©Journal of Sports Science and Medicine (2019) **18**, 229-238
http://www.jssm.org

Research article

The Training Effects of Foam Rolling on Core Strength Endurance, Balance, Muscle Performance and Range of Motion: A Randomized Controlled Trial

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Abstract
Self myofascial therapy via foam roller is a common technique used by many athletes and patients to aid recovery, improve range of motion (ROM) and prevent injury. Further, it is suggested that foam rolling improves core stability. However, research about the training effects of foam rolling on measures of core "strength endurance", muscle performance, balance and flexibility is limited. Forty recreationally active females and males (age: 18-48 yrs) were randomly assigned to a foam roll (FOAM, n = 14), a core stabilization (CORE; n = 12) and a control group (CG, n = 12). FOAM massaged their lower leg muscles (5 exercises) with the foam roll 2 times per week for 8 weeks while CORE was assigned to core stability training including 5 exercises. CG underwent no intervention. Applied tests for outcome measurements were the Bourban trunk muscle strength test (TMS), standing long jump (SLJ), single leg triple hop for distance (SLTH) test, Y-Balance test and stand and reach test. There was an interaction effect (time x treatment) for the dorsal TMS ($p = 0.043$), demonstrating greater improvements in CORE compared with FOAM and CG with no difference between FOAM and CG. For the stand and reach test a main effect for time ($p < 0.001$) and time x treatment interaction ($p = 0.005$) were found, indicating an increase in ROM in FOAM compared with CORE and CG with no difference between the latter. No significant effects were found for balance and muscle performance. An 8-week training with the foam roll is effective in increasing ROM in the stand and reach test without concomitant decreases in core "strength endurance", muscle performance and balance parameters. The core stabilization training was sufficient to improve performance in dorsal TMS test.

Key words: Core stabilization, fascia, myofascial therapy, Y-Balance.

Introduction

Fascia refers to all fibrous connective tissue under tension that both penetrates and surrounds muscles, bones, organs, nerves, blood vessels and other structures and extends from head to toe in an uninterrupted, three-dimensional web (Findley, 2009). As a natural consequence of trauma, inflammation, or immobility the fascia loses flexibility and becomes restricted (Barnes, 1997; Schleip and Müller, 2013), which in turn leads to local and global problems in the body with acute and chronic imbalance (myofascial imbalance, joint dysfunction, pain, dysfunction in venous and lymphatic system). The purpose of a myofascial treatment is to facilitate soft-tissue extensibility and to reduce pain (Aboodarda et al., 2015).

During the last years, the popularity of training with the foam roll (FR) has grown. FR is a relatively new technique and a common form of self-myofascial training that is done by individuals themselves rather than by a clinician (Beardsley and Skarabot, 2015). The FR is a solid foam cylinder that is available in different degrees of hardness and size. Athletes or patients are encouraged to roll their bodyweight over in order to work each muscle group through and to loosen up tight areas of the muscle. A possible effect is an improved hydration of tissues. When applying FR, soft tissue is squeezed like a sponge and subsequently, it is soaked through with fluid, which improves motion between the different layers of fascia (Schleip and Müller, 2013).

Scientifically, many positive effects of FR are assumed, but in many cases not proven. The majority of studies, concerning self-myofascial techniques address acute effects (Aboodarda et al., 2015; Cavanaugh et al., 2017; Halperin et al., 2014; Healey et al., 2014; MacDonald et al., 2013; Skarabot et al., 2015) while there is limited clinical research on training effects of FR.

Miller and Rockey (2006) reported an improvement of hamstrings flexibility after an 8-week FR intervention but with a similar extent as in the control group. Both, Sherer (2013) and Junker and Stöggl (2015) demonstrated an increase in sit and reach, respectively stand and reach, test performance with no change in the control group following a 4-week FR training. Macdonald et al. (2014) demonstrated that three 20-min FR sessions (0, 24 and 48 hrs) following an exercise induced muscle damage protocol resulted in improved passive and dynamic ROM. In contrast, Hodgson et al. (2018) reported no effect of a 4-week roller massage training (similar principle to FR) on ROM. Finally, Halperin et al. (2014) demonstrated that an acute bout of stick roller massage led to similar improvements of ankle ROM compared with static stretching, while Grabow et al. (2017) found no acute effects of unilateral foot rolling on ankle dorsiflexion or sit and reach ROM.

With respect to the effects of FR on athletic performance, discrepant findings are reported. Healey et al. (2014) determined no acute effect of FR on athletic performance (vertical jump height and power, isometric force and agility) in comparison with planking exercises (trunk stabilization) while Halperin et al. (2014) demonstrated that an acute stick roller massage improved and static stretching reduced force production of plantar flexors at 10 min post-intervention. Macdonald et al. (2014) demonstrated that three 20-min FR sessions (0, 24 and 48 hrs) fol-

Received: 25 January 2019 / Accepted: 15 February 2019 / Published (online): 01 June 2019

lowing an exercise induced muscle damage protocol resulted in improved jump height, muscle activation and attenuated muscle soreness compared with a control group. In contrast, the 4-week roller massage intervention of Hodgson et al. (2018) led to no effects on voluntary contractile properties and jump performance.

