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**Original Article**

# Effect of the pre-warm-up exercise program on muscle performance

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**Abstract**
**Problem statement:** Pre-warm-up actions have gained popularity in soccer in recent years but their effectiveness has not been sufficiently researched. **Purpose:** The aim of this study was to investigate the effect of a pre-warm-up exercise program, with emphasis on muscular activation and neuromuscular control, on selected performance and injury-related markers. **Methods:** The study involved twenty three soccer players (n = 23), each of whom was randomly assigned to either an experimental group (n=13) that performed the pre-warm-up exercise protocol or a control group (n = 10) that performed 5 minutes of cycling. The hip flexion Range of Motion, Countermovement jump, free hands countermovement jump, and Peak Torque of concentric knee extensors and concentric/eccentric knee flexors at $60^0$/sec and $180^0$/sec, for both limbs, were measured using an isokinetic dynamometer before and immediately after exercise intervention. Conventional and Functional isokinetic strength ratios were also calculated for further analysis. **Results:**The results showed a significant improvement in the range of motion (5.4%), countermovement jump (4.7%), and knee flexor and extensor concentric peak torque in the dominant leg at $180^0$/sec (5% and 5.9%, respectively) in the experimental group, and a significant improvement in the countermovement jump (8.5%) in the control group. However, a significant decrease (-5.6%) was observed in the functional ratio at $180^0$/sec due to the greatest effect of pre-warm-up actions on the knee flexor and extensor concentric strength. **Conclusions:**The results indicate the effectiveness of pre-warm-up exercise program on most of the muscle performance markers. Further consideration is needed to improve the eccentric strength during warm-up.
**Keywords: Range of Motion (ROM), power, peak torque, injury, performance**

## Introduction

Warm-up is the first part of a training process; it is aimed at maximizing performance and reducing the injury risk of athletes, particularly soccer players (Young and Behm, 2002). In recent years, soccer coaches and fitness experts have been conducting pre-warm-up actions for better preparation of soccer players, using individual portable instruments (e.g. foam rollers (FR), Both Sides Utilized (BOSU) balance trainer, resistance elastic bands) (Kyranoudis et al., 2018; Madoni et al., 2018; Wallace et al., 2006), specific muscle strengthening exercises (e.g. core stabilizing and strengthening exercises) (Healey et al., 2014), or even specific prevention programs (e.g. FIFA 11+, Harmoknee) (Ayala et al., 2017; Bizzini et al., 2013; Brito et al., 2010; Daneshjoo et al., 2012), the use of which, however, has not been adequately studied.

A typical warm-up structure in soccer includes a general and a specific part, with a stretching phase between them. The general part includes aerobic running and body activation exercises designed to increase muscle and body temperature, while stretching aims to increase joint flexibility (Behm and Chaouachi, 2011; Young and Behm, 2002). The pre-warm-up actions are applied before warming up, to reduce or replace the general part. Therefore, the aim of these actions has to be increasing the muscle and body temperature, as well as joint mobility and flexibility. To the authors' knowledge, no studies have examined the effects of all pre-warm-up actions combined. But several studies have applied such actions individually, although not as pre-warm-up actions (Cheatham et al., 2015; Healey et al., 2014; Kyranoudis et al., 2018; Madoni et al., 2018; Wallace et al., 2006). In soccer training, FR use has become a common practice. Short-term FR interventions (30 sec) at the lower extremities do not appear to adversely affect muscle performance and possibly alter the perception of fatigue (Cheatham et al., 2015). Explosive-type actions, such as jumping and sprinting, have been affected by the duration of static stretching (Behm and Chaouachi, 2011). The combination of FR and static stretching seems to have a better response to muscle performance and flexibility (Cheatham et al., 2015; Kyranoudis et al., 2018). Furthermore, coaches pay particular attention to the strengthening and stabilizing of core muscles using


