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Research article

Preventive and Regenerative Foam Rolling are Equally Effective in Reducing Fatigue-Related Impairments of Muscle Function following Exercise

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Abstract
Objectives of the study were to compare the effects of a single bout of preventive or regenerative foam rolling (FR) on exercise-induced neuromuscular exhaustion. Single-centre randomised-controlled study was designed. Forty-five healthy adults (22 female; 25±2 yrs) were allocated to three groups: 1) FR of the lower limb muscles prior to induction of fatigue, 2) FR after induction of fatigue, 3) no-treatment control. Neuromuscular exhaustion was provoked using a standardized and validated functional agility short-term fatigue protocol. Main outcome measure was the maximal isometric voluntary force of the knee extensors (MIVF). Secondary outcomes included pain and reactive strength (RSI). Preventive (-16%) and regenerative FR (-12%) resulted in a decreased loss in MIVF compared to control (-21%; $p < 0.001$) five minutes after exhaustion. Post-hoc tests indicated a large-magnitude, non-significant trend towards regenerative foam rolling to best restore strength (Cohen's $d > 0.8$, $p < 0.1$). Differences over time ($p < 0.001$) between groups regarding pain and RSI did not turn out to be clinically meaningful. A single bout of foam rolling reduces neuromuscular exhaustion with reference to maximal force production. Regenerative rather than preventive foam rolling seems sufficient to prevent further fatigue.

Key words: Rehabilitation; self-myofascial release; manual medicine; pain therapy; sports medicine; neuromuscular fatigue.

Introduction

Impaired sports performance and increased injury risk in athletes have both been related to the occurrence of neuromuscular fatigue following training (Murphy et al., 2003; Nicol et al., 2006). Methods alleviating or preventing exercise-induced muscular exhaustion are demanded by high level and recreational athletes. Besides other common therapeutic approaches such as nutritional supplementation (Nedelec et al., 2013), laser therapy (Leal-Junior et al.), wearing of compression garments (Hill et al.), cryotherapy (Hohenauer et al., 2015), and active methods including stretching and low-intensity exercise (i.e. massage that has been highly emphasized) (Torres et al.), have been recommended. Self-myofascial release (an umbrella term for tissue-assisted self-treatment) using a foam roll, is considered a promising massage technique in this regard, gaining momentum over the last years (Aboodarda et al., 2015; Cavanaugh et al., 2017b; Cheatham et al., 2015).

The current literature evaluating the effects of self-myofascial release is still emerging. Self-myofascial release following a workout was shown to reduce the self-perceived intensity of muscle soreness and pressure pain of the afflicted muscles (Jay et al.). Foam rolling applied both, immediately after induction of fatigue and on the following days, was found to be effective in reducing muscle soreness (Macdonald et al.). Additionally, in some follow-up measurements, jump height, muscle activation and range of motion increased compared to the control group. A similar design incorporating post-exercise foam rolling and follow-up treatments on the following days was also chosen by Pearcey and colleagues.(Pearcey et al.) They observed reduced pressure pain as well as increases in sprint time and jump height. There is evidence that rolling increases the neuromuscular efficiency, i.e. subjects need less muscle activation to perform the same tasks (Bradbury-Squires et al., 2015). A systematic review suggests that foam rolling and roller massage may be effective interventions for enhancing joint range of motion, and pre and post exercise muscle performance (Cheatham et al., 2015).

The mechanisms of foam rolling are still unknown, although research has started to focus this issue (Krause et al., 2017). While the tissue-specific response of muscle and fascia is not yet elucidated, there is evidence for a beneficial circulatory response. Foam rolling has been demonstrated to reduce the arterial stiffness and to improve vascular endothelial function (Okamoto et al., 2014). Further, foam rolling has been associated with an improved arterial tissue perfusion by increasing the arterial blood flow (Hotfiel et al., 2017). These vascular effects are relevant for warm-up and recovery in sports. This is in agreement with a recent study, showing that a constant arterial blood flow could be an underlying physiologic mechanism in preventing exercise-related muscle fatigue (Weber et al., 2014).

