Journal of Bodywork & Movement Therapies 24 (2020) 206–211

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Mentored Research: Randomised Study

Moderate volume of sprint bouts does not induce muscle damage in well-trained athletes

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ARTICLE INFO

Article history:
Received 3 May 2019
Accepted 15 May 2019

Keywords:
Power
Fatigue
High-velocity
Sprint training
Muscle damage
Recovery

ABSTRACT

Introduction: Understanding the recovery in response to different sprint protocols is important for optimizing neuromuscular gains and organizing training sessions in sports. The current study aimed to investigate acute neuromuscular changes following a moderate volume of sprint protocols with and without change-of-direction.
Methods: 26 well-trained male collegiate athletes from different sports were randomly allocated into straight-line group (SLG) or change-of-direction group (CODG). The protocols were 1×15 repetitions of 20-meter sprints in line (SLG) or with two changes in each repetition (CODG). Knee extension maximal and explosive strength, jump performance, serum creatine kinase, and quadriceps and hamstrings echo intensity were collected pre-, post- 0, 24, 48, and 72 h post-exercise.
Results: There were no significant changes in any of the variables at any time point after the exercise protocols in comparison with pre-exercise values ($p > 0.05$).
Conclusions: The present study suggests that sprint training with moderate volume with or without change of direction does not induce neuromuscular or physiological changes during 72 h post-exercise. This information is especially important for sports staff in order to optimize training prescription and frequency.

1. Introduction

Sprint exercises are a widely used training method due to the physical demands they impose, and their association with sports performance (Ross and Leveritt, 2001; Mero et al., 1992). In addition, sprint training (SpT) is largely applied in different modalities in which muscle power output and a high speed of displacement are absolutely necessary (e.g., soccer, handball, basketball, and sprint). Moreover, long-term SpT promotes significant enhancements in muscle power output, maximal speed, and horizontal acceleration (Ross and Leveritt, 2001; Mero et al., 1992; Keane et al., 2015; Taylor et al., 2015). These adaptations may reduce the time required to overcome distances and improve several explosive motor skills (Comfort et al., 2014; Baker and Nance, 1999; Keiner et al., 2014; McBride et al., 2009; Wisløff et al., 2004). Furthermore, proper diverse sprint performance (i.e., straight-line or with change of direction) is critical for success in 1-on-1 duels, and these situations are normally associated with score production in sports (Comfort et al., 2014; Keiner et al., 2014; Haugen et al., 2014). Therefore, prescriptions using changes of direction as well as straight-line sprints could improve the training ecological value once they are more closely related to the sports actions.

Regarding these long-term adaptations to repeated sprinting actions, it is important to note that a moderate volume of SpT (i.e., a total distance of approximately 300 m) seems to promote important increases in neuromuscular performance, such as lower limb muscle power and speed capacity at 20-meter and 30-meter sprints (Taylor et al., 2015). Moreover, recent power training findings suggest that high volume and high fatigue index are not the most appropriate conditions for developing lower limb power output (Pareja-Blanco et al., 2017). In this context, a moderate volume of

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https://doi.org/10.1016/j.jbmt.2019.05.019
1360-8592/

sprint training, which requires only a few minutes per session, can be considered an easy and efficient instrument for developing power performance in sports dynamic routines (Taylor et al., 2015; Haugen et al., 2015; Iaia et al., 2017). However, no previous study has compared the recovery (e.g., muscle damage, performance impairment, and changes in physiological parameters) after one session of SpT protocols with and without change of direction. This information is essential for monitoring and optimizing recovery periods and for prescribing sports training (e.g., improving physical sets and tactical/physical periodization). Although these long-term adaptations to moderate volume of SpT are largely shown in the literature (i.e., increases of 1.4 ± 1.5 cm in countermovement jump and decreases of 0.07 ± 0.08 and 0.30 ± 0.41 in 20-meter and 30-meter sprint times, respectively) (Taylor et al., 2015), the needed recovery or the possible performance maintenance after one SpT session is poorly investigated in athletes who perform high training frequency.

Literature has focused on recovery assessments after eccentric (Chen et al., 2011), plyometric (Cadore et al., 2013), and traditional strength training routines (Radaelli et al., 2012; Soares et al., 2015). In relation to SpT, Keane et al. (2015) investigated the recovery time course in collegiate women athletes after 1 set of 15 repetitions of 30 m in straight SpT, demonstrating decreases in power output and creatine kinase (CK) increases after exercise. However, to the best of our knowledge, no previous study has investigated the muscle damage induced by SpT using image techniques nor with shorter and sport-specific distances (i.e., 20 m) (Carling et al., 2008; Barros et al., 2007). In this context, exercise-induced muscle damage has been associated with an increase in muscle echo intensity (EI), a non-invasive parameter to assess muscle damage after exercise with a low cost and high reproducibility (Chen et al., 2011). Because muscle EI describes the muscle damage magnitude and recovery after different types of exercise (Chen et al., 2011; Radaelli et al., 2012), it would be interesting to assess these outcomes induced by SpT protocols.

