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Original Article

The foam rolling of quadriceps decrease the kinematics of step during a 30-m sprint run

MARCIN STARZAK[1], HUBERT MAKARUK[2], BARTŁOMIEJ MAKARUK[3], PAWEŁ WIŚNIOWSKI[4], ANNASTARZAK[5], MONIKAZAJĄC[6]
[12,5]Department of Athletics and Swimming, The Josef Pilsudski University of Physical Education in Warsaw, Faculty of Physical Education and Sport in BiałaPodlaska, POLAND
[3,4]Department of Environmental Rehabilitation,The Josef Pilsudski University of Physical Education in Warsaw, Faculty of Tourism and Health in BiałaPodlaska, POLAND
[6]The Josef Pilsudski University of Physical Education in Warsaw, Faculty of Physical Education and Sport in BiałaPodlaska, POLAND
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Abstract
The objective of this study was to investigate the effects of foam rolling of the hamstrings or quadriceps muscle groups on the step kinematics during a30-m sprint run.Moderately active physical education male students (*n* =23, 21.4 ± 0.7 years, 79.2 ± 8.3 kg, 1.80 ± 0.06 m) participated in this study. The Optojump Next with the Witty timing system were used to measure the kinematics of sprint running (contact time, step length, flight time, step velocity). Each subject completed two maximal 30-m sprints after the warm-upunder three conditions: foam rolling of quadriceps, foam rolling of hamstrings, and dynamic stretching. The main results of this study showed that the foam rolling of quadriceps decreased velocity of step, step length and flight time as well as increased contact time during sprint immediately after warm-up (2 min) compared to warm-up with foam rolling of hamstrings. There were not significant differences between the three warm-up conditions during the second run (after 8 min passive break). The results suggest that practitioners should avoid the foam rolling of quadriceps exclusively in terms of performance a 30-m maximal sprint. It should also pay more attention to apply the optimal volume of quadriceps to hamstrings foam rolling during the warm-up procedures.
Keywords: self-myofascial release, warm-up, contact time, step length, step velocity

Introduction

It has been well documented that the ability to accelerate rapidly and reach the maximum speed is mainly the product of the step length (SL) and step frequency (SF) (Hunter, Marshall, & McNair, 2004) which, in turn, depends on biomechanicslike contact time (CT) or flight time (FT)(Morin et al., 2012). Generally, the sprint running cycle consist of two main phases: stance phase and swing phase (Ounpuu, 1994). In order to increase maximum running speed, the athlete must reduce the CT during the stance phase while increase swing phase which influenced the step length (SL) (Lockie, Murphy, Schultz, Jeffriess, & Callaghan, 2013).

Shorter CTis the product of the athlete's efficiency to withstand ground reaction forces and the ability to produce forward propulsion at once(Hunter, Marshall, & McNair, 2005). The step length is mainly influenced by morphological factors as lower extremities lengths and body proportions. Both factors are linked with a lower-limb power and muscle stiffness of the hip and knee extensors during the sprint cycle(Coh, Milanović, &Kampmiller, 2001; Lockie, Murphy, Schultz, Knight, &Janse de Jonge, 2012).Some evidence implies that the optimal amount of muscle stiffness provides greater efficiency of the stretch-shortening cycle during explosive actions like short sprints. This has an influential impact on force production and steps kinematic i.e. a decrease of CT or an increase of SF (McMahon, Comfort, & Pearson, 2012;Cissik, 2010). These require, both, the proper mechanics and great muscular force outputs within the hip, knee, and ankle musculature (Mero, Komi, &Gregor, 1992; Spinks, Murphy, Spinks, &Lockie, 2007).Especially, the hamstrings and quadriceps muscles are considered to be particularly important during the acceleration phase and to set up for maximum sprint velocity (Wiemann&Tidow Gunter, 1995; Schache et al., 2011).Researchers indicate that the muscles of the hip and knee joint must be at their full ROM to effectively generate horizontal forces which are needed for increasing velocity (Schache et al., 2011; Dugan & Bhat, 2005).Therefore, the ability to run at higher velocity requires the capacity to generate optimal horizontal forces which, in turn, could be determined by either the running mechanics(Morin et al., 2012; Murphy, Lockie, & Coutts, 2003) orpre-performance preparation i.e. properly warm-up procedures (Fletcher & Jones, 2004; Behm&Chaouachi, 2011). Various warm-up protocols are recommended when preparing the body before explosive activities which at once involves an optimal ROM and some amount of leg muscles stiffness (Brughelli& Cronin, 2008). It seems that researches and practitioners generally accepted that dynamic stretching, unlike the static stretching exercises, is the most effective for increasing ROM (Behm& Chaouachi, 2011). Recently, a technique of self-myofascial release (SMR) using a different form of foam rollers has become an integral part of the warm-up procedures (Cheatham, Kolber, Cain, & Lee, 2015;

