Physical Therapy in Sport 40 (2019) 213–217

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

Superficial heat administration and foam rolling increase hamstring flexibility acutely; with amplifying effects

Dustin J. Oranchuk [a, b, *], Matthew R. Flattery [a], Tracey L. Robinson [a]

[a] Department of Human Performance and Physical Education, Adams State University, USA
[b] Sports Performance Research Institute New Zealand, Auckland University of Technology, New Zealand

ARTICLE INFO

Article history:
Received 15 August 2019
Received in revised form
6 October 2019
Accepted 6 October 2019

Keywords:
Hip-flexion
Massage
Moist-heat
Self-myofascial release

ABSTRACT

Objectives: To compare the objective and subjective efficacy of three treatments on acute hip-flexion range of motion (ROM).
Design: Assessor-blind, randomized within-subject cross-over.
Setting: University athletic training clinic.
Participants: Twenty-two female collegiate lacrosse and soccer athletes.
Main outcome measures: The passive straight-leg-raise (PSLR) was used to measure acute hip-flexion ROM pre- and post foam rolling (FR), superficial heating (SH), combination (SH + FR) and control treatments. A seven-point Likert scale statement measured the perceived effectiveness of each treatment.
Results: Superficial heat (+10.4%, ES = 0.78), FR (+7.26%, ES = 0.52), and SH + FR treatment (+12.9%, ES = 1.26) improved hip ROM when compared to the control (+2.4%, ES = 0.24) (all $p < 0.001$). The SH + FR treatment resulted in a greater improvement in hip ROM compared to FR ($p = 0.001$, ES = 0.95), whereas no significant difference was observed between the SH and FR ($p = 0.083$, ES = 0.68) or SH and SH + FR treatment ($p = 0.270$, ES = 0.43). SH + FR was perceived as more effective than FR ($p = 0.033$, ES = 1.21), but not SH ($p = 0.193$, ES = 0.63). However, only a moderately positive correlation ($r = 0.508$) between objective and subjective measures of hamstring flexibility was found.
Conclusions: All treatments significantly improve hamstring flexibility with SH + FR being the most effective. Rehabilitation professionals should practice caution when relying on athlete perception and should prescribe treatments on an individual basis.

1. Introduction

Acute alterations in joint range of motion (ROM) are underpinned by several factors. One proposed factor contributing to changes in ROM is self "myofascial release", whereby manual manipulation, such as self-massage or foam rolling (FR) would decrease viscosity and improve compliance of the fascia and other local connective tissues. However, while FR has been previously believed to result in positive alterations in the viscoelastic and properties of the fascia, the ability of manual therapies to substantially alter these qualities is unlikely as the pressure required to substantially deform fascia beyond the capability of self "myofascial release" (Behm & Wilke, 2019; Schleip, 2003a, 2003b). Additionally, thixotropic effects depreciate faster than the reported duration of FR induced ROM improvements (Behm & Wilke, 2019; Schleip, 2003a, 2003b). Therefore, neural mechanisms, including altered central pain-modulatory system (Aboodarda, Spence, & Button, 2015; Cavanaugh et al., 2017), are more likely to underpin acute improvements in ROM (Behm & Wilke, 2019).

Warm-up (Morales-Artacho, Lacourpaille, & Guihem, 2017), FR (Sullivan, Silvey, Button, & Behm, 2013), static, dynamic and proprioceptive neuromuscular facilitation stretching (Konrad, Gad, & Tilp, 2015; Konrad, Stafilidis, & Tilp, 2016), are all recommended treatments for altering neuromuscular qualities, and therefore, acutely improving ROM. However, there are conflicting reports regarding the potentially deleterious effects of stretching, on dynamic performance and isometric force-time characteristics (Blazevich et al., 2018). To circumvent the limitations of static stretching, alternative techniques such as FR and rolling massage

* Corresponding author. AUT-Millennium, 17 Antares Place, Mairangi Bay, Auckland, New Zealand.
E-mail address: dustinoranchuk@gmail.com (D.J. Oranchuk).

https://doi.org/10.1016/j.ptsp.2019.10.004
1466-853X/

have gained attention (Aboodarda et al., 2015; Halperin, Aboodarda, Button, Andersen, & Behm, 2014; Okamoto, Masuhara, & Ikuta, 2014). Some of the proposed benefits of FR include reducing the sense of fatigue (Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2014), increased ROM (Sullivan et al., 2013), increased blood flow (Okamoto et al., 2014).

