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Research article

Foam Rolling and Joint Distraction with Elastic Band Training Performed for 5-7 Weeks Respectively Improve Lower Limb Flexibility

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Abstract

Both foam rolling and joint distraction training with elastic bands are very popular interventions designed to improve muscular function, motor performance, and joint range of motion, as well as to reduce feeling of fatigue and delayed onset of muscle soreness. The heterogeneity of methods used among studies however prevents from drawing firm conclusions about the optimal content of pre/post interventions. The present study aims at answering the following questions: *i)* Do foam rolling and joint distraction with elastic band training improve joint range of motion in national rugby players? *ii)* Do short and long rolling durations have similar effects on range of motion? In a first experiment, we compared ankle, knee, and hip flexibility scores in 30 national rugby players after a 7-week foam rolling training program involving either a short (20s) or long (40s) rolling duration. Data revealed that foam rolling substantially improved all range of motion scores, regardless the rolling duration (performance gains ranged from 9 to 18° in the foam rolling groups, i.e. 8 to 20% increase, but remained under 2° in the control group). In a second experiment, we investigated the effect of a 5-week joint distraction with elastic band training program on hamstring and adductor range of motion in 23 national rugby players. Data showed that elastic band training significantly improved sit-and-reach (29.16% increase, $p = 0.01$) as well as side split (2.31% increase, $p < 0.001$) stretching performances. Taken together, present findings confirm that both foam rolling and joint distraction exercises with elastic bands are likely to enhance joint range of motion and specific mobility patterns during sport performance, and further serve prophylaxis. Such effects therefore constitute a promising avenue for clinical, home therapy, and personal flexibility training.

Key words: Self-myofascial release, elastic resistance training, range of motion, motor performance, functional mobility, stretching.

Introduction

Developing flexibility by improving both active and passive range of motion (ROM) is crucial in many sporting activities. Static, ballistic and dynamic stretching as well as proprioceptive neuromuscular facilitation are relevant methods to increase ROM (Behm and Chaouachi, 2011; Behm et al., 2016; Kay and Blazevich, 2012; Page, 2012). Static stretching is one of the most widely used method, due to its simplicity and low risks of tissue trauma (Alter, 1988; Roberts and Wilson, 1999; Sady et al., 1982). Alternative techniques have been recently investigated. Among them, foam rolling (FR) through foam roller or roller massager became a very popular method to improve functional mobility and ROM (for an extensive review, see Cheatham et al., 2015). Likewise, variable resistance training using elastic bands may contribute to assist stretching techniques and improve flexibility by facilitating joint distraction and decoaptation, hence allowing the joint surfaces to gap away from one another (Page and Ellenbecker, 2003; Rosengart, 2013).

FR is believed to positively affect fibrous adhesions in the fascia, and to restore muscles, tendons, ligaments, fascia, and soft-tissue extensibility. Although he did not directly study the effect of FR, Barnes (1977) provided a theoretical framework for the possibility of affecting fibrous adhesions, while Schleip (2003) reported that supra-physiological forces are needed to break-up fascial adhesions. Cheatham et al. (2015) extensively described the impact of FR on the properties of the fascia (e.g., alteration of the viscoelastic and thixotropic properties), and how it contributed to increase the intramuscular temperature and blood flow. FR also results in reduced arterial stiffness and improved vascular endothelial function (Okamoto et al. 2014). The vast majority of experimental research revealed that FR may offer different kinds of benefits in terms of motor performance, flexibility and recovery (for reviews, see (Beardsley and Škarabot, 2015; Cheatham et al., 2015; Schroeder and Best, 2015; Kalichman and Ben David, 2017; Mauntel and Padua, 2014). Two studies even demonstrated that rolling the contralateral limb contributed to significant decreases in pain in the affected limb (Aboodarda et al., 2015; Cavanaugh et al., 2016). More generally, prophylactic effects of FR have been reported, due to its effect on the connective tissue and local blood flow. FR was found to attenuate the decrease in muscle performance, and both reduce and delay muscle soreness (Aboodarda et al., 2015; Cheatham et al., 2015; Jay et al. 2014; MacDonald et al., 2014; Pearcey et al., 2015; Schroeder and Best, 2015; Romero-Moraleda et al., 2017). Experimental studies did not report, in contrast, clear effects of FR when performed prior to motor performance. While it may not be harmful for subsequent performance, FR was not found to positively impact performance gains such as strength, power, jump, or shuttle run tasks (Fama and Bueti, 2011; Halperin et al., 2014; Healey et al., 2014; Jones et al. 2015; Mikesky et al., 2002; Peacock et al. 2015, but see the recent study by Romero-Moraleda et al., 2017 for positive effects of FR on strength). Interestingly, and despite some conflicting results (Couture et al., 2015), FR has been found to substantially increase ROM of the hip (Behara and Jacobson, 2015; Bushell et al., 2015; De Souza et al., 2017; Mohr et al., 2014; Monteiro et al. 2017), knee (Button and Behm,

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2014; Bradbury-Squires et al., 2015; MacDonald et al., 2013, 2014; MacDonald et al., 2013; 2014; Vigotsky et al., 2015), and ankle (De Souza et al., 2017; Halperin et al., 2014; Škarabot et al., 2015), without hampering muscle performance (see Halperin et al., 2014). Similar findings were reported for the sit and reach test (Sullivan et al., 2013; Pearcey et al., 2015). As both FR and stretching are likely to improve ROM, combining these two types of practice may result in greater performance gains (MacDonald et al., 2014; Roylance et al., 2013; Škarabot et al., 2015). Altogether, these data support the benefits of FR for enhancing joint ROM (Cheatham et al., 2015). While some studies compared the effectiveness of different types of roller (during either pre or post-exercise), as well as the nature and the duration of the massage pressure (Cheatham et al., 2015; Curran et al. 2008; Debruyne et al., 2017; De Souza et al., 2017; Monteiro et al., 2017), the effects of a longer FR intervention targeting several muscles on ROM, throughout several training sessions, has received little attention. Junker and Stöggl (2015) investigated the effectiveness of a 4-week training with the foam roll method on hamstring flexibility. They provided evidence that FR is effective to improve range of motion, such beneficial effects being comparable with those provided by the well-known contract-relax proprioceptive neuromuscular facilitation stretching method. There is a lack of unanimity in the literature, however, as a recent study by Hodgson et al. (2018) did not show improved flexibility after 4 weeks of rolling. Spurred by the positive findings and due to the conflict in the scientific literature, further experimental data looking at the long-term effects of FR are required to confirm the benefits of FR on the thixotropic properties of the muscle (Axelson and Hagbarth, 2001), with long-term effects which may arise from decreasing tissue adhesion (McHugh et al., 2012), and improving fascia elasticity (Wilke et al., 2016).