Corresponding Author: MARCIN STARZAK, E-mail: marcin.starzak@awf-bp.edu.pl

Freiwald, Baumgart, Kühnemann, & Hoppe, 2016).It is commonly accepted as toll for improve flexibility (Schroeder & Best, 2015), and both, passive and active ROM on hip, and knee joints without inducing force and the neuromuscular activity (Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2014; MacDonald et al., 2013). In regard to sprint and agility performance, there is no clear agreement on whether SMR interventions may have a positive effect of performance. Although a study of Peackok et al.(2014)confirmed that implementing foam roller exercises into a warm-up routine have the influence on sprint time, other suggest that there is no direct enhancement in performance (Healey et al., 2014;Richman, Tyo, & Nicks, 2019).Furthermore, findings do not indicate the negative effects of FR application of speed tests, shows only the observable increased in perceived fatigue (Cheatham et al., 2015). Interestingly, a similar no beneficial effects on short sprint performance were also observed via different forms of massage (Goodwin, Glaister, Howatson, Lockey, &McInnes, 2007).

All these results maylead to ambiguous conclusions within the existing research. Studies present a diverse range of loads including a different form of foam rolls, intervention time, and pressure loads used during foam rolling.An explicit statement on the optimal foam rolling intervention have been discussed within the literature.(Cheatham et al., 2015; Mauntel, Clark, & Padua, 2014).For example, an inappropriate load selection, i.e. foam-rolling of one muscle group exclusively or inadequate rolling time of given muscle group may lead to disturbed efficiency of agonist-antagonist coordination around the joint. In light of the study of Cavanaugh et al. (2017) foam rolling of the quadriceps group could have a detrimental effect on the hamstrings muscle activation. This may be particularly important during both speed training and performance. The reduction of the quadriceps-to-hamstrings activation may lead to negative changes in the release of stored elastic energy from the muscle-tendon complex and in consequences may affect the kinematic variables during the sprint run (i.e. CT or SL).

Although researchers have widely considered a role of implementing FR into warm-ups on ROM and a possible effect on performance, however, to date there is a lack of studies examined how an acute bout of FR resulted on step variables during sprint performance. Therefore, the main purpose of this study was to determine whether foam rolling the hamstrings or quadriceps muscle group would change the crucial step kinematics during the maximal sprint effort.It was hypothesized that foam rolling intervention would affect the step kinematic variables. The second goal was to determine whether foam rolling of quadriceps or hamstrings exclusively would improve their ROM.Based on the previous research we hypothesized that foam rolling intervention will increase ROM of hip or knee joints.

Methods

Experimental Approach to the Problem

The study used a within-subject design comprising 3 testing sessions separated by 48-72 hours of rest periods conducted at the same time of day (Figure 1). Prior to the investigation, all subjects completed a familiarization session in which they were instructed about a proper technique used during the foam rolling. All subjects completed 3 warm-up protocols which were randomized and counterbalanced to avoid the potential order effect. The experimental conditions included a foam-rolling of quadriceps muscles group (QFR), hamstrings muscles group (HFR) and a control session (CON). After the warm-up protocol, subjects were performed testing measure which included two 30-meter sprints at maximal effort. The second run was followed by an 8-minutes passive break, without any additional warm-up procedures. The following dependent variables were evaluated: ground contact time (CT), flight time (FT), step length (SL), velocity and step rate.

