Hong Kong Physiotherapy Journal (2017) 36, 57–62

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RESEARCH PAPER

Acute effects of different foam rolling volumes in the interset rest period on maximum repetition performance

Estêvão Rios Monteiro, BSc [a,*], Andrew Vigotsky, BSc [b], Jakob Škarabot, MSc [c], Amanda Fernandes Brown, MSc [a], Aline Gomes Ferreira de Melo Fiuza, BSc [a], Thiago Matassoli Gomes, MSc [a,d], Israel Halperin, MSc [e], Jefferson da Silva Novaes, PhD [a]

[a] Department of Gymnastics, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
[b] Leon Root M.D. Motion Analysis Laboratory, Department of Rehabilitation, Hospital for Special Surgery, New York, NY, USA
[c] Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland
[d] Estácio de Sá University, Exercise Physiology Laboratory – LAFIEX, Rio de Janeiro, Brazil
[e] School of Exercise and Health Sciences, Edith Cowan University, Western Australia, Australia

KEYWORDS
fatigue;
massage;
self-manual therapy;
self-myofascial release

Abstract *Background:* Foam rolling (FR) is a ubiquitous intervention utilised for the purpose of acutely increasing the range of motion without subsequent decreases in performance. Thus, it is commonly used during the periworkout period—that is, prior to, during, or after an athlete's workout.
Objective: This study investigated how different FR durations applied to the quadriceps during the interset rest periods affects the numbers of repetitions in the knee extension exercise.
Methods: Twenty-five females completed four sets of knee extensions with 10 repetitions of maximum load to concentric failure on four occasions. Between each set, a 4-minute rest interval was implemented in which participants either passively rested or performed FR for different durations (60 seconds, 90 seconds, and 120 seconds). The 95% confidence intervals revealed a dose-dependent relationship in which longer durations of FR resulted in fewer completed repetitions.
Results: On average, the number of repetitions with PR was 13.8% greater than that in FR120, 8.6% greater than that in FR90, and 9.1% greater than that in FR60.

* Corresponding author. Department of Gymnastics, School of Physical Education and Sports, Federal University of Rio de Janeiro, 540 Carlos Chagas Filho Avenue, 21941-599, Rio de Janeiro, Brazil.
E-mail address: profestevaomonteiro@gmail.com (E.R. Monteiro).

http://dx.doi.org/10.1016/j.hkpj.2017.03.001

Conclusion: For the purposes of performance and likely adaptation, interset FR seems to be detrimental to a person's ability to continually produce force, and should not be applied to the agonist muscle group between sets of knee extensions.

Introduction

Foam rolling (FR) is a ubiquitous intervention utilised for the purpose of acutely increasing the range of motion without subsequent decreases in performance [1,2] Thus, it is commonly used during the periworkout period—that is, prior to, during, or after an athlete's workout. Although much of the previous research on FR interventions examined the effects of FR on range of motion or on explosive or nonfatiguing tasks [1,2], to our knowledge only two studies to date have investigated the effects of FR on an anaerobic, fatiguing task. The first study observed equivocal outcomes, in which the power output during Wingate testing decreased for females, but increased for males, following FR [3]. The second study utilised interset FR applied to the antagonist muscle group between sets of knee extensions, and found a dose—response decrease in repetition performance with large amounts of FR volume [4].

Resistance training is one of the most widely practiced types of physical activity and is used both for performance benefits as well as in clinical settings (e.g., rehabilitation after an injury) [5,6]. Anecdotally, it is not uncommon for athletes to foam roll agonist muscle groups during a warm-up, between warm-up sets, or between working sets, as it believed that greater ranges of motion can be achieved by doing so. At present, there is paucity of investigations on the effects of interset FR applied to an agonist muscle group on resistance training performance, such as the number of repetitions that participants can complete. Therefore, the purpose of this study was to investigate the effects of different volumes of FR applied to the quadriceps muscle during the interset rest period on repetition performance of a knee extension exercise.

Methods

Participants

Twenty-five recreationally active females (Table 1) were recruited for the study based on an *a priori* sample size calculation [7]. An *a priori* sample size calculation ($\eta_p^2 = 0.34$; $\beta = 0.95$; $\alpha = 0.05$) using G*Power [8] found that six participants would be adequate; however, in order to increase statistical power, 25 individuals were recruited. The participants performed the procedures in the luteal phase of the menstrual cycle [9]. Anthropometric data included body mass (Techline BAL — 150 digital scale, São Paulo, Brazil) and height (Stadiometer ES 2030 Sanny, São Paulo, Brazil).

