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RESEARCH ARTICLE

Effects of Warm-Up and Fatigue on Knee Joint Position Sense and Jump Performance

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ABSTRACT. The purpose of this study was to evaluate the effects of a warm-up and fatigue protocol on the vertical jump and knee joint position sense of sprinters. Thirty-two sprinters were randomly allocated to either a control group (CONT) or a plyometric group (PLYO) that performed a warm-up, followed by a high-intensity plyometric protocol. Absolute (AAE), relative (RAE), and variable (VAE) angular errors and vertical jump were evaluated before and after the warm-up, as well as after the plyometric protocol and again 5 min later. After the warm-up, athletes improved RAE and jump performance. After the plyometric protocol, scores on the RAE, VAE, and the vertical jump performance worsened compared to the control group and to the values obtained after the warm-up. Five minutes later, RAE and vertical jump continued to be impaired. AAE did not show significant differences. The vertical jump is improved after the warm-up, although it is deteriorated after high-intensity plyometry. Regarding knee proprioception, the lack of impairments in the AAE make unclear the effects of the plyometric exercises on knee proprioception**.**

Keywords: athletes, fatigue, plyometric exercise, proprioception, sports performance

Plyometric training requires explosive muscle movements from an elongation to a shortening of the muscle (McNeely & Sandler, 2006). Most athletes perform plyometrics to increase their sports performance due to the benefits of plyometrics on muscle strength and power after several weeks of training. Coaches include this exercise as a part of training routines because it maximizes vertical jump and sprints (Markovic, 2007; Myer, Ford, Brent, & Hewett, 2006; Saez-Saez de Villarreal, Requena, & Newton, 2010).

However, because of the explosivity that plyometric training requires, it is one of the most exhausting and damaging exercises for the athletes, who reach high levels of peripheral and central fatigue (Comfort & Abrahamson, 2010; Drinkwater, Lane, & Cannon, 2009). Therefore, authors suggest at least 42 hr to recover the athlete's entire physical capacity after plyometric training (Lepin & Andrade, 2012; Meylan & Malatesta, 2009). Thus, studies analyzing effects of plyometrics reported immediate impaired physical abilities (i.e., vertical jump, rate of force development, strength, and agility), as well as proprioceptive skills, which could make athletes more prone to injury (Drinkwater et al., 2009; Givoni, Pham, Allen, & Proske, 2007; Romero-Franco & Jimenez-Reyes, 2015; Twist, Gleeson, & Eston, 2008).

To date, several researchers have analyzed the effects of fatigue on proprioceptive skills by using general exercise protocols involving the whole body (e.g., 212 continuous ground contacts, stepping down 792 stairs, or repetitions with weighted balls and elastic tubes), as well as local exercise protocols involving part of the body (e.g., isokinetic concentric and eccentric muscle actions in the shoulder or ankle regions, or flexion-extension movements in the knee or elbow regions; Drinkwater et al., 2009; Givoni et al., 2007; Ribeiro, Venancio, Quintas, & Oliveira, 2011; Sandrey & Kent, 2008; Tsay, Allen, Leung, & Proske, 2012; Twist et al., 2008; Walsh, Hesse, Morgan, & Proske, 2004). However, the variety of plyometric protocols and the population used by the authors hampers comparisons of the results (Drinkwater et al., 2009; Romero-Franco & Jimenez-Reyes, 2015; Sandrey & Kent, 2008; Tsay et al., 2012). Additionally, as very few studies have evaluated the joint position sense after the high-intensity plyometric protocol (Vila-Cha et al., 2011), its influence remains controversial.

The purpose of the present study was to analyze the immediate effects of warm-up and plyometric exercises on the knee position sense of sprinters, as well as the effects found 5 min after the exercises were completed. Additionally, athletes performed a maximum squat jump to evaluate the level of fatigue as a result of the plyometric protocol. We hypothesized that the plyometric protocol would blunt the physical abilities (e.g., a decrease in the vertical jump height) and knee proprioception, and 5 min later the athletes would have only slightly recovered.

Methods

This research utilized a repeated measures, randomized controlled trial. Thirty-two male sprinters from an athletic club were recruited for this study in March 2014. The athletes were included in this study according to the following criteria: training for sprint races (100, 200, and 400 m), having at least two years of experience in the modality, being free from injuries in the last six months, and competing a the national level. Athletes were excluded from this study if they did not train

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regularly or had recently interrupted their training routine (at least three months without interruptions).