Therefore, because of the lack of studies assessing acute responses to different sprint training routines, the present study aimed to investigate the neuromuscular, physiological (CK), and muscle imaging outcomes in response to two different sprint training protocols (i. e., with and without change of direction) in well-trained collegiate athletes. Our hypothesis was that SpT with change of direction would induce greater neuromuscular impairment during recovery.

2. Materials and methods

2.1. Participants

The initial sample comprised 30 well-trained collegiate athletes from different sports, including soccer (n = 10), handball (n = 4), basketball (n = 8), futsal players (n = 4), and sprinters (n = 4). Although there are different sport-based traditional interventions and match-related demands for each sport, the acceleration demands are commonly needed for all. Participants were randomly allocated into two groups, which performed different sprint protocols. Four individuals were excluded from the analyses; one because of a hamstring strain (third recurrence) during the straight-line sprint protocol, and three because they did not attend subsequent assessments after anamnesis and familiarization session. Twenty-six well-trained male collegiate athletes (22.3 ± 3.2 years old; 82.2 ± 10.7 kg; 182.0 ± 7.9 cm), with no training interruptions during the past year, were finally included and assigned to the change of direction group (CODG, n = 15) or straight line group (SLG, n = 11). Participants were selected based on their participation in sports teams at local universities. The inclusion criteria were (a) men between 18 and 30 years old with training frequency of four or more times per week (b) without neuromuscular, cardiovascular, pulmonary, or metabolic diseases and (c) no use of any type of substances that could improve the neuromuscular performance and recovery. Participants' weekly training frequency varied about 4–7 days including strength, power, and technical/tactical sessions. After recruitment and allocation, individuals received a consent form to read and sign if they agreed. This study was approved by the local Research Ethics Committee (approval number 1.392.145) and was performed in accordance with the Helsinki Declaration.

2.2. Intervention and measurements

In order to compare the acute responses to different sprint protocols, we chose to allocate the participants to different sprint protocols to avoid the repeated bout effect, which could mask possible muscle damage (Chen et al., 2011). All assessments were executed in the same order at all time points: blood CK, ultrasonography, jump performance, and isokinetic dynamometer. Once included, the participants attended five sessions in the laboratory for: (a) familiarization with procedures and evaluations; (b) collecting body mass and height, pre-exercise evaluations, sprint protocols session, immediate post-exercise evaluations; (c) 24 h post-exercise evaluations; (d) 48 h post-exercise evaluations; and (e) 72 h post-exercise evaluations. The same investigator who was an experienced evaluator executed each procedure. All investigators, except those who applied the training sessions, were blinded to group allocation.

2.3. Sprint bout protocols

Both CODG and SLG performed the same sprint bout volume (1 set of 15 repetitions of 20 m) with 20 s of rest between repetitions. However, CODG performed 2 changes of direction to the right side in each repetition (a total of 30 changes of direction), while SLG performed all sets in a straight line (Fig. 1). According to the teams' coaches, the most common applied change of direction protocols

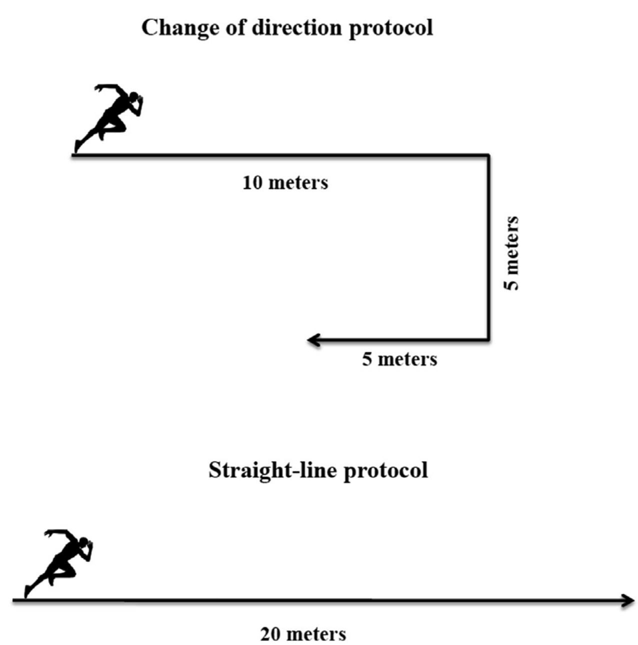

Fig. 1. Sprint protocols.

during their usual training routines was 90° cuts. Thus, we opted for 90° changes to establish accentuated eccentric actions, as it was in accordance and familiarity to the athletes training routines. Maximal (all-out) effort was required for each participant, with verbal encouragement implemented during all repetitions.

