with the surface of the roller in contact with the skin. This involves 1 second for distal to proximal and 1 second for proximal to distal movement; the entire motion is repeated for 30 seconds (Nakamura *et al.*, 2021a).

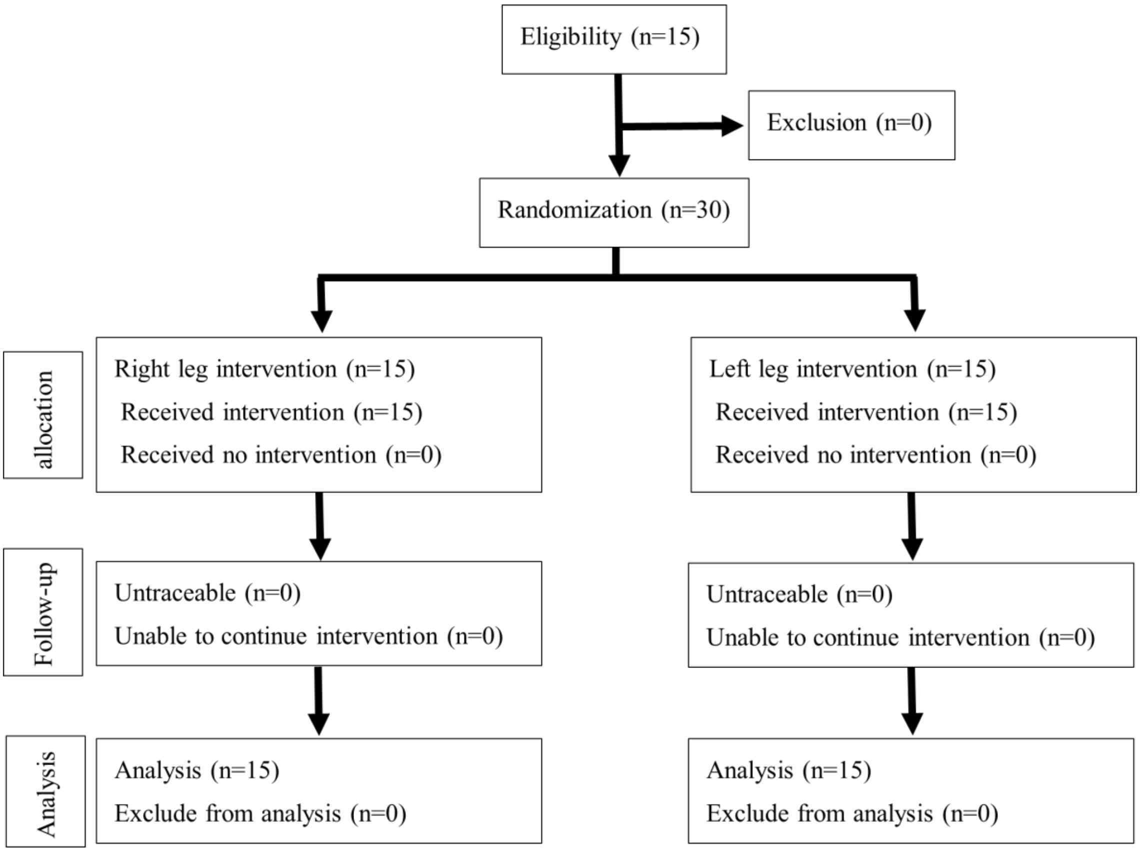

Fig. 5. Depiction of the order of participant allocation.

E. Statistical Analysis|

All data were described as average ± standard deviation (SD). All statistical analyses were performed using the SPSS v.23 software. The statistical significance level was set at 0.05.

The dominant and non-dominant legs were compared using two-way ANOVA (time × group) with repeated measures.

If a main effect of time was observed in a two-way ANOVA comparing the dominant and non-dominant legs with repeated measures, a post hoc comparison was conducted using the Wilcoxon single-rank test to compare the pre- and post-intervention values of ankle dorsiflexion in the dominant and non-dominant legs. The relationship between foam rolling sensitivity and the amount of change in ROM from the PRE-test to the POST-test was determined using Pearson's correlation coefficient. Additionally, the effect size (ES) was calculated from the results of the Wilcoxon signed-rank tests using Cohen's Δ. These were classified as 0.2 ≤ small < 0.5, 5.0 < medium < 0.8, and 0.8 ≤ large.