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isometric exercises such as planking, as well as exercises on unstable surfaces (e.g. BOSU ball) that help increase the core and lower extremity muscle activation (Behm et al., 2010). Anderson and Behm (2005) reported greater activation of the subcutaneous (30–40%) and quadriceps (5–15%) muscles when participants performed semi-squats on unstable surfaces. The use of unstable surfaces has a positive effect on player balance and proprioception, elements that are considered essential to increased performance during a soccer game (e.g. shooting, passing) (Cherah et al., 2016). The use of elastic resistance bands seems to have a positive effect on the muscle performance of athletes (Rhea et al., 2009; Wallace et al., 2006) and is considered a more appropriate means of muscle recruitment (Brandt et al., 2013). Rhea et al. (2009) found improvements in lower limb strength by 9.6% and 3.2% with the use of elastic band resistance exercises with slow and fast execution respectively, while Wallace et al. (2006) found greater gains in strength performance (16%) using elastic resistance bands during back squat exercise. At the same time, specially designed warm-up programs have been implemented for soccer players, such as FIFA 11+ and Harmoknee (Daneshjoo et al., 2012), whose acute effect presents conflicting results on both performance (e.g. sprints) and injury risk factors (Ayala et al., 2017; Bizzini et al., 2013). Soccer performance depends on a number of parameters related to technique, tactics, fitness, and physiological and mental functions (Ruas et al., 2015). During a game, players (except the goalkeepers) cover 10–13 km mostly in low speed or even by walking (Bangsbo et al., 2006). Also, they run with high intensities (19.8 km/h-1), do sprint actions (>25 km/h-1) every 70–90 sec (Bangsbo and Mohr, 2005), and perform 1000–1400 quick actions every 4–6 seconds (Stølen et al., 2005). Accelerations and decelerations also increase the total workload of soccer players (Russell et al., 2016). The players' performance in the above parameters is constantly increasing over the years due to the increased demands of the sport (Barnes et al., 2014). The increased running speed observed in the game, combined with shorter but also more explosive sprints, leads to the improvement of acceleration capacity, which, however, tends to increase the injury risk (Barnes et al., 2014).

In soccer, the majority of injuries (87%) occur at the lower extremities (Healey et al., 2014). The most common injuries are muscle strains, with the knee flexors (KF) being the most common muscle group of such strains (12%), while strains of the knee extensors (KE) occur less often (5%) (Ekstrand et al., 2011). Muscle weakness in the KE, but especially in the KF, leads to injuries (Croisier et al., 2002). The KE are activated during jumping, sprinting and shooting, and most of the time operate concentrically, while, simultaneously, the KF work eccentrically to protect the knee joint from overloading, decelerating the forward movement of the tibia (Denadai et al., 2014; Yeung et al., 2009). However, one of the major causes of injury to players' lower limbs, especially in the posterior thigh muscles and Anterior Cruciate Ligament (ACL), is the muscle imbalance between the KF and KE (Brito et al., 2010; Yeung et al., 2009). Also, during sprinting, jumping or shooting, when the KF act as extensors, their function shifts abruptly from eccentric to concentric, thus increasing the injury risk (Petersen and Homlich, 2005). Other factors that can lead to such injuries are decreased flexibility of the KF (Croisier et al., 2002) and muscle fatigue (Draganidis et al., 2015). Isokinetic dynamometers are used for the assessment and evaluation of muscular peak torque (PT) (Zakas et al., 1995), as well as the control of muscular imbalances between the knee joint muscles (Bogdanis and Kalapotharakos, 2016). The most common method of estimating muscle imbalances between the KF (hamstrings, H) and KE (quadriceps, Q) is the hamstrings to quadriceps ratio (H/Q) (Myer et al., 2009), which is used to examine and evaluate knee functional ability and stability as well as the muscular balance between agonist and antagonist knee joint muscles during explosive movements (Aagaard et al., 1995). The most frequently recorded PT balance indices are the conventional ratio (CON H/Q) (Hconcentric/Qconcentric) and the functional ratio (FUN H/Q) (Heccentric/Qconcentric) (Croisier et al., 2002; Ruas et al., 2015), with FUN H/Q considered the most appropriate assessment of muscle imbalance (Aagaard et al., 1998) because the actual knee movement is performed with an eccentric contraction of the KF and a simultaneous concentric contraction of the KE at knee extension, or vice versa during knee flexion (Yeung et al., 2009). Given that coaches and fitness experts adopt various instruments or exercises as pre-warm-up actions to increase muscle temperature and stretching, as well as joint mobility, it would be useful to explore the effect of a combined pre-warm-up exercise program that includes foam rolling, static stretching, neuromuscular control exercises on unstable surfaces, and muscle activation exercises on flexibility, lower limb PT and, in particular, H/Q PT ratio, which is a lower limb muscle imbalance indicator and prevents the risk of injury. The purpose of the present study, therefore, was to evaluate a combined pre-warm-up exercise program that included warm-up exercises for muscular activation, strengthening and neuromuscular control, which fitness experts use prior to warming up to boost soccer players' flexibility, strength and power.

**Materials and methods**

**Participants**

Twenty-three (n=23) lower-level professional male soccer players (3rd Greek professional league) participated voluntarily in this study. The selection criteria included: a) no recent musculoskeletal injuries, b) no medication, c) participation in at least three training sessions/week of 90 minutes each, and d) participation in one game/week. Participants were informed in writing of the purpose of the study, the benefits and risks, and signed the consent form for their participation in the research. After the end of the second visit, they were randomly assigned to two groups: a) control (N=10) (20.95 ± 0.8 years, 179 ± 0.59 cm, 78.32 ± 7.67 kg) and b) experimental (N=13) (21.18 ± 1 years, 178 ± 0.55 cm, 76.4 ± 4.57 kg). The study was approved by the Democritus university of Thrace institutional review board and ethics committee. All the procedures were in accordance with the Helsinki Declaration.