Individuals were included if they had been involved in resistance training programme for at least 1 year prior to the experiment, 3—4 sessions per week, using loads equal to 8—12 repetitions maximum, and had experience with the knee extension machine exercise. Participants were free from any functional limitation or medical condition that could have compromised their health or confounded results of the study. During the 16-day period of data collection, participants were instructed not to engage in any strenuous lower body resistance training exercise. Prior to the study, all participants were provided verbal explanation of the study and read, and signed the informed consent form and Physical Activity Readiness Questionnaire [10]. All procedures were in accordance with Declaration of Helsinki. The local ethics committee approved the study (57023616.7.0000.5257/16).

Experimental design

The participants visited the laboratory on six occasions during a 16-day period with at least 48 hours' interval between each visit. They underwent a 10-repetition maximum (RM) test and retest procedure on the first and second visits. After the two 10-RM tests, they visited the laboratory on four occasions. Each session consisted of four sets of knee extension 10 RM load to concentric failure, interspersed by 4-minute rest intervals, with the goal of completing the maximum number of repetitions. During the interest rest periods, participants underwent one of the following interventions in each of the testing days in a randomised (aleatory entry in latin square format) crossover order: (1) passive rest (PR), (2) FR for 60 seconds (FR60), (3) FR for 90 seconds (FR90), and (4) FR for 120 seconds (FR120) (see Figure 1 for the experimental setup).

Table 1 Participant characteristics

Age (y)	27.8 ± 3.6
Height (cm)	168.4 ± 7.2
Body mass (kg)	69.1 ± 10.2
BMI (m^2/kg)	24.2 ± 2.1
RTE (mo)	23.0 ± 6.6
Knee Extension 10RM (test) (kg)	70.7 ± 11.1
Knee Extension 10RM (retest) (kg)	71.4 ± 11.2
ICC (test—retest)	0.981 (95% CI = 0.966—0.996)

BMI = body mass index; CI = confidence interval; ICC = intraclass correlation coefficient; RM = repetition maximum; RTE = resistance training experience.

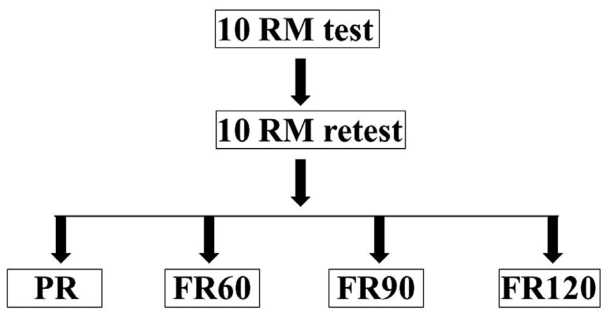

Figure 1. Study design. PR = passive rest; FR60 = foam rolling for 60 seconds; FR90 = foam rolling for 90 seconds; FR120 = foam rolling for 120 seconds. FR = foam rolling.

Ten-RM testing

Ten RM was determined similar to Simão et al [11]. Participants were instructed to sit on a knee extension machine (Selection Line Leg Extension, Technogym, Cesena, Italy), with the lumbar spine in contact with the back support, and ankle in slight dorsiflexion. Range of motion was between 100° of knee flexion and full extension (0°). Participants initially performed a standardised warm-up consisting of 15 repetitions of knee extensions with self-suggestion load, approximately 50% of normal training load. After the warm-up, 10-RM testing was performed. Execution of the knee extension exercise was standardised insofar as no pauses were allowed between the concentric and eccentric portion of the movement. A maximum of three trials were allowed per testing session, separated by 3 minutes of PR. Testing was then repeated on another day at least 48 hours later (retest). The higher load between the two testing days was considered as the 10 RM load. The 10 RM load was confirmed by calculating the intraclass correlation coefficient (ICC) (Table 1). In an effort to minimise the margin of error, the following strategies were adopted [11]: (1) all participants received standardised instructions about the exercise technique and data collection; (2) participants received feedback as to their technique and were corrected if appropriate; (3) all participants were always verbally encouraged. The knee extension apparatus used for 10 RM testing and during the experimental sessions was the same.

