ABSTRACT

Aims: The study compares the effects of varying foam roller density (FRD) on hamstring flexibility (HF) and eccentric hamstring strength (Ham_{ecc}) in active males.

Methods: Twenty-eight healthy male participants (height 176.7±5.9 cm; body mass 75.8±9.6 Kg; age 21.6±4.0 years) were randomly allocated to receive either a low density (TriggerPoint™, CORE roller, Texas), medium density (TriggerPoint™, GRID roller, Texas), high density foam roller (FR) (TriggerPoint™, GRID X roller, Texas) or allocated to a control group. Outcome measures included hamstring flexibility (HF) through active knee extension (AKE) (°) and Ham_{ecc} by Nordic hamstring curl exercise using the Nordbord, pre and immediately-post FR application.

Findings: Significant FR *x* time interactions were found for HF *($p<0.05$)*. Significant increases in AKE were reported post-FR application for all FR densities *($p<0.05$)*. No significant changes in strength parameters (break Angle, Peak and Average Force and Torque) were found ($p>0.05$). No significant interactions between strength parameters, limb, type of roller or time were found *($p>0.05$)*.

Conclusions: FR elicits immediate positive increases in HF through AKE assessment, with the lower density FR displaying the largest increases in HF. No change in strength parameters were noted with the increases in flexibility, however this does not denote that injury risk is reduced because of this. Findings provide practitioners with insight to inform decision making for the implementation of different densities of FR in practical settings.

Keywords:
Muscle, Sport, Strength, Recovery, Flexibility.

INTRODUCTION

Foam Rolling (FR) is a self-myofascial release (SMR) technique prescribed by sports medicine and performance practitioners thought to reduce stretch related inhibition rather than historically considered to release 'myofascial restrictions' (Behm and Wilke, 2019). FR uses body mass to exert force over a region of soft tissue via a foam roller (Cheatham et al, 2015). Manufactured in various shapes and sizes, differences between surface pattern, diameter and density may influence the quality of massage on the soft tissue (Cheatham et al, 2015). Several studies have explored the effects of FR, reporting changes in joint range of motion (ROM) (Halperin et al, 2014; Cheatham et al, 2015; Cheatham and Stull, 2018), neuromuscular recovery (Bradbury-Squires et al, 2015), pressure-pain thresholds (Cheatham and Stull, 2018), exercise recovery, performance preparation (Cheatham et al, 2015) and identified differences in pressure between rollers (Curran et al, 2008). Recently, Wiewelhove et al, (2019) suggested the consensus in the evidence base is for foam rolling to be more effective as a warm-up tool, rather than a recovery strategy. Furthermore, the combinations of FR and stretching, heat or warm-up applications support current interest in this area for research and applied practice for improving recovery as one example (Mohr et al, 2014; Oranchuk et al, 2019). Studies that consider the effects of FR on strength parameters are suggestive that strength is unaffected by FR (Madoni et al, 2018; Connolly et al, 2020), which is important for injury risk reduction approaches and suggestive of changes in muscle architecture in relation to joint ROM. Experimental paradigms fail to fully elucidate the effect of FR on functional strength and comparison between studies is difficult due to differences in methodological approaches or application of FR. Furthermore, no study, to our knowledge considers the effect of varying densities as a factor on strength response. Consequently, this provides limitations for a practitioner's justification of application, posing questions on performance effects, dose response, timing and optimal type of roller. Consensus for the optimum protocol with regards FR for exercise preparation is lacking in the literature, with current literature highlighting the need for further investigations required to define performance effect, with clarity needed on the effect of varying densities of roller (Cheatham, 2018).