The FR represents an unstable surface and thus the body is challenged to maintain stability and balance during training (Lukas, 2012). Further, based on the application of the own body weight and postures during the single exercises (e.g. variations of planking) with FR, possible side effects on core stability might be assumed. Therefore, it might be assumed that FR might improve core stability, power and balance. With respect to balance, no acute effects of roller massage (Halperin et al., 2014) or foot rolling (Grabow et al., 2017) on measures of balance were detected. Surprisingly, there are only a few studies that investigated the effect of core strength training particularly on core strength parameters, and in none of the studies the effects of FR were analyzed. In general, strength training on unstable surfaces has a positive effect on strength performance, power and balance when compared with no training. However, there is no consistent advantage of training on unstable surfaces as compared to training on stable surfaces particularly in adolescents and young adults (Behm et al., 2015).

Thus, the purpose of this study was to examine the effect of an 8-week FR intervention on core "strength endurance", jump performance, dynamic balance and flexibility. Moreover, the effects of FR are compared with a trunk stabilization intervention and control group. The specific hypotheses were that FR increases core strength endurance, muscle performance, dynamic balance and flexibility to a greater extent than core stabilization training.

Methods

Participants

Forty recreationally active female and male participants performing 2-3 times per week sport activity (mean ± SD; age: 29.3 ± 8.5 years, weight: 71.3 ± 10.6 kg, height: 1.76 ± 0.10 m, body mass index: 22.9 ± 2.0 kg·m-2) volunteered for the study (Table 1.). They were advised to maintain their usual training activities over the course of the study. Exclusion criteria were recent injuries in the last six months entailing a more than 1-week rest in doing sports. Participants who completed at least 75% of the training sessions were admitted to posttests. All participants had previous experience in FR and core stabilization training. Participants were informed in detail about the testing and training procedures as well as possible benefits and risks of the investigation before signing a written informed consent. Additionally, they received a written description of the training program. The Ethics Committee of the University of Salzburg granted ethical approval (EK-GZ: 34/2014).

Overall design

A randomized controlled clinical trial using a pretest/posttest design was applied. All participants completed baseline tests, after which they were randomly assigned to two intervention groups, the FR group (FOAM, n = 14) and the core stabilization group (CORE, n = 14), and a control group (CG, n = 12). Baseline testing included the Bourban trunk muscle strength test (core "strength endurance") (TMS), the standing long jump test (SLJ),the single leg triple hop for distance test (muscle performance) (SLTH), the Y-balance test (balance) and the stand and reach test (flexibility). Subsequently, the intervention groups were instructed about the FR and the core stabilization exercises. In addition, participants obtained a written training protocol in which they were asked to document in detail (exercises, number of repetitions, total training duration) each training session. After an 8-week training period, the tests were conducted again. Baseline and post-intervention testing were performed at the same time of the day after 5 PM.

Intervention

The intervention period consisted of two training sessions per week for eight weeks and included a progression after week 4. The progression was applied to ensure an appropriate training intensity and to meet the overload and progressive loading training principle (Katch et al., 2011). Both training programs (FOAM, CORE) were organized as home circuit training. Cheatham et al. (2017) observed no difference in knee flexion ROM and pressure pain threshold between a live instructed, a video-guided and a self-guided FR intervention. In addition to the documentation of the training, the participants were encouraged to note their rate of perceived exertion (RPE) after each training. The intensity and volume of exercises in both FOAM and CORE group were progressed gradually. Overall training time per week changed from 27 minutes in week 1-4 to 30 minutes in week 5-8. In the study by Riegler and Stöggl (2014) it was emphasized that a training time of 25 minutes per week is the lower limit to achieve adequate core strength. Intensity progression in the present study led from mainly bilateral to unilateral execution.

The FOAM program was composed of five exercises for specific muscles and both body sides, that is: 1) calf muscles, 2) quadriceps femoris, 3) hamstrings, 4) iliotibial-band, and 5) gluteal muscles. The FOAM group was instructed to use the FR with a pressure associated with individual mild to moderate pain (i.e. 7 out of 10 on a visual analogue scale) and without eliciting muscle spasms or cramping. In each training session, three sets per exercise with one-minute rest between sets were performed. In each subset, they rolled the required muscle group back and forth for the specified time (Table 2). The FR training

Table 1. Participant's characteristics at baseline testing mean ± SD.

	Training sessions	Height [m]	Weight [kg]	Body mass index [kg·m-2]	Age [years]
FOAM	15.5 ± 1.1	1.76 ± 0.07	70.6 ± 10.8	22.6 ± 2.4	30.5 ± 10.2
CORE	14.9 ± 1.0	1.77 ± 0.09	71.4 ± 10.6	22.7 ± 1.9	28.2 ± 7.8
CG		1.75 ± 0.10	71.8 ± 10.3	23.2 ± 1.6	29.1 ± 6.9

FOAM = foam roll group; CORE = core stabilization group; CG = control group

Table 2. The FOAM program.