The athletes were randomly allocated into either a control group (CONT; $n = 16$) who rested or a plyometric group (PLYO; $n = 16$) who performed a warm-up followed by a protocol of plyometric exercise. An external assistant randomized the intervention to each participant using the Epidat software v.4.1, a computerized randomization program used to generate intervention allocation (Xunta de Galicia, 2014). Hence, the investigators who analyzed the data for each intervention were blinded to the subjects' group assignments. Additionally, subjects were blinded to the group to which they belonged due to the fact that we did not inform the participants about the actual purpose of the study and the existence of a parallel group.

Weight and height of the athletes were collected with a 100–300 g precision digital weight scale (Tefal, France) and a t201-t4 adult height scale (Asimed, Spain), respectively (Table 1). Before the start of the study, all athletes were briefed on the nature of testing and written informed consent was obtained from each subject, according to the standards of the Declaration of Helsinki (Goodyear, Eckenwiler, & Ells, 2008). The ethics board of our university approved this study.

All the athletes performed the pretest (Pre), consisting of a knee joint position sense test, a maximum squat jump, and a muscle soreness scale, to determine the level of fatigue of the athletes at every time point. These tests were repeated after the warm-up (Post-WU), right after the high-intensity plyometric protocol (Post0min), and 5 min later (Post5min). The Post5min measurement was included to evaluate the status of the athletes right before beginning other types of exercise in the same training session, which is very common after plyometric exercises (McNeely & Sandler, 2006). Although control group did not engage in any physical activity, the period of time between every measure was the same as that of the plyometric group.

The Joint Position Sense Test was assessed in the dominant knee in active–active modality (athletes actively reached and maintained the knee position; afterwards, they actively tried to repeat the position) and closed kinetic chain (CKC; Figure 1). To determine the dominant limb, the athletes were asked about the leg with which they would normally kick a ball. The athletes should stand on their dominant leg while supporting themselves using a chair as a stable object, as previous studies have recommended (Magalhaes, Ribeiro, Pinheiro, & Oliveira, 2010; Stillman & McMeeken, 2001), with a wedge under the heel of their dominant leg (height: 5 cm) to reduce passive tension on the triceps surae during the test (Magalhaes et al., 2010). Covering the eyes with a mask blocked the visual inputs for the athlete. Four markers were positioned on the dominant limb: (a) at the greater trochanter, (b) at the iliotibial tract level with the posterior crease of the knee when flexed to 80°, (c) at the fibula neck, and (d) at the fibular malleolus. From a standing position, the athletes actively positioned their knee at the target joint position, which was considered to be 50° (between 40° and 60° of knee flexion refers to intermediate ranges of knee flexion, where the mediation of muscle sensory in the sense of knee position predominate; Ribeiro et al., 2011). They actively held this position for five seconds to recognize the exact angle of the knee before then returning to the standing position. At the reposition voice order, the athletes were to reproduce the target joint angle as close as possible. They were then to maintain the

TABLE 1. Means and standard deviations of anthropometric characteristic of athletes allocated into the plyometric and control groups.

	Plyometric group ($n = 16$)	Control group ($n = 16$)
Age (years)	25.0 ± 3.6	24.7 ± 3.4
Weight (kg)	71.8 ± 9.2	72.7 ± 12.2
Height (m)	1.78 ± 0.05	1.78 ± 0.04
Body mass index (kg/m^2)	22.7 ± 3.0	22.8 ± 3.6

FIGURE 1. Test of knee joint position sense.

position for three seconds until the return voice order. The trial was repeated three times. The athletes were instructed to perform the test with a slow velocity of the repositioning movement (approximately 30°/s). The whole sequence was recorded with a video camera resting on a tripod placed at 7 m from the athlete, at the same level of the knee joint. To correct the parallax, natural vertical and horizontal lines in the videotaped environment were aligned parallel to the horizontal and vertical edges of the viewfinder. The images were analyzed using the Ariel Performance Analysis System software (Ariel Dynamics, CA; Ribeiro, Mota, & Oliveira, 2007). Every response position was determined as the average of seven consecutive knee angles, digitized at 50 Hz from the videotape view of each position. Reliability of this method was shown in previous studies (Magalhaes et al., 2010). Variables from the test were the following:

- Absolute angular error (AAE), defined as the difference between the target position and the mean of repositioning that the athlete carried out, without taking into account the direction of the difference.
- Relative angular error (RAE), defined as the difference between the target position and the mean of repositioning that the athlete carried out, taking into account the direction of the difference.
- Variable angular error (VAE), defined as the standard deviation from the mean of the relative errors.