Heat application is another beneficial strategy for acutely improving ROM (Funk, Swank, Adams, & Treolo, 2001; Hanson & Day, 2012); furthermore, there is an emergence of investigations on the potential augmenting effects of common ROM promoting strategies (Funk et al., 2001; Mohr, Long, & Goad, 2014). For example, Mohr et al. (2014) compared the effects of FR, static stretching or a combination protocol. The researchers demonstrated that a combination was significantly more effective in improving passive hip-flexion ROM than rolling or stretching in isolation (Mohr et al., 2014). Similarly, Funk et al. (2001) reported a benefit to applying heat before static stretching on measures of hamstrings flexibility and subjective participant satisfaction. As warm tissues are more compliant and extensible (Hanson & Day, 2012; Stark et al., 2014), it is possible that heating before foam rolling would lead to greater improvements in flexibility.

Therefore, the primary purpose of the present study was to compare the efficacy of FR and heat application, individually, and in combination, with the absence of treatment, on hip-flexion ROM in healthy, female athletes. The primary hypothesis was that while acute ROM would be significantly improved following each treatment, the combination of heating and foam rolling would be most effective. Additionally, the present study aimed to determine which treatment would be perceived as being most effective and to compare the objective and subjective measures of hamstring flexibility.

2. Methods

2.1. Participants

Thirteen female NCAA Division II collegiate lacrosse athletes, and 13 female NCAA Division II collegiate soccer athletes, who were in the pre-season, volunteered to participate. Following a familiarization session, each participant completed, in random order, superficial heating (SH), foam rolling (FR), superficial heating and foam rolling in combination (SH + FR), and control treatment. Two of the lacrosse and soccer athletes, respectively, did not complete all the sessions due to personal time commitments. The mean age, height, weight and years of playing experience of the final 22 participants was 19.4 ± 1.7 years, 164.8 ± 9.2 cm, 61.4 ± 8.9 kg, and 6.9 ± 4.1 years, respectively. All participants had asymptomatic hamstring muscle groups as confirmed by the Physical activity readiness questionnaire (PAR-Q). Informed consent was obtained from all subjects once the study had been approved by the University's Institutional Review Board and Human Research Ethics Committee in the spirit of the Helsinki Declaration.

2.2. Design

An assessor-blind, within-subject cross-over design was implemented to examine and compare the effects of SH administration, FR, and a SH + FR treatment on acute hamstrings muscle flexibility. Participants were required to visit the university's athletic training clinic at the same time of day (±1 h) on five occasions, separated by seven days. Each session took place before practice or other forms of physical activity. The five visits consisted of one familiarization and four randomized experimental sessions.

2.3. Procedures

The participants arrived at the clinic for each of the five sessions, dressed in shorts and a T-shirt. During the familiarization session, the health-history questionnaire was administered, and the participants' height and weight were recorded. Baseline hip-flexion ROM evaluations were performed on each participant, and a seven-point Likert style questionnaire (Preston & Colman, 2000) was explained. The participants were given a hamstring rolling demonstration with verbal instructions to ensure a proper technique was used throughout the study. The participants returned every seven days over the following four weeks and underwent hip-flexion ROM evaluations on the dominant leg (i.e. the preferred leg used to kick a ball) before and after SH, FR, SH + FR treatment, and no treatment (i.e. the control session) in random order. Random order of treatments was accomplished via a balanced Latin square spreadsheet (Excel, version 2016; Microsoft Corporation, Redmond, WA).