III. Results

This study was conducted between June and July. Dominant leg and non-dominant leg statistical analyze were performed in randomized numbers. No adverse events due to FR were observed in this study.

A. Ankle Dorsiflexion

Two-way repeated-measures ANOVA did not show a significant main effect of group (F = 0.003, p = 0.95) or an interaction effect (F = 2.28, p = 0.14). However, time had a significant effect (F = 39.65, p = 0.001). There was no significant difference between the dominant and non-dominant legs before foam rolling. (Dominant leg: 19.7 ± 7.6°, Non-dominant leg: 20.0 ± 7.8°, p = 0.73; see Table I).

Ankle dorsiflexion of both the dominant and non-dominant legs significantly increased after the FR (Dominant leg: PRE: 19.7 ± 7.6 °, POST: 22.2 ± 7.3°, p = 0.001, Δ = 0.33; Non-dominant leg: PRE: 20.0 ± 7.8°, POST: 21.6 ± 7.8°, p = 0.01, Δ = 0.21; see Table II).

TABLE I: Comparison of Dominant and Non-dominant Leg Dorsiflexion on PRE-test

	Dominant leg	Non-dominant leg	p-value
Ankle dorsiflexion (°)	19.7 ± 7.6	20.0 ± 7.8	0.73

Note. Data showed mean ± SD.

TABLE II: COMPARISON OF PRE- AND POST-TEST ANKLE DORSIFLEXION OF THE DOMINANT AND NON-DOMINANT LEGS

	PRE	POST	p-value	Effect size
Dominant leg ankle dorsiflexion (°)	19.7 ± 7.6	22.2 ± 7.3	0.001	Δ = 0.33
Non-dominant leg ankle dorsiflexion (°)	20.0 ± 7.8	21.6 ± 7.8	0.01	Δ = 0.21

B. Visual Analogue Scale (VAS)

Relationship between foam rolling sensitivity and amount of change in ROM from PRE-test to POST-test. Significant negative correlations were observed between the third set VAS and the amount of change in ankle dorsiflexion from PRE-test to POST-test of the dominant leg. On the other hand, no significant correlation was observed between first and second set of VAS scores and the amount of change in ankle dorsiflexion from PRE-test to POST-test of the dominant leg (first set: r = -0.29, p = 0.12; second set: r = -0.36, p = 0.05; third set: r = 0.38, p = 0.04; see Fig. 6). Significant correlation was observed between the third set VAS and the amount of change in ankle dorsiflexion from PRE-test to POST-test of the non-dominant leg. On the other hand, no significant correlation was observed between the first and second set VAS scores and the amount of change in ankle dorsiflexion from PRE-test to POST-test dorsiflexion of the non-dominant leg (first set: r = 0.17, p = 0.36; second set: r = 0.17, p = 0.7; third set: r = 0.41, p = 0.03; see Fig. 7).