**Procedures**

The study was conducted on three laboratory visits in three consecutive weeks on the same day and time for each participant. Program participation and measurements were made 48–72 hours after each game to reduce the effect of fatigue (Draganidis et al., 2015), and participants were asked not to engage in any other activity until the day of the measurements. The first visit included body measurements and familiarization with the intervention protocol and measurements. The height and weight of the participants were measured with an electronic scale (SECA 767 scale; Body Scale 500, Seca Gmbh & Co. Kg., Hamburg, Germany). During the second visit, hip flexion range of motion (ROM), countermovement jump with the arms akimbo (CMJ), countermovement jump with free arms (CMJ FREE), and measurements of PT on the isokinetic dynamometer (KF and KE concentric and eccentric PT) were evaluated after a 5-minute warm-up with light aerobic exercise. The same sequence was followed in the final measurements after the implementation of the intervention program. The measurements of the isokinetic PT were done first on the dominant leg (DL) (the one used to kick the ball for maximal distance) of every participant in the following order: isometric PT, isokinetic PT (concentric–eccentric). The same measurements on the non-dominant leg (NDL) followed. Afterwards, the participants were randomly assigned to two groups: control and experimental. On the third visit, the experimental group participants performed the intervention program in the following sequence: flexibility exercises (FR, static stretching), planking, exercises for muscle activation (dynamic passages over hurdles, resistance elastic bands) and balance exercises (BOSU). This program was chosen for two reasons: first, to the best of our knowledge, the coaches use these exercises or instruments in no specific order, probably due to the lack of sufficient number of the same instruments, and, secondly, this program includes the same parts of other specific warm-up programs, such as FIFA 11+ and Harmoknee (Ayala et al., 2017). After a 1-minute break, the participants started the final measurements for flexibility, and the measurements for power followed. Initially, 2 jumps (CMJ) were performed with a 30-second break in between and 2 more jumps followed with the players' hands free (CMJ FREE) with the same length of break in between. After 2 minutes, the participants performed the isokinetic measurements. The control group participants performed 5-minute warm-up on the cyclometer and stayed inactive (without doing anything) for approximately 20 minutes until their final measurements. This time corresponded to the rest of the intervention program of the experimental group.

**Measures**

*Warm-up intervention:*

Each participant performed a 5-minute warm-up on the cyclometer at 74 watts (1.5kg, 50rpm, Monark cycle). Immediately after, the following intervention program was performed:

*Foam rolling protocol*

Participants performed massage exercises using FR, which lasted for 30 seconds for each of the following muscle groups in the given order: KE, KF, gastrocnemius, abductors and adductors. Exercises for the KE and KF as well as for the gastrocnemius were performed simultaneously for both limbs, as described in the protocol of Jones et al. (2015) and Kyranoudis et al. (2019), using a FR of larger dimensions (Power Force FR 60x14cm- BR-2010). Exercises for the abductors and adductors were performed for 30 seconds per limb without a break between limb shifts using a smaller FR (Amila 33x13cm, FR-48197). The 30-second duration is in agreement with the duration in other studies (Healey et al., 2014; Jones et al., 2015; Kyranoudis et al., 2019). After each exercise, there was a 30-second break when participants performed no activity.

*Static stretching protocol*

Participants performed static stretches of the KE, KF, abductors and gastrocnemius for 10 seconds per limb, as in previous research (Kyranoudis et al., 2019). There was no break between exercises or between legs. The short duration (10 seconds) of the stretch was chosen due to the players' daily habit of performing short stretches during training sessions (Kyranoudis et al., 2019).

*Core stability exercises*

Participants performed stabilization exercises on a flat surface on the ground. The exercises included the "forearm bridge", the "lateral bridge" and the "back bridge". The duration of each "bridge" was 20 seconds, with an intermediate 15-second break, while the total duration of the exercises was approximately 2 min.

*Dynamic passages over hurdles*

Participants performed muscular activation exercises over 5 hurdles, each of height 85 cm, with a 70-cm space between two consecutive hurdles. Initially they performed with the right foot, and then with their left after changing sides, except for the last exercise which was performed in the opposite order. There was a 10-second break between the exercises, with no break after performing exercises with the other legs when sides were changed. The total duration of the exercises was approximately 2 minutes. After the end of all exercises, there was a 30-second break.