In conclusion, the use of foam roll may present a suitable and promising tool in the prevention and treatment of neuromuscular fatigue. The present study aims to further explore these effects of foam rolling over time, and to elucidate its suitability and importance in the setting of a validated functional agility short-term fatigue protocol (Wilke et al., 2016).

Methods

Study design and ethics
A randomized controlled study was designed to compare three groups undergoing a validated functional agility short-term fatigue protocol (Wilke et al., 2016). Two of

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the groups received a foam roll intervention, either prior to or after exercise induced fatigue. The third group served as a no-intervention control. The local Ethics Committee (reference 2014-86K) approved the study which was conducted in accordance with the Declaration of Helsinki with its recent modification (WMA General Assembly, Fortaleza, Brazil, October 2013). Each subject signed a written informed consent.

Participants

Forty-five healthy, asymptomatic adults (23♂, 24.8 ± 2.3 years) volunteered to participate in the study. All subjects were students and engaged in regular physical activity. Exclusion criteria included pregnancy or lactation, analgesics intake in past 48 hours, muscle soreness, acute or chronic musculoskeletal disorders as well as psychiatric, neurological, pulmonary, cardiovascular, renal or inflammatory-rheumatic diseases. Recruitment was based on flyers and personal contact.

Fatigue protocol

Neuromuscular exertion was induced by means of the validated functional agility short-term fatigue protocol (FAST-FP) which had been proposed in different variations (Wilke et al., 2016). This protocol induces alterations in kinematic variables, and affects fatigue-related parameters of muscle function (see outcomes).

The modified FAST-FP comprises four components: With maximum breaks of five seconds between, participants consecutively performed three countermovement jumps (90 % of individual maximum or higher), a 20-s bout of step-ups on a 40 cm box at a frequency of 220 beats per minute, three bodyweight squats and an agility drill (Pro Agility Shuttle). This procedure was repeated until subjects were no longer able to attain 90 % of their individual maximal jump height (computerized contact mat, refitronic®, Schmitten, Germany) in two consecutive rounds. The minimum number of rounds to be performed was three. Fatigue severity was assessed by means of a visual analogue scale ranging from 0 (no fatigue) to 10 cm (worst imaginable fatigue).

Interventions and randomization

All subjects were randomly allocated to three groups using the app-based randomization tool provided by random.org (School of Computer Science and Statistics, Trinity College, Dublin, Ireland Version 1.2.11): foam rolling immediately prior to the fatigue protocol (prevention), foam rolling immediately after the fatigue protocol (regeneration) and a no-treatment control (CON).

The foam rolling procedure for prevention or regeneration consisted of five minutes dynamic self-massage using a commercially available foam roll (Blackroll AG, Bottighofen, Switzerland). The knee extensors, hamstrings, adductors, calf muscles and the iliotibial tract were treated bilaterally for 30 s each, with slow movements at constant pressures between the origin and the insertion of the muscle. To standardize foam rolling velocity, a mechanical metronome was used: The participants were instructed to change the rolling direction with every tap of the device. Thus, at 60 beats per minute, each stroke had a duration of one second (Mohr et al., 2014). A subjective pain intensity of seven on a 10 mm visual analogue scale (mild to moderate pain not causing muscle spasms or cramping) was sought for, in order to standardize pressure exertion. The control group remained seated for five minutes.

Outcome measurements

Data collection was carried out at baseline (T0), after completion of the fatigue protocol (T1), and five minutes post fatigue (T2), as previously suggested (Weber et al., 2014).