2.4. Jump performance

Participants performed a jump test using an electronic contact mat system (Cefise, Jump System Pro, São Paulo, Brazil). Jump height was determined using an acknowledged flight-time calculation (Bosco and Rusko, 1983) and the software Jump System Pro 1.0. Each participant was instructed to use maximum effort to perform the double-leg squat jump (SJ) and countermovement jump (CMJ) tests. They were given 3 attempts to obtain their maximum jump height in each test, with 10 s of rest between attempts, with the highest value utilized for subsequent analysis. Moreover, a variation of 3% was established as a minimum between valid attempts. During the SJ test, participants were instructed to start the jump with their knees close to 90° and to avoid any countermovement. During the CMJ test, participants started in the orthostatic position. They were instructed to jump for maximal height. Participants were again instructed to leave the electronic contact mat system with their knees and ankles fully extended and to land in a similarly extended position to ensure the validity of the test. Four techniques were stressed: (a) correct posture (i.e., spine erect, shoulders back) and body alignment (e.g., chest over knees) throughout the jump; (b) jumping straight up with no excessive side-to-side or forward-backward movement; (c) soft landing, including toe-to-toe heel rocking and bent knees; and (d) instant recoil preparation for the next jump (Cadore et al., 2013). When performing the jumps, all the participants held their hands on their hips in order to standardise jumps and avoid upper limb help on lower limb power output development, since the participants can have different lever arms and upper limb techniques to optimize jump height.

2.5. Maximal voluntary contraction and rate of torque development

Maximal isometric peak torque (PT) and rate of torque development (RTD) were assessed using an isokinetic dynamometer (Cybex Norm, Ronkonkoma, NY, USA). Participants were seated with their hips and thighs firmly strapped to the seat of the dynamometer, with the hip angle at 85°. They then warmed up performing 12 submaximal knee extension and flexion repetitions at 120°/s using the right leg. Thereafter, the participants were instructed to isometrically produce the maximal knee extension force as fast as possible (Maffieuletti et al., 2016; Sahaly et al., 2001) at 60° (0° represents full extension) while verbal encouragement was given during the test. Before sprint exercise protocols and 0 h to 72 h after, the participants performed 3 maximal voluntary contractions (MVC) of the knee extensors with a duration of 5 s for each one. The rest interval between each attempt was 2 min. The torque-time curve was obtained using Miotool software, with an acquisition rate of 2000 Hz. Maximal PT was defined as the highest torque value determined with the dynamometer's HUMAC2009 software – with gravity corrections – recorded during the unilateral knee extension (N.m). The RTD was derived as the average slope of the moment-time curve ($Nm.s^{-1}$) over time intervals of 0–350 milliseconds relative to the onset of contraction, which was considered the point at which the torque exceeded 7.5 N m and was determined using the MATLAB software routine. The isometric force-time analysis on the absolute scale included the maximal RTD, defined as the greatest torque value obtained in 0–350 ms using Excel software. In addition to the maximal RTD, the RTDs at 0–50 ms, 0–100 ms and 0–300 ms intervals were calculated.

2.6. Ultrasonography

Quadriceps femoris and biceps femoris B-mode ultrasound images were obtained with a 38-mm, 9.0 MHZ linear-array probe (image depth 70 mm; 90 dB general gain, time gain compensation at neutral position) with a Nemio XG ultrasound (Toshiba, Japan). Before any measurement in all moments (pre, 0 h, 24 h, 48 h, and 72 h) participants rested in the supine position with the lower limbs extended and relaxed for 15 min to allow fluid shifts stabilization (Arroyo et al., 2016; Berger and Talbot, 1983). Transverse images of the right vastus lateralis (VL), rectus femoris (RF), vastus intermedius (VI), vastus medialis (VM), and biceps femoris (BF) muscles were acquired. The probe was coated with water-soluble transmission gel to provide acoustic contact, and care was taken to avoid compression of the dermal surface. The measurement sites were the same as those adopted in previous studies (Chen et al., 2011; Rech et al., 2014; Wilhelm et al., 2014). All images were acquired and analysed by the same investigator. Echo intensity was determined according to previous studies (Radaelli et al., 2012; Rech et al., 2014; Wilhelm et al., 2014) by computer assisted gray scale analysis using the standard function of ImageJ 1.42q software (National Institutes of Health, Bethesda, Maryland). Single images of each muscle were digitized and analysed. Regions of interest of each quadriceps muscle portion and hamstrings were selected, including as much muscle as possible but avoiding other tissues (such as bone and surrounding fascia) for EI calculation of each component of the muscle (Fig. 2). The mean EI was determined using a standard gray-scale histogram function and expressed as a value between 0 (black) and 255 (white).

2.7. Creatine kinase

Blood samples were drawn from the vein of the antecubital region and routinely centrifuged in EDTA tubes (4 mL) at 1,500g and at 4 °C for 10 min. After that, plasma was stored at −80 °C for further analysis. CK values were determined using an automated enzymatic colorimetric method (Cobas C111; Roche Diagnostics, Basel, Switzerland).

2.8. Statistical analysis

Data are presented as the mean ± SD. The data presented normality and homogeneity of variance between groups. The Shapiro–Wilk test was used for normality, and the Levene test was used for homogeneity. Two-way (group x time) repeated measures ANOVA were performed to analyse the effects of SpT on the study outcomes. Significance level was considered $p \leq 0.05$ for all analysis. Statistical Package for Social Sciences (SPSS 17.0 Inc, Chicago, USA) was utilized.

3. Results

There were no significant differences in the age, body composition, and basal values for all variables between the groups (Tables 1 and 2). There were no differences between the athletes from the different sports ($p > 0.05$). Data for physical