*Muscle activation and strengthening with resistance elastic bands*

Participants performed muscle activation and strengthening exercises for KE, KF, adductors and peroneus muscles, using a THERABANDTM green resistance elastic band mounted on the base of a bench.

Participants, starting with the right limb, performed 15 repetitions per muscle group with a 15-second interval, and then changed to the left limb. The total exercise duration was 4 minutes, followed by a 30-second break.

*Balance exercises*

Participants, barefoot, performed balance exercises using the BOSU ball (BOSU; Fitness Quest, Canton, OH), which was 25.4-cm high and 54.5 cm in diameter. In single-leg exercises, they always started with the right foot (R). They started with a unilateral stance on the ball for 15 seconds with each limb, followed by a unilateral stance with trunk excursion on the ball for 10 repetitions on each limb, and ended with 12 semi-squats on the ball. At the end of each exercise, the participants had a 30-second passive break, with a total duration of 4 min. The muscle activation and balance exercises are described in Table 1.

**Table 1. Muscle activation and balance exercises.**

| Intervention | Exercise | Duration |
|---|---|---|
| **Dynamic passages over hurdles** | Participants were standing next to the hurdle, facing forward, with their hands at the waist. With the right knee bended they passed the leg over the hurdle, extended it, landed it on the ground and with a slight bounce on the landing leg they repeated the motion over the next hurdles. Immediately after they did the same exercise with the left leg of the opposite side. | 5 rep/leg |
| | Participants were standing next to the hurdle, facing forward, with their hands at the waist. With the right knee bended they were passing their leg lateral and over the hurdle, landing it on the ground and with a slight bounce on the landing leg, they repeated motion with the same leg at the next hurdles. Immediately after they did the same exercise with the left leg of the opposite side. | 5 rep/leg |
| | Participants were standing side by side in the hurdle with their hands free. With the right knee extended they were passing their leg lateral and over the hurdle, landing it on the ground and with a slight bounce on the landing leg they repeated the same movement and the next hurdles. Immediately after they did the same exercise with the left leg of the opposite side. | 5 rep/leg |
| | Participants were standing next to the hurdle, facing it, with their hands at the waist. With the right knee extended they passed the leg over the hurdle with an inward turn, landed it on the ground and with a slight bounce on the landing leg they repeated the motion with the same leg at the next hurdles. Immediately after they did the same exercise with the left leg of the opposite side. | 5 rep/leg |
| | Participants were standing next to the hurdle, facing it, with their hands at the waist. With the left knee extended they passed the leg over the hurdle with an outward turn, landed it on the ground and with a slight bounce on the landing leg they repeated the motion with the same leg at the next hurdles. Immediately after they did the same exercise with the right leg of the opposite side. | 5 rep/leg |
| **Resistance elastic bands** | Participants, standing upright, placed the resistance elastic band above the ankle joint and extended it to the point where it was not loose. From this position they moved the leg forward, with the knee joint extended, to the point of disruption and returned to the original position. | 15 rep/leg |
| | Participants, on a prone position, supported on their elbows, placed the resistance elastic band exactly over their Achilles tendon and bending the leg, extended it to the point where it was not loose. From this position they bended the leg to the buttocks and returned to the original position. | 15 rep/leg |
| | Participants, standing upright, placed the resistance elastic band above the ankle joint and extended it to the point where it was not loose. From this position, they adducted the leg until the height of the stable leg, with the knee joint extended, and returned to the original position. | 15 rep/leg |
| | Participants, in seating position and supporting on their palms, put the resistance elastic band at the height of their fingers of the remote leg and extended it to the point where it was not loose. During the exercise the working leg was extended while the opposite leg was bent and the sole was beneath the knee of the working leg. From this position, they were performing outside turn and returned to the original position. | 15 rep/leg |
| **Balance** | Participants were on the BOSU, barefoot, with eyes open and hands free for better balance, standing on a leg, that was slightly bent. The other leg was bent under the body, not touching the BOSU surface. They held this position for 15 sec and then repeated with the other leg. | 15 sec/leg |
| | Participants were on the BOSU, barefoot, with eyes open and hands free for better balance, standing on a leg, that was slightly bent. The other leg was bent under the body, not touching the BOSU surface. From this position they bended the trunk forward, lifted the free leg backwards and returned to their original position for 10 repetitions, repeating with the other leg. | 10 rep/leg |
| | Participants were on the BOSU, barefoot, with eyes open and hands free for better balance. Both legs were symmetrically around the center of the ball and slightly bent. From this position they did a squat at a $90^0$ angle (approx.), extending both hands forward, parallel to the ground, and returned to the initial position for 12 repetitions. | 12 rep |

***Assessments***

*Flexibility*: Hip flexion measurement was performed using the Myrin goniometer (Lic. Rehab. 17183 Solna, Sweden).