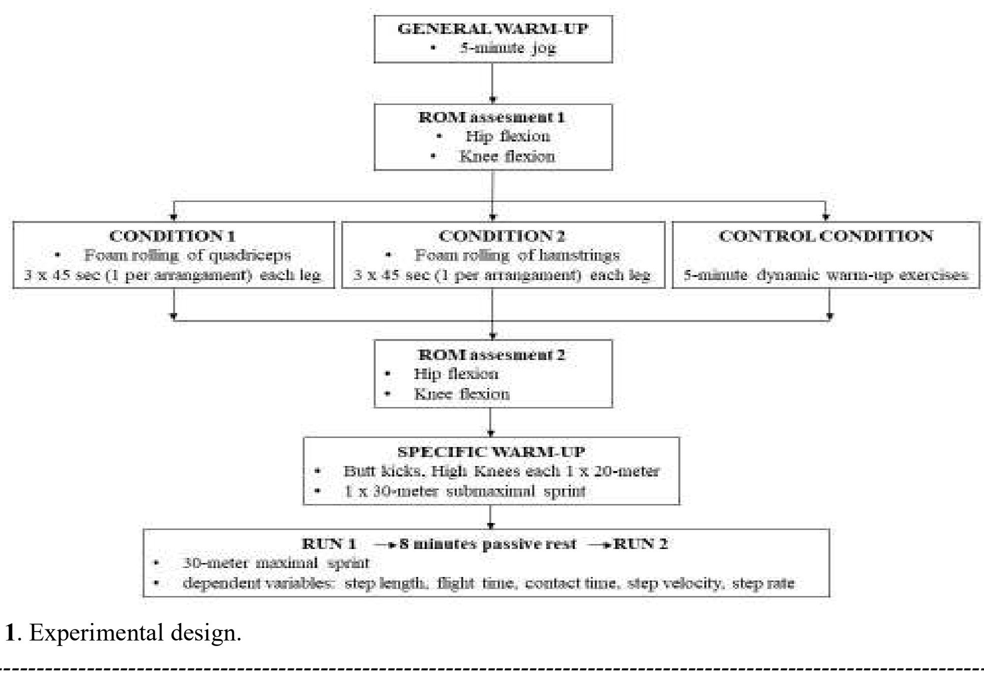

Figure 1. Experimental design.

Subjects

Twenty-two men physical education students aged 21.4±0.7 years (age range 20-23 years), body mass 79.2±8.3 kg, body height 1.80±0.06 m (mean ±*SD)*, volunteered for this study. The participants were classified as moderately active because of the nature of their studies containing a number of classes during a weekly schedule plan, including team sports and individual sports such as athletics or gymnastics. All subjects were injury free for the 3 month period before and during the study.All participants had no previous experience using any form of a foam-rolling.Participants were asked to limit their own sports activities and to not take any supplements as well as to not use any additional warm-up tools between testing days. Before the start of this experiment, all participants were written and signed informed consent. The study was approved by the University Ethics Committee.

Procedures

The study was performed at the athletics hall with the synthetic tartan track surface. During the experiment, subjects wore standard athletic shoes, shorts, and a t-shirt. Each session started with generally warm-up consisted of low rate 5-minute jog at 60% of age predicted max heart rate (at moderate intensity). After general warm-up participants completed one of the randomly selected foam rolling or control conditions.

ROM assessment. The ROM was tested twice during each experimental session. The first assessment was performed after the general warm-up, the second measurement was conducted after one of the experimental conditions. The ROM was tested in a position which prevented moving to other joints in an active way, without interference by external forces. The standardized manual goniometer with accuracy up to 1^o was usedfor measure the ROM of hip and knee joints. When testing the length of hamstring muscle, the subject was in supine position (Figure 2a, 2b). The goniometer was placed on the greater trochanter. The stationary arm direction was lateral mid-line of the pelvis and moving arm direction was malleolus lateralis. The examined rose straight knee leg to maximal ROM in a hip joint. The second leg knee was below the massage table and it was stabilized by the hand of the experimenter.