The athletes performed the squat jump test as the maximum jump from an initial position where athletes should have their hands on the waist and 90° of knee flexion. From this position, athletes were asked to jump as high as possible without any counter-movement. When jumping, knees had to be extended up to 180° without hyperextending the hips. Subjects did three trials, with the best one used for the assessment. An OptoJump (Microgate Srl, Bolzano, Italy) photoelectric cell system was used in this test and its validity and reliability was shown in previous studies (Glatthorn et al., 2011).

Muscle soreness was evaluated and athletes were to indicate the level of pain they felt in the thigh and calf regions, with zero indicating no pain and 10 indicating maximum pain.

The plyometric exercise that athletes from PLYO group performed consisted of a 15-min warm-up involving 5 min of jogging (8 km/hr), 5 min of ballistic stretching and dynamic exercises, 10 repetitions of squats, and two sets of three vertical jumps (progressive intensity). After the warm-up, the experimental subjects completed a high-intensity plyometric exercise protocol consisting of 10 × 15 jumps (10 sets of 15 repetitions) with 45 s of recovery between sets. The maximum jump performed in the squat jump test determined the height target to which athletes were encouraged to reach during every vertical jump. The height was recorded by the infrared plate on the OptoJump interfaced with a laptop, whose validity and reliability was shown in previous studies (Glatthorn et al., 2011).

In the statistical analysis, values are reported as $M \pm SD$. The normal distribution of continuous variables was verified using the Shapiro-Wilk test due to the small simple size ($p < .05$). For the anthropometric variables, a Student's *t* test for independent samples was used. The general linear model for repeated measures with Bonferroni's post hoc comparisons was used to assess the effect of the intervention groups, with time and intervention group as intra- and inter-subject variables, respectively (repeated measures analysis of variance). Significance was determined at $p < .05$. Data were analyzed using SPSS for Windows, version 17 (SPSS, Inc., Chicago, IL) and MedCalc 12.1. (Mariakerke, Belgium).

Results

Table 1 shows the anthropometric characteristic of the athletes. No significant difference was found between the experimental and control groups.

Table 2 shows the values of AAE, RAE, and VAE from the JPS test, as well as data from the vertical jump performance. Regarding AAE, no significant differences were found between and within groups ($p > .05$) However, RAE showed a decrease of 3 degrees right after the warm-up in PLYO athletes ($p < .001$). This value increased 2.1° just after the plyometric protocol ($p = .001$) and remained increased 5 min later in the PLYO group ($p = .003$). In VAE, athletes from the PLYO group had higher values just after the plyometric protocol ($p = .040$), as well as 5 min later ($p = .011$; Table 2). The CONT group did not show any significant difference ($p > .05$).

Results from squat performance show 3.5 cm of increase in the vertical jump after the warm-up by the PLYO group compared with the baseline ($p < .001$) and 5.8 cm compared with the control group ($p = .012$). The vertical jump height decreased by 5.1 cm after the plyometric protocol ($p < .001$) compared to Post-WU measurements and increased 1.6 cm 5 min following plyometric exercise compare to the measurements that were taken immediately after the plyometric exercises ($p = .007$; Table 2). The CONT group did not show any significant difference ($p > .05$).

Muscle soreness in the thigh and calf regions increased just after the plyometric protocol in the PLYO group: 7.1 ± 2.0 and 8.3 ± 1.1 points, respectively ($p < .001$ and $p < .001$). Five minutes later, the level of muscle soreness decreased up to 4.1 ± 1.5 and 4.8 ± 0.5 points ($p < .001$ and $p < .001$), but was still higher than were the measurements taken prior to the plyometric protocol ($p < .001$). The CONT group did not show any significant difference ($p > .05$; Table 2).

Discussion

The present study showed that a short warm-up involving 5 min of jogging, dynamic stretching, and progressive sprints helped to improve the jump performance of the

TABLE 2. Means and standard deviations of joint position test of the knee, squat jump, and muscle soreness.