2.3.1. Assessments

The passive straight-leg-raise (PSLR) was utilized to evaluate hip-flexion ROM. Previous investigations have reported that the PSLR holds high inter-rater (interclass correlation coefficient (ICC) = 0.86–0.91) intra-rater (ICC = 0.92) (Boland & Adams, 2000), and intra-session (ICC = 0.88) reliability (Davis, Quinn, Whiteman, Williams, & Young, 2008). As described by Davis et al. (Davis et al., 2008) subjects were positioned supine on a padded treatment table (4002: H-Brace; Hausmann Industries, Northvale, NJ) with their non-dominant leg secured to the table with a non-compliant strap. The strap was positioned over the thigh of the non-dominant leg directly proximal to the patella (Davis et al., 2008). The examiner lifted the dominant extremity by flexing the hip-joint and maintaining full knee-extension with the ankle slightly plantarflexed throughout the movement (Davis et al., 2008). The primary examiner continued to flex the participants' hip until the point of discomfort, or when space between the treatment table and the lower back, pelvis or ipsilateral limb was present (Davis et al., 2008). The hip-joint angle was measured with a goniometer (model G300; Whitehall Manufacturing, City of Industry, CA) once the end ROM was reached (Davis et al., 2008). The post-treatment ROM evaluation took place immediately following the FR session (Mohr et al., 2014). The same certified athletic trainer (ATC) executed all assessments while a research assistant recorded the measurements and ensured that the participants were not made aware of the scores. To keep the assessors blinded to each condition, both the ATC and research assistant were stationed in and performed each evaluation in a room adjacent to the treatment room. Once treatments were completed, participants entered the assessment room for the post-assessments. Following the post-treatment flexibility assessment, a seven-point (Preston & Colman, 2000) Likert-style statement 'The treatment was effective for improving hamstrings range of motion' was verbally administered. Responses of 'one' through 'seven' corresponded to 'completely disagree', 'strongly disagree', 'partly disagree', 'neither agree nor disagree', 'partly agree', 'strongly agree' and 'completely agree', respectively. Previous investigations have determined the 7-point Likert-style scale to be highly reliable ($p < 0.05$, ICC = 0.93, Cronbach's $\alpha = 0.85$) (Preston & Colman, 2000).

2.3.2. Treatments

Within 5 min of the conclusion of each initial ROM evaluation, participants underwent moist SH application, a FR session, a SH + FR treatment or time-matched 10-min rest (Control) in random order. As described by Mohr et al. (2014), the FR session consisted of three, 1-min bouts of FR with 30 s of passive rest

between sets. The participants rolled, with as much pressure as tolerated, from the popliteal fossa to the ischial tuberosity and back in 1-s intervals, as regulated by an electronic metronome (Fig. 1) (Mohr et al., 2014). Each participant was provided with a previously unused foam roller (GRID TriggerPoint; Implus LLC, Alexander Drive, NC) for the duration of the study.

The participants were positioned in a prone position on a treatment table during the SH treatment. As described by Hanson and Day (2012), a large moist hot pack (Theramed; Pro Healthcare Products, Park City, UT) was removed from a hydrocollator set at 71 °C and placed in a terry cloth cover. The moist hot pack was applied to the posterior thigh of the dominant limb for 10 min (Hanson & Day, 2012). The post-treatment evaluation was performed immediately after the termination of SH application. The participants performed the same, previously described, FR protocol, directly after SH application when undergoing the SH + FR treatment. In the control session, participants remained seated on the ground in a comfortable position with both knees fully extended.

2.4. Statistical analysis

An analysis of the intersession variability of the baseline PSLR scores was conducted using an Excel spreadsheet where all data were log-transformed to correct for heteroscedastic effects (Hopkins, 2000; Hopkins, Marshall, Batterham, & Hanin, 2009). Mean, and standard deviation (SD) was calculated for PSLR baseline scores. All data were log-transformed to correct for heteroscedastic effects. Intersession analysis was performed on the mean results of the variables for each session. The ICC (type 3,1) and coefficient of variation (CV) were used to explore relative and absolute variability, respectively. Variability was also examined via the typical error of measure (TEM) to provide a practical interpretation of the magnitude of error expected for any change in the mean.