*Power measurements*: The OptoJump photoelectric cell system (Microgate, Bolzano, Italy) was used to measure jump height and power (CMJ test and CMJ free test). The procedure for performing the two tests has been described by Kyranoudis et al. (2019).

*Isokinetic measurement*: Force measurements (isometric, concentric and eccentric KE and KF PT) were carried out with the ISOFORCE isokinetic dynamometer (Isoforce, TUR Gmbh, Berlin, Germany) at 60o/sec and 180o/sec on both limbs, initially on the dominant one, according to the instructions of Draganidis et al. (2015).

***Statistical Analyses***

All statistical analyses were performed using SPSS version 20.0 for Windows (SPSS Inc., Chicago, IL, USA). The Shapiro–Wilk test was utilized to verify data normality. A two-way repeated measurements ANOVA ("group" and "time") analysis were used to analyze the data. Wherever significant interaction was found, the paired sample t-test was used for further study. Statistical significance was accepted at $p < .05$.

**Results**

The results are presented in Table 2 as mean ± standard deviation (SD). The two-factor repeated measurements ANOVA resulted in a significant interaction between the factors ("group" and "time") in ROM ($F_{1,21}$=60.373, p=0.000, $\eta_p^2$=0.742), CMJ ($F_{1,21}$= 7.916, p=0.01, $\eta_p^2$=0.274), right limb KE concentric PT (CONQR) at the 1800/sec angular velocity ($F_{1,21}$= 11.838, p=0.002, $\eta_p^2$=0.360), right limb KF concentric PT (CONHR) at the same angular velocity ($F_{1,21}$= 4.337, p=0.05, $\eta_p^2$=0.171), and FUN H/Q of the right knee at the same angular velocity ($F_{1,21}$= 4.659, p=0.04, $\eta_p^2$=0.182) (Figure 1). Further analysis of the interaction using paired sample t-test showed a significant main effect of the "group" factor on the experimental group in all of the above measurements (ROM: t(12)=-12.58, p=0.000; CMJ: t(12) =-10.38, p=0.000; CONQR: t(12) =-4.31, p=0.001; CONHR: t(12) =-2.6, p=0.02; FUNH/Q: t(12) =2.84, p=0.01), while a significant effect was also observed in the control group in CMJ (t(9) = -6.73, p = 0.000).

Table 2: Flexibility, Power, Quadriceps and Hamstrings Peak Torque

| | PRE (means±SD) | | POST (means±SD) | |
|---|---|---|---|---|
| measurements | Control | Exper | Control | Exper |
| ROM | 110.4±4.69 | 107±4.93 | 110.9±5 | 112.85±5.64* |
| CMJ | 34.81±4.72 | 36.06±1.82 | 37.77±5.15* | 37.76±1.77* |
| CMJFREE | 43.45±7.75 | 43.96±4.08 | 44.16±7.68 | 44.6±4.11 |
| CONQR60 | 215.28±35,12 | 223.68±28.6 | 214.14±36.27 | 225.03±25.51 |
| CONQL60 | 208.17±42.26 | 225.18±28.2 | 208.72±42.52 | 225±31.49 |
| CONQR180 | 152.32±20.22 | 159.83±18.02 | 152.94±19.46 | 169.33±18.67* |
| CONQL180 | 149.1±25.5 | 161.29±15.82 | 149.35±25.67 | 161.99±14.63 |
| CONHR60 | 134.39±25.22 | 137.03±24.52 | 135.22±26.57 | 131.73±27.68 |
| CONHL60 | 120.14±23.73 | 133.01±23.53 | 120.22±23.81 | 134.07±18.84 |
| CONHR180 | 104.55±22.88 | 101.23±21.72 | 104.84±23.69 | 106.36±23.4* |
| CONHL180 | 93.85±21.34 | 99.48±25.41 | 94±22.36 | 101.1±21.14 |
| ECCHR60 | 171.68±26.03 | 181±29.85 | 172.36±27.52 | 180.06±24.15 |
| ECCHL60 | 159.26±26.43 | 167.2±22.84 | 159.52±28.07 | 168.63±23.29 |
| ECCHR180 | 157.08±25.26 | 171.03±27.52 | 156.99±26.32 | 169.87±21.18 |
| ECCHL180 | 150.42±33.63 | 164.1±23.43 | 150.53±34.45 | 160.71±20.94 |
| CONHQR60 | 0.62±0.07 | 0.61±0.08 | 0.62±0.07 | 0.60±0.06 |
| CONHQL60 | 0.57±0.07 | 0.58±0.07 | 0.57±0.08 | 0.59±0.07 |
| CONHQR180 | 0.67±0.12 | 0.62±0.1 | 0.67±0.12 | 0.62±0.01 |
| CONHQL180 | 0.61±0.10 | 0.61±0.11 | 0.62±0.09 | 0.61±0.09 |
| FUNHQR60 | 0.81±0.14 | 0.81±0.1 | 0.81±0.01 | 0.79±0.06 |
| FUNHQL60 | 0.78±0.16 | 0.74±0.08 | 0.78±0.17 | 0.75±0.11 |
| FUNHQR180 | 1.03±0.17 | 1.06±0.13 | 1.03±0.17 | 1±0.1* |
| FUNHQL180 | 1.01±0.2 | 1.01±0.09 | 1.01±0.2 | 0.98±0.01 |