	Preintervention	Post-WU	Post0min	Post5min	Effects	p	η^2
AAE (°)					Time	.549	.023
Control	4.7 ± 3.0	4.0 ± 2.6	4.3 ± 2.8	3.7 ± 2.6	Training	.087	.094
Plyometry	5.8 ± 3.9	4.7 ± 2.1	6.0 ± 3.3	5.8 ± 4.9	Time*Training	.758	.013
RAE (°)					Time	< .001	.233
Control	1.9 ± 5.3	–1.6 ± 4.1	1.9 ± 4.6	1.1 ± 4.4	Training	.179	.059
Plyometry	4.6 ± 5.2	1.6 ± 4.3[b]	3.7 ± 5.4[c]	3.4 ± 6.6[c]	Time*Training	.367	.034
VAE (°)					Time	.123	.062
Control	2.5 ± 1.5	2.2 ± 1.7	2.2 ± 1.7	1.5 ± 0.9	Training	.043	.130
Plyometry	2.6 ± 1.6	2.7 ± 2.9	3.9 ± 2.8[a]	2.6 ± 1.6[a]	Time*Training	.144	.058
SJH (cm)					Time	< .001	.268
Control	29.7 ± 6.0	29.5 ± 5.7[a]	29.4 ± 6.1	29.3 ± 6.0	Training	.286	.038
Plyometry	31.8 ± 5.6	35.3 ± 6.5[b]	30.2 ± 5.9[c]	31.8 ± 5.6[d]	Time*Training	< .001	.259
Muscle soreness thigh (0–10 points)					Time	< .001	.828
Control	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	Training	< .001	.884
Plyometry	0.0 ± 0.0	0.0 ± 0.0	7.1 ± 2.0[abc]	4.1 ± 1.5[abcd]	Time*Training	< .001	.828
Muscle soreness calf (0–10 points)					Time	< .001	.899
Control	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	Training	< .001	.843
Plyometry	0.0 ± 0.0	0.0 ± 0.0	8.3 ± 1.1[abc]	4.8 ± 0.5[abcd]	Time*Training	< .001	.859

AAE = absolute angular error; Post-WU = measurements right after warming-up; Post0min = measurements right after the plyometric exercises; Post5min = measurements 5 min after plyometric exercises; RAE = relative angular error; SJH = squat jump height; VAE = variable angular error; [a]Between-group differences $p < .05$. [b]Within group differences from preintervention measurements $p < .05$. [c]Within-group differences from Post-WU measurement $p < .05$. [d]Within-group differences from post-0 min measurement $p < .05$.

athletes. The warm-up protocol was designed according to the previous literature and encourages the inclusion of aerobic exercise, stretching and activity similar to the physical exercise to be performed during the session (Fradkin, Zazryn, & Smoliga, 2010). Our findings support most of the previous studies that determined the warming up as an almost mandatory part of sports practice, prior to any training session or competition. The main reason concerns the effects on performance, which may increase up to 20% following the warm-up (Fradkin et al., 2010). Despite the high variability of warm-up protocols, warm-ups, in general, seem to improve performance in almost the 80% of the studies. It seems to be that the warm-up may facilitate the sports performance because of a higher muscle temperature, which would improve the jump performance, as our results showed (Hedrick, 1992). However, the duration and exercises of the warm-up protocol for optimizing and maximizing the sports performance remains unclear (Fradkin et al., 2010).

Regarding the effects of the warm-up on knee proprioception, our data showed that values of errors during repositioning tasks remained stable after warming-up, except for RAE, which improved after the plyometric protocol compared to the baseline. Previous studies, such as Magalhaes et al (2010), found that warming-up helped to improve joint position sense in karate. In addition, Subasi, Gelecek, and Aksakoglu (2008), reported proprioceptive improvements after five and, especially, 10 minutes of warming-up. Bartlett and Warren (2002) also showed that knee position sense was more sensitive after a warm-up and Salgado, Ribeiro, and Oliveira (2015) evaluated the effects of a 25-min warm-up on the knee proprioception of football players and reported decreases in AAE and RAE with an underestimation of the angle. The authors suggest that neurophysiological changes in the ligaments and muscles after exercise improve the joint appreciation of athletes (Bartlett & Warren, 2002). Despite the trend of improving knee proprioception that was shown in the present study, our findings do not support the previous studies due to lack of statistical differences in the AAE. The small sample may have led to the lack of statistical significance in the present study.

In reference to the effects of the high-intensity plyometric protocol, the jump performance decreased compared to the status reached after the warm-up, although the differences were not significant compared to the baseline. In this sense, it would be appropriate to compare the deterioring effects to the status reached by the athletes after the warm-up due to the fact that the warm-up is an almost mandatory part of the training. According to the literature, the warm-up may increase sports performance up to 20% (Fradkin et al., 2010). Also, to support our findings and taking into account the measures after the warm-up, Gorostiaga et al. (2010) developed a study to analyze decreases in the vertical jump performance during a high-intensity intermittent running session, and at the same time, analyzing blood lactate and ammonia levels. These authors compared decreases in the vertical jump to the baseline, which referred to the status reached by the athletes after a 20-min warm-up. In this sense, they reported that vertical jump began to decrease compared to the baseline (just after warming-up) when blood lactate levels exceeded 8–12 mmol/l (Gorostiaga et al., 2010). This situation is suggested as a decreased availability of ATP and a significant contribution factor to fatigue (Balsom, Seger, Sjodin, & Ekblom, 1992).