Statistical analyses were performed using the SPSS statistical analysis software (Version 24, IBM Corporation, Armonk, NY) with the significance level set at $p < 0.05$. The assumptions of normality and sphericity were evaluated with the Shapiro Wilk's and Mauchly's tests, respectively. A two-way analysis of variance (ANOVA) with repeated measures (4 treatments × 2 time-points) was performed to measure the effect of the three treatments on acute hip-flexion ROM. If a significant result was obtained from the treatment × time interaction, a series of paired t-tests with Bonferroni correction were used to compare different treatments. Cohen's *d* effect sizes (ES) were calculated to measure the magnitude of practical effect, with the following criteria used: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = medium and >0.80 = large (Ellis, 2010). In addition, a one-way ANOVA (4 treatments) with Bonferroni correction were used to compare different treatments for the Likert score. The relationship between perceived efficacy and the change in hip ROM were assessed via the Pearson's (*r*) correlation coefficient and interpreted as: 0.10–0.29 = small; 0.30–0.49 = moderate; 0.50–0.69 = large; 0.70–0.89 = very large; and 0.90–1.00 = near perfect (Hopkins et al., 2009). Data are reported as the mean ± standard deviation (SD) with 95% confidence intervals (CI) where appropriate. Post-hoc statistical power was determined using G*Power (Düsseldorf, Germany) (Faul, Erdfelder, Lang, & Buchner, 2007), examining the change-scores between the control and all other treatments.

3. Results

3.1. Intersession variability

The intersession, pre-treatment PSLR scores were not significantly different ($F_{2,42} = 0.77$, $p = 0.466$). Pre-treatment PSLR scores held acceptably small intersession variabilities (ICC = 0.80 (95% CI: 0.62–0.92); CV = 6.8% (95% CI: 5.5–8.9%); TEM = 0.48 (95% CI: 0.39–0.62).

3.2. Hip-flexion range of motion

Achieved statistical power for the change in hip-flexion ROM between the control and FR, SH, and SH + FR was $\beta = 0.839$–0.999, based on $p = 0.001$, ES = 1.38–2.28 and $N = 22$.

Raw pre and post-treatment PSLR scores, change scores, and percent change are summarized in Table 1. The SH, FR and SH + FR treatments significantly improved hip ROM, (interaction effect: $F_{3,63} = 14.23$, $p < 0.001$) with the pre-to post-assessments following SH (7.66 ± 3.3°, +10.4%, ES = 0.64), FR (5.38 ± 5.6°, +7.3%, ES = 0.47), and SH + FR treatment (9.53 ± 5.2°, +13%, ES = 1.03) improving hip ROM when compared to the control treatment (1.88 ± 1.3°, +2.4%, ES = 0.25) (all $p < 0.001$). In addition, combined treatment resulted in a greater gain in the hip ROM compared to FR ($p = 0.001$, ES = 0.95), whereas no significant difference was observed between the SH and FR ($p = 0.083$, ES = 0.68) or SH and SH + FR ($p = 0.270$, ES = 0.43).

3.3. Perceptions of efficacy

Likert score means and SDs are summarized in Table 2. The ANOVA exhibited a significant perceived efficacy (Likert scale points) ($F_{3,63} = 18.91$, $p < 0.001$) where all three intervention sessions exhibited a greater value (i.e. more perceived efficacy) than control session (all $p < 0.001$). In addition, the combined treatment

Fig. 1. Metronome guided foam rolling of the hamstrings.

Table 1
Passive straight leg raise summary table.

Treatment	Pre	Post	Change	% change	Effect size
Superficial heat	78.1 ± 12.6°	85.7 ± 11.4°	7.7° (6.3,9.1) *	10.4% (7.9,12.9)	0.64 (0.12,1.13)
Foam rolling	78.1 ± 11.6°	83.5 ± 11.1°	5.4° (4,6.8) *	7.3% (5,9.6)	0.47 (0.04,0.97)
Heat & rolling	76.5 ± 9.6°	86 ± 8.9°	9.5° (7.4,11.7) *	13.1% (7.8,16.4)	1.03 (0.48,1.54)
Control	78.3 ± 7.7°	80.2 ± 7.3°	1.9° (1.3,2.4)	2.5% (1.8,3.3)	0.25 (−0.26,0.74)

± denotes standard deviation. 95% Confidence intervals are provided in the brackets. * denotes $p < 0.001$. Effect size = Cohen's *d*.

