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ORIGINAL RESEARCH

SPECIFIC AND CROSS-OVER EFFECTS OF FOAM ROLLING ON ANKLE DORSIFLEXION RANGE OF MOTION

Shane Kelly, MSc[1]
Chris Beardsley, MA (Hons)[2]

ABSTRACT

Background: Flexibility is an important physical quality. Self-myofascial release (SMFR) methods such as foam rolling (FR) increase flexibility acutely but how long such increases in range of motion (ROM) last is unclear. Static stretching (SS) also increases flexibility acutely and produces a cross-over effect to contralateral limbs. FR may also produce a cross-over effect to contralateral limbs but this has not yet been identified.

Purpose: To explore the potential cross-over effect of SMFR by investigating the effects of a FR treatment on the ipsilateral limb of 3 bouts of 30 seconds on changes in ipsilateral and contralateral ankle DF ROM and to assess the time-course of those effects up to 20 minutes post-treatment.

Methods: A within- and between-subject design was carried out in a convenience sample of 26 subjects, allocated into FR ($n = 13$) and control (CON, $n = 13$) groups. Ankle DF ROM was recorded at baseline with the in-line weight-bearing lunge test for both ipsilateral and contralateral legs and at 0, 5, 10, 15, 20 minutes following either a two-minute seated rest (CON) or 3 × 30 seconds of FR of the plantar flexors of the dominant leg (FR). Repeated measures ANOVA was used to examine differences in ankle DF ROM.

Results: No significant between-group effect was seen following the intervention. However, a significant within-group effect ($p < 0.05$) in the FR group was seen between baseline and all post-treatment time-points (0, 5, 10, 15 and 20 minutes). Significant within-group effects ($p < 0.05$) were also seen in the ipsilateral leg between baseline and at all post-treatment time-points, and in the contralateral leg up to 10 minutes post-treatment, indicating the presence of a cross-over effect.

Conclusions: FR improves ankle DF ROM for at least 20 minutes in the ipsilateral limb and up to 10 minutes in the contralateral limb, indicating that FR produces a cross-over effect into the contralateral limb. The mechanism producing these cross-over effects is unclear but may involve increased stretch tolerance, as observed following SS.

Levels of Evidence: 2c

Key Words: Flexibility, self-massage, self-myofascial release

[1] School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, United Kingdom.
[2] Strength and Conditioning Research Limited, Holborn Viaduct, London, United Kingdom

CORRESPONDING AUTHOR
Shane Kelly, MSc
Right to Dream Academy
Atimpoku, Volta Region, Ghana, Africa.
Phone: +233 0505405562 or +44 7597385507
E-mail: shanekellyhealth@gmail.com

INTRODUCTION

Flexibility is an important physical quality. Many factors contribute to flexibility such as joint structure, muscle length, age, and activity level. In this study, flexibility will be defined as the range of motion (ROM) available at a joint, where ROM describes the degree of angular motion.[1] Although the overall role of flexibility in determining injury risk is unclear, there is evidence to suggest that restricted ankle dorsiflexion (DF) ROM, is a contributing factor for some lower extremity injuries[2,3,4] and is commonly seen after ankle sprains, fractures, and Achilles tendon injuries.[5] This may be because restricted ankle DF ROM limits the forward translation of the tibia over the foot during gait, possibly leading to dysfunction and an altered gait pattern.[2] Such changes may increase the risk of developing patellofemoral pain syndrome,[6] patellar tendinopathy,[7] lateral ankle sprains,[5, 8,9] plantar fasciopathy,[10] and medial tibial stress syndrome.[11] Furthermore, drop or jump landings in subjects with a reduced ankle DF ROM result in greater peak landing forces.[12, 13] Decreased ankle DF ROM is also associated with increased knee valgus.[4] Both greater peak landing forces and increased knee valgus are associated with increased anterior cruciate ligament injury risk.[3] Increasing ankle DF ROM may therefore help reduce incidence of lower limb dysfunction and lower musculoskeletal injury risk.[11,14]