Exercise	Instruction and progress	Volume
Week 1-4		**13.5 min./session; 27 min./week**
Calf muscles	rolling both sides simultaneously back and forth (bilateral)	3 sets of 50 s
Quadriceps	rolling both sides simultaneously back and forth (bilateral)	3 x 50 s
Hamstrings	rolling both sides simultaneously back and forth (bilateral)	3 x 50 s
IT-band	rolling left side (L), right side (R) separately (unilateral	3 x 30 s L, R
Glutes	rolling left glute (L), right glute (R) separately (unilateral)	3 x 30 s L, R
Week 5-8		**15 min./session; 30 min./week**
Calf muscles	rolling left calf (L), right calf (R) separately (unilateral)	3 sets of 30 s L, R
Quadriceps	rolling left side (L), right side (R) separately (unilateral)	3 x 30 s L, R
Hamstrings	rolling left side (L), right side (R) separately (unilateral)	3 x 30 s L, R
IT-band	rolling left side (L), right side (R) separately (unilateral)	3 x 30 s L, R
Glutes	rolling left side (L), right side (R) separately (unilateral)	3 x 30 s L, R

Table 3. The CORE program.

Exercise	Instruction and progress	Volume
Week 1-4		**13.5 min./session; 27 min./week**
Front plank	supporting with 4 points	3 sets of 50 s
Back bridge	dynamic lifting and lowering of the hips	3 x 50 s
Side plank	left side lying (L), or right side lying (R)	3 x 30 s L, R
Quadruped	raise right arm and left leg (A), left arm and right leg (B)	3 x 2 x 15 s A, B
Back extension	raise trunk and hold, push back shoulder blades	3 x 50 s
Week 5-8		**15 min./session; 30 min./week**
Front plank	raise alternately left (A) and right leg (B)	3 sets of 50 s
Back bridge	marching (knee to chest alternately	3 x 50 s
Side plank	left side lying (L), or right side lying (R)	3 x 30 s L, R
Quadruped	right arm / left leg (A), left arm / right leg (B); increase time	3 x 2 x 15 s A, B
Back extension	raise trunk and hold, bob extended arms alternately	3 x 50 s

protocol was based on the recommendations of Lukas (2012) which represent practical recommendations known from clinical experience.

The CORE program was based on the trunk stabilization protocol of Imai et al. (2014) and comprised five exercises, that is, 1) front plank, 2) back bridge, 3) side plank right and left, 4) quadruped exercise: raising arm and leg diagonally and 5) back extension. Three sets per exercise were performed and it was important that a neutral position of the spine during exercise was maintained. Participants were instructed to take a rest for one minute between each set (Table 3).

The CG had to maintain their usual training regime without additional intervention exercises. They completed only the pre- and post-test.

Testing

General testing procedure

The warm-up prior to pre- and post-test was standardized. All subjects performed 10 min of light jogging. All tests were accomplished indoors at a standardized room temperature after 5 PM. With the exception of TMS (only one trial), two measurements for each participant were taken for each test and the best value was used for further analysis. After warm-up, the tests were demonstrated by the instructor and were performed in the following order.

Bourban Trunk Muscle Strength Test (TMS)

The TMS was used to assess core "strength endurance" of the ventral, lateral and dorsal trunk muscle chains. The tests were conducted in a predetermined order (ventral, lateral and dorsal) with 10 min rest in between. After a familiarization with each test item for 6 repetitions, the participants had to perform one trial. During the ventral trunk muscle chain test (Figure 1a.), participants had to take up a prone bridge position on their shoulder-widths apart elbows and toes, with legs extended and with their forearms flat on a fitness mat. An adjustable alignment device consisting of two stable vertical poles and two vertically adjustable horizontal poles was applied. In this position, an adjustable horizontal bar was moved into contact with the spina iliaca posterior superior. Subsequently, the participants had to lift their feet alternately for 2-5 cm according to the beat of a metronome (1 second per foot) and had to hold the contact to the horizontal reference bar as long as possible. The test was terminated when the participant lost contact with the reference bar for the third time. The contact time in seconds until test termination was recorded and used for further analysis.

During the lateral trunk muscle chain test (Figure 1b.), participants were instructed to take up a side bridge position with legs extended, the upper foot on top of the lower foot and the supporting shoulder superior to the respective elbow. The supporting forearm lay on the fitness mat and the uninvolved arm was placed on the iliac crest. The test was performed only at the dominant side. The horizontal bar of the alignment device was adjusted on the greater trochanter. Participants were asked to raise and to lower their hips up and down continuously, according to the rhythm of a metronome (2 s per lowering and lifting

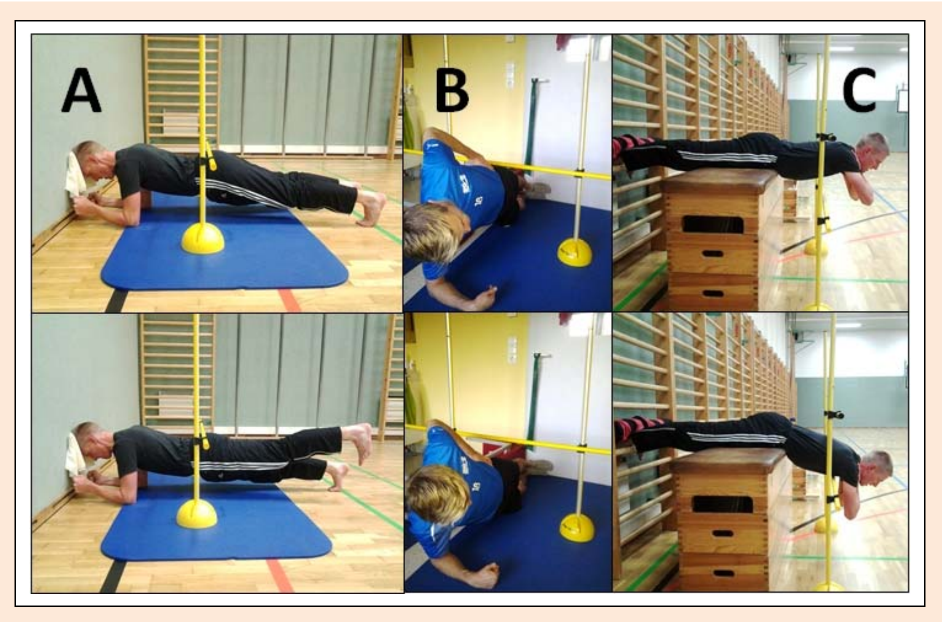

Figure 1. Schematic description of the Bourban TMS test (a: ventral chain, b: lateral chain, c: dorsal chain).