Hamstring flexibility is an essential component in sport particularly for functional movements to be performed efficiently (Hoff et al, 2004). Reduced flexibility of knee and hip flexor musculature is historically noted as a key factor for heightened hamstring injury risk (Henderson et al, 2010), although O'Connor et al, (2019) recently suggested poor flexibility during AKE assessment of Gaelic footballers was not suggestive of hamstring injury risk prediction. The historical approach is identified as a centralised and simplistic aetiological explanation, with a resounding acceptance in current evidence that injury risk is multifactorial (Freckleton et al, 2013), and therefore there is an ambiguity in flexibility being considered a risk factor for hamstring injury alone. That said, eccentric strength and muscle pliability have been indicated as key aetiological risk factors associated with sustaining hamstring injury, and improvements in flexibility must be accompanied with associated functional strength gains to reduce injury risk from a multi-factorial perspective (Timmins et al, 2016; Rhodes et al., 2018). Consequently, this approach may better reflect typical demands of land team-based sports. Garcia-Pinillos et al, (2015) identified that limited hamstring flexibility in male football players affected key performance parameters such as sprinting ability, vertical jump height, agility and kicking speed, signifying the importance of hamstring flexibility and the need for regular stretching to aid sports performance.

Despite positive physiological effects of FR and use of SMR reported in athletes and clinical practice (Cheatham et al, 2015) optimal protocols with regards to roller density are yet to be established. Minimal studies are available that investigate therapeutic effects of varying densities of foam rollers (Curran et al, 2008; Cheatham et al, 2018), and differences in methodology struggle to demonstrate consensus in outcomes. Although the effects of FR are well documented research on the efficacy of parameters such as cadence, technique and type of foam roller are limited, with differences in methodology across studies proving difficult to decipher optimal SMR protocols. To the authors knowledge no research is available on the effect of hamstring eccentric strength (Ham_{ecc}) following a bout of SMR. The aim of the current study is to compare the effects of varying foam roller density (FRD) on hamstring flexibility (HF) and Ham_{ecc} in active males. We hypothesized that FR would result in increases of AKE with no associated strength changes in the hamstrings musculature, and that they effects would vary depending on the density of the FR.

MATERIALS AND METHODS

Participants

Twenty-eight healthy male participants (height 176.7±5.9 cm; body mass 75.8±9.6 kg; age 21.6±4.0 years) volunteered and were randomly allocated (randomisation.com) into a control group (CONT) or one of the three FR intervention groups (low density = SD; medium density = MD; high density = HD). All participants provided written and verbal informed consent to participate and completed the full study. The authors confirm that the study was both reviewed and approved by the institutional review board (STEMH University Research Ethics Committee) and carried out in accordance with the 2013 Helsinki Declaration. To be considered as part of the appropriate sampling population, each participant met the inclusion criteria of; participate in competitive team sport totalling at least 4-hours per week, of male gender and no lower limb injury within 12-months. Participants were not currently applying any form of SMR at the time of participation. Participants were advised not to take part in strenuous exercise of up to 48 hours before participating in the study following previous protocols adopted (Lee et al, 2017b). To accommodate participants normal training schedules or participation in their team sport, data collection was scheduled so a minimum of 48 hours remained exercise-free before testing. This ensures standardisation throughout testing to control the variability in participants activity levels prior to testing.

Experimental Design

Participants completed a familiarisation trial 7 days prior to testing to negate learning effects (Hinman., 2008) and improve validity and reproducibility of results (O'Hara et al, 2012; Lim et al, 2016). Familiarisation trials included repetitions of the Ham_{ecc} testing battery, hamstring flexibility testing and trial repetitions of the FR. Prior to any testing all participants completed a standardised warm up consisting of 5-minutes cycling at submaximal intensity, and a combination of skipping, high knees and buttock kicking drills, ten forward lunges per leg and two Nordic hamstring movements with low resistance (Buchheit et al, 2016). All testing was completed between 13:00 and 17:00hrs to account for the effect of circadian rhythm and in accordance with regular competition times (Sedliak et al, 2011).

Assessment Procedures

All measurements were collected by the same researcher throughout. Bilateral measures of hamstring flexibility were quantified by performing a unilateral active knee extension (AKE) test, a highly reliable test of HF (Hamid et al, 2013) quantified using a Smartphone inclinometer application. The free angle measurement application (G Pro 2.3) was downloaded to the Smartphone and zeroed to the horizontal position. Previous work has identified the reliability of the G Pro 2.3 with ICC reported at 0.82 – 0.92 (Pourahmadi et al., 2016; Keogh et al., 2019) With the patient in a supine position a starting point for each trial was established by placing the Smartphone against the mid-point of the anterior tibia. The testing limb was positioned in 90° of hip flexion and the knee resting in a flexed position with the contralateral limb resting in hip and knee extension. The testing limb was held by the researcher on the hamstrings to maintain to maintain the 90-90-degree limb position previous methods (Hansberger et al, 2019). Whilst maintaining 90 degrees of hip flexion, the participant then performed knee extension to the point of discomfort (Huang et al, 2010) and the angle measured. Normal ROM on the AKE test is defined as a knee flexion angle of 20° or less (Cook, 2010), and angles greater than 20° have identified participants with decreased hamstring extensibility (Mhatre et al, 2013).