Self-myofascial release (SMFR), is a form of manual therapy in which the individual applies a manual treatment to themselves with foam rolling (FR) being the most commonly used practice.[15] The literature indicates that FR improves flexibility for approximately 10 minutes post-treatment[15] but the mechanism or mechanisms by which SMFR exerts its effects are currently unclear and many possible explanations exist. Such mechanisms can be differentiated into mechanical and neurophysiological types. Within mechanical models, it is theorized that the material properties of fascia are affected by the pressure exerted through SMFR, thereby altering its viscoelastic properties. Many possible mechanisms exist including thixotrophy, piezoelectricity, fascial adhesions, cellular responses, fluid flow, fascial inflammation, and myofascial trigger points. Within neurophysiological models, it is theorized that the mechanical pressure from SMFR influences a state of tissue relaxation through afferent signal input to the central nervous system via stimulation of the Golgi reflex arc and other mechanoreceptors.[15] In contrast to such potential mechanisms of SMFR, acute increases in flexibility produced by static stretching (SS) are most likely caused by increases in stretch tolerance.[16] It remains possible that SMFR may also be effective through a similar mechanism,[15,17] particularly as manual therapies in general are typically reported as having a number of pain-relieving effects.[18,19]

The cross-over effect was first observed by Scripture et al. [20] It describes how resistance training in an ipsilateral limb produces strength gains in the contralateral limb and indicates that strength training produces a central adaptation and not just a local one.[20] Munn et al[21] reviewed the literature and concluded that unilateral strength training produces modest increases in contralateral strength and similar findings have been shown on contralateral limbs in respect of acute fatigue.[22,23] There is also a cross-over effect in relation to flexibility, as static stretching of the ipsilateral limb produces acute increases in ROM in the contralateral limb,[24] as well as other limbs across the upper and lower body.[25] Static stretching of the ipsilateral limb may also affect force production in the contralateral limb.[26] Such findings indicate that SS likely produces its cross-over effects by means of a global improvement in stretch-tolerance. In contrast to SS, there has been little exploration of the cross-over effect of flexibility in SMFR. Nevertheless, Jay et al[27] found that SMFR using FR reduced delayed onset muscle soreness, suggesting the presence of a cross-over effect of analgesic effects, which raises the possibility that similar cross-over effects might be observable in relation to flexibility.

Therefore, it was the purpose of this study to explore the potential cross-over effects of SMFR by investigating the effects of a FR treatment of 3 bouts of 30 seconds to the ipsilateral limb on changes in in ipsilateral and contralateral ankle DF ROM and to assess the time-course of those effects up to 20 minutes post-treatment.

METHODS

Subjects

A convenience sample of 26 (16 male and 10 female) recreationally active, university students were

Table 1. *Participant Characteristics ± Standard Deviations*

	SEX	AGE (YRS)	HEIGHT (CM)	WEIGHT (KG)
FOAM ROLLING	Male: n = 8 Female: n = 5	24.8 ± 2	174 ± 7.1	73.5 ± 9.5
CONTROL	Male: n = 8 Female: n = 5	24.4 ± 1.7	174 ± 5.6	72.6 ± 8.3

recruited through email and posters (Table 1). Recreationally-active was defined as performing exercise approximately two to three times per week[28] as this is the population that is believed to use and therefore benefit from SMFR,[29] thereby improving external validity. Participants were included if they were healthy and free from ankle injuries in the six months preceding the testing.

Experimental approach

A randomized controlled between-subjects design was used. The between-subjects design was selected in order to provide a 'true' control group, and thereby reduce the impact of the familiarization of the testing protocol.[30] Participants were randomly assigned to either FR or CON group using a computer-generated model for randomization in order to comply with risk of bias in trials.[31] Subjects were asked to refrain from strenuous exercise for at least three hours prior to testing as this may affect flexibility.[32] Upon arriving at the laboratory, the subjects signed consent forms, after which sex, age, height and weight were recorded. Subjects then carried out a warm up of 10 double-leg heel raises to the floor. Previous similar studies have included warm ups,[28,17] although others have not[33] and the nature and extent of the warm-up may affect the results observed.[17] Nevertheless, a warm up is more likely to mimic what happens in real life[32] and therefore improves external validity.

Immediately after the warm up, a baseline measurement of DF ROM for both ankles for subjects in both groups was measured using the weight-bearing lunge test (Figure 1). The weight-bearing lunge test has been shown to have high inter-rater ($r = 0.99$) and intra-rater ($r = 0.98$) reliability.[34] Several previous studies have used this test successfully.[34,28,33] Subjects stood with their foot approximately 10cm back, perpendicular to the wall. They were then instructed to look forward and to flex their knee until it reached the wall.