cycle). One cycle consisted of touching the horizontal bar and the fitness mat. Additionally, they were not allowed to unload their body mass on the floor. Warnings were given and the test was terminated after three warnings or if they failed to keep up the beat of the metronome. Time until test termination was measured in seconds and used for further analysis.

During the dorsal trunk muscle chain test (Figure 1c.), the participant lay prone on a vaulting box with their trunk unsupported and with extended legs. The spina iliaca anterior superior was positioned 4 cm behind the border of the box. They were instructed to hold their arms across the chest resting their hands on the shoulders. The feet were firmly fixed in wall bars. From the horizontal position (0°), participants had to lower their trunk by 30°. Both positions were controlled while using a mechanical goniometer. The upper horizontal reference bar was fixed in 0° position and the lower horizontal reference bar in 30° position. Participants continuously raised and lowered their trunk to the beat of a metronome (2 seconds per lowering and lifting cycle). Again, time until test termination was taken and used for further analysis. The criterion for test stop was failing to reach the upper horizontal bar for the third time (Markus Tschopp, 2003). Reliability measures demonstrated that the Pearson's correlation coefficient and coefficient of variation for the ventral, lateral and dorsal chain were r = 0.87 (14.1%), r = 0.81 (14.6%) and r = 0.80 (11.7%) (Tschopp et al., 2001).

Standing Long Jump Test (SLJ)

The SLJ is an inexpensive and simple test to assess lower leg power (Maulder & Cronin, 2005). When compared with different indicators of the gold standard for lower leg power testing using a force plate [counter movement jump (CMJ), squat jump (SJ), one leg jump right and left], the SLJ was correlated with r = 0.60 – 0.86 (Hübner et al., 2005; Rosser et al., 2008). The SLJ presents a good test-retest reliability (r = 0.95) and it has been reported to be reliable with a coefficient of variation of 2.4%. Furthermore there is a good correlation (r = 0.76) between the principal component of explosive power and the SLJ (Markovic et al., 2004). Therefore, the SLJ can be classified as a valid and reliable tool to measure lower leg power. Subjects had to stand with both feet behind a starting line and with their arms placed on the iliac crest. They were not allowed to use arm swings during the test. Subsequently, they were encouraged to jump as far as possible landing with both legs. Two rehearsals and two testing trials were conducted with a 2-min rest between each jump. The maximal distance from the starting line to the landing point at heel contact was measured in centimeters with a standard tape measure fixed at the floor. The trial was accepted if participants were able to land in a stable position on both legs without losing contact of hands from the iliac crest. The best trial was used for statistical analysis.

Single-Leg Triple Hop for Distance Test (SLTH)

The SLTH is a functional performance test designed to assess unilateral lower limb power. It is a strong and valid predictor of lower extremity strength and power (Hamilton et al., 2008) and can be classified as reliable with an intraclass correlation coefficient (ICC) of 0.95 and a standard error of measurement (SEM) of 15.44 cm (Bolgla and Keskula, 1997). Subjects were instructed to stand on their preferred leg, with the great toe on the starting line. The hands were placed at the iliac crest not allowing using an arm swing. They had to perform three consecutive hops as far as possible at the chosen limb landing with the same one. Again, two practice trials and two test trials with the same leg were accomplished with a 2-min rest in between. The distance from the starting line to the point, where the back of the heel hit the ground upon completing the third jump was recorded with a standard tape measure perpendicular to the starting line. The trial was accepted if subjects were able to land in a stable position at the jumping leg and if hands did not lose contact to the iliac crest. The best performance was used for further analysis.

Y-Balance Test

The lower quarter Y-balance test uses an instrumented device for measuring three components (anterior, posteromedial and posterolateral direction) of the SEBT. It has got an intrarater reliability with ICC values ranging from 0.85 – 0.91 and an ICC for interrater reliability ranging from 0.99 – 1.00 (Plisky et al., 2006). It was designed to measure unilateral balance and neuromuscular control that are important requirements in nearly all types of sport (Plisky et al., 2006). The test was carried out only with the preferred leg as stance leg and without shoes. At the beginning, the participants´ length of the stance leg was measured in centimeters in a supine lying position from the anterior superior iliac spine to the most distal portion of the medial malleolus. Prior to formal testing participants were allowed to perform two test trial in each of the three reach directions to get familiar with testing procedure. Subjects were instructed to stand with the dominant leg on the center footplate with the great toe at the starting line. Then they were encouraged to push the reach indicator in the red target area with the free limb in the anterior, posteromedial and posterolateral direction as far as possible while maintaining single leg stance. After each trial, participants had to return to the starting position under control. The testing order was standardized using two trials in each direction allowing a rest of 15 s between reaches. The testing order of reaching distances was anterior, posteromedial and posterolateral in relation to the stance foot. The trial was discarded and repeated if the subject (1) failed to maintain single leg stance (e.g. touched down to the floor with the free limb or fell off the center plate with the stance foot), (2) failed to maintain reach foot contact with the red target area while the reach indicator was in motion (e.g. kicking the reach indicator), (3) used the reach indicator for support, or (4) did not maintain start and return position for one second. The best reach of each direction was used for further analysis. According to Plisky et al. (2006), a composite score was compiled to express reach distance as a percentage of limb length. The composite score was the sum of the three reach distances divided by three times limb length, and then multiplied by 100.