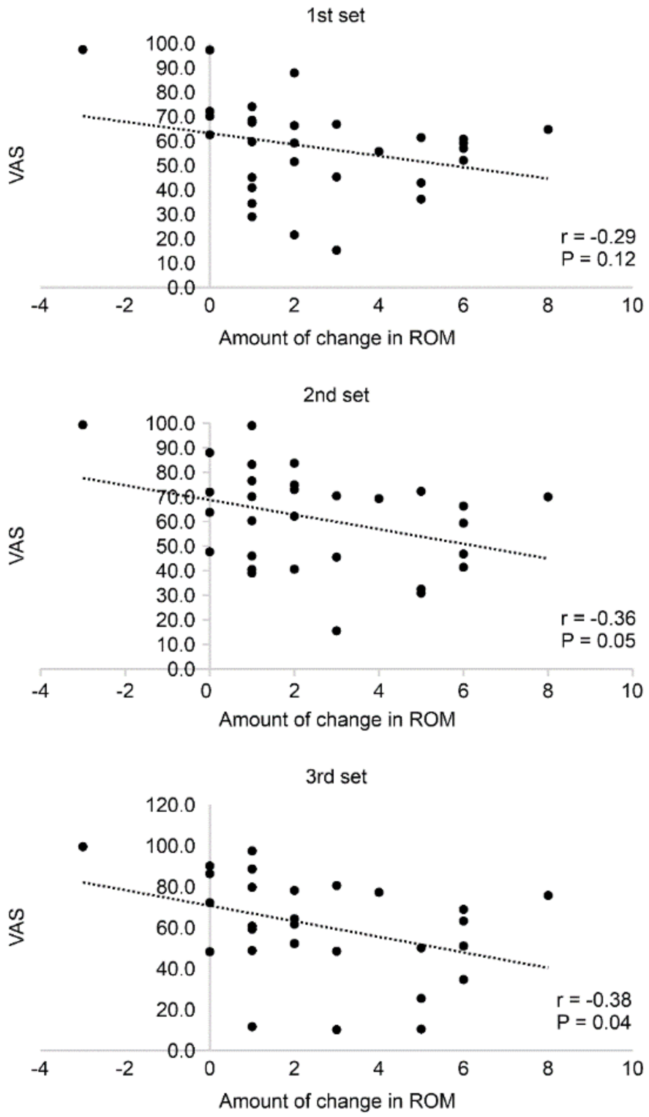

Fig. 6. Correlation between the VAS and amount of change in ankle dorsiflexion from PRE-test to POST-test of dominant leg.

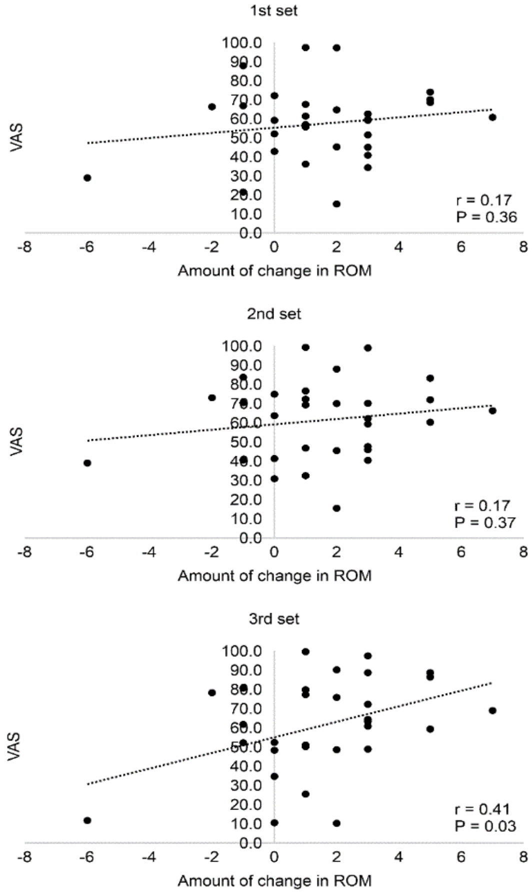

Fig. 7. Correlation between the VAS and amount of change in ankle dorsiflexion from PRE-test to POST-test of non-dominant leg.

IV. Discussion

In this study, ankle dorsiflexion was compared before and after FR. Second, we investigated the relationship between foam rolling sensitivity and changes in ROM from PRE-test to POST-test. The dominant and non-dominant legs showed a significant increase after foam rolling. In addition, the relationship between FR sensitivity and the amount of change in ROM from PRE-test to POST-test was significant. This is the first study to show that FR sensitivity is significantly associated with changes in ankle dorsiflexion.

A. Ankle Dorsiflexion ROM

The results of this study are similar to those of previous studies that used body weights placed on a foam roller (Nakamura *et al.*, 2021a; Smith *et al.*, 2019). Therefore, we also thought that stick-type foam rollers would have the same effect as the body weight placed on the foam roller. However, ES (Δ) observed was small in this study (Comparison of PRE-test and POST-test in dominant leg showed Δ = 0.33, non-dominant leg showed Δ =0.21). Therefore, a significant difference was observed between groups. However, the observed effect size (Δ) was small. We believe that this was due to the large variation in data and small changes in ROM in healthy subjects.

In this study, an increased non-dominant leg ROM was observed. This is called the crossover effect or cross-education (García-Gutiérrez *et al.*, 2018; Kelly & Beardsley, 2016; Killen *et al.*, 2019). In this study, the results were similar to those of previous studies. The reason for the increase in ROM is increased stretch tolerance (Behm *et al.*, 2016; Hodgson *et al.*, 2018; Konrad *et al.*, 2022).