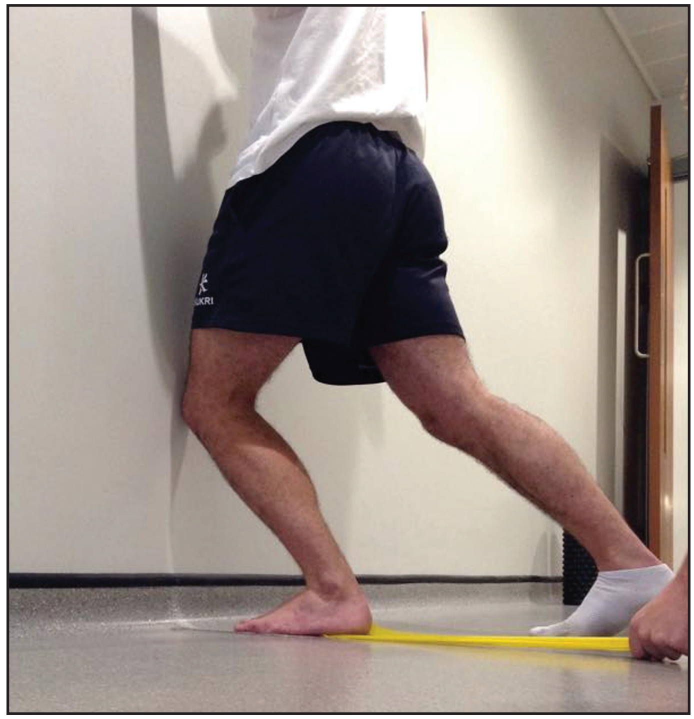

Figure 1. *Weight Bearing Lunge Test with tester holding thera-band under subjects heel.*

The knee was to touch the wall, travel over the mid-line of the foot and the heel was to stay firmly on the ground for it to be considered a successful attempt.[28,33] The subject was then instructed to either slide their foot forward or back depending whether their knee failed or successfully touched the wall in the previous test. A ruler attached to the ground measured the distance of their big toe from the wall at the point where the subject was at the limit of their ROM, where the knee was just making it to the wall with the heel on the ground.[28,33] To ensure no elevation of the heel took place, a theraband was put under the heel and tension was applied by the same experimenter.[28] If the heel came off the floor, the theraband would snap back and would be deemed a failed attempt.

Immediately after the baseline ankle DF ROM measurements, subjects in the CON group remained in a long sitting resting position for two minutes while subjects in the FR group carried out the FR intervention, which involved foam rolling the calf musculature of the dominant leg (leg used to kick a ball) for three bouts of 30 seconds, with 10-second rest intervals between bouts, for a total time of two minutes. Subjects were instructed to place the top of their calf musculature of their dominant leg onto the roller, to place their other leg on top, to raise their buttocks off the floor, place as much force through the roller as possible, and roll down slowly in kneading like motions until they reached the Achilles tendon insertion (Figure 2). Subjects were instructed to roll back up to the top and repeat until 30 seconds had elapsed, using a slow pace (approximately three seconds down and one second up) in order to reduce variance in rolling technique.[17] Subjects were instructed to focus on the lateral aspect of the calf for the first set, the middle aspect for the second set and the medial aspect for the third set to ensure that the entire calf area was treated. A foam roller (The Grid Roller - Escape Fitness, Cambridgeshire, UK) made from a hard, hollow uniform cylinder enclosed with a layer of ethylene vinyl acetate foam was used. This type of foam roller was used as harder foam rollers are thought to elicit a greater benefit in ROM through increased pressure on the tissue.[29] Each subject in the FR group sat in a long sitting resting position between ROM measurements to control for any effect moving around may have on flexibility.[27] After the two-minute rest (CON) or the foam rolling intervention (FR), ankle DF ROM was measured for both legs, dominant leg first. Identical measurements were taken at 0, 5, 10, 15 and 20 minutes.