Joint distraction with elastic bands training (EBT) is another emerging and cost-effective component of strength and conditioning programs. Traditionally, this method has been used for strengthening muscle and improving power and velocity (Jakobsen et al., 2013; Joy et al., 2016; Jakubiak and Saunders, 2008; Rhea et al., 2009; Smith et al., 2011; Treiber et al., 1998). As well, EBT has been found to enhance jumping and sprinting performance, hence providing an alternative training method as a part of plyometric programs (Argus et al., 2011; Janot et al., 2013) or during warm-up (Wyland et al., 2015). Soria-Gila et al. (2015) reported that EBT might even result in greater strength gains than conventional weight training, while Park et al. (2015) illustrated its benefits to improve endurance, balance, agility and quality of life in elderly persons (see also Oesen et al., 2015, but Vinstrup et al., 2016, for challenging results). Another promising effect of EBT is that it may facilitate the effectiveness of motor recovery by maximizing strength gains in injured athletes while being less boring than conventional stretching, and therefore more likely to be adhered to (Lorentz, 2014). Surprisingly, very few studies investigated the effect of EBT on flexibility, although its properties make it ideal for providing load during stretching exercises (Carrio, 2012; Donatelli and McMahon, 1997; Page and Ellenbecker, 2003). Practically, joint distraction exercises might be incorporated during stretching routines in order to create more space in the joint complex (Rosengart, 2013). During joint distraction, elastic bands act as wedges to separate the joint surfaces from one another (Rosengart, 2013), hence presumably providing more space for synovial fluid to fill the joint and reduce the amount of friction (Bourneton, 1981; Le Roux and Dupas, 1995). Another advantage is that the resistance can be individually adjusted to the tolerance of the person. Joint distraction using elastic bands might thus be used not only to assist static stretching, but also active and dynamic stretching. Including elastic band training in a specific experimental protocol designed to improve flexibility appeared an original approach which has been quite neglected in the literature, with the advantage of providing an individualized form of practice with a constant traction. In addition, due to its self-adjusting nature, elastic band exercises allow participants to apply a closed-loop motor control to promote and reinforce joint distraction before performing the stretching routine.

The present study included two experiments designed to respectively investigate the effectiveness of FR and EBT on range of motion in national rugby players. In contrast to the majority of experimental studies looking at the immediate and short term effects on functional performance, we tested the effect of a 7-week training program on the performance of several stretching exercises. We hypothesized that both FR and EBT would contribute to improve joint flexibility and facilitate stretching processes.

Table 1. **Anthropometric characteristics of the participants.**

	Size (m)	Mass (kg)	Body fat percentage
Exp. 1	1.79 (±.06)	87.5 (±11.2)	15.6 (±6.4)
	1.81 (±.07)	88.6 (±15.4)	16.3 (±8.6)
Exp. 2	1.78 (±.09)	89.7 (±17.6)	17 (±5.3)
	1.80 (±.08)	88.3 (±14.5)	14.6 (±7.8)

Methods

Participants

Thirty professional national-level male rugby players (M = 18.85 years, SD = 1.10 years) voluntarily participated in Experiment 1. Twenty-three professional national-level male rugby players (M = 17.22 years, SD = 0.60 years) were recruited for Experiment 2, which was performed 1 month after Experiment 1. None of the participants were enrolled in both experiments, so that all players were selected from different Rugby teams. Anthropometric characteristics of the participants are displayed in Table 1. Players provided written and informed consent in agreement with the terms of the Declaration of Helsinki (1982). Prior ethical approval was granted by the Research Ethics Committee of the Center of Research and Innovation in Sport (University Claude Bernard Lyon 1). Any foam rolling training was suspended for 72 h prior to each experiment, and participants were requested to not practice outside of the supervised sessions until completion of the experimental procedure. Participants were not enrolled if they had suffered from any traumatic injury requiring a healing rest-period during the month preceding the experiments. None of the participants was injured during the experimental interventions.

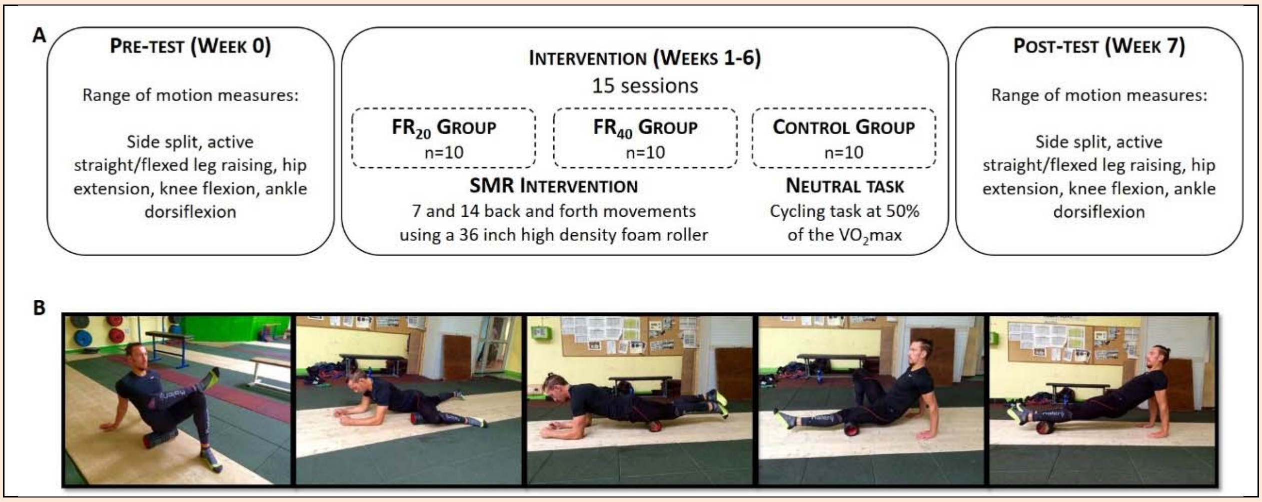

Figure 1. Flow-Chart of the experimental design (Panel A) and foam rolling procedures for each muscle (Panel B). FR = Foam Rolling.

Experimental designs

Experiment 1

The test-retest study spanned over a 7-week period and consisted in a pre-test (Week 0), a FR intervention including 15 rolling sessions (Weeks 1-6), and a post-test (Week 7, Figure 1). Participants were randomly assigned to one of three groups (n = 10 in each group) that differed in the activities to be performed during the FR intervention (Figure 1). Two experimental groups were subjected to supervised FR sessions. The FR_{40} group foam rolled each target muscle during 40s, while the FR_{20} group foam rolled muscles during 20s, and then had rest for the remaining time. A third CONTROL group did not perform any kind of FR, but only a neutral activity during an equivalent amount of time (i.e., active constant low-intensity cycling task, at 50% of the VO_2, controlling the engagement in a self-regulated form of practice involving the lower limbs). All groups therefore spent similar total time in the presence of the experimenter. To ensure participants' blindness, participants from the CONTROL group were planned to benefit from each experimental procedure later in the season, while the experimental groups would be subjected to the active constant low-intensity cycling task during equivalent time.