The length of quadriceps muscle was tested in prone position (Figure 2c, 2d). The goniometer was placed on the lateral epicondyle. The stationary arm direction was greater trochanter and moving arm direction was malleolus lateral. The examined bent knee joint in a maximal straight hip joint. The second leg knee was next to the massage table on the floor for better stabilization.In our study, we tested rectus femoris muscle, semitendinosus, semimembranosus and long head of biceps femoris. From the point of view of anatomy, these muscles move in more than one joint and if there are some tissue restrictions, the problem may also arise in the joints where they move. The length of these muscles can be tested by ROM in hip or knee joints.

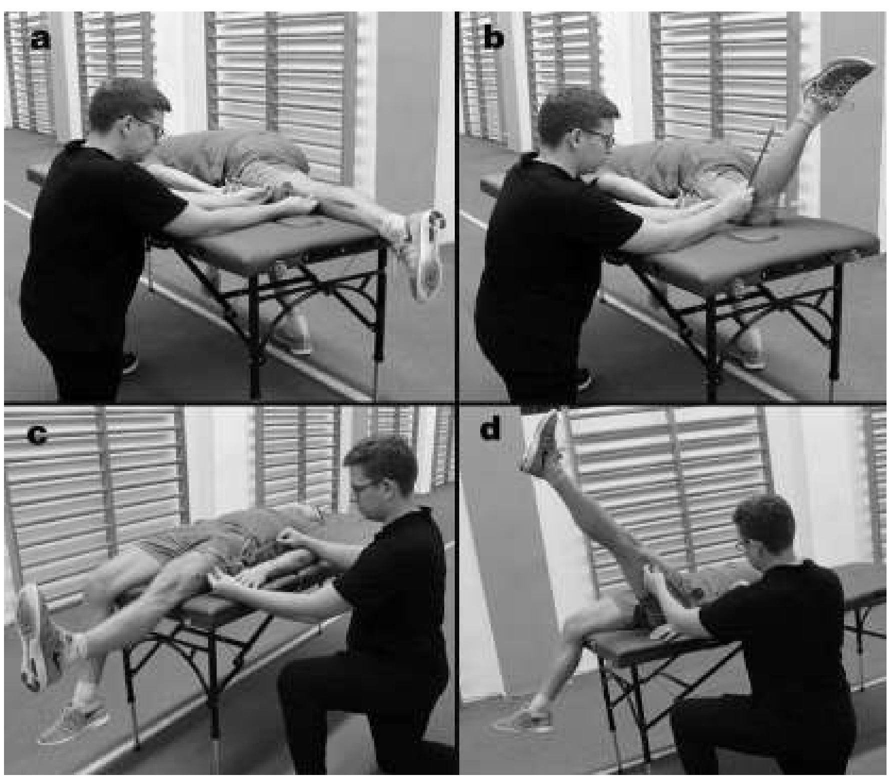

Figure 2. Positions used for measurement of knee flexion (a, b) and hip flexion (c, d) range of motion.

Foam rolling. The participants used a polypropylene foam roller (Blackroll, Bottighofen, Switzerland) with a length of 30 cm and 15 cm in diameter. Both under QFR and HFRconditions the foam rolling was performed bilaterally, each leg separately in randomized order. A single massage for both conditions lasted 45 s, 15 s for each side of the muscle (medial, central and lateral) for three times during one intervention with a cadence of 3-4 s of rolling on the full length of muscle group (from proximal to distal end of muscle). Participants used their body weight on a foam roller with constant pressure on their own pain threshold.For the HFR conditions participants were rolled hamstrings muscle group from the ischial tuberosity to the posterior knee in maximal extension (bent hip joint and extended knee joint) (Figure 3a). The participants were sitting with one leg on the foam roller with their hands for support and the second leg placed on the floor. In the QFR conditions a foam roller was used to massage quadriceps muscle in a maximal stretch (extended hip joint and bended knee joint). The participants laid face down on planking position on the ground with the foam roller under their thigh and the second leg was on the floor (Figure 3b). Subjects rolled distally and proximally from hip to knee joints.