Stand and Reach Test

The flexibility of test persons was measured using the stand and reach test. It is a common, simple and fast test concept for measuring flexibility of hamstrings and the lower back. Reliability ($r = 0.88$-0.98) and objectivity ($r = 0.95$-0.98) of the stand and reach test meet the required scientific quality criteria (Fetz and Kornexl, 1993). The participants stood on a wooden box, feet together, with legs extended and toes touching the test panel. The participants were then encouraged to bend forward as far as possible touching the test panel with their fingers, holding the reached position for 2 s. The distance from the panel was recorded from a vertical scale in 0.5 cm. Data above the toe line were noted with a minus and data below with a plus. After performing two test trials, two measurements for each participant were taken, and the best value was used for further statistical analysis.

Statistical analyses

Data were pooled for males and females because there were comparatively few female participants. Normal distribution was determined by the Shapiro Wilk test. Two-way repeated-measures analyses of variance (ANOVA) (time x treatment) on variables of core strength endurance, muscle performance, balance and ROM were performed to determine treatment, time, and interaction (time x treatment) effects. In the case of an interaction effect, a one-way ANOVA over the delta values between pretest and posttest was performed with Tukey post-hoc procedures. In case of a main effect for time and/or interaction effect, paired sample t-tests for post hoc comparisons were applied. The level of significance was set at alpha < 0.05. In addition, the values obtained were evaluated by calculating the effect size Cohen's f classified as trivial (< 0.10), small (0.10 ≤ to <0.25), moderate (0.25 ≤ to < 0.40) or large (≥ 0.40). Data were reported as mean ± SD. All statistical analyses were carried out using SPSS 24.0 (SPSS Inc, Chicago, IL, USA) and Office Excel 2010 (Microsoft Corporation, Redmond, WA, USA) software.

Results

There were no differences in, anthropometric, age-related and baseline values between the three groups. Thirty-six participants completed the study with compliance >75% and no training-related injuries were reported. Four participants (3 females and 1 male) were incapable to take part in post-tests due to severe non-intervention related injury. Participants of both intervention groups (FOAM; CORE) trained 15 ± 1 times (range, 13-16 times) within the 8-wk period. The FOAM group reported a RPE value of 13 ± 2 in training period 1 (week 1-4) and an equal RPE of 13 ± 2 in period 2 (week 4-5). In the CORE group a RPE of 13 ± 2 in period 1 and a RPE of 15 ± 2 in period 2 were documented. RPE between groups were not statistically different neither in period 1 ($p = 0.654$) nor in period 2 ($p = 0.064$). Baseline and post-intervention values for all outcome variables are presented in Table 4.

Bourban Trunk Muscle Strength Test (TMS)

For the lateral TMS a main effect of time ($p < 0.001$) with no main effect for group and no interaction effect time x treatment was found. Improvements were found for FOAM ($p = 0.015$), CORE ($p = 0.002$) as well as for CG ($p = 0.002$). An interaction effect of time x treatment for the dorsal TMS test ($p = 0.043$) was found with an improvement in CORE ($p = 0.02$) compared with no changes in FOAM ($p = 0.625$) and CG ($p = 0.921$). The delta changes from baseline to post-intervention measurements are presented in Figure 2. For the ventral TMS a tendency towards a main effect of time ($p = 0.09$) with no main effect of group or time x treatment interaction were found.

Jump Performance and Balance

There were no main or interaction effects for the SLJ and the SLTH test. For the Y-balance test a main effect of time ($p = 0.019$) with no main effect for group and no interaction

Table 4. Overall effects of foam roll training (FOAM), core strength training (CORE), and the control group (CG) on outcome measurements (mean ± SD; 95% CI).

	FOAM (n=13)		CORE (n=11)		CG (n=12)		ANOVA (p-value, effect size f)		
	Pre	Post	Pre	Post	Pre	Post	Time	Group	Time x Group
Core Strength Endurance									
Ventral TMS test (s)	118 ± 39	128 ± 41	98 ± 38	112 ± 36	123 ± 37	126 ± 38	0.092 (0.30)	0.378 (0.25)	0.709 (0.15)
Lateral TMS test (s)	58 ± 20	76 ± 28 *	46 ± 13	65 ± 18*	66 ± 22	79 ± 28*	<0.001 (0.99)	0.188 (0.33)	0.696 (0.15)
Dorsal TMS test (s)	92 ± 20	89 ± 22	73 ± 8	92 ± 36*	88 ± 20	88 ± 31	0.150 (0.28)	0.708 (0.15)	0.043 (0.46)
Muscle Performance									
SLJ (cm)	155 ± 19	152 ± 22	172 ± 26	173 ± 29	159 ± 23	150 ± 24*	0.076 (0.31)	0.129 (0.36)	0.230 (0.31)
SLTH (cm)	472 ± 48	474 ± 62	516 ± 80	518 ± 84	474 ± 70	475 ± 75	0.696 (0.07)	0.270 (0.29)	0.997 (0.00)
Balance									
Y-Balance test (%)	106 ± 6	107 ± 6	104 ± 9	106 ± 7	105 ± 7	107 ± 8	0.019 (0.43)	0.926 (0.07)	0.758 (0.14)
ROM									
Stand and reach test (cm)	3.4 ± 8.8	7.3 ± 6.9*	6.4 ± 5.1	8.6 ± 5.1*	8.4 ± 5.6	9.0 ± 5.3	<0.001 (1.05)	0.405 (0.24)	0.005 (0.61)