Pre- and post-test sessions included different ROM measures performed by a physical therapist blinded to which intervention the participant was randomized to. Data were collected with an electronic goniometer (MLTS700, AD Instruments, Sydney, NSW, Australia) after a brief standardized and controlled warm-up (3 min home trainer cycling at moderate intensity, 10 squats and lunges without resistance, 3 countermovement jumps and 3 squat jumps, 10 sprints of 10 m), during the following exercises, which were administered in a randomized order: side split, hip flexion (both active straight leg raising and active flexed leg raising), hip extension, knee flexion, and ankle dorsiflexion. Although rugby performance does not require a high level of flexibility, improving joint flexibility during standardized split exercises or sit and reach test seems relevant to adopt a prophylactic approach. All participants were scheduled at the same time for testing, unilateral measures being subsequently collected in both sides (except for the side split). For the side split, participants laid on their back with legs straight up the wall, and let legs draw apart up to the maximal amplitude, with feet sliding down the wall. The axis of the goniometer was placed on the midline of the pelvis, the stationary and moving arms being aligned with the internal condyles. Hip flexion was measured from the supine position. For the active straight leg raising, participants performed a straight leg raise up to the maximal amplitude, and then maintained the final position (Göeken and Hof, 1991; Cho et al., 2015). The axis of the goniometer was on the grand trochanter, the stationary arm was aligned with the lateral malleolus of the opposite leg, and the moving arm was aligned with the lateral epicondyle of the femur (usual men reference values based on the position of the goniometer = 90°). For the active flexed leg raising, the hip, with the knee flexed, was progressively flexed up to the chest (Harvey, 1998; Su et al., 2017). The axis of the goniometer was on the lateral epicondyle of the femur, the stationary arm was aligned with the grand trochanter and the moving arm was aligned with the lateral malleolus (usual men reference values based on the position of the goniometer = 0° to 130°). These two measures of hip flexion were selected as they were likely to provide complementary information about hip mobility by targeting different muscles and, therefore, both passive and dynamic hip flexibility. Hip extension and knee flexion were collected from the modified Thomas test position, participants lying supine at the edge of an examination table and holding the uninvolved knee flexed to the chest. This test is frequently used by rugby practitioners. For the hip extension, particular attention was paid to control the pelvic tilt (Vigotsky et al., 2016). The axis of the goniometer was placed on the grand trochanter, the stationary arm was aligned with the midline of the pelvis and the moving arm with the lateral epicondyle of the femur (usual men reference values based on the position of the goniometer = 180° to 170°). For measuring the knee flexion, the axis of the goniometer was on the lateral epicondyle of the femur, the stationary arm was aligned with the grand trochanter and the moving arm was aligned with the lateral malleolus. Finally, active ankle dorsiflexion was measured from the weight-bearing lunge test position (Bennell et al., 1998; Kelly and Beardsley, 2016). Participants stood with their foot approximately 10 cm back, perpendicular to the wall. They were then instructed to look forward and to flex their knee until it reached the wall. The knee was to touch the wall, travel over the mid-line of the foot and the heel was to stay firmly on the ground. Participants were asked to slide their foot forward or back depending whether their knee failed or successfully touched the wall, and prevent any elevation of the heel. The axis of the goniometer was placed on the lateral malleolus, the stationary arm was aligned with the fibular head and the moving arm was aligned with the fifth metatarsal. In each case, the mean of three consecutive measures performed by the same experimenter was considered (usual men reference values based on the position of the goniometer = 90° to 50°).

The FR intervention was self-administered by the participants under the direct supervision of the same experimenter, throughout the experimental design. A similar 91 cm high-density (51 $kg.m^3$) foam roller was used by each athlete. Five muscles were successively foam-rolled on both right and left sides, separately (hip extensors, hip adductors, knee extensors, knee flexors and plantar flexors). The protocol consisted of one bout for each muscle, participants rolling back and forth between insertions. For each muscle, participants from the FR_{20} and FR_{40} respectively performed 7 and 14 back and forth movements (i.e. each back and forth movement did not exceed 3s). FR procedures are summarized in Figure 1. For the hip extensor, participants sat on the floor and placed the foam roller on the top of the muscle, the other leg and the hands supporting the body during the back and forth movement. To roll out the hip adductor, participants lied face down to the ground, resting on the forearms, and placed the roller under the side of the knee flexed out of a side at 90°. They then moved back and forth the roller up to the inner thigh. For the knee extensor, participants also lied face down on the floor resting on the forearms, with the foam roller at the top of their quadriceps, and foam rolled from the top to the bottom, above the patella. To foam roll the knee flexor, participants rolled from the ischial tuberosity to the back of the knee. Hands were set on the floor without moving, and participants shifted their body back and forth, guiding the movement with the contralateral leg. Finally, for the plantar flexor, participants sat on the floor with the foam roller placed below the knee joint, and rolled back and forth to the ankle joint.

Overall, participants were requested to support their body weight with the arms and the other leg during the FR protocol. While the pressure applied on the tissue was not directly controlled, participants were asked to carefully apply pressure on the targeted muscle group during FR. Pain and comfort were managed by the participants during each exercise. Subjective reports delivered by the participants did not reveal discomfort o the target muscle or other place. In particular, they did not feel that the arms were overloaded while supporting the body weight during the exercises.