*ROM: Range of Motion, CMJ: Countermovement jump akimbo, CMJFREE: Countermovement jump with free hands, PT: Peak Torque, CON: Concentric PT, ECC: Eccentric PT, Q : Quadriceps, H: Hamstrings, R: Right Foot, L: Left Foot, CONHQ: Conventional ratio H/Q, FUNH/Q: Functional ratio H/Q, 60,180: $60^o$/sec, $180^o$/sec angular velocity. *: p≤0.05.*

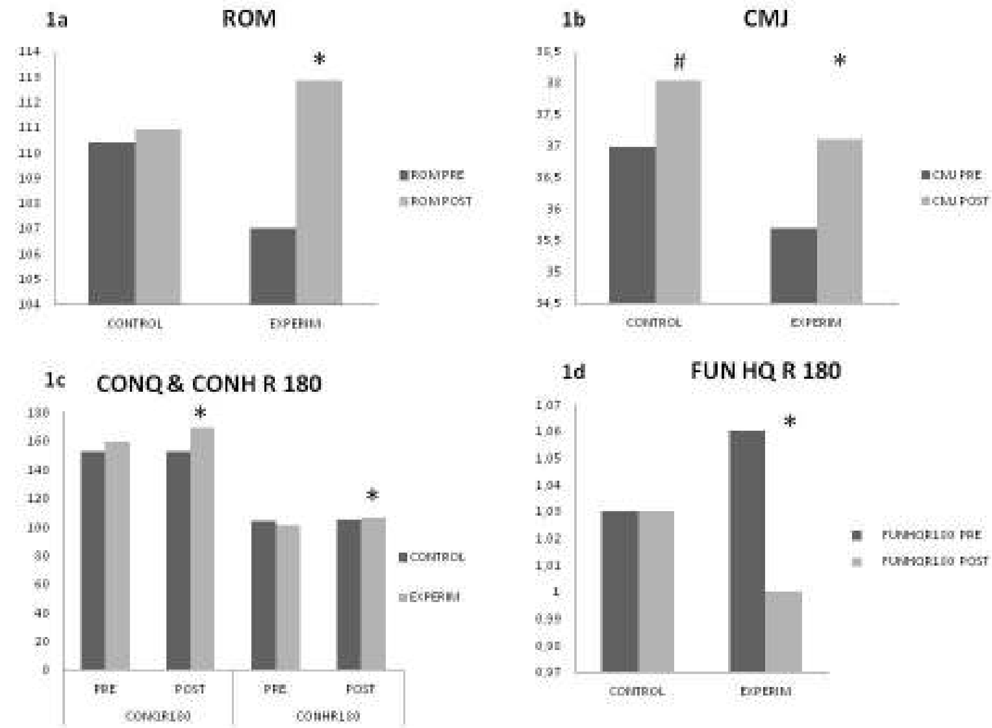


Fig. 1. Changes in performance: ROM (1a), CMJ (1b), CONQ & CONH in $180^0$/sec (1c) and CON H/Q in $180^0$/sec (1d). * Significant differences between PRE-POST in experimental group. # Significant differences between PRE-POST in control group. $p \leq 0.05$. ROM: Range of Motion, CMJ: Countermovement Jump, CON: Concentric peak torque, Q: Quadriceps, H: Hamstrings, FUN H/Q: Functional strength ratio, 180: $180^0$/sec angular velocity, R: Right foot, L: Left foot.

**Discussion**

The findings of the present study showed improvement in the hip flexion ROM, jumping ability after the CMJ, and KF and KE muscle concentric PT at an angular velocity of $180^o$/sec for the right leg after the implementation of a warm-up exercise program for lower-level professional soccer players. On the other hand, there was a significant decrease, for the same leg and at the same angular velocity, in the FUN H/Q of the experimental group (but not below the cutoff value).