Foam rolling

FR was performed using The Grid Foam Roller (Trigger Point Technologies, Austin, TX, USA), which is composed of a hard inner core enclosed in a layer of ethylene vinyl acetate foam. This kind of foam roller has been shown to produce more pressure on the soft tissue than those made out of polystyrene foam [12]. FR was performed bilaterally in a prone position while maintaining the legs extended (in contact with the foam roller), but relaxed. The participants were instructed to propel their body backward and forward between acetabulum and patellar tendon, in dynamic motions, while trying to exert as much pressure on the foam roller as possible. As per randomisation, FR was performed during the interset rest period for 60 seconds, 90 seconds, or 120 seconds. For better representation of real work training environments, participants were free to choose the pace in which foam rolled.

Statistical analyses

In order to identify within-set, between-protocol differences, 95% confidence intervals (CIs) were calculated [13]. For example, set number one in FR60 was compared with all other first sets (PR, FR90, and FR120 — between-protocol), but no second sets (within-set). Normality of the differences was ensured using the Shapiro—Francia test. Rather than traditional null hypothesis statistical testing, 95% CI were used in order to prevent dichotomous interpretation of the results [13,14], to increase the likelihood of correct interpretation [14], and to allow for a more nuanced and qualitative interpretation of the data [15]. For differences with a 95% CI that includes zero, traditional null hypothesis testing would say that the observed differences may have been due chance alone. In other words, the observations are statistically different from one another when the 95% CI of differences does not include zero. Additionally, Cohen's *d* effect sizes were calculated using the formula $d = \frac{M_d}{s_d}$, where M_d is the mean difference and s_d is the standard deviation of differences. This calculation differs slightly from traditional Cohen's *d* calculations, in that it better represents within-subject differences, whereas the traditional Cohen's *d* formula is better fit for between-subject comparisons [16—18]. Cohen's *d* effect sizes were defined as small, medium, and large for 0.2, 0.5, and 0.8, respectively [19]. All statistical analyses were performed using SPSS version 20 (SPSS Inc., Chicago, IL, USA) and Excel (Microsoft Office 365 Home Corporation, Redmond, WA, USA).

Results

There were no statistical differences in 10 RM between the two testing days ($t_{24} = -1.661$, $p = 0.11$), and reliability was considered high (ICC = 0.981, Table 1).

On average, the number of repetitions with PR was 9.1%, 8.6%, and 13.8% greater than FR60, FR90, and FR120 (Table 2), respectively. Furthermore, although no statistical difference was observed between FR60 and FR90 (0.5%), a statistically greater number of repetitions were performed in FR60 (4.8%) and FR90 (5.2%) when compared to FR120 (Table 2).

In Figure 2, the number of repetitions in the first set with PR was 6.0% and 6.5% greater than with FR60 and FR120, respectively. Furthermore, a greater number of repetitions was performed with FR90 compared to FR120 (4.1%). No other differences between conditions were observed during the first set. Still, the number of repetitions in the second set with PR was 8.6%, 7.2%, and 11.8% greater compared with those in FR60, FR90, and FR120, respectively. No other differences between conditions were observed during the second set. The number of repetitions with PR was 10.2%, 10.7%, and 16.9% greater compared with those in FR60, FR90, and FR120, respectively, during the third set. Statistically greater number of repetitions was also performed with FR60 (6.8%) and FR90 (6.3%) when compared to FR120.