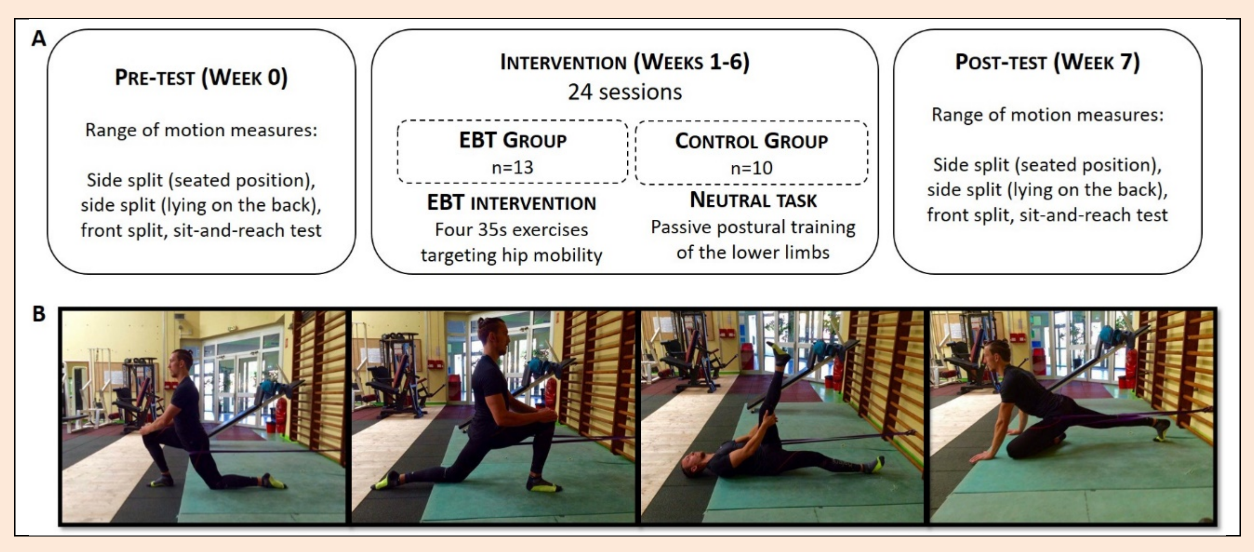

Figure 2. Flow-chart of the experimental design (Panel A) and joint distraction with elastic bands training procedures for each muscle (Panel B). EBT= Elastic Band Training.

Experiment 2

The test-retest study spanned over a 5-week period and consisted of a pre-test (Week 0), a variable resistance training including 24 sessions of elastic band exercises (Weeks 1-4), and a post-test (Week 5). Participants were randomly assigned to an experimental (n = 13) or a CONTROL group (n = 10) that differed in the activities to be performed during the intervention. The experimental group used elastic band resistance to assist four active exercises for the mobility of the hip (24 sessions). EBT was self-administered by the participants under the direct supervision of the experimenter, throughout the experimental design. EBT exercises were performed on each side for 35 s (Figure 2). The traction exerted by the elastic band (tension of 18 ± 2

Kg) should remain in a predetermined comfort range, without eliciting pain. Participants were orally asked about their comfort as soon as they reached the targeted position for each exercise. For the first exercise, participants lunged forwards with the front leg at a right angle, and the back knee to foot along the ground. Elastic resistance was applied on the back leg, below the gluteus maximus, in order to tract the femoral head backward. The second exercise started from the same lunge position, but the elastic resistance was applied on the back leg, below the gluteus maximus, in order to tract the femoral head forward. In the third exercise, participants lied on their back on the floor and extended the leg out straight with the toes pointing up. The elastic resistance was applied in order to tract the femoral head backward. Finally, for the last exercise, participants flexed their front leg at 90° and straightened their back leg behind. The elastic resistance was again applied below the gluteus maximus in order to tract the femoral head backward. Before the beginning of the experimental procedure, the experimenter checked that all participants were able to spend less than 40s to appropriately place the elastic bands, using a video tutorial, and, if needed, instructor assistance. The experimenter subjectively reported a low inter-individual variability in terms of preparation time for the exercises. The Control group performed a neutral activity, i.e. adopting a passive postural training of the lower limbs without any elastic band resistance, during an equivalent amount of time. Each group therefore spent similar total time to practice in the presence of the experimenter. As in Experiment 1, participants' blindness was controlled as the experimental procedure was integrated into a large training protocol including several periods of specific practice. Specifically, players from the control group were likely to benefit from the experimental procedure later in the season, while participants from the experimental group would be subjected to the passive postural training during equivalent time.

Pre- and post-test sessions included different ROM measures performed by a physical therapist blinded as to group allocation. Data were collected after the same standardized and controlled warm-up than Experiment 1, during the following exercises: side split from a seated position, side split lying on the back against a wall, front split and the sit-and-reach test. All testing measures were scheduled at the same time of the day to avoid circadian influences. For the seated side split, participants sat on the floor, opened their straight lean, and stretched their body forward between their legs, up to the maximal amplitude with a straight back. The side split against a wall was performed while lying on the back, with feet sliding down the wall. Flexibility score for the two side split exercises was evaluated through the distance between the two internal malleolus, legs being separated to the maximum. For the front split, participants stood on the floor while extending the front leg forward and keeping the back straight. Range of motion was determined by the distance between the ischial tuberosity of the front leg and the floor. Finally, the flexibility of hamstrings muscles was evaluated with the sit and reach test. Participants seated on the floor and reached towards the toes as far as possible. Flexibility score was recorded to the nearest centimeter from the distance above (negative) or past (positive) the toes.

Statistical analysis

We used R (R Core team, 2015) to perform a parametric analysis of the dependent variables of interest (i.e., ROM of the target muscles for Experiment 1, metric measures of stretch performance for the seated, side and front splits, as well as for the sit-and-reach test for Experiment 2). Visual inspection of Q-Q plots did not reveal any obvious deviations from normality for both experiments. In Experiment 1, we used a two-way analysis of variance with repeated measures testing the effect of Group (FR_{40}, FR_{20} and Control) and Test (Pretest, Posttest) on ROM measures. In Experiment 2, we carried on a two-way analysis of variance with repeated measures to test the effect of Group (EBT, Control) and Test (Pretest, Posttest) on the stretching performance. The statistical significance threshold was settled for a type 1 error rate of 5%. As measure of effect size, we calculated and reported the partial eta-squared. As post-hoc investigations, we used Student's t-tests for paired and independent samples and applied Holm's sequential corrections to control the false discovery rate (Holm, 1979).

Results

Experiment 1

Data revealed a significant Group × Test interaction for the side split ($F_{(2, 54)}=3.56$, $\eta^2p = 0.13$, $p = 0.03$), the active flexion of the right and left hips ($F_{(2, 54)} = 4.59$, $\eta^2p = 0.17$, $p = 0.01$, and $F_{(2, 54)} = 3.23$, $\eta^2p = 0.12$, $p = 0.04$, respectively), the passive flexion of the right and left hips ($F_{(2, 54)} = 5.31$, $\eta^2p = 0.20$, $p = 0.007$, and $F_{(2, 54)}=3.60$, $\eta^2p = 0.13$, $p = 0.03$, respectively), as well as the extension of the right and left hips ($F_{(2, 54)} = 10.63$, $\eta^2p = 0.39$, $p < 0.001$, and $F_{(2, 54)}=9.68$, $\eta^2p = 0.36$, $p < 0.001$). No interaction was found for the flexion of the right and left knees ($F_{(2, 54)} = 0.63$, $\eta^2p = 0.02$, $p = 0.53$, and $F_{(2, 54)} = 0.77$, $\eta^2p = 0.02$, $p = 0.46$), and the active dorsiflexion of both right and left ankles ($F_{(2, 54)} = 0.41$, $\eta^2p = 0.01$, $p = 0.66$, and $F_{(2, 54)} = 0.56$, $\eta^2p = 0.02$, $p = 0.57$).