Maximum isometric voluntary force of the knee extensors ($MIVF_{ke}$) was obtained by means of the m3 Diagnos+ (Schnell© Trainingsgeräte GmbH, Peutenhausen, Germany) at 60 ° knee flexion in the sitting position. Sufficient test–retest reliability and construct validity of the device has been shown (Nedelec et al., 2013). After a specific warm-up (one submaximal practice trial), 3 tests were performed with contractions lasting five seconds, separated by one min rest intervals. Force × time was displayed on a screen providing an immediate feedback. Subjects were verbally encouraged to elicit maximal effort. Sampling was performed with the software package Diagnos 2000 (Trainsoft© GmbH, Moorenweis, Germany). The highest value of the three trials (randomized leg selection) ($Nm\ kg^{-1}$) was considered to be representative of MIVF and used for statistical analysis.

Self-perceived muscular exhaustion of the lower limb was assessed by means of a 10 cm visual analogue scale (VAS, with 10 cm being the worst imaginable pain).

The reactive strength index (RSI) was calculated as the vertical jump height divided by the ground reaction time, with the highest value of all trials used for analysis (Young and Behm, 2003).

Sample size estimation and statistical methods

The sample size was calculated with G*Power (Version 3.1.9.2, University of Düsseldorf, Germany) estimating a medium effect size of foam rolling on the maximum isometric force (effect size = 0.4), with alpha set at 0.05 and beta at 0.8; presuming a repeated measures analysis of variances. Taking a drop out ratio of 10% into account, 45 participants had to be enrolled in this study.

Baseline characteristics were analysed with ANOVA (for continuous measures) to assess for differences among the three study groups. Statistical analysis was conducted for comparison of the outcome measures between the three study groups. No evidence was found that the parametric tests used were inappropriate. As data is longitudinal, we applied a mixed-effects analysis, i.e. a 3x3 model (time x group) adjusting for baseline to analyse the effects on force, pain, and performance.

Data was analysed according to Mauchly's test for sphericity and the Greenhouse-Geisser correction was used in case that sphericity was not present. If statistically significant, the mixed-model used for each outcome variable was followed by three post-hoc pairwise comparisons of change scores between each of the three time points and baseline. This resulted in 6 post-hoc tests for each outcome, so we adjusted for multiple comparisons among these tests using the Sidak correction. This corresponds to using a threshold for significance in post-hoc testing of alpha = 0.01. The level of significance was achieved at $p < 0.05$ if corrections were not needed. Cohen's d was calculated to estimate the effect sizes, defined as small (d = 0.2), medium (d = 0.5), and large (d = 0.8).

Data are presented as mean ± standard deviation. All calculations were performed with SPSS 22 (IBM SPSS Statistics, SPSS Inc., Chicago, IL, USA).

Results

Forty-five sportsmen were included into the study and could be analysed as no drop-outs occurred (23, 24.8 ± 2.3 years). Fatigue at baseline was 1.7 ± 1.2 cm VAS, and jump height was 29.0 ± 6.4 cm (see Table 1). There were no differences between the groups at baseline regarding the outcome parameters (see Table 2).

Following the FAST-FP, overall fatigue was rated with 7.4 ± 2.3 ($p < 0.001$ CI [1.9,4.1]), and jump height lowered to 26.0 ± 5.9 cm ($p < 0.001$ CI [-6.5,-5.0]) which is indicative of the successful implementation of the fatigue protocol. No between differences of neither jump height nor fatigue severity were found, indicating a similar exhaustion of all groups (see Table 1).

Mixed effects analysis (group x time) revealed significant differences in MIVF ($F_{125.274}(3,32)$; $p < 0.001$). The post-hoc analysis did not show significant differences between groups based on the Sidak correction. However, there was a large-magnitude non-significant trend when comparing the changes in MIVF between the regeneration and control group at T1 (-13.8 ± 28.0 N vs. -43.7 ± 37.1 N, Cohen's d = 0.80, p = 0.064 CI[-61.8,1.9]) and T2 (-50.8 ± 55.6 N vs. -103.4 ± 63.9 N, d = 0.88, p = 0.044 CI[-103.9,-1.5]). Differences in the change of force in the prevention group were clinically meaningful based on the effect sizes, but not significant when compared to control at T1 (-8.5 ± 64.1 N, Cohen's d = 0.67; p = 0.1 CI[-78.1,7.7]) and T2 (-73.1 ± 92.4 N, d = 0.38, p = 0.346 [-95.6,34.9]; Table 2).