Table 2
Likert scores for each treatment.

Statistic	Superficial heat	Foam rolling	Heat & rolling	Control
Mean	5.23	4.64	5.86	2.69
SD	0.89	1.22	1.13	1.11

SD = Standard deviation.

resulted in a greater value than FR ($p = 0.033$, ES = 1.21). There was no significant difference between SH and SH + FR treatment ($p = 0.193$, ES = 0.63).

There were significant correlations between the percent change in hip ROM and perceptions of efficacy across all treatments ($p < 0.001$). Pearson's correlation coefficient revealed a largely positive ($r = 0.508$) relationship between the changes in hip ROM and perceptions of efficacy when all treatments were pooled. When analyzed separately, weak, and non-significant correlations between the objective and subjective measures of acute hamstring flexibility were found for SH ($r = 0.25$, $p = 0.258$), FR ($r = 0.075$, $p = 0.739$), and SH + FR ($r = 0.178$, $p = 0.455$) treatments. Conversely, a very large, yet non-significant correlation between objective and subjective efficacy was present for the control ($r = 0.878$, $P = 0.331$) treatment.

4. Discussion

The objective of the present study was to examine the effect of SH application, FR, and a SH + FR treatment on acute hamstring flexibility. Therefore, the primary hypothesis that all treatments would significantly improve hip ROM was correct. The combined treatment also improved hip ROM by a greater degree than FR alone. However, the difference between the SH + FR and SH did not result in statistically greater hip ROM improvements, despite moderate effect sizes in favor of the combined treatment. The SH + FR treatment was widely perceived as most effective. These results suggest that implementing any of the present treatment options can acutely improve hamstring flexibility while the combined treatment may provide the largest benefits.

All treatments, with the exception of the control treatment, significantly improved hamstring ROM. The combined treatment (ES = 1.03) resulted in a larger magnitude of practical effect when compared to SH (ES = 0.64) or FR (ES = 0.47) alone. However, only a small difference in PSLR changes existed between SH and the SH + FR treatments ($p = 0.270$, ES = 0.43) despite no means of manual tissue manipulation in the SH treatment. Funk et al. (2001) reported significantly greater improvements in hamstring flexibility following the application of moist-heat vs. static stretching, supporting our findings. Similarly, Morales-Artacho et al. (2017) found that increasing muscle temperature via cycling (2.9%) or a combination of cycling and FR (3.2%) provided superior improvements ($p \leq 0.001$, ES ≥ 0.30) in hamstring ROM 5 min post-treatment when compared to FR alone ($p \geq 0.12$, ES ≤ 0.23). The potential mechanisms contributing to muscle tissue compliance and extensibility following SH application have been suggested as an increase in tissue compliance and elasticity, and an increased pain pressure threshold (French, Cameron, Walker, Reggars, & Esterman, 2006; Malanga, Yan, & Stark, 2015; Stark et al., 2014). Substantial evidence exists suggesting that alterations in the pain pressure threshold underpin acute improvements in ROM. For example, Aboodarda et al. (2015) demonstrated that heavy rolling massage on hypersensitive tender spots could increase the pain pressure threshold on both ipsilateral and contralateral plantar flexor muscles. Therefore, it could be postulated that the heat-packs may have allowed for greater pressure to be used when rolling, and therefore greater effect size in ROM improvements following the SH + FR treatment.

Understanding which treatments are perceived as most effective may be useful to practitioners as athletes are more likely to adhere to treatment when they believe it will be effective (Mothes, Leukel, Seeling, & Fuchs, 2017). All three treatments were widely perceived as an effective means of acutely improving hamstring flexibility. A significant difference in perceived efficacy was found between groups ($p = 0.01$), with SH + FR intervention was generally perceived to be more effective than FR (ES = 1.21). Therefore, the SH + FR treatment may be more likely to be regularly utilized by participants. However, none of the correlations between the objective and subjective measures of efficacy reached significance ($r = 0.075$–0.878, $p = 0.258$–0.739) suggesting that the participants could not reliably identify which treatment was most effective. It should also be noted that the SH (~10 min), FR (~5 min) and SH + FR (~15 min) treatments were not time equated. Therefore, athletes and practitioners should be cognizant of the time-costs of each treatment outlined in the present study.