There was a significant increase in the hip flexion ROM for the experimental group. Although not many studies have examined the acute effect of a combined program on the ROM, Ayala et al. (2017) recorded improvement trends in the ROM of the lower limb joint after the implementation of the Harmoknee due to static stretching, which was included in this program. The use of static stretching in combination with FR appears to improve hip flexion ROM (Kyranoudis et al., 2019; Mohr et al., 2014), a combination that was included in the present study. Other researchers reported that core stability exercises are related to FR exercises due to the similarity observed in the position of the body during the execution of these exercises, which may contribute, additively, to increased muscle temperature, blood flow and flexibility (Healey et al., 2014). Generally, factors responsible for this improvement may be the increased muscle temperature, thixotropic property of fascia, and decreased resistance to stretch (Mohr et al., 2014), as well as the shorter duration of the stretches (Behm and Chaouachi, 2011; Kyranoudis et al., 2019).

A significant increase in vertical jump height was observed during the CMJ both in the experimental and control group, but there was no improvement during the CMJ FREE performance. Elevated muscle temperature, as well as the no-temperature-related factors, such as post-activation potentiation (PAP) appearing after resistance-based exercises, might be factors that led to improved jump height (Bishop, 2003a). Power improvement, as recorded during the CMJ test, might have been due to an increase in the rate of force development (RFD), which was observed after resistance band exercises because of the stretch-shortening cycle, as the muscle stored elastic energy during the eccentric phase and released it during the concentric phase of the lift (Rhea et al., 2009). In a study by Kyranoudis et al. (2019), a similar combination of FR and static stretching to that employed in the present study showed a significant improvement in lower limb power (CMJ). A significant improvement in CMJ performance was also observed in the control group after they used the cyclometer for only 5 minutes. Andrade et al. (2015) also recorded similar improvement where participants performed a 5-minute run at an intensity corresponding to 70% of the predicted maximum heart rate. This improvement may be attributed to the increased muscle temperature. On the other hand, there was no significant difference in jump height during the CMJ FREE. This might have been due to the role of the hands during the jump. Hands were used for storing energy in the early stages and transferring energy in the later stages of the jump (Lees et al., 2004). Since there was no intervention of the protocol for the hands, it is likely that their role remained dominant even after the implementation of the intervention program, and thus no significant difference in the height of the jump occurred.

As mentioned, PT and muscular imbalances between KF and KE muscles are evaluated with isokinetic dynamometers (Bogdanis and Kalapotharakos, 2016; Zakas et al., 1995). The most common method of estimating muscle imbalances between the KF and KE is the H/Q ratio (Myer et al., 2009), which is distinguished into the conventional ratio (CON H/Q) (Hcon/Qcon) and the functional ratio (FUN H/Q) (Hecc / Qcon) (Croisier et al., 2002; Ruas et al., 2015), with FUN H/Q ratio considered the most appropriate indicator. The mean values of the above ratios, according to the literature, are 0.60 (Yeung et al., 2009) and 1.0 respectively (Aagaard et al., 1995; Baroni et al., 2018), where these values are proportional to the angular velocity of movement.

The present study showed a positive effect on the concentric PT of KF and KE at an angular velocity of 180°/sec for the right leg only. This was probably due to the use of the DL and also the level of the participants. Of the 13 participants in the experimental group, only 3 were left-footed, while the rest had the right leg as the DL. In soccer, the DL is used mostly for the technical execution of soccer actions (shoot, pass), while the NDL has a more stabilizing role (Daneshjoo et al., 2012; Draganidis et al., 2015). Draganidis et al. (2015) reported greater reductions in DL performance after a soccer game, particularly in the KF PT at higher speeds, as the DL was used more. Lower-level soccer players (e.g. amateurs) seem to use the DL more than professionals (Daneshjoo et al., 2012), which may justify the results of this research, since the sample, as mentioned, was comprised of semi-professional players (3rd professional league) and the majority had the right foot as the DL. Commeti et al. (2001) observed similar results in soccer players, where amateur players had greater values of KE PT than professional players.