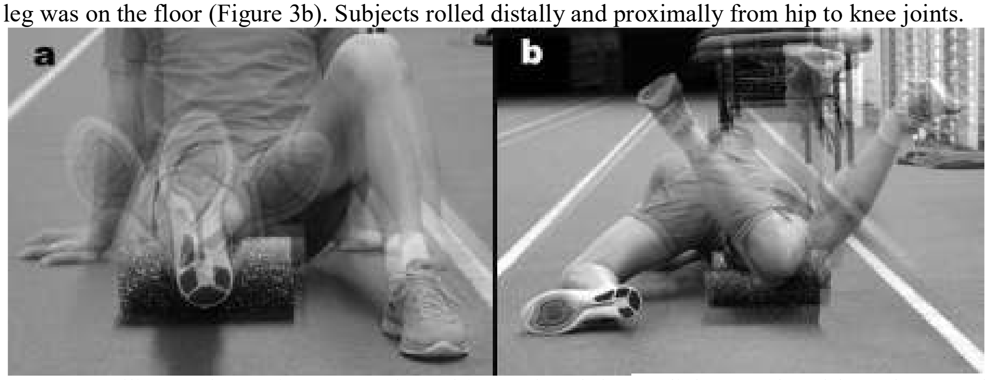

Figure 3. Foam rolling on hamstrings (a) and quadriceps (b) of the medial, central and lateral parts of muscle groups.

Sprint kinematic assessment. Testing was conducted after foam-rolling interventions. The participants performed two 30-m sprints used a two-point starting position with one foot in the front behind the start line. They were instructed to start when ready with any additional command and run as fast as possible. The Optojump Next (Microgate, Italy) was used to evaluate the kinematic variables in this study. This equipment is a valid optical measurement system consisting of transmitting and receiving measurement bars (1-m each) which were placed parallel to each other. For the purpose of this study, we used a 30-m path with the 1,5-m distance between the bars. The measurement bars communicate by LED solid infrared light beams at a height of 2 mm above the ground with sampling at 1000 Hz and timing accuracy of 1 ms.For all tested parameters the intra-class correlation coefficients were strong (ICCs=0.91-0.96).

Statistical Analyses

Overall step kinematics data were determined as the mean of the trial during each condition. The Shapiro-Wilk statistic was used to test the homogeneity of variance of the data. Analysis of variance (ANOVA) with repeated measures was used to evaluate the significant differences in step kinematics between conditions. To determine if significant differences existed between FR conditions on ROM, a 3 (HFR, QFR, CON) x 2 (1-testing, 2-testing) analysis of variance (ANOVA) was used. In both cases, if significant differences were found, Tukey post hoc analysis was used to compare the parameters. The level of significance was established at $p = .05$. All statistical analyses were computed using the Statistica (version 13.1).

Results

Range of Motion. The descriptive data for pre- and post-intervention knee ROM for left and right leg for each of conditions are presented in Table 1. For the left knee ROM there were significant interaction between group and time ($F_{2.42}$= 3.57, $p<0.05$) and main effect of time ($F_{2.42}$= 23.86, $p<0.001$). The effect of condition was no significant ($F_{2.42}$= 1.98, $p=0.15$). There were significant conditions x time interaction for the right knee ROM ($F_{2.42}$= 5.67, $p<0.001$) and effect of time ($F_{2.42}$= 39.52, $p<0.001$). There was no significant effect of condition ($F_{2.42}$= 0.78, $p=0.47$). It was found that QFR intervention significantly incresed the left and right knee ROM.Table 2 reports the pre- and post-intervention of hip ROM for left and right leg for each of conditions. The analysis of left hip flexion ROM showed that there were significant group x time interaction ($F_{2.42}$= 3.56, $p<0.05$) and effect of time ($F_{2.42}$= 33.77, $p<0.001$). There was no significant effect of conditions ($F_{2.42}$= 0.88, $p=0.42$). There were no significant main effects for the right hip ROM for pre- and post-intervention between conditions ($p=0.54$).Post hoc analysis showed that there were significantly increased in left hip ROM following QFR intervention. Notably, the QFR also resulted in acutely increased hip ROM, however, only in the left leg.