Post-hoc tests yielded no statistically significant difference during the pre-test between FR_{40} and FR_{20} and Control groups for all dependent variables of interest (all $p > 0.05$, Figure 4). Interestingly, both FR_{40} and FR_{20} groups improved their performance from the pre- to the post-test, and significantly outperformed the Control group for the side split, hip flexion (active straight and flexed leg raising), and the hip extension (Figures 3 and 4, Tables 2 and 3). For the side split, performance improved by 17.70° in the FR_{20} group ($t = 3.6$, $CL_{95\%} = [-28.04 / -7.36]$, $p = 0.002$; i.e., +16.25% relative to the pretest values) and 18.00° (i.e., +16.53%) in the FR_{40} group ($t = 3.22$, $CL_{95\%} = [-29.82 / -6.18]$, $p = 0.005$), while ROM did not change in the CTRL group (+1.80°, $t = 0.43$, $CL_{95\%} = [-10.54 / 6.94]$, $p = 0.67$). For the right and left active straight leg raising, the FR_{20} group respectively improved performance by 14.00° ($t = 3.35$, $CL_{95\%} = [-22.89 / -5.11]$, +18.56%, $p = 0.004$) and 9.20° ($t = 1.95$, $CL_{95\%} = [-19.10 / -0.70]$, +12.16%, $p = 0.06$).

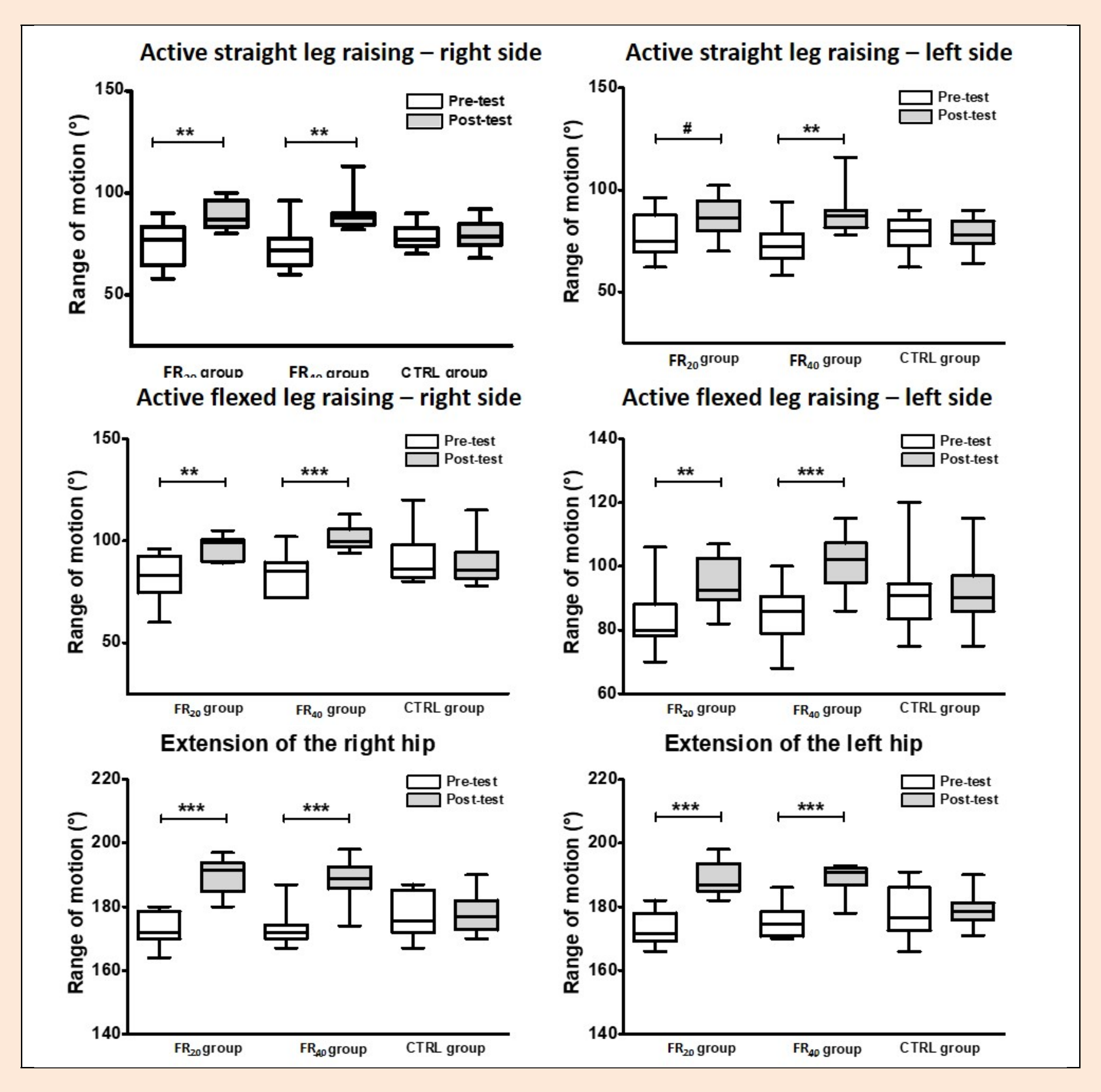

Figure 4. Range of motion before and after the foam rolling intervention. The figure shows the median and quartile values. Only significant differences in ROM between the pretest and the post-test are displayed. # p = 0.06, * p < 0.05, ** p < 0.01, *** p < 0.001.

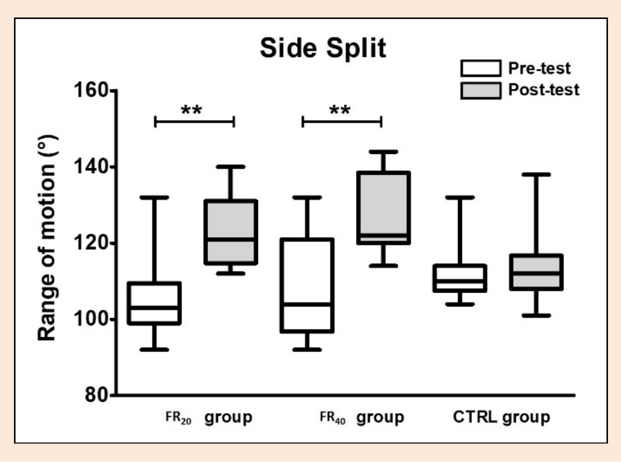

Figure 3. Side split performance measures before and after the foam rolling intervention. The figure shows the median and quartile values. The initial level of performance was comparable in the three groups. Only significant gains in ROM observed during post-hoc tests are displayed. **=p<0.01.