TMS, Bourbon trunk muscle strength test; SLJ, standing long jump test; SLTH, single leg triple hop for distance test; * significantly different from pre-test to post-test within the group.

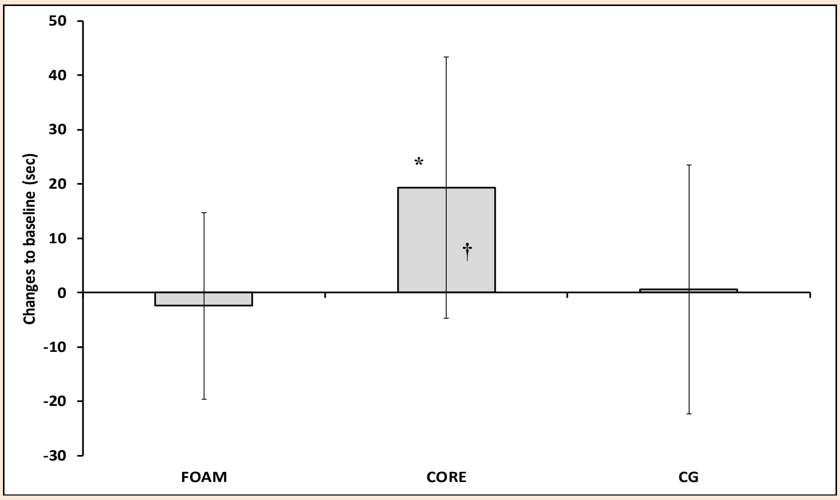

Figure 2. Delta changes (mean ± SD) in dorsal TMS from baseline to post-intervention measurements. * $p < 0.05$, significantly different between groups; † $p < 0.05$, significantly different from baseline levels within the group. FOAM = foam roll group; CORE = core stabilization group; CG = control group.

effect were found. However, no within subject effects were found (FOAM: p = 0.244; CORE: p = 0.156; CG: p = 0.161).

Stand and Reach Test

A significant main effect of time was found for the stand-and-reach test ($p < 0.001$). In addition, there was an interaction effect time x treatment (p = 0.005), demonstrating greater improvements in FOAM (p = 0.003) compared with CG, whereas no differences were found between FOAM and CORE (p = 0.218) and between CORE and CG (p = 0.217). Within groups, FOAM increased ROM by 3.8 ± 3.0 cm ($p < 0.001$), CORE by 2.3 ± 1.3 cm ($p < 0.001$), and no change in CG (0.7 ± 1.7, p = 0.213). The delta changes from baseline to post-intervention measurements are presented in Figure 3.

Discussion

The main findings of this study were that the training period of eight weeks with two training sessions per week (1) improved performance in the dorsal TMS test in the CORE group compared with no changes in FOAM and CG and (2) increased ROM in stand-and-reach test in the FOAM group compared with CG. Additionally, there were within group improvements in lateral TMS test in all groups and in the stand-and-reach test in the FOAM and CORE group as well.

Core "Strength Endurance"

There is evidence that poor core stability is related to a higher injury risk, and poor core strength endurance is associated with low back pain. However, there is little research on the efficacy of core strength training programs on explicit core strength endurance (Borghuis et al., 2008). The results of the current study indicate that core strength endurance only for the dorsal muscle chain is improved by the trunk stabilization exercises, but not by the FR program.

It is claimed that a training with the FR leads to an improved core stability because of the static effort that has to be done during FR (Lukas, 2012). To the best of our knowledge this is the first study that investigated the training effect of FR on core "strength endurance". Based on