Table 1. Mean (±*SD*) for range of motion of the active knee flexion in all conditions for pre- and post-intervention.

	Knee flexion (°)			
	LL		RL	
Group	Pre-	Post-	Pre-	Post-
HFR	109.64±9.34	113.50±10.41	114.91±11.15	117.18±8.95
QGR	107.14±12.21	114.18±10.53#	110.14±11.53	116.55±10.02#
CON	104.64±11.67	106.18±11.90	111.91±11.43	112.14±10.99

HFR – rolling of hamstrings muscle group, QGR – rolling of quadriceps muscle group, CON – warm-up group, LL – left leg, RL – right leg
 # p≥0.001 from pre- to post-intervention

Table 2. Mean (±*SD*) for range of motion of the active knee flexion in all conditions for pre- and post-intervention.

	Hip flexion(°)			
	LL		RL	
Group	Pre-	Post-	Pre-	Post-
HFR	65.59±6.62	70.80±8.16¥	65.45±7.86	70.05±9.35¥
QGR	64.84±7.35	68.59±7.57#	63.45±11.43	67.82±11.22#
CON	64.11±8.72	65.84±8.02	63.55±12.09	65.14±9.44

HFR – rolling of hamstrings muscle group, QGR – rolling of quadriceps muscle group, CON – warm-up group, LL – left leg, RL – right leg
 # p≥0.01 from pre- to post-intervention, ¥ p≥0.001 from pre- to post-intervention

Step kinematics. The results of analysis of step kinematics in the first 30-m run between conditions are displayed in Table 3.There were significant main effect for CT ($F_{2.42} = 5.72$, $p<0.001$), SL ($F_{2.42} = 3.65$, $p<0.05$), FT ($F_{2.42} = 6.27$, $p<0.01$) and step velocity ($F_{2.42} = 5.32$, $p<0.01$). The effect of step rate ($F_{2.42} = 0.22$, $p=0.82$) was no significant. Post-hoc analysis demonstrated that there were significantly higher value of CT and lower values of SL, FT and velocity after QFR compared with the HFR group.The results of analysis of step kinematics in the second 30-m run between conditions are shown in Table 4. There were no significant effects in CT, SL, FT, velocity and step rate between conditions.

Table 3. Mean (±*SD*) contact time (CT), step length (SL), flight time (FT), velocity and step rate for different conditions in the first 30-m sprint.

Group	Step kinematics				
	CT (s)	SL (m)	FT (s)	Velocity ($m \cdot s^{-1}$)	Step rate (Hz)
HFR	0.155±0.015	1.58±0.12	0.088±0.013	6.77±0.27	4.14±0.36
QFR	0.160±0.015*	1.56±0.11*	0.083±0.011#	6.71±0.24#	4.14±0.31
CON	0.158±0.016	1.58±0.11	0.086±0.011	6.76±0.25	4.12±0.33

HFR – foam-rolling of hamstrings muscle group, QFR – foam-rolling of quadriceps muscle group, CON – warm-up group
** p≥0.05 – statistically different from HFR, # p≥0.01 – statistically different from HFR*

Table 4. Mean (±*SD*) contact time (CT), step length (SL), flight time (FT), velocity and step rate for different conditions in the second 30-m sprint.

Group	Step kinematics				
	CT (s)	SL (m)	FT (s)	Velocity ($m \cdot s^{-1}$)	Step rate (Hz)
HFR	0.156±0.017	1.55±0.12	0.086±0.013	6.69±0.30	4.16±0.36
QFR	0.159±0.015	1.55±0.12	0.084±0.013	6.70±0.26	4.15±0.35
CON	0.158±0.017	1.56±0.10	0.084±0.011	6.72±0.28	4.14±0.31

HFR – foam-rolling of hamstrings muscle group, QFR – foam-rolling of quadriceps muscle group, CON – warm-up group

Discussion

The main finding of this study was that the foam rolling of thigh musclesinfluenced the step kinematics during the 30-m maximal effort. The results found that QFR intervention resulted in a significant increase of CT and a decrease in average values of SL, FT, and step velocity compared to HFR intervention. However, there were no reported changes in the second testing effort after the 8-m passive full recovery break.