With its reliability previously described (Opar et al, 2013), Ham_{ecc} strength metrics of peak force (PF), peak torque (PT), average force (AF), average torque (AvT) were quantified using the Nordbord™ (Vald Performance, Queensland). Whilst completing testing on the Nordbord™ break angle (°) was ascertained by recording each trial from the sagittal plane using a Canon XA35 camera. The camera was placed on a fixed stand set 3m away and 0.5m from the floor. Three reflective circular markers were attached to the right greater trochanter, right lateral femoral condyle, and right lateral malleolus to calculate knee joint kinematics. Minimal clothing was recommended to avoid movement of markers. Participants knelt on the padded section of the NordBord with each ankle secured superior to the lateral malleolus by individual braces. Participants were instructed to gradually lean forward at the slowest possible speed, maximally resisting this movement with both limbs, while holding their trunk and hips in a neutral position throughout, with their hands across their chest (Buchheit et al, 2016). Individual's knee position on the NordBord was recorded using the integrated knee position guides with the ankle restraints at 90º, 2 cm superior to the lateral malleolus to ensure the body position remained consistent between repetitions. Participants were loudly exhorted to provide maximal effort throughout each repetition. A trial was deemed acceptable when the force output reached a distinct peak (indicative of maximal eccentric strength), followed by a rapid decline in force when the participant was no longer able to resist the effects of gravity acting on the segment above the knee joint (Buchheit et al, 2016). Participants performed one set of three maximal repetitions of the Nordic bilateral hamstring exercise based on previous investigations (Buchheit et al, 2016). The Nordic hamstring exercise completed on the NordBord was analysed using a variation of the motion analysis protocol adopted from a previous study (Lee et al, 2017a). Average and peak data was utilised for Ham_{ecc} analysis. Video clips were digitized and transformed into a two-dimensional space using motion analysis application software (IOS Nordics Application). Each participants' break point angle was calculated using the reflective markers placed on the landmarks previously identified. The Nordic break point angle defined the angle between the line joining knee and hip markers and the initial position of the participant in vertical. Break angle (Ɵ) was determined by identifying the average of the 3 repetitions completed individually for each participant.

Pre and post FR application, Ham_{ecc} and AKE measures were taken for all participants. Each intervention group received one type of FRD, either the low density (TriggerPoint™, CORE roller, Austin, Texas) (LD) n=7), medium density (TriggerPoint™, GRID roller, Austin, Texas) (MD) n=7), or high density foam roller (TriggerPoint™, GRID X roller, Austin, Texas) (HD) n=7). All foam rollers had the same surface pattern and diameter for comparison however differed in density. The hard FRD was constructed with a hard core wrapped in a firm ethylene-vinyl acetate (EVA) foam. The medium FRD had a hard-plastic core covered in a comparatively softer EVA foam. Lastly, the low-density FR was manufactured with soft EVA foam and without a hard core. The rolling procedure consisted of 4-bouts of 60s intervals with a recovery period of 30s to allow the participants to rest their arms from supporting their body weight. The application technique of FR required the participant to be seated on the floor with the roller positioned underneath their dominant hamstring. The ipsilateral limb remained in a flexed position with the sole of the foot placed firmly on the floor. Both arms were extended behind the body to fully support the participant's body weight. The movement began with the roller at the point of the ischial tuberosity and ended at the popliteal fossa. A digital timer recorded the time of each rolling session and a mobile application metronome (Soundbrenner Ltd. 2018) standardised the rolling cadence at 60-beats per minute to ensure participants were able to adhere to the speed (Mohr et al, 2014; Jay et al, 2014; Halperin et al, 2014; Bradbury-Squires et al, 2015). Participants were instructed to remain, to the best of their ability at the speed of one second up and one second down the posterior thigh and advised to place as much weight through the roller as possible (Mohr et al, 2014; MacDonald et al, 2014). All participants followed the same testing order and were verbally encouraged by the same researcher throughout (Marinho et al, 2015). The control group completed pre and post measures with a period of 360s between measures, corresponding to the time period the intervention groups completed FR for and timed with the same mobile application metronome. During the period of 360s the control group adopted a supine position on a plinth, whilst maintaining a knee joint angle of ~ 60° (with 0° being 'full extension') by resting their dominant limb upon the foam roller (Macgregor et al, 2018). All participants were right leg dominant, determined by the limb they would naturally kick a ball with (van Melick et al, 2017).