Studies using combined programs almost similar to the current intervention (FIFA 11+, Harmoknee) have shown conflicting results for the FUN H/Q ratio either after chronic or mainly acute implementation (Aguilar et al., 2012; Ayala et al., 2017). Aguilar et al. (2012) did not observe a decrease in the FUN H/Q ratio at an angular velocity of 60°/sec despite an increase in KE torque, as there was probably no proportional increase in KF PT. In contrast, Ayala et al. (2017) recorded that there was greater improvement in the FUN H/Q ratio after dynamic warm-up than after the combined programs, like FIFA 11+ and Harmoknee, at an angular velocity of 180 °/sec. It should be noted, however, that the FUN H/Q value after the Harmoknee warm-up program was lower than after the other two programs. This reduced FUN H/Q ratio response might have been due to the decrease in the body temperature observed after the Harmoknee, while isokinetic measurements were made 3 minutes after the end of the program, but these minutes should have been added to the 4 minutes of "bridge" exercises for core stability included in the above program where there was no movement. The drop in body temperature began to occur gradually after 5 minutes of the interruption of the effort (Towlson et al., 2013) and thus a longer inactivity might have led to a decrease in performance. In contrast, the last part of the FIFA 11+ consisted of running exercises and the dynamic warm-up program included acceleration and jumping exercises. Similarly, the warm-up exercise program implemented in the present study probably had a negative effect on body temperature, since its latter part had no significant movement decreasing or even maintaining body temperature (BOSU balance exercises). The duration of these exercises was 4 minutes, in addition to at least 4 more minutes for break and flexibility and power measurements, until the isokinetic measurements were carried out.

The increased FUN H/Q ratio can be attributed to the torque–speed ratio in both the concentric and eccentric muscular effort (Aagaard et al., 1995; Cometti et al., 2001). However, Ruas et al. (2015) reported that eccentric contraction appears not to be particularly affected during fast muscle contractions, or even appears to be more sensitive to reduction in response to soccer-related actions than concentric contraction (Draganidis et al., 2015). In the FUN H/Q ratio, the eccentric contraction of the KF, expressed as the ratio numerator, remains constant regardless of the angular velocity, while the denominator, representing the KE concentric PT, decreases with increasing angular velocity, thus achieving a value around the unit (1.0) more easily at higher angular velocities (Baroni et al., 2018). However, in the present study, the denominator (KE concentric torque) increased, while the numerator (KF eccentric torque) remained almost constant, so a decline in FUN H/Q ratio was observed at 180°/sec. The imbalance in FUN H/Q ratio, according to Bogdanis and Kalapotharakos (2016), might be due to disproportionately high quadriceps PT and not only due to reduced hamstring muscle PT. Daneshjoo et al. (2012) also observed a decrease in FUN H/Q ratio, after an 8-week application of the FIFA 11+ and Harmoknee programs, due to increased quadriceps PT. It is likely that the basic parts of the combined programs had a higher effect on the isokinetic PT of the KE than the KF PT (Daneshjoo et al., 2012). To this end, there is probably the need to reinforce these programs with exercises that further strengthen the KF (e.g. Nordic, hamstrings curl, prone leg drops) (Daneshjoo et al., 2012) or to modify the order of the constituent parts to maximize the benefits of the individual parts of the combined programs.

Last but not least, another possible reason for the decrease in FUN H/Q ratio as a result of the increased KE PT may be the professional level of the sample participants. The players in this sample, as mentioned already, were lower-level professional players, as opposed to higher professionals in other studies (Bogdanis and Kalapotharakos, 2016; Cometti et al., 2001). In the study by Commetti et al. (2001), professional players had stronger KF than amateurs, particularly eccentric torque, which also enhanced the FUN H/Q ratio. However, Bogdanis and Kalapotharakos (2016) reported that the professional soccer players involved in their research had higher KE PT values and, therefore, reduced FUN H/Q ratio. Generally, professional players have a higher PT than amateurs due to the form of the training and competition, leading to a greater increase in KF and KE PT (Oberg et al., 1986), since these muscle groups are involved more in soccer actions such as shooting, running and jumping (Daneshjoo et al., 2012; Denadai et al., 2014). Finally, Commetti et al. (2001) reported that PT enhancement favors KE more than KF, although there is an opposite view (Denadai et al., 2014).

**Conclusions**

The present study examined the effect of a combined program involving muscular activation and neuromuscular control with or without instruments (FRs, static stretching, core stability exercises, elastic bands, BOSU ball), used as pre-warm-up actions, on performance markers and injury prevention. This program seemed to improve flexibility, concentric PT of the KF and KE at relatively high angular velocity, and the jumping ability of soccer players, thereby assisting in soccer actions that require high speed and power output (e.g. shooting, jumping). Therefore, the program could be implemented before the traditional warm-up or to replace part or all of the general warm-up, as it seemed to contribute to increased muscle temperature and joint flexibility and mobility. On the other hand, the program did not seem to help particularly in injury prevention, as expressed by the FUN H/Q ratio between the KF and KE muscles, due to the lack of increase in the KF eccentric force. A modification of the program parts or an inclusion specific exercises focused on KF to an order that will help soccer players maximize benefits and enhance more KF strengthening is likely to have a greater impact and produce better results in player preparation. Our suggestion is that such a warm-up exercise program could be made part of the warm-up routine of soccer players in the gym before they leave for the field for the specific part of warm-up.

**Conflicts of interest**
The authors have no conflict of interest to declare.

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