To the authors' knowledge, this was the first study to examine the effect of foam rolling intervention on step kinematics during the maximal sprint performance. There are a fewunderlying mechanisms incorporating neurological and biomechanical factors that have to be addressed when interpreting the findings in this study. The first possibility it might be a result of reciprocal inhibition affected by increased pressure on agonist (quadriceps) during foam rolling. The study of Cavanaugh et al.(2017) implied that the foam rolling of the quadriceps muscle group could have a detrimental effect on hamstrings activation through the effect of increased pain perception. The number of studies indicates the crucial role of hamstring activation in running mechanics at top speed, pointing the importance of swing phase in the gait cycle(Morin et al., 2012; Schache et al., 2011). The high level of knee flexors activity mainly determines the horizontal force production during the end of the swing phase (Morin et al., 2015). It is also particularly important concerning the effect of pre-activation before the contact time with the ground (Bret, Rahmani, Dufour, Messonnier, &Lacour, 2002).In light of our results, the QFR intervention might induce a reduction of hamstrings activity which resulted in increased in average CT during the 30-m performance. This,in turn,could be considered due to other important aspects of the sprint performance variables.First, based on the previous studies the CT, SL, FT, and velocity are correlated to each other and they are main indicators of the fast sprint performance (Lockie et al., 2013). Even small changes between these factors could lead to a possible negative influence on sprint efficiency. Secondly, in terms of the influence on the sprint kinematics i.e. shorter SL is strongly related to force production during the stance phase (Morin et al., 2012). The participants might not be able to generate a high amount of ground reaction forces which is needed to produce horizontal velocity during a run. Therefore, shorter SL could be responsible for reduced step velocity in this study.In consequence, since the FT is a function of SL, shorter steps were also likely influenced on longer flight times over the 30-m distance run.Additionally, Cavanaugh et al.(2017) found that the effect of a decrease in muscle activation was not reciprocated so the foam rolling of hamstrings not reduced the quadriceps activity. In contrary, an acute FR application may have a global effect by acting on ipsilateral antagonist muscle group (Cheatham &Kolber, 2018) or on the contralateral muscle (Aboodarda, Spence, & Button, 2015). However, we also did not report any significant changes in step parameters after the HFR compared with other conditions.

The other explanation of the impede step kinematics trough quadriceps foam rolling could be related to the process of autogenic inhibition of the muscle spindles. Researchers proposed that stimulation of mechanoreceptors (i.e. Golgi tendon organs) inhibits the muscle spindle activity thus decreases muscular tension and ultimately relaxing the muscle(Schleip, 2003). Such activation of the Golgi tendon organs (GTO) could be generated through the use of foam rolling influences on the muscle tension due to a reduction in pain perception which leadsto temporally increased in ROM (Škarabot, Beardsley, &Štirn, 2015). This underlying mechanism may responsible for ROM improvement which was observed after the foam rolling in both QFR and HFR application in this study.

Based on participants' feedback about foam rolling the application the QFR induced a higher level of pain sensation compared with HFR conditions. However, we did not report the subjects' pain threshold during the FR interventions.Despite that the subjects exerted pressure on the roller only with their own body weight, the arrangement was different depending on the muscle group being rolled. It seems that during QFR, the exerted pressure might be greater compared with HFR. Furthermore, quadriceps it is a larger muscle group than hamstrings which could increase pain pressure threshold and result in larger inhibition effect. The greater stretch of the tendon structures may lead to increased compliance of the musculotendinous unit. Therefore, this may result in a reduced rate of force generation and muscle activation (Fletcher & Jones, 2004).