STATISTICAL ANALYSIS

A univariate repeated measures general linear model quantified main effects for FRD, time and limb. Interaction effects were also quantified, and significant main effects of FRD were explored using post hoc pairwise comparisons with a Bonferonni correction factor. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138) (Cohen, 1988). All statistical analysis was completed using PASW Statistics Editor 26.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $p \leq 0.05$, and all data are presented as mean ± standard deviation.

RESULTS

Mean scores and standard deviations bilaterally for each strength metric quantified (PT, PF, AvT, AVF and °) and AKE performance post FR intervention are seen in Table 1.

****Insert Table 1 Here****

AKE

Figure 1 summarises the effects of low, medium and high-density FR on AKE pre and post application. There was a significant main effect of time post FR ($F=59.79,\ p\leq 0.001,\ n^2=0.384$), with bilateral post-FR values significantly higher post FR ($p\leq 0.001$) for all densities of roller. There were no significant differences between limb identified for any group ($p>0.05$). The control group displayed no significant increase bilaterally in post AKE measures ($p>0.05$). There was a significant FR *x* time interaction ($F=5.348,\ p=0.002,\ n^2=0.143$). No other significant interactions were displayed between limb *x* time, limb *x* roller density ($p>0.05$). Collapsing of the data to analyse the effect of FR density displayed significant increases in range post FR intervention (Low Density: $F=23.47$, $p\leq 0.001$, $n^2=0.494$; Medium Density: $F=30.57$, $p\leq 0.001$, $n^2=0.560$; Hard Density: $F=9.11$, $p= 0.006$, $n^2=0.275$).

Insert Figure 1 Here

Eccentric Hamstring Strength

Pre and post measures of PT, PF, AvT, AvF and ° are summarised in Figures 2-4. There was a significant main effect for density of roller bilaterally for PT ($F=3.6$, $p<0.01$, $n^2=0.384$) PF ($F=3.137$, $p<0.05$, $n^2=0.089$) AvF ($F=4.427$, $p<0.05$, $n^2=0.122$) AvT ($F=4.293$, $p<0.05$, $n^2=0.118$), *and* ° ($F=4.107$, $p<0.01$, $n^2=0.204$), but no significant effect of time for any of these strength metrics ($p>0.05$). No significant difference between pre and post measures were found for PT, PF, AvT, AvF and ° for any group ($p>0.05$). There were also no significant differences between limb detected for any group ($p>0.05$). No significant interactions were detected across any of the quantified strength metrics, limb or FR density ($p>0.05$). Collapsing of the data to analyse the effect of FR density displayed no significant effect on eccentric strength metrics post FR intervention ($p>0.05$)

Insert Figure 2 Here

Insert Figure 3 Here

Insert Figure 4 Here

DISCUSSION

The aim of the present study was to investigate the effects of varying densities of FR on HF and Ham_{ecc} parameters in physically active males. The main findings from this body of work highlighted significant improvements in HF quantified via AKE immediately-post a 5-minute bout of FR applied to the hamstring musculature. These significant improvements were identified across all FR groups, with varying mean percentage improvements bilaterally in HF displayed in relation to density of roller (low: 23% and 23%;