Although the primary aim of this study was accomplished, there are several limitations and suggestions for future research. Firstly, only single objective and subjective assessments were utilized. While the PSLR is a widely used assessment and is both valid and reliable (Boland & Adams, 2000; Davis et al., 2008; Hanson & Day, 2012; Mohr et al., 2014), including any of the myriad of other flexibility assessments could have been valuable. However, multiple flexibility assessments may, on their own, acutely improve ROM. It is also difficult to quantify the effect of the repeated PSLR trials. The present study was also limited by the inability to monitor the exerted pressure during the FR, and alterations in blood flow, pain pressure thresholds, and stretch-induced pain tolerance. Likewise, the subcutaneous tissue thickness of the posterior thigh was not assessed, making it difficult to quantify the level of tissue warming as a result of each treatment (Draper, Harris, Schulthies, & Durrant, 1998). Finally, while precedent exists for the FR treatment utilized in the present study, data on the brief 10 min SH application exists in paucity (Hanson & Day, 2012). Therefore readers should be aware that longer periods of SH application may have resulted in greater acute improvements in the PSLR. It would be interesting to examine the acute and chronic effects of heat and FR techniques on the physical properties of muscle and tendon (Konrad et al., 2015; Konrad et al., 2016; Morales-Artacho et al., 2017). As it is speculated that the treatments in the present study were effective by decreasing pain perception, further elucidating neuromuscular alterations via peripheral nerve and transcranial

magnetic stimulation may be a fascinating path for future research. It is also important to note that due to the difficulty in studying an adequate sample of participants with HSI, the present study exclusively included young, asymptomatic female athletes. Therefore, exploring the effects of SH, FR and other treatments within a multi-variate return to play protocol would be of interest.

5. Conclusions

Superficial heat, FR and F + FR were all effective treatments for acutely improving hamstring ROM in young asymptomatic female athletes. However, small to large effect sizes were present in favor of the SH + FR treatment. Perceptions of efficacy were not significantly different between treatments, despite relatively large differences in the time cost of each treatment. Additionally, outside of the control treatment, only weak correlations between objective and subjective measures of efficacy were found; therefore, practitioners should prescribe treatments on an individual basis and may which to administer the SH + FR treatment when seeking optimal results, or SH when time is a limiting factor.

Ethical statements

Ethical approval for the present study was granted by the Adams State University Institutional Review Board. All participants were briefed on the study procedures and provided written consent before participating in any study procedures in the spirit of the Helsinki Declaration.

Funding disclosure

None.

Declaration of competing interest

None.

Acknowledgments

The authors acknowledge Dr. Saied Jalal Aboodarda of the University of Calgary for his contribution to this study.

References

Aboodarda, S. J., Spence, A. J., & Button, D. C. (2015). Pain pressure threshold of a muscle tender spot increases following local and non-local rolling massage. *BMC Musculoskeletal Disorders, 16*, 1–10.

Behm, D. G., & Wilke, J. (2019). Do self-myofascial release devices release myofascia? Rolling mechanisms: A narrative review. *Sports Medicine, 49*, 1173–1181.

Blazevich, A. J., Gill, N. D., Kvorning, T., Kay, A. D., Goh, A. G., Hilton, B., et al. (2018). No effect of muscle stretching within a full, dynamic warm-up on athletic performance. *Medicine & Science in Sports & Exercise, 50*, 1258–1266.

Boland, R. A., & Adams, R. D. (2000). Effects of ankle dorsiflexion on range and reliability of straight leg raising. *Australian Journal of Physiotherapy, 46*, 191–200.

Cavanaugh, M. T., Döweling, A., Young, J. D., Quigkey, P. J., Hodgson, D. D., Whitten, J. H. D., et al. (2017). An acute session of roller massage prolongs voluntary torque development and diminishes evoked pain. *European Journal of Applied Physiology, 117*, 109–117.