Another possibility is that increase inhibition effect due to quadriceps foam rolling may also be contributed with changes in agonist muscle stiffness and restitution of elastic energy.The capacity to storage and utilization of the elastic energy of the muscle-tendon structure are essential to the efficiency of the stretch-shortening cycle during maximal effort in sprint running(Brughelli& Cronin, 2008; Shorten, 1988). A number of studies have reported that leg stiffness is essential in order to the efficiency of the stretch-shortening cycle during maximal run(Chelly& Denis, 2001; Shorten, 1988), however, some amount of this reduction is beneficial as it can acutely increase ROM (Cheatham et al., 2015; MacDonald et al., 2013).In regard to flexibility,as we expected after the QFR implementation we observed an increased active knee flexion in both legs. Similarly, a significant bilateral improvement in the hip ROM was found after the HFR intervention. These findings are in line with the majority of other studies suggesting the implementation of FR in the warm-up protocols (Wiewelhove et al., 2019). However, using this technique one's may pay attention due to the possible similar negative alternations which occur afterthe massage orstatic stretching. Although, these interventions are effective in producing more compliant tissue, and could contribute to step kinematics i.e. increase in SL due increase in ROM (Fletcher & Jones, 2004), the more compliant musclemay lead to reduce the ability to store energy and force production.For example, the adverse changes in a biomechanical factor of the viscoelastic properties of the muscle contributed with a massage induced intervention was indicated by the study ofArabaci et al.(2008). However, they found significantly decrement in 30-m sprint performance with simultaneously significantly increased flexibility of the hip joint.Similar changes were observed after static stretching due to the effect of stretch tolerance (Weppler& Magnusson, 2010).It is possible that the utilization of FR during the QFR intervention in this study maylead to diminish the muscle stiffness and negatively contribute to restitution of elastic energy in the muscle spindles. This may have a detrimental effect on time spenton the ground during the stance phase which results in significant increase in CT, and also lead todecrease in SL.

Finally, to date, there is no clear consensus on the optimal FR load intervention, which can be effective for increase ROM without decreasing performance before high-speed activities (Wiewelhove et al., 2019).As we assumed, the volume dose (3 sets of 45 s) of FR applied in this study would be beneficial to increase ROM without affecting performance (Cheatham et al., 2015).In this regard, the duration of FR intervention seems to be particularly important,similar to static stretching intervention. It is generally accepted that short duration on stretching (<30 s) could not impede an acute effect of muscular performance whereas the long bout (> 60s) to a single muscle may result with significant impairments(Behm& Chaouachi, 2011).However, in other studies (i.e.Kyranoudis et al., 2019), participants generally performed an FR to different muscle groups without focusing to a single one, thus the influence of an acute dose of quadriceps or hamstrings FR on sprint performance may be diminished. The study of Monteiro et al.(2017)supports this assumption showing that larger doses of FR to the agonist muscle group may hinder performance (ability to produce force during the knee extensions). In contrary, MacDonald et al.(2013) showed that the 2 minutes of an acute bout of FR on quadriceps did not have a detrimental effect either force production or muscle activity. Therefore, the applied volume of foam rolling,especially during a QFR, may have a pending effect on muscle efficiency. We suppose that a dose-dependent response of this foam rolling application, may contribute to a negative effect on step kinematics found in this study.Further research is needed to examine the different volume of FR of quadriceps in regard to step kinematics during a sprint run.

Conclusions

The results from this study indicate that a single bilaterally quadriceps foam rollingcompared with hamstrings foam rolling, in addition to overall warm-up, negatively influenced the CT, SL, FT and step velocity during a 30-m sprint performance.However, these adverse changes in step kinematics were notfound during the second run after the full recovery passive brake. For the purpose of the practical application, it seems that before short sprint performance an FR should not be applied to quadriceps exclusively. Furthermore, in terms of warm-uppreparation before the speed training,it should be taken into consideration determining a proper proportion between foam rolling of quadriceps to hamstrings muscle groups. In particular, for the subjects with any or little experience in foam rolling application.

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