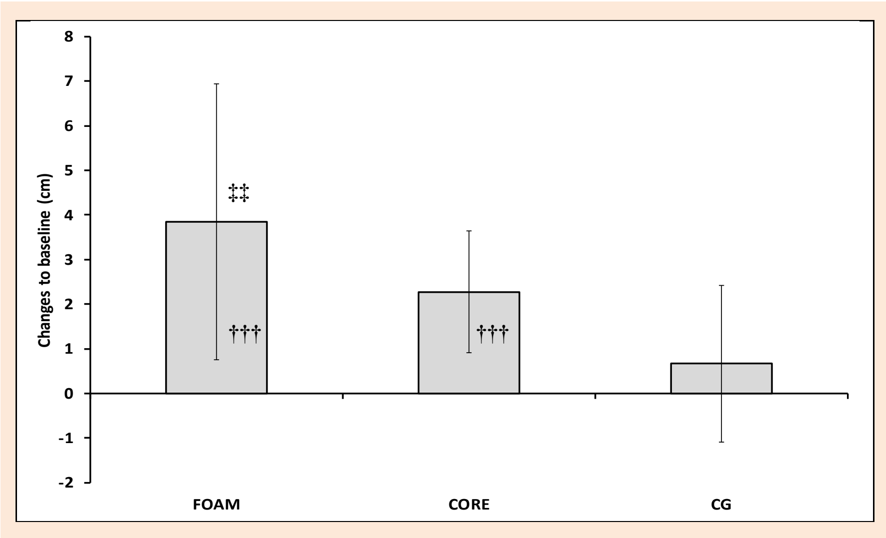

Figure 3. Delta changes (mean ± SD) in stand-and-reach performance from baseline to post-intervention measurements. ‡‡ $p < 0.01$, significantly different to CG; ††† $p < 0.001$, significantly different from baseline levels within the group. FOAM = foam roll group; CORE = core stabilization group; CG = control group

the results of the current study, this assumption has to be rejected but it is to mention that FR did not decrease core "strength endurance" of ventral, lateral and dorsal muscle chain. Admittedly, FR in the current study applied similar positions to the core stabilization exercises but the exercises done by the CORE group were superior in improving the trunk muscle endurance.

Granacher et al. (2014) investigated the effect of core strength training using stable versus unstable surfaces on trunk muscle endurance in adolescents. They demonstrated that both groups significantly increased performance in the TMS for the ventral and the lateral left chain following a 6-week core strength training with two training sessions per week. In the study by Granacher et al. (2014) no CG was used. In the present study, all three groups improved performance in the lateral TMS test concluding a learning effect. However, in the dorsal TMS test the CORE group performed better than FOAM and CG. In contrast to the study of Granacher et al. (2014), recreationally active adults were examined. In the study by Riegler and Stöggl (2014), core strength training with a sling trainer (unstable surface) was compared to trunk stabilization exercises on the floor (stable surface) in athletes. They found that a 6-week training intervention (two sessions per week) with a sling trainer was more effective in improving performance in the TMS than trunk stabilization exercises on the floor which in turn is a little bit different to the findings of Granacher et al. (2014) where both groups improved. This leads to the conclusion that the effect of trunk stabilization exercises on core "strength endurance" remains still unclear.

Muscle Performance

In the current study, it was demonstrated that neither FR nor CORE had any effects on SLJ or SLTH performance. This is comparable with the results of the study by Hodgson et al. (2018) revealing no training effects of a 4-week roller massage training on jump performance and quadriceps and hamstrings strength. Several studies regarding acute effects of FR on performance are in accordance with the findings of the present study. In the study by Healey et al. (2014), no acute effects of FR or planking exercises on performance (vertical jump height and power, isometric squat force and agility) were found. Similarly, MacDonald et al. (2013) determined no acute effect after FR on maximum voluntary contraction force, evoked force and activation of the quadriceps. In a study by Sullivan et al. (2013), a stick roller massager for self-myofascial release was used instead of a FR. Analogous to above, no influence of the roller massage on maximum voluntary contraction force and electromyography muscle activation of the hamstrings was found.

However, in discrepancy to the studies above, acute effects of self-myofascial release on muscle performance are documented. Halperin et al. (2014) conducted a study on the acute effects of self-myofascial training with a roller massager and static stretching on maximum voluntary contraction force and electromyography of calf muscles. They demonstrated an increased maximal force output 10 min post roller massaging relative to static stretching. As opposed to this, Fama and Bueti (2011) compared a dynamic warm-up protocol to FR on bilateral depth jump, countermovement jump and squat jump performance and revealed an acute detrimental effect of FR on countermovement jump performance.

Due to the variety of applied methodologies, it is difficult to pinpoint the exact mechanisms explaining the differences in outcome measurements. However, results from the majority of studies – including the current study - suggest that self-myofascial release with the FR or the roller massager has no and at most small effects on muscle performance. All studies but one point out that FR has no detrimental effect on muscle performance.

The literature, concerning the effects of a core stability intervention on lower leg performance, is conflicting. In a meta-analysis by Behm et al. (2015) strength training on unstable surfaces was shown to be effective in improving parameters of muscle strength, as well as power and balance. However, training on unstable surfaces like the FR was not superior to conventional training on stable surfaces. Imai et al. (2014) reported a significant increase in the rebound jump and vertical jump after a 12-week core stability training. Similar to our study, Steffen et al. (2008) found no effect of a mixed ten-week injury prevention program consisting of core stability, balance, dynamic stabilization and eccentric hamstring exercises on lower extremity strength in adolescent female soccer players. In addition, no improvements were determined in jumping ability, 40-m sprint and shooting distance. Many athletic training programs include core training, but in most cases it is not the sole component making it difficult to isolate direct effects of core training on muscle performance (Reed et al., 2012). Therefore, it is necessary to conduct further research on the effects of core stability and strength on muscle performance.

Balance

There were no effects of the interventions either of FOAM or of CORE on dynamic balance. This finding is in agreement with Halperin et al. (2014), who reported no acute effect of self-myofascial release with a roller-stick on static balance measured with the stork single limb balance test. To the best of our knowledge, the present study is the first to examine the training effects of FR on dynamic balance. Hence, more studies are needed to confirm the results of FR on balance of the current study.