Mixed effects analysis over time revealed significant differences in perceived muscle pain ($F_{10.012}(3,41)$; $p < 0.001$) and RSI ($F_{118.947}(3,39)$; $p < 0.001$) between groups. Post-hoc analysis did not reveal any significant differences between groups (Table 2).

Participants did not report any side effects.

Discussion

The present study shows clinically meaningful effects of foam rolling in an experimental setting of sports-related fatigue. Although not reaching statistical significance, a large magnitude decrease in muscular force could be observed in the regenerative foam rolling group. There was a trend towards less perceived muscular exhaustion, and decreased reactive strength for both, the preventive and regenerative approach. This study was conducted in agreement with a recent literature review, providing methodological suggestions for self-myofascial release studies (Schroeder and Best, 2015). Nonetheless, the results need to be interpreted carefully, as we present the data of a proof-of-concept study, with limited case numbers. Confirmatory research will be necessary to strengthen the observed effects.

Our main finding was that the generally statistically insignificant force losses achieved moderate to large magnitude changes. Despite a large variability, individual responses were consistent (Figure 1). This is in line with previous studies demonstrating restorative effects of foam

Table 1. Determinants of the FAST-FP protocol. Data are displayed as mean ± standard deviation (SD).

	Prevention		Regeneration		Control		Statistics (intergroup)
	N	mean ± SD	N	mean ± SD	N	mean ± SD	ANOVA
Drop Jump Height T0 (cm)	13	28.7 ± 6.4	15	27.1 ± 6.8	15	31.1 ± 5.7	$F_{1.562}(2,42)$ p = 0.222
Drop Jump Height T1 (cm)	14	25.5 ± 6.8	15	24.5 ± 5.7	15	28 ± 5.2	$F_{1.356}(2,42)$ p = 0.269
Drop Jump Height T2 (cm)	15	26.7 ± 7.2	15	25.1 ± 6.5	15	30.1 ± 5.9	$F_{2.226}(2,42)$ p = 0.121
Fatigue T0 (cm VAS)	15	1.4 ± 1.4	15	2 ± 1	15	1.7 ± 1.1	$F_{0.940}(2,42)$ p = 0.399
Fatigue T1 (cm VAS)	15	7.9 ± 2	15	6.9 ± 2.4	15	7.4 ± 2.4	$F_{0.767}(2,42)$ p = 0.471
Fatigue T2 (cm VAS)	15	4.1 ± 2.1	15	4 ± 2.7	15	3.9 ± 2.5	$F_{0.028}(2,42)$ p = 0.973

Fatigue was successfully induced in all groups as indexed by jump height and perceived fatigue with no differences between groups.

Table 2. Outcome measures. Data are displayed as mean ± standard deviation (SD).