Table 2 Repetitions in each set of each condition of interset foam rolling

	Set 1		Set 2		Set 3		Set 4		Average	
	95% CI	*d*	95% CI	*d*	95% CI	*d*	95% CI	*d*	95% CI	*d*
FR60—PR	−0.87, −0.33[a]	1.3	−1.14, −0.46[a]	1.3	−1.33, −0.51[a]	1.3	−1.48, −0.60[a]	1.4	−1.02, −0.66[a]	1.1
FR90—PR	−0.56, 0.82	0.5	−1.09, −0.27[a]	1.0	−1.29, −0.63[a]	1.7	−1.67, −0.97[a]	2.0	−0.98, −0.62[a]	1.0
FR120—PR	−0.93, −0.35[a]	1.4	−1.49, −0.67[a]	1.7	−1.82, −1.14[a]	2.6	−2.09, −1.51[a]	3.1	−0.98, −0.62[a]	1.5
FR60—FR90	−0.67, 0.05	0.7	−0.55, 0.31	0.2	−0.40, 0.48	0.1	−0.14, 0.70	0.3	−0.24, 0.16	0.0
FR60—FR120	−0.24, 0.32	0.1	−0.16, 0.72	0.4	0.13, 0.99[a]	0.7	0.31, 1.21[a]	1.0	0.21, 0.61[a]	0.4
FR90—FR120	0.11, 0.69[a]	0.7	−0.08, 0.88	0.5	0.12, 0.92[a]	0.8	0.12, 0.84[a]	0.7	0.27, 0.63[a]	0.4

Statistically different as CI does not include 0.
CI = confidence interval; FR = foam rolling.
[a] Average stands for between-protocol differences in the number of repetitions across all sets.

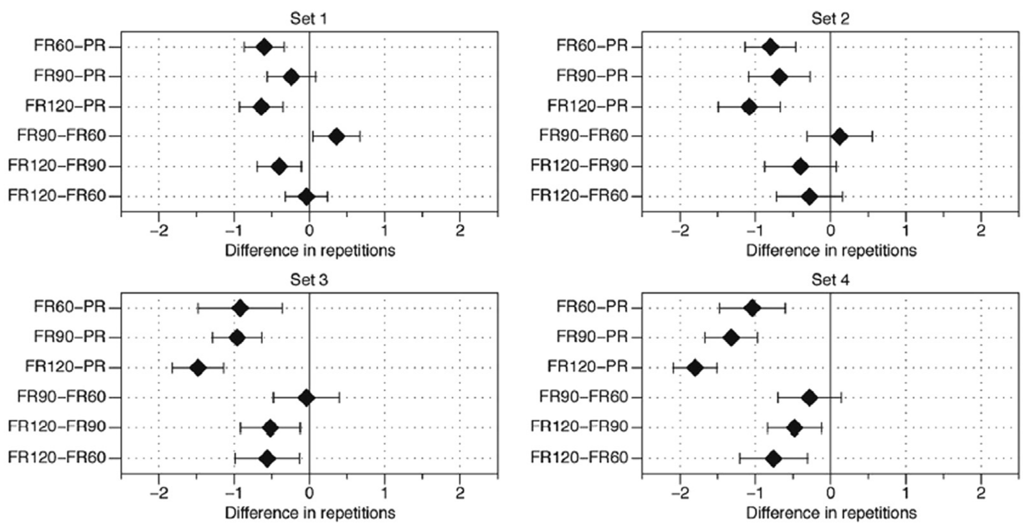

Figure 2. Mean differences ± 95% confidence interval (CI) between each condition across all sets. FR = foam rolling; PR = passive rest.

There was no statistical difference between FR60 and FR90. Finally, during the fourth set the number of repetitions with PR was 9.1%, 8.6%, and 13.8% greater compared with those in FR60, FR90, and FR120, respectively. A statistically greater number of repetitions was also performed with FR60 (9.7%) and FR90 (6.2%) when compared with FR120, whereas there was no statistical difference between FR60 and FR90.

Discussion

The results of this study suggest that FR preceding, and between sets of, resistance training can impede performance. These results are comparable to those reported in previous reports on static stretching of the agonist muscle group [20—23], and in line with previous work by our group on interset FR applied to the antagonist muscle group [4]. Whereas Monteiro et al [4] observed a dose-dependent response in which longer durations of FR in the hamstrings hinder performance, the present study found comparable results with the main differences being the FR was applied to the agonist muscle group. As evidenced by the lack of differences between FR conditions after the second set in the present study, the effects may be weak and unclear at first, but they become apparent with larger doses and more sets, suggesting that the effects are additive. Collectively, these results point to the hindrance effects of FR the agonist and antagonist muscle groups on performance, in which larger reductions in repetition number are observed with longer durations of FR.