In contrast, a recent study suggested that the FR mechanism is influenced by changes in the muscle fiber viscosity. This change in viscosity is commonly referred to as thixotropy (García-Gutiérrez *et al.*, 2018; Kelly & Beardsley, 2016). Thixotropy is caused by the application of pressure stimulation to muscle fibers, which liquefy as a result of pressure stimulation. However, thixotropy has not been reported in any studies. An ultrasound device can be used for observation. The advantage of using ultrasound devices is that they can be performed non-invasively, eliminating the influence of invasiveness on the experimental results. A previous study evaluated the pinnate angle of the triceps surae using an ultrasound device to evaluate the effect of FR (Yoshimura *et al.*, 2020). Before conducting this study, we attempted to evaluate changes in the muscle fiber elongation rate using ultrasound, referring to a previous study; however, the same images could not be obtained before and after the intervention. Therefore, we believe that the evaluation of thixotropy using ultrasound is unreliable. We believe that it is necessary to establish a thixotropy evaluation method by repeating these experiments in the future.

B. Visual Analogue Scale (VAS)

The main finding of the present study was that FR sensitivity was significantly associated with the degree of change in ankle dorsiflexion. In this study, we evaluated the relationship between foam rolling sensitivities and the amount of change in ROM from PRE-test to POST-test, which revealed significant negative correlations between the third set VAS and the amount of change in ankle dorsiflexion from PRE-test to POST-test of the dominant leg. However, a negative correlation was observed overall and not only in the third set. This result contradicted our hypothesis.

The same examiner performed all interventions. Therefore, the magnitude of the stimulation was the same. However, individuals exhibit different FR sensitivities. Our study revealed a negative correlation between the participants' perceived pain, as measured by their VAS score for FR, and the extent of their ROM changes. This finding indicates that as participants perceive FR to be more painful, its effectiveness in improving ROM decreases. On the contrary, it has been reported that the higher the intensity of stretching, the better the ROM (Kataura *et al.*, 2017; Nakamura *et al.*, 2021a). Stretching is thought to improve the ROM by increasing stretch tolerance. Stretching is performed to stretch the muscles. In contrast, FR is applied to the muscle as a pressure stimulus. This mechanical stimulus differs from stretching.

The pressure stimulus is painful. Thus, we thought that this was due to the flexion caused by the stimulation of nociceptors by FR. Consequently, the flexors of the triceps surae became tense. Therefore, the triceps surae extension rate and ROM decreased.

However, a significant difference was observed in the non-dominant leg. This phenomenon is known as cross-education (García-Gutiérrez *et al.*, 2018; Kelly & Beardsley, 2016). The crossover effect and cross-education were evaluated in a previous study. However, this study is the first to evaluate the relationship between the amount of change in ROM and FR sensitivity. In previous studies, cross-education was thought to involve the central nervous system (García-Gutiérrez *et al.*, 2018; Kelly & Beardsley, 2016). This was considered the result of the crossed extensor reflex, which causes an accelerated contraction of the extensor muscles in non-dominant leg. We believe that this contributed to ROM improvement in non-dominant leg and the ROM improved in non-dominant leg as the participant felt that the stimulus was stronger. Thus, the improvement in ROM in non-dominant leg is also called cross-education. However, the stimulus intensity required to generate cross-education remains unclear. Therefore, we believe that this study will help generate a stable cross-education.

We believe that the results of this study can be applied in the clinic. Some of the current clinical issues are joint contracture and ROM restriction due to long-term immobilization. Performing FR on the affected limb to improve ROM may be painful at times. In such cases, we hypothesized that the ROM of the affected limb can be improved by performing FR on the unaffected limb. In the future, we will investigate whether a decrease in ROM can be prevented by performing FR during immobilization.

V. Conclusion

This study investigated the effect of different foam rolling sensitivities on the change in the ROM. FR had less of an effect, and the participants felt that the FR stimulus was stronger in the dominant leg. On the other hand, non-dominant leg improved ROM, and the participant felt that the stimulus was stronger. Based on the results of this study on the dominant leg, it is necessary to perform FR with a comfortable stimulus to maximize the effect of FR. Therefore, we believe that future interventions in the study of FR will be most effective if the subjects perform FR using a comfortable stimulus. Therefore, we believe that this will be useful for determining the stimulation intensity in FR interventions.

The amount of change in ankle dorsiflexion ROM was very small, and the participants' ROM was highly variable. Therefore, it is necessary to recruit more participants to increase data reliability. The participants in this study were mainly young individuals. Therefore, the results of this study may not be applicable to all age groups.

We would like to this opportunity to thank the researchers and participants involved in this study. There are no conflicts of interest to disclose in this study.

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