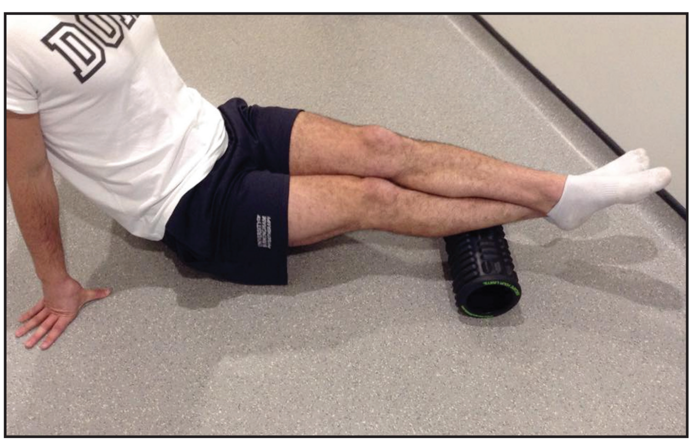

Figure 2. *Foam Rolling of the plantar flexors.*

STATISTICAL ANALYSIS

Normality of the data was firstly established using the Shapiro-Wilk Test, where skewness and kurtosis were identified through histogram presentation.[35] The Shapiro-Wilk Test was used given its power and appropriateness given the small sample size.[36] Mauchly's test of sphericity was used to ensure there was homogeneity of variance between conditions. If the laws of sphericity were violated the Greenhouse Geisser correction was used.[35] A two-way repeated measures analysis of variance (ANOVA) was used to explore the hypotheses over time where an alpha level of 0.05 was set, representing significance.[35] If a significant ($p < 0.05$) effect was found, analysis was continued with a one-way ANOVA and post-hoc testing involving pairwise comparisons with Bonferonni corrections, as suggested by Munro.[37] SPSS version 22 (SPSS Inc., Chicago, IL, USA) was used to carry out all of the statistical analysis.

RESULTS

Between groups

No statistically significant differences ($p \geq 0.05$) between groups for ankle DF ROM at baseline for either leg were identified. Significant main effects for time ($p = 0.00$; $F(5,20) = 59.28$; partial $\eta 2 = .937$), and significant interaction effects for time*group ($p = 0.00$; $F(5,20) = 43.40$; partial $\eta 2 = 0.916$), time*leg ($p = 0.00$; $F(5,20) = 15.27$; partial $\eta 2 = 0.792$) and time*leg*group ($p = 0.00$; $F(5,20) = 8.38$; partial $\eta 2 = 0.677$) were found. However, follow-up analysis using pairwise comparisons with Bonferonni corrections revealed that all individual between-group effects were not statistically significant (all $p \geq 0.05$) (Table 2).

Within groups

Within the FR group, a significant main effect for time for the dominant leg and for the non-dominant leg were identified ($p = 0.00$; $F(3.91, 93.935) = 48.66$; partial $\eta 2 = 0.670$). Pairwise comparison of different time points for the dominant leg showed significant ($p < 0.05$) differences for all time-points compared to baseline ROM, which suggests that FR improved ROM up to 20 minutes (Table 2). Similarly, pairwise comparison of different time points for for the non-dominant leg showed significant ($p < 0.05$) differences at 0, 5 and 10 minutes compared to baseline

Table 2. *Differences in ROM scores from Baseline at the various timepoints given in centimetres (cm) and percentage (%)*

Baseline	Post (0mins)	5mins	10mins	15mins	20mins
FOAM ROLLING					
Dom (12.77cm)	1.12cm (8.79%)*	1.12cm (8.79%)*	1.01cm (7.89%)*	0.72cm (5.60%)*	0.51cm (3.97%)*
Non-Dom (12.88cm)	0.72cm (5.55%)*	0.44cm (3.40%)*	0.25cm (1.97%)*	0.24cm (1.85%)	0.11cm (0.84%)
CONTROL					
Dom (12.9cm)	0.11cm (0.83%)	0.09cm (0.72%)	0.14cm (1.07%)	0.13cm (1.01%)	0.15cm (1.19%)
Non-Dom (12.8cm)	0.04cm (0.30%)	0.08cm (0.60%)	0.00cm (0.00%)	-0.01cm (-0.06%)	0.05cm (0.36%)

* = Statistical difference (p<0.05) noted when compared to baseline ROM.
Key: Dom = dominant leg; Non-Dom; non-dominant leg

ROM, suggesting a cross-over effect that lasted for approximately 10 minutes (Table 2).

DISCUSSION

Although no significant differences were noted in the between-group analysis, there were significant within-group effects in the FR group. The within-group effects suggest that FR improves ankle DF ROM for at least 20 minutes in the ipsilateral limb and up to 10 minutes in the contralateral limb, indicating that FR produces a cross-over effect into the contralateral limb. The mechanism producing these cross-over effects is unclear but may involve increased stretch tolerance, as observed following SS.

The change in ankle DF ROM on the dominant leg in the weight-bearing lunge test was small (1.12cm/8.79%) and even smaller in the non-dominant leg (0.72cm/5.55%) immediately post-rolling and therefore the clinical impact in healthy populations is questionable. Nevertheless, in a rehabilitation setting, where ankle DF ROM may be limited, small changes could be beneficial and so have a greater clinical relevance.[5] Additionally, a longer intervention may provide greater improvements in Ankle DF ROM, a potential area for future research. The cross-over effect has potential applications where ROM is restricted on one side of the body as a result of injury, post-operation immobilization or neurological conditions. In such cases, SMFR treatment of the healthy limb may have benefits through the cross-over effect into the injured limb, although longitudinal trials are necessary to find out whether the cross-over effect persists beyond a single treatment.