As regards, the effects of core strength training on dynamic balance, our results are in contrast to the existing literature. There is evidence, that a core strength training improves dynamic balance of healthy participants in the SEBT and Y-Balance test (Filipa et al., 2012; Granacher et al., 2014; Imai et al., 2014). The main difference lies in the fact that the training interventions were supervised in all above-mentioned studies. In the present study, a home-based FOAM and CORE intervention was applied consciously because the FR is a tool designed for SMR without the help or supervision of a trainer or therapist.

Range of Motion

The results of the current study revealed a difference in improvement of ROM between FOAM and CG. No differences were found between FOAM and CORE as well as for CORE and CG. This result is similar to findings of other studies regarding the training effects of FR on ROM. Junker and Stöggl (2015) demonstrated that a 4-week FR training as well as a CRPNF stretching yield to an improvement of ROM in the stand and reach test compared with a control group. The changes in flexibility in the FR group were even comparable with those observed in the CRPNF that is a common and effective method to increase ROM (Page, 2012). In a study by Sherer (2013), FR was shown to be more effective in increasing flexibility in the sit and reach test after a 4-week training than a control group. However, Hodgson et al. (2018) did not find any changes in active, as well as passive hamstrings and quadriceps ROM following a 4-week roller massage training. Their participants used a stick roller to massage their muscles and in contrast to the present study, the roller massage was performed only for the dominant thigh muscles and not bilaterally for the complete lower limb.

An alteration in stretch tolerance is discussed to be an important factor explaining the increase in ROM by FR (Beardsley and Skarabot, 2015). In the review by Weppler and Magnusson (2010), it was pointed out that an increased tolerance to stretching and not an increased muscle length is the reason for an improved flexibility following either acute or chronic bouts of static stretching. The pain relieving effects of manual therapies using pressure to affect the musculature as in myofascial release techniques (Bialosky et al., 2010) are considered to be responsible for the increased stretch tolerance (Beardsley and Skarabot, 2015). Both, Vaughan et al. (2014) and Cheatham et al. (2017) reported a short-term increase in pressure pain threshold following a FR intervention. Interestingly, following a roller massage application of the contralateral side, an increase in pressure pain threshold in myofascial tender spots (Aboodarda et al., 2015) and a diminished evoked pain (Cavanaugh et al., 2017) was demonstrated. The authors suggest that these non-localized effects of pressure stimulation are attributed to central nervous system modulation or psycho-physiological mechanisms rather than a biomechanical release of adhesions in soft-tissue.

Within-groups, there was a significant increase of ROM in the CORE group as well. In a study by Moreside and McGill (2012) the effects of three different exercise interventions (stretching, stretching with motor control exercises for the hip and trunk, core endurance and motor control exercises) plus a control group on hip ROM was investigated. Interestingly, after a 6-week home exercise program they observed improvements in hip ROM not only in the stretching groups. There was also an increase in hip rotation ROM in the group receiving core endurance and motor control exercises with no stretching. In the case of poor core stability the nervous system limits joint motion to protect tissues from getting injured and tightness of tissues emerges (Oberst, 2013). Vice versa, a better core stability and with it an improved proprioceptive and kinesthetic awareness lead to a better mobility and is a plausible explanation of this finding.

Limitations

Though test trials took place after 5 PM, it was not possible to standardize the daily routine of participants so that fatigue might have influenced the test performance. A home-based FR and CORE intervention was applied and treatments were not supervised. It might be speculated that a supervised intervention protocol would have revealed more significant results, however Cheatham et al. (2017) investigated a similar increase in knee flexion ROM and pressure pain threshold following a live-instructed, a video-guided, and a self-guided FR intervention. Due to a lack of female participants, data were pooled for males and females. Perhaps, there are gender differences, which cannot be elucidated by this study. Both hamstring flexibility and lower back flexibility influence the stand-and-reach test. However, in this study, only hamstring muscles were considered.

Conclusion

The purpose of this study was to examine the clinical effectiveness of FR on core “strength endurance”, muscle performance, balance and ROM and to compare it with core stabilization training (CORE) and a control group (CG). In summary, the study demonstrates that FR can be applied as an effective technique for increasing ROM in the stand and reach test within an 8-week training period without a concomitant decrease in core “strength endurance”, balance and jumping ability. In comparison with CORE, no differences were revealed except of dorsal TMS. CORE significantly improved performance in dorsal TMS compared with FOAM and CG.

The exact mechanisms of FR still remain unclear, and future studies are needed to investigate this issue further. Furthermore, it seems to be recommendable to conduct further research on various training parameters of FR (training period, sessions per week, training time, and sets) to reveal the most effective FR training protocol. With different training parameters, there might be effects of FR not only on ROM, but also on core strength, balance and muscle performance.

Acknowledgements

The authors would like to thank the participants for their participation, enthusiasm, and cooperation. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The experiments comply with the current laws of the country in which they were performed. The authors have no conflicts of interests to declare.

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Key points

- Eight weeks of core-stability training two times per week improved dorsal trunk strength with no changes in a foam rolling group or the control.
- Hamstring flexibility was improved both by an eight-weeks core-strength and foam rolling training interventions.-
- Neither foam rolling nor core-strength training had an effect on muscle performance (horizontal jump performance) and balance
- Both foam rolling and core-strength training demonstrated no detrimental effects on performance and balance.

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