We also reported that 5 min of resting was not enough to restore the level of jump performance reached after the warm-up. In this sense, Chatzinikolaou et al. (2010) reported jump impairments until 72 hr after a plyometric exercise training session (Chatzinikolaou et al., 2010). The authors suggested short-term muscle damage and a transient inflammatory response to explain the deleterious effects of the plyometric exercises protocol (Chatzinikolaou et al., 2010; Drinkwater et al., 2009).

In addition, after the high-intensity plyometric protocol, acuity of the knee joint position sense tended to decrease in RAE and VAE. Despite the detriment of the RAE and VAE just after the fatigue protocol, the lack of significant differences in the AAE prevented us from confirming a clear impairment due to the fatigue. Apart from the small sample, the level of fatigue reached by the athletes was not enough to produce a proprioceptive impairment. In fact, although the jump performance decreased compared to the Post-WU measurement, it did not decrease under the baseline. Therefore, despite the fatigue that occurred from the jump detriment, there may not have been enough for propioceptive deterioration. Maybe the experience of athletes in plyometric exercises could explain the lower level of detrimental effects because of these exercises. Along this vein, Torres, Vasque, Duarte, and Cabri (2010) evaluated the knee JPS after quadriceps eccentric exercises until exhaustion. These authors found proprioceptive deterioration up to 48 hours after the fatigue protocol (Torres et al., 2010). The main difference with our study was that our athletes did not reach the exhaustion status, which may explain the differences between both studies.

Regarding the muscle soreness in the thigh and calf regions, after the plyometric protocol, the athletes reached 7 and 8 points on the 10-point muscle soreness scale in the thigh and calf regions, respectively. The significant increase of the values indicated the presence of certain level of fatigue that was slightly higher in the calf region (Hody, Rogister, Leprince, Wang, & Croisier, 2013; Taylor, 2012). In addition, the muscle soreness in both the calf and the thigh regions decreased to 4 points 5 min later, but it was not enough to completely return the level of muscle soreness to baseline. These results were along the same line as those found in the jump performance and the RAE and VAE.

This study presents some restrictions: due to the limited access to high level athletes and the influence of the high-intensity plyometric protocol in the training routines because of the delayed-onset muscle soreness, the sample size was small. In the future, it would be interesting to conduct this study using more athletes, even from other sports, as well as female participants. Also, it would be interesting to use a longer follow-up period to determine the time point when the athletes' performance and proprioception are completely restored.

The present study showed that a 15-min warm-up increased jump performance, but a high-intensity plyometric protocol may deteriorate this level of jump performance reached. Regarding knee proprioception, the warm-up may improve RAE, while the high-intensity plyometric protocol may deteriorate RAE and VAE; however, the effects were more vague and unclear because we only found a statistical significance in RAE and VAE, but not in AAE. Five minutes after the fatigue protocol, the jump and joint position errors remained impaired, indicating the need for a longer resting period prior to continuing the training session. This is an important consideration if we take into account that athletes often perform plyometric exercises as a part of the training session, prior to other kind of exercises to which athletes rest about 5 min (Chatzinikolaou et al., 2010).

As a practical application, coaches and physiotherapists should consider the inclusion of a short warm-up prior to any exercise. Also, high intensity levels should be avoided because of the possible deleterious effects on jump perfomance and the trend to impair knee proprioception. In addition, sports and health professionals should plan an appropiate rest period within a training session or rehabilitation to optimize the posterior exercise and prevent sports injury, the likelihood of which is increased in fatigue conditions (Ekstrand, Hagglund, & Walden, 2011). The consideration of our findings could assist coaches and physiotherapists in making evidence-based practice decisions since monitoring determinant factors is related to fatigue in order to plan a more effective warm-up protocol.

Conclusion

A short warm-up improves jump performance, although this improvement is lost when a high-intensity plyometric protocol is included. Regarding knee proprioception, the warm-up may optimize the relative errors while the high-intensity plyometric protocol tends to deteriorate it; however the results are unclear due to the lack of detriment in the absolute errors. A 5-min period after the fatigue protocol is not enough to recover the whole jump performance and proprioception.

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