Time course of effects

The findings of this study are broadly in line with earlier studies that have investigated the time course of the acute effects of FR on flexibility. In general, it has been found that acute increases in flexibility can be observed for at least 10 minutes post-treatment but not longer than 30 minutes.[27,28,33,38] MacDonald et al[38] reported that there was no difference in the acute effects at two and 10 minutes and Halperin et al[28] similarly found no differences between measurements taken at one and 10 minutes. Jay et al[27] found that increases in flexibility were recorded at 10 minutes but not at either 30 or 60 minutes. Finally, Škarabot et al[33] found no differences between time points up to 20 minutes. Adding to these findings, the current study reported significant differences at all post-intervention time-points for the ipsilateral leg compared with baseline ROM, which suggests that FR improved ROM up to 20 minutes in the treated leg. However ROM was trending towards baseline levels following the 10 minute mark. Whether measurements taken at 30 or 60 minutes in the present study would have demonstrated a return to baseline is unclear. Additionally, it is important to note that a range of factors could affect differences in reported results between trials, including the population, the measurement method used for joint ROM, the muscle group being treated, and the nature, intensity, volume and method of application of the SMFR tool.[15,33]

Cross-over effects

In this study, a crossover effect of flexibility from the ipsilateral limb to the contralateral limb was observed immediately, 5 and 10 minutes post rolling. In one previous investigation, Jay et al[27] reported a reduction in delayed onset muscle soreness in the contralateral limb after SMFR of the ipsilateral limb but did not suggest any mechanism by which such cross-over effects might have occurred. Investigating SS applied to an ipsilateral limb, Chaouachi et al[24] found increased flexibility in the contralateral limb and suggested that changes in the somatosensory perception of tissue length and tension occurred, which likely required cortical involvement. Similarly, Behm et al[25] observed global effects of an acute bout of SS by testing upper and lower body flexibility after bouts of lower and upper body SS, respectively. Behm et al[25] also investigated changes in electromyography amplitude after SS and reported no alterations despite the increased ROM, which they interpreted as suggesting no influence on neural drive. Consequently, they also concluded that the mechanism by which SS produced these global effects on flexibility was enhanced stretch tolerance.

As previous studies have indicated that FR interventions may possess an additive effect on increasing ROM when combined with SS,[33] it is plausible that the force applied during rolling may serve to increase parasympathetic nervous activity through the stimulation of mechanoreceptors.[39] As this would be a global response, it could allow the contralateral limb to gain and may further explain the cross-over effects seen in this study. In support of this possibility, a recent study reported reduced electromyography amplitude during a lunge following a bout of roller-massage in which the authors suggested suppression of H-reflexes may be an explanation for the reduction in electromyography amplitude.[40]

Limitations

This study was limited in several important respects. Firstly, the current sample size was not chosen based upon a power analysis, although it was comparable in size to similar studies. Since the observed improvements in ROM were relatively small, the study may not have been sufficiently powered to detect a significant difference between groups.[35] Secondly, the subjects and the sole examiner were not blinded to the groups in which the subjects were placed, which increases the risk of bias and type I error.[35] Thirdly, the warm-up of heel raises to the floor is a shortening contraction without a lengthening following it, this may have affected the flexibility of the muscle and therefore results also. Future studies should address this when planning their methodology. Fourthly, the number of attempts to achieve maximal ROM may have affected flexibility due to tissue 'creep'[41] or improvements in stretch tolerance.[42] In this respect, a strength of the current study was the use of the control group, where the effect of repeated measures can be seen to be minimal, with the largest increase in ROM being just 0.14cm from baseline, which is very small in comparison with the 1.12cm improvement observed in the treatment group. Lastly, although a significant effect was found for the FR group over time, the clinical relevance of such findings is uncertain and further research is required to determine the role of foam rolling within the clinical environment.

CONCLUSION

An acute bout of FR in the ipsilateral leg produced significant increases in ankle DF ROM for at least 20 minutes in the ipsilateral limb and up to 10 minutes in the contralateral limb, indicating that FR produces a cross-over effect into the contralateral limb. The mechanism producing these cross-over effects is unclear but may involve increased stretch tolerance, as observed following SS. Although the absolute increase in ankle DF ROM was small and may not be clinically meaningful for healthy populations, the cross-over effect has potential applications where ROM is restricted on one side of the body as a result of injury, post-operation immobilization or neurological conditions. In such cases, SMFR treatment of the healthy limb may have benefits through the cross-over effect into the injured limb.

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