As well, the FR$_{40}$ group improved performance by 6.20° for the right side (t=3.57, CL$_{95\%}$=[-25.77 / -6.63], +8.21% p=0.002) and 15.70° for the left side (t = 3.42, CL$_{95\%}$ = [-25.34 / -6.06], +20.58%, p = 0.003), whereas no change in performance was observed for the CONTROL group (+0.60° for the right side and +0.10° for the left side, t = 0.21, CL$_{95\%}$ = [-6.75 / 5.55], p = 0.84, and t = 0.03, CL$_{95\%}$ = [-7.92 / 7.72], p = 0.98, respectively). For the active flexed leg raising, the FR$_{20}$ group respectively improved performance by 14.20° for the right side (t = 3.51, CL$_{95\%}$ = [-22.93 / -5.47], +16.55%, p = 0.004) and 11.50° for the left side (t = 2.79, CL$_{95\%}$ = [-20.20 / -2.80], +12.93%, p = 0.01). As well, the FR$_{40}$ group improved performance by 16.90° cm for the right side (t = 4.35, CL$_{95\%}$ = [-25.22 / -8.58], +19.69%, p < 0.001) and 16.40° for the left side (t = 4.09, CL$_{95\%}$ = [-24.83 / -7.97], +18.94%, p < 0.001), while no difference was found when comparing data from the CONTROL group (-1.80° for the right side and -0.10° for the left side, t = 0.35, CL$_{95\%}$ = [-8.96 / 12.56], p = 0.73, and t = 0.02, CL$_{95\%}$ = [-

10.78 / 10.98], p = 0.98, respectively). For the hip extension, the FR_{20} group respectively improved performance by 17.10° for the right side (t = 7.15, $CL_{95\%}$ = [-22.12 / -12.08], +9.81%, p < 0.001) and 15.50° for the left side (t = 6.67, $CL_{95\%}$ = [-20.38 / -10.62], +8.82%, p < 0.001). Likewise, the FR_{40} group improved performance by 15.10° cm for the right side (t = 5.40, $CL_{95\%}$ = [-21.00 / -9.20], +8.66%, p < 0.001) and 13.50° for the left side (t = 5.90, $CL_{95\%}$ = [-18.31 / -8.69], +7.79%, p < 0.001), while the CONTROL group did not show any change in performance (+0.90° for the right side and +0.70° for the left side, t = 0.31, $CL_{95\%}$ = [-7.03 / 5.23], p = 0.76, and t = 0.23, $CL_{95\%}$ = [-7.19 / 5.79], p = 0.82, respectively). Finally, no group difference was found when comparing changes in performance from the FR_{20} and FR_{40} groups for any ROM measure (p > 0.05).

Finally, participants subjectively reported that they experienced greater discomfort when foam-rolling target muscles during 40s compared to 20s.

Table 2. **Raw stretching performance data (mean ± sd). Values are in degree.**

<table>
<tr><th colspan="2"></th><th colspan="6">Side split</th></tr>
<tr><th colspan="2"></th><th colspan="2">Control</th><th colspan="2">FR20</th><th colspan="2">FR40</th></tr>
<tr><td colspan="2">Pre-test</td><td colspan="2">112 ± 8.21</td><td colspan="2">105.8 ± 11.83</td><td colspan="2">108.8 ± 14.34</td></tr>
<tr><td colspan="2">Post-test</td><td colspan="2">113.8 ± 10.21</td><td colspan="2">123.5 ± 10.05</td><td colspan="2">126.8 ± 14.34</td></tr>
<tr><th colspan="4">Active straight leg raising of the right hip</th><th colspan="4">Active straight leg raising of the left hip</th></tr>
<tr><th></th><th>Control</th><th>FR20</th><th>FR40</th><th></th><th>Control</th><th>FR20</th><th>FR40</th></tr>
<tr><td>Pre-test</td><td>78.5 ± 5.91</td><td>74.8 ± 11.12</td><td>73 ± 11.32</td><td>Pre-test</td><td>78.2 ± 8.76</td><td>77.8 ± 11.01</td><td>72.8 ± 9.94</td></tr>
<tr><td>Post-test</td><td>79.1 ± 7.10</td><td>88.8 ± 7.13</td><td>89.2 ± 8.79</td><td>Post-test</td><td>78.3 ± 7.86</td><td>87 ± 10.03</td><td>88.5 ± 10.56</td></tr>
<tr><th colspan="4">Active flexed leg raising of the right hip</th><th colspan="4">Active flexed leg raising of the left hip</th></tr>
<tr><th></th><th>Control</th><th>FR20</th><th>FR40</th><th></th><th>Control</th><th>FR20</th><th>FR40</th></tr>
<tr><td>Pre-test</td><td>90.8 ± 12.15</td><td>82.4 ± 11.42</td><td>84.2 ± 10.68</td><td>Pre-test</td><td>91.9 ± 12.22</td><td>83.5 ± 10.10</td><td>84.4 ± 9.55</td></tr>
<tr><td>Post-test</td><td>89 ± 10.67</td><td>96.6 ± 5.79</td><td>101.1 ± 6.06</td><td>Post-test</td><td>91.8 ± 10.89</td><td>95 ± 8.27</td><td>100.8 ± 8.32</td></tr>
<tr><th colspan="4">Active extension of right hip</th><th colspan="4">Active extension of left hip</th></tr>
<tr><th></th><th>Control</th><th>FR20</th><th>FR40</th><th></th><th>Control</th><th>FR20</th><th>FR40</th></tr>
<tr><td>Pre-test</td><td>176.9 ± 7.04</td><td>172.8 ± 5.26</td><td>173 ± 5.45</td><td>Pre-test</td><td>178.3 ± 8.05</td><td>173.1 ± 5.32</td><td>175.4 ± 5.08</td></tr>
<tr><td>Post-test</td><td>177.8 ± 5.94</td><td>189.9 ± 5.42</td><td>188.1 ± 6.95</td><td>Post-test</td><td>179 ± 5.35</td><td>188.6 ± 5.05</td><td>188.9 ± 5.15</td></tr>
<tr><th colspan="4">Active extension of right knee</th><th colspan="4">Active extension of left knee</th></tr>
<tr><th></th><th>Control</th><th>FR20</th><th>FR40</th><th></th><th>Control</th><th>FR20</th><th>FR40</th></tr>
<tr><td>Pre-test</td><td>50.9 ± 9.26</td><td>64 ± 17.32</td><td>59.5 ± 10.98</td><td>Pre-test</td><td>50.1 ± 9.38</td><td>67.9 ± 19.72</td><td>58.6 ± 16.43</td></tr>
<tr><td>Post-test</td><td>52.6 ± 9.28</td><td>57.9 ± 16.44</td><td>53 ± 12.65</td><td>Post-test</td><td>52.2 ± 8.09</td><td>59.1 ± 17.92</td><td>51.5 ± 14.09</td></tr>
<tr><th colspan="4">Active dorsiflexion of right ankle</th><th colspan="4">Active dorsiflexion of left ankle</th></tr>
<tr><th></th><th>Control</th><th>FR20</th><th>FR40</th><th></th><th>Control</th><th>FR20</th><th>FR40</th></tr>
<tr><td>Pre-test</td><td>67.8 ± 4.36</td><td>70.1 ± 4.28</td><td>72.5 ± 7.38</td><td>Pre-test</td><td>71.1 ± 3.47</td><td>71.7 ± 3.65</td><td>74 ± 6.81</td></tr>
<tr><td>Post-test</td><td>71.7 ± 4.13</td><td>71.5 ± 4.64</td><td>73.9 ± 4.58</td><td>Post-test</td><td>73.8 ± 2.69</td><td>71.6 ± 4.19</td><td>73.9 ± 6.50</td></tr>
</table>