medium: 18% and 21%; high: 16% and 12%, left and right hamstrings respectively). Results identified that the low-density FR displayed the largest increases in AKE measures. Although, it is important to note that each participant was not exposed to all densities of roller in the present body of work. In addition, no significant differences were identified between pre and post FR measures for any of the strength parameters taken in line with previous literature (Madoni et al., 2018) and supporting our hypothesis. Literature has identified that injury risk is heightened when increases in flexibility are not accompanied with associated functional strength gains (Timmins et al, 2016). Significant differences between FR densities were identified when analysing Ham_{ecc} strength metrics, however these differences are best explained by each group within the present study representing a separate cohort of participants. Thus, only identifying there were significant differences between groups of their strength outputs, which is represented by each groups mean values. Further work should consider analysing the individual effect of FR on HF and Ham_{ecc} strength metrics.

Previous research has identified that FR improves ROM across a range of joints (Bushell et al, 2015; Cheatham et al, 2018; Mohr et al, 2014, MacDonald et al, 2013; Škarabot et al, 2015). Importantly the current study does not assess or comment on resultant strength changes as a result of FR. This is an important factor to consider, as it influences when FR may be more appropriate in terms of optimal application. Hamstring injury risk is multi factorial, with flexibility and functional strength being identified as two key aetiological factors (Freckleton et al, 2013). It is a common misconception in the field that increases of both factors reduces injury risk (Timmins et al., 2016). Recent literature has identified that increases in flexibility have been associated with reductions of functional strength through range, and thus increased injury risk (Opar, 2013; Timmins et al, 2016). This body of work highlighted changes in muscle architecture as a key aetiological factor, with º representing a metric to provide insight into this factor within the present study (Greig., 2008; Rhodes et al., 2018; Rhodes et al., 2020). The present body of work identified no significant changes in functional strength metrics and break angle despite increases in flexibility. The consequences of these findings in a sporting context may lead practitioners to interpret that no change in pre and post strength measures, with increases in flexibility mean that FR contributes to reducing injury risk and may therefore be a good preparation tool for sports performance.

Solely analysing strength parameters such as AvF, PF, PT and AvT, alongside resultant improvements in flexibility would suggest FR pre-training could potentially reduce injury risk. Increases in flexibility without increases in break angle however may heighten injury risk (Opar, 2013; Timmins et al, 2016). This risk would be relative to each individual athlete and consideration needs to be given to break angle in conjunction with the athletes ROM. This approach supports recent findings by Oranchuk et al (2019) in terms of individual application prescription of such therapeutic or recovery modalities. Further research is required in this area and should consider a multi factorial individualised approach and longer-term effect on muscle architectural changes. Consideration must be given to individual athlete analysis within practical environments. This should drive decision making in relation to injury risk reduction strategies and when FR should take place.

It is suggested that the increase in HF was caused by a tissue relaxation effect brought on by the direct pressure of the foam roller to produce local mechanical effects. Future work should consider quantifying longer-term effects of FR application and physiological mechanisms that may rationalise current findings. Theorised by Krause et al, (2017), local pressure of the foam roller may affect the viscoelastic properties of myofascia enabling a greater stretch to be achieved. Research has demonstrated that FR acutely decreases arterial stiffness and improved vascular endothelial function, which induces a tissue relaxation effect enabling a greater flexibility score to be achieved (Okamato et al, 2014). Furthermore, ROM changes may be caused as a result of a combination of other mechanisms. Such mechanisms have been postulated by numerous authors (MacDonald et al, 2013; Mohr et al, 2014, Bradbury-Squires et al, 2015; Cheatham et al, 2015), with little scientific evidence to support, therefore, should be met with skepticism. Theories in the aforementioned work include changes in the thixotropic property of the myofascia, increases in intramuscular heat and blood flow, changes in muscle spindle length, stretch perception, physical breakdown of scar tissue and remobilisation of myofascia. Measuring or quantifying many of these factors is impossible and conclusions drawn in the listed literature are questionable. Although the present study identifies changes in muscle length, the longevity and cause of these changes in ROM are unknown and the only conclusion drawn is that they are associated with FR.