Davis, D. S., Quinn, R. O., Whiteman, C. T., Williams, J. D., & Young, C. R. (2008). Concurrent validity of four clinical tests used to measure hamstring flexibility. *The Journal of Strength & Conditioning Research, 22*, 583–588.

Draper, D. O., Harris, S. T., Schulthies, S., & Durrant, E. (1998). Hot-pack and 1-MHz ultrasound treatments have an additive effect on muscle temperature increase. *Journal of Athletic Training, 33*, 21–24.

Ellis, P. D. (2010). *The essential guide to effect sizes: Statistical power, meta-analysis, and the interpretation of research results*. New York: Cambridge University Press.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191.

French, D. N., Cameron, M., Walker, B. F., Reggars, J. W., & Esterman, A. J. (2006). Superficial heat or cold for low back pain. *Cochrane Database of Systematic Reviews, 1*.

Funk, D., Swank, A. M., Adams, K. J., & Treolo, D. (2001). Efficacy of moist heat pack application over static stretching on hamstring flexibility. *The Journal of Strength & Conditioning Research, 15*, 123–126.

Halperin, I., Aboodarda, S. J., Button, D. C., Andersen, L. L., & Behm, D. G. (2014). Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *International Journal of Sports Physical Therapy, 9*, 92–102.

Hanson, M., & Day, J. (2012). Effects of different heating modalities on hip flexion range of motion. *International Journal of Athletic Therapy & Training, 17*, 27–30.

Healey, K. C., Hatfield, D. L., Blanpied, P., Dorfman, L. J., & Riebe, D. (2014). The effects of myofascial release with foam rolling on performance. *The Journal of Strength & Conditioning Research, 28*, 61–68.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*, 1–15.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise, 41*, 2009.

Konrad, A., Gad, M., & Tilp, M. (2015). Effect of PNF stretching training on the properties of human muscle and tendon structures. *Scandinavian Journal of Medicine & Science in Sports, 25*, 346–355.

Konrad, A., Stafilidis, S., & Tilp, M. (2016). Effects of acute static, ballistic, and PNF stretching exercise on the muscle and tendon tissue properties. *Scandinavian Journal of Medicine & Science in Sports*, 1–11.

Malanga, G. A., Yan, N., & Stark, J. (2015). Mechanisms and efficacy of heat and cold therapies for musculoskeletal injury. *Postgraduate Medicine, 127*, 57–65.

Mohr, A. R., Long, B. C., & Goad, C. L. (2014). Effect of foam rolling and static stretching on passive hip-flexion range of motion. *Journal of Sport Rehabilitation, 23*, 296–299.

Morales-Artacho, A. J., Lacourpaille, L., & Guihem, G. (2017). Effects of warm-up on hamstring muscle stiffness: Cycling vs foam rolling. *Scandinavian Journal of Medicine & Science in Sports, 27*, 1959–1969.

Mothes, H., Leukel, C., Seeling, H., & Fuchs, R. (2017). Do placebo expectations influence perceived exertion during physical exercise? *PLoS One, 12*, e0180434.

Okamoto, T., Masuhara, M., & Ikuta, K. (2014). Acute effects of self-myofascial release using a foam roller on arterial function. *The Journal of Strength & Conditioning Research, 28*, 69–73.

Preston, C. C., & Colman, A. M. (2000). Optimal number of response categories in rating scales: Reliability, validity, discriminating power, and respondent preferences. *Acta Psychologica, 104*, 1–15.

Schleip, R. (2003a). Fascial plasticity - a new neurobiological explanation. Part 2. *Journal of Bodywork and Movement Therapies, 7*, 104–116.

Schleip, R. (2003b). Fascial plasticity - a new neurobiological explanation: Part 1. *Journal of Bodywork and Movement Therapies, 7*, 11–19.

Stark, J., Petrofsky, J., Berk, L., Bains, G., Chen, S., & Doyle, G. (2014). Continuous low-level heatwrap therapy relieves low back pain and reduces muscle stiffness. *The Physician and Sportsmedicine, 42*, 39–48.

Sullivan, K. M., Silvey, D. B., Button, D. C., & Behm, D. G. (2013). Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *International Journal of Sports Physical Therapy, 8*, 228–236.