A number of underlying mechanisms can help explain the findings of the present study. First, it is possible that FR elicits an endogenous opioid response, which will modulate the perception of effort [4,24]. This perception modulation may result in an increase in power output early in a set owing to a decrease in afferent feedback from agonist muscles, followed by a drastic decrease in power output as a result of greater fatigue [24]. In females, such an effect appears to be more pronounced; for example, Janot et al [3] found that power output during a Wingate decreases in females, but not males, following an FR intervention. The results of Janot et al [3] are comparable to those of the present study as both observed a decrease in anaerobic endurance following FR in female populations; however, whereas Janot et al [3] observed an improvement in performance following FR in males, this present study did not utilise a male population, so such results cannot be compared.

The second possibility is more peripheral in nature. That is, the act of rolling could have influenced the muscles tissues or their biochemical environment and thereby hindered performance. For example, the applied pressure may have affected the contractile proteins, or changed the compliance of the muscles, which may have reduced the muscles' ability to produce force. However, this possibility is unlikely, as both FR and/or massage therapy do not increase tissue compliance [25–27] or influence other mechanical properties of the tissues [25,26]; nevertheless, the peripheral effects cannot be ruled out. Another possibility is that FR may affect lactate clearance, as massage appears to hinder its removal [28], but active recovery seems to enhance it [29]. This presents a conundrum, in that the active component in FR may be beneficial for lactate clearance, but the massage, or FR, component may be detrimental. Such outcomes warrant further investigation.

Finally, the very act of rolling could have fatigued the participants and thus contribute to the negative effects on performance. Indeed, FR one's knee extensors requires balance and stabilisation of the trunk, which may lead to activation of various muscles group. Thus, in addition to the high intensity sets of knee extension, the FR could have required more effort from participants, thereby inducing more fatigue, or may have simply not allowed them to fully recover.

There are several limitations and delimitations to bear in mind when interpreting the results of this present study. First, only female participants were utilised, so these results cannot be extrapolated to males. Because females are less fatigable than their male counterparts when it comes to dynamic contractions [30], females have more room for fatigue, and thus an effect, in studies of this nature. Second, as was previously mentioned, it is possible that the effort required to foam roll in and of itself was fatiguing, which could have somewhat confounded the results [31]. Specifically, some participants may have been contracting their knee extensors to help the propulsion, thereby not allowing the quadriceps to fully rest when compared to the PR condition. This possibility was not ruled out by questionnaires or any other means. Nevertheless, it can be argued that comparing FR to PR, rather than a sham group, increases ecological validity. Third, it could be argued that knee extension is a simple, single-joint task, and its functional relevance is limited. However, given the popularity of resistance training exercise, the findings of the present study do have clinical applications for both athletes and general population alike. For example, knee extension exercise has been shown to improve functional capacity in the elderly [6]. Furthermore, although a complex, multijoint task such as the squat would have been more functional, our results could have been confounded by the action of the synergist muscles, which is avoided in a single-joint task such as knee extension. However, further research is required to extend the observations of the present study to complex, multijoint tasks during resistance training as well as functional tasks such as locomotion. Finally, the duration of each roll on the quadriceps was not tightly controlled for. This can be considered as both a limitation and a strength of this design. Specifically, the lack of control reduces the internal validity of the results, as the number/duration of each roll could possibly influence the outcome. Conversely, the freedom to choose the pace duration of each roll enhances the ecological validity of the findings, as it better represents real-life training scenarios.

Conclusion

The finding that interset FR of the agonist muscle group seems to decreases performance has implications for FR prescription and implementation, in both rehabilitation and athletic populations. For the purposes of performance and likely adaptation, it seems as if FR should not be applied to the agonist muscle group between sets of knee extensions. Moreover, it seems that more interset FR is detrimental to the ability to continually produce force.

Conflicts of interest

The authors have no conflict of interests to declare.

Funding/Support

No financial or material support of any kind was received for the work described in this article.

Authors' contribution

Estêvão Rios Monteiro—study conception, data collection and writing the manuscript; Andrew Vigotsky—data analysis and writing the manuscript; Jakob Škarabot—data analysis and writing the manuscript; Amanda Fernandes Brown—study conception and writing the manuscript; Aline Gomes Ferreira de Melo Fiuza—data collection and revising the manuscript; Thiago Matassoli Gomes—data analysis and writing the manuscript; Israel Halperin—data analysis and writing the manuscript; Jefferson da Silva Novaes—study conception and revising the manuscript.

Acknowledgements

We acknowledge the contributions of all participating and the Bodytech Gym.

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