Table 3. **Performance gains after the foam rolling (FR) intervention.**

	Control Group		FR_{20} group		FR_{40} group	
	Performance gains	*p*	*Performance gains*	*p*	*Performance gains*	*p*
Side Split	1.80°	*0.67*	17.70°	***0.002***	18.00°	***0.005***
Active straight leg raising - Right side	0.60°	*0.84*	14.00°	***0.004***	6.20°	***0.002***
Active straight leg raising - Left side	0.10°	*0.98*	9.20°	*0.060*	15.70°	***0.003***
Active flexed leg raising - Right side	-1.80°	*0.73*	14.20°	***0.004***	16.90°	***0.001***
Active flexed leg raising - Left side	-0.10°	*0.98*	11.50°	***0.010***	16.40°	***0.001***
Hip Extension - Right side	0.90°	*0.76*	17.10°	***0.001***	15.10°	***0.001***
Hip Extension - Left side	0.70°	*0.82*	15.50°	***0.001***	13.50°	***0.001***

Table 4. **Raw stretching performance data (mean ± sd). Values are in degree.**

	Front split	
	EBT	**Control**
Pre-test	111.69 ± 12.24	107.4 ± 15.67
Post-test	115.07 ± 11.73	106.95 ± 16.10
	Sit and reach	
	EBT	**Control**
Pre-test	4.73 ± 8.55	4.5 ± 6.68
Post-test	6.07 ± 8.89	4.35 ± 6.98
	Seated side split	
	EBT	**Control**
Pre-test	150.30 ± 17.57	140.85 ± 13.54
Post-test	151.5 ± 19.93	141.4 ± 12.84
	Side split against the wall	
	EBT	**Control**
Pre-test	149.84 ± 16.69	141.90 ± 13.73
Post-test	149.69 ± 17.57	141.45 ± 14.24

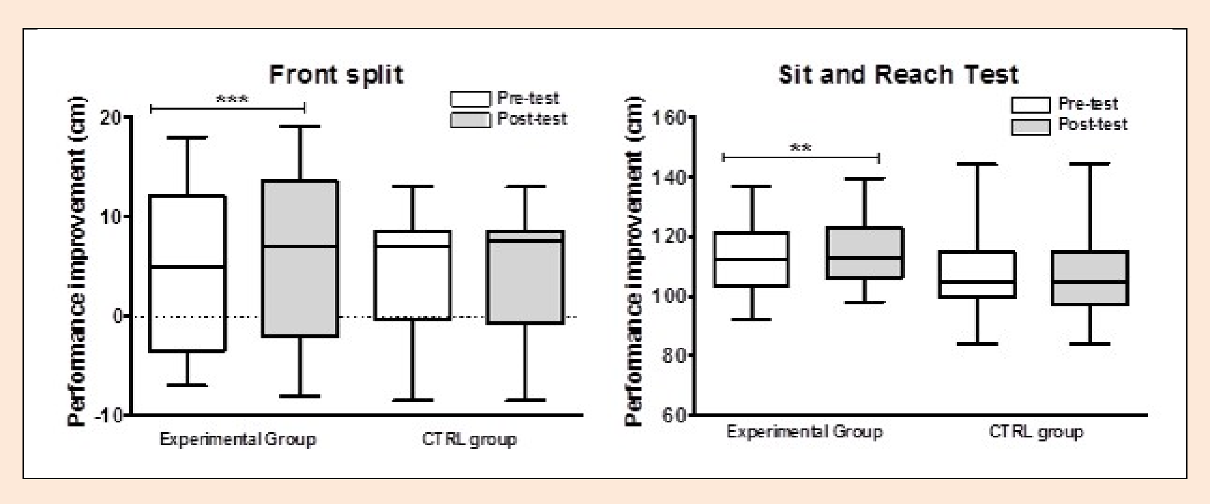

Figure 5. Performance gains before and after the intervention. The figure shows the median and quartile values. Only significant performance gains between the pretest and the post-test are displayed. ** $p < 0.01$, *** $p < 0.001$.

Experiment 2

Data revealed a significant Group × Test interaction for the front split ($F_{(1, 21)} = 21.21$, $\eta^2 p = 1.00$, $p < 0.001$) and sit and reach test ($F_{(1, 21)} = 7.34$, $\eta^2 p = 0.35$, $p = 0.01$). No interaction was found for the seated side split and the side split against the wall ($F_{(1, 21)} = 0.23$, $\eta^2 p = 0.01$, $p = 0.64$, and $F_{(1, 21)} = 0.04$, $\eta^2 p = 0.001$, $p = 0.84$, respectively). No main Group or Test effect was observed for these two measures.

Post-hoc tests revealed no statistically significant difference during the pre-test between the Control and EBT groups for all stretching variables (all $p > 0.05$, Figure 5). The post-hoc analysis yielded that the EBT group improved performance from the pre- to the post-test, while there was no substantial change in performance for the Control group (Figure 5, Table 4). For the front split, performance was improved by 3.38 cm (i.e., +2.31% relative to the pretest) in the EBT group ($t = 5.14$, $CL_{95\%} = [-4.8 / -1.95]$, $p < 0.001$), while ROM did not change in the Control group (-0.45 cm, $t = 1.11$, $CL_{95\%} = [-0.47 / 1.36]$, $p = 0.29$). For the sit and reach test, the EBT group significantly improved performance by 1.35 cm ($t = 2.96$, $CL_{95\%} = [-2.34 / -0.36]$, +29.16%, $p = 0.01$), while ROM did not change in the Control group (-0.15 cm $t = 0.7$, $CL_{95\%} = [-0.32 / 0.63]$, $p = 0.50$).

Discussion

The present study was designed to evaluate whether a training program of several FR or EBT sessions might enhance flexibility in expert rugby players. Overall, results demonstrated the effectiveness of these two forms of practice and therefore support their relevance as an adjunctive training method to enhance flexibility.