Other stretching modalities have been shown to be detrimental when preparing for athletic performance, such as static stretching (Fletcher et al, 2004; Wallmann et al, 2005). Results from the current study demonstrate increases in hamstring flexibility, with no change reported within functional strength metrics. It is important to note that the low-density FR elicited the biggest percentage change from pre to post measures of flexibility. Reasons for this are unclear, however it is suggested that this may have been due to the amount of pressure the participant can exert through the tissue when rolling on varying densities or potentially the perception of the participants roller. The present study utilised different participants within each group assigned and future work should consider a mixed method cross over design, with additional measures of pressure of rolling and perception. Perceptually if participants felt they could apply more pressure to a lower (‘softer’) FR then greater effects on tissue response, supporting the theory presented earlier by Krause et al, (2017) may have occurred, resulting in a greater increase in HF in the current study. Sports persons may consider the inclusion of FR as part of their routines to improve hamstring flexibility. Caution must be taken however, in relation to injury risk reduction and improvements in flexibility, which must be closely analysed in conjunction with break angle in association with other strength parameters. Isolation of strength parameters of force and torque alongside increases in flexibility can be misleading and misinterpretation of what these metrics represent can heighten injury risk.

Whilst findings in the current study provide insight for sports medicine and performance practitioners as to the differences between FR densities and their effects on HF and Ham_{ecc} in active males which may be advantageous to sport recovery or injury risk reduction strategies, there are limitations to the study. Results may only be generalised to active males rather than elite populations, athletes or the female gender, with each group representing a relatively small population. Future work should consider the completion of a power calculation to identify optimal participant numbers. It is important to note that post FR strength and flexibility measures were taken immediately post rolling in the current study. Thus, the lasting effects of varying densities of FR are unknown with inconsistent results noted in literature suggesting that lasting physiological impacts from repeated or single bouts of FR applications last between 1-3 weeks, suggesting a dose-response which requires further investigation (Macgregor et al, 2018). Future studies may consider observing the latent effects of these applications to determine the length of impact on HF or Ham_{ecc}. It would be beneficial to report actual density values of the products utilised to determine how different they are; however, density values are not reported by the manufacturer and hence the terminology of low, medium or high is reported in the current study.

Conclusion

A controlled bout of FR elicits immediate positive increases in hamstring flexibility, but has no effect on strength measures of PT, PF, AvT, AvF or °. Practitioners interpretation of these findings are important, as it cannot be assumed that because there are no changes in strength metrics that the athlete is at a lower injury risk and careful consideration must therefore be given to when FR is performed. In addition, the lower density of FR displays the largest increases in flexibility which suggests varying densities of FR elicit differences in functional response. Consequently, choice of FR depending on treatment or recovery aim could be disseminated more accurately to athletes' requirements individually to support performance in terms of readiness to train or play. Findings advocate that clear reasoning and justification for the use of FR is necessary for optimal application. Future research that considers both physiological and psychological effects of FR, with quantification of pressure during FR application may provide further insights into optimizing modality choice for recovery approaches in sport.

Key Points

1. A bout of foam rolling to the hamstrings increases flexibility but no effect on muscle strength parameters in a population of males.
2. Consideration as to the periodisation of foam rolling is important as it cannot be assumed that no effect on strength metrics defines a lower risk of injury.
3. Lower density of foam roller demonstrates a greater increase in hamstring flexibility.
4. Choice of foam roller density is reliant on the therapeutic aims of treatment or recovery however lower density foam rollers may be preferable for greater improvements in flexibility by sports medicine or performance practitioners.

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FIGURE CAPTIONS

Figure 1. Active Knee Extension (AKE) (°) quantifying hamstring flexibility for each group (Control, Low, Medium and High FR Densities) and limb, at Pre and Post-FR application timepoints. * = Significant differences reported pre-post.

Figure 2. Average (AvT) and Peak Torque (PT) for Each Group (Control, Low, Medium and High FR Densities) and limb, at Pre and Post-FR Timepoints. * = Significant differences reported pre-post.

Figure 3. Average (AvF) and Peak Force (PF) for Each Group (Control, Low, Medium and High FR Densities) and limb, at Pre and Post-FR Timepoints. * = Significant differences reported pre-post.

Figure 4. Breaking Angle (°) for each group (Control, Low, Medium and High FR Densities), for Pre and Post-FR application timepoints. * = Significant differences reported pre-post.