	Prevention		Regeneration		Control		Mixed-Methods Analysis and Post-hoc t-tests (change to baseline)		
	N	mean ± SD	N	mean ± SD	N	mean ± SD	Prevention vs. Regeneration	Prevention vs. Control	Regeneration vs. Control
MIVF T0 (N)	12	467.7 ± 130.1	11	432.7 ± 103.4	13	493.6 ± 60.3		< 0.01	
MIVF T1 (N)	13	452.6 ± 155.6	11	418.9 ± 102.7	13	449.9 ± 59.7	.815	.103	.064*
MIVF T2 (N)	12	394.7 ± 95.1	11	381.9 ± 121.9	13	390.2 ± 67.2	.496	.346	.044*
$Pain_{muscle}$ T0 (cm VAS)	15	0.9 ± 1.2	15	1.6 ± 1.3	15	1.2 ± 1.4		< 0.01	
$Pain_{muscle}$ T1 (cm VAS)	15	4.4 ± 2.3	15	4.6 ± 3.5	15	4.2 ± 2.8	.689	.596	.916
$Pain_{muscle}$ T2 (cm VAS)	15	2.8 ± 2.2	15	2.7 ± 2	15	2.2 ± 2.3	.225	.182	.794
RSI T0	13	1.6 ± 0.5	15	1.4 ± 0.4	15	1.6 ± 0.3		< 0.01	
RSI T1	14	1.3 ± 0.4	15	1.2 ± 0.4	15	1.5 ± 0.4	.690	.187	.495
RSI T2	15	1.5 ± 0.5	15	1.3 ± 0.4	15	1.6 ± 0.4	.880	.466	.689

The statistical analysis was performed as time x group analysis and subsequent t-tests for intragroup comparisons. There was a trend towards significance when comparing MIVF between the regeneration and the control group at T1 and T2. MIVF mean isometric voluntary force, RSI reactive strength index.

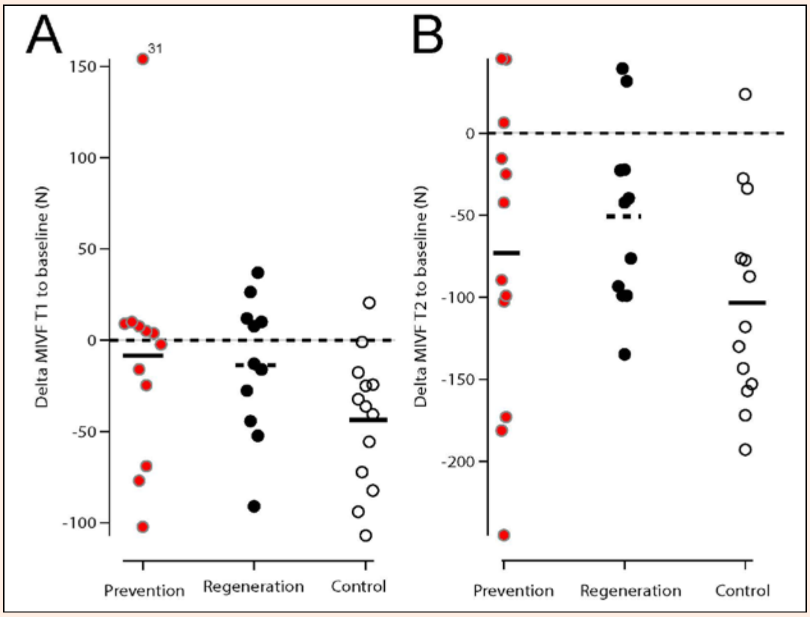

Figure 1. Scatter dot plot. Figures depict the changes in MIVF to baseline at T1 (Figure 1 A) and T2 (Figure 1B). The dotted line crossing zero illustrates whether changes indicate loss or gain of force. Smal lines indicate the mean change within the three groups, i.e. prevention (red), regeneration (black), control (open circles). There was one outlier (subject 31) with reasonable raw data.

rolling, e.g., on exercise-induced pain (Cavanaugh et al., 2017a), on the sit-and-reach range (Sullivan et al., 2013), or isolated on the quadriceps maximum voluntary contraction force (MacDonald et al., 2013), In sum, these studies suggest foam rolling not to impair performance in regard to explosive strength and maximum power output. The present study emphasizes these observations adding a preventive effectiveness regarding development of fatigue to the current knowledge.

To our knowledge, only two studies yield indications for the suitability of foam rolling prior to exercise with reference to muscular exhaustion. Healey et al. compared foam rolling and a planking control condition using four athletic tests (Healey et al.). The subjects reported their subjective exhaustion to be smaller in the foam roll condition. Although no fatigue protocol was applied, and thus no conclusive evidence is available for the efficacy of preventive self-myofascial release, this finding suggests potential benefits. A second study investigated the effects of different foam rolling volumes on knee extension fatigue following a protocol of maximum load (Monteiro and Neto, 2016). Authors showed a reduced fatigue index following foam rolling, calculated by the summation of work produced during the absolute peak torque of knee flexors and extensors, and total work (Dipla et al., 2009). Still, the group did not apply a validated functional fatigue protocol, and exhaustion was induced using a dynamometer. However, i.e. stretch shortening cycles that can be considered a key contributor to fatigue in sports activities (Komi, 2000; Nicol et al., 2006). As foam rolling is carried out pre and post to athletic exercise, the present study is of improved clinical and practical generalizability. It can be derived from the data that both foam rolling regimen help to counteract exercise-related fatigue. An intriguing suggestion of our work is the possibility to use foam rolling during sports activities. The short duration of application might help athletes to reduce fatigue at game breaks (e.g. half-time in soccer) or substitutions (e.g. in basketball or handball). However, for final recommendations in athletic routine, further confirmatory studies will be necessary. To our knowledge, clinical guidelines for the prevention or regeneration of muscular fatigue are sparse, and restricted to single types of sport (Nedelec et al., 2013; Tavares et al., 2017). In this study, we have chosen the FAST-FP as the source of fatigue. This protocol has been shown to adequately reflect the symptomatic and physiologic peculiarities of team sports (Wilke et al., 2016). Thus we believe, that our data may be more generalizable and may have impact on diverse kinds of team-sports with similar loads. Systematic reviews point towards an overall benefit of self-myofascial release, but are less specific in regard of practical instructions (Beardsley and Skarabot, 2015). Our results suggest the reasonableness of both, preventive and regenerative interventions. Still, our data may implicate that there is a trend towards regenerative foam rolling, with the smallest magnitude of fatigue-related force losses, and the largest effect size (d = 0.8). Finally, our data do not state, if a combination of pre and post foam rolling might also be beneficial. It would be intriguing to study the effects of combined preventive and rehabilitative foam rolling which might maximize effectiveness.

The following methodological limitations need to be taken into account. The optimal application parameters (e.g. time, duration, velocity, load and intensity, frequency) in foam rolling are still a matter of debate (Schroeder and Best, 2015). Although our study adds interesting data regarding the time point of application, several other variables might contribute to the treatment effect. In the present study, foam rolling speed was not controlled. This approach was chosen in order to realistically simulate foam roller application in practice. Nonetheless, different velocities might modify the tissue response to the intervention. Initial data from our lab suggest no influence of foam rolling speed on the range of motion or myofascial stiffness (Niemeyer et al., 2017). Still, this argument cannot be ruled out completely. Another aspect is the quantity of the exerted pressure. We used a visual analogue scale to standardize foam rolling intensity, which nicely reflects the possible application in rehabilitative and sports settings. Recent research demonstrated the intensity of foam rolling not to significantly influence the physiologic response (Grabow et al., 2017). Authors implemented force transducers applying consistently amounts of pressure, which can be regarded a gold-standard technique in foam-rolling research. Finally, we are aware that the study is still of a pilot character, with results to be carefully discussed, even as our sample size seems reasonable.

Conclusions

This study suggests the response to foam rolling can be diverse and individual. Although generally non-significant, the large magnitude effect sizes suggest foam rollers could be an effective treatment for many individuals to prevent or to regenerate from muscular fatigue following team-sports. From a physiologic perspective, a combination of both –regenerative and preventive- approaches should be subject to further studies.

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Key points

- Foam rolling directly affects muscular structures following exhaustion.
- The effects are independent of the time of intervention (whether pre or post to the load).
- Regenerative foam rolling seems adequate to elicit beneficial effects.
- Foam rolling could be helpful in preventing sports-related muscular injury.

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