In contrast to previous studies which primarily investigated the short-term effects of FR on flexibility (i.e., test-retest following one single session), we tested the effects of a 7-week training program. Data provided evidence of significant increases in ROM during side split performance, as well as hip extension and both passive and active hip flexion, bilaterally. This finding corroborates the results pattern yielded by previous short-term interventions, which underlined the positive effects of FR on hip ROM (Behara and Jacobson, 2015; Bushell et al., 2015; Cheatham et al., 2015; De Souza et al., 2017). While challenging the recent study by Hodgson et al. (2018), these findings are in keeping with the study by Junker and Stöggl (2015), who explored the effects of a 4-week period of FR on hamstring flexibility. Mohr et al. (2014) reported that FR followed by static stretching contributed to increase the intramuscular tissue temperature and blood flow, and concomitantly reduce viscosity due to changes in the thixotropic properties of the muscle. Such FR-induced changes in the histological properties may explain, at least partially, the observed ROM improvements. Unexpectedly, the lack of positive effects of FR for the ankle dorsiflexion and the knee flexion are in disagreement with previous experimental data (Button and Behm, 2014; Bradbury-Squires et al., 2015; Halperin et al., 2014; MacDonald et al., 2013; 2014; Vigotsly et al. 2015; Škarabot et al., 2015; De Souza et al., 2017). While the use of a stick might be more efficient to investigate the effects of FR on ankle ROM (Halperin et al., 2014), such important difference in the results pattern may be explained by the fact that, in the present study, both the quadriceps and the triceps surae muscles were not in a stretched position when athletes performed FR. This possibly limited performance gains. This assumption is congruent with the fact that under the other experimental conditions, where FR was practiced on stretched muscles, positive effects were recorded. Furthermore, the half kneeling dorsiflexion involves mainly the soleus muscle while gastrocnemii muscles are slack (Cresswell et al., 1995; Maïsetti et al., 2012). Considering that the FR protocol was applied on the gastrocnemii, it might likely explain the absence of increase in dorsiflexion ROM.

Practically, including FR as a part of training programs designed to develop stretching capacities constitutes a promising avenue for both practitioners and clinicians. As suggested by Mohr et al. (2014) and Škarabot et al. (2015), combining FR and static stretching might be the optimal strategy to increase ROM and improve stretching performance. Interestingly, our data did not show any difference when comparing performance from the FR_{20} and the FR_{40} groups. This finding corroborates previous research by De Souza et al. (2017), who provided evidence that increasing the FR volume from 10 to 20 repetitions per set did not promote additional gains. In the present study, participants however experienced greater discomfort when foam-rolling target muscles during 40 sec. In terms of practical applications, these findings thus suggest that FR each muscle during 20s is sufficient and might be regularly included as part of a stretching routine.

Joint distraction techniques are commonly used to alleviate pain and are casually administered to patients in clinical settings (Cahill and Theopold, 2016). Their use to enhance performance in athlete is quite novel. Elastic bands provide a constant resistance expected to maximize its mechanical effects, i.e., increase in synovial fluid motion bringing nutrients to the avascular portions of the intra-articular fibro-cartilage (Kisner and Cloby, 2012). Based on present data in rugby players, we hypothesized that this would not only result in lower pain, but may also contribute to improve flexibility and ROM. Interestingly, results of Experiment 2 showed that compared to a passive postural training, performing joint distraction using elastic band resistance during 5 weeks resulted in stretching gains during both the front split and the sit and reach test. Yet, scientific reports of such effects of EBT remain sparse in the scientific literature, albeit some authors underlined its empirical efficacy (Carrio, 2012; Rosengart, 2013).

Specifically, significant performance gains were observed for stretching movements primarily involving the hamstrings, which are strongly involved during active running phases in rugby, but also commonly injured (Roberts et al., 2013). Stretching routines combined with joint distraction and EBT may specifically improve ROM of muscles which are highly stressed during actual practice. Accordingly, selective effects on muscles predominantly involved in rugby-specific tasks should be expected. This is congruent with the fact that adductors flexibility (a determinant of side split performance) is secondary compared to that of the hamstrings in most rugby actions. Finally, recent results showed that both dynamic and static stretching had no influence on hamstrings response times, and therefore did not contribute to reduce this primary risk factor for anterior cruciate ligament injury (Ayala et al., 2013; 2014). Replicating a similar set of measures after a program of active/dynamic stretching assisted by joint distraction with elastic band resistance might be of interest to investigate injury prevention more extensively.

The fact that EBT facilitated stretching performance for hamstrings exercises but did not substantially impact the flexibility of the adductors might also be explained by the nature of the traction applied during the joint distraction tasks. Accordingly, the elastic band was systematically wrapped to the pelvis along the antero-posterior axis, thus possibly limiting the effects on the mobility of the adductors, while facilitating more extensively the flexibility of the hamstrings. Although less frequently performed in EBT routines, wrapping the elastic band around the thigh, up close towards the knee, while keeping the body perpendicular to the band, might be more beneficial to target the flexibility of the adductors.

Aside the relatively small sample sizes tested in these two experiments, one main limitation of the present study is that ROM, collected using an electronic goniometer placed on the joint of interest, was the only one outcome. Even if care was taken to the joint of interest, the angle of other joints was therefore not directly considered. As shown recently by Andrade et al. (2016), who showed the influence of the hip position in the ankle ROM, one cannot totally rule out the influence of the other joints on the targeted ROM. Another limitation is that the Thomas test is certainly not the most appropriate way to assess knee mobility, as the knee flexion might increase not because of worse flexibility, but rather due to the position of the thigh during the test. This test, which remains frequently used by practitioners, is indicative, but should ideally be combined with another assessment. Otherwise, participants were not allocated to groups controlling their rugby field position, which may be interesting in future experimental studies. In addition, although we controlled in the two experiments that the main rugby training activity was performed by all players during the intervention period, future studies should ideally include participants who do not train rugby at all during the intervention.

Conclusion

Taken together, present findings suggest that a training program including either FR or joint distraction exercises with elastic bands is likely to enhance joint ROM as well as specific mobility patterns. The findings have thus strong implications in terms of prophylaxis in athletes such as rugby players but also in non-athletes. Data also revealed that FR substantially improved players' flexibility scores regardless the rolling duration, and that EBT primarily contributes to improve ROM for muscles highly stressed during actual practice. Along with previous results from the scientific literature, as well as empirical findings, the present study confirms that these two forms of practice constitute a promising avenue for clinical, home therapy, and personal flexibility training. Whether improvements in flexibility might positively influence subsequent motor and sport performance remain uncertain. Medeiros and Lima (2017) nicely reviewed the experimental studies investigating the influence of stretching on muscle performance. Interestingly, they reported that while some studies showed some improvements in muscle performance after flexibility training, the selective influence of this latter form of practice remains difficult to interpret and comprehend. Future experimental research will certainly contribute to resolve this issue.

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Key points

- Foam rolling substantially improved hip range of motion scores, regardless the rolling duration.
- Joint distraction with elastic bands significantly improved sit-and-reach as well as side split stretching performances.
- Foam rolling and joint distraction exercises with elastic bands appear of specific interest to improve flexibility and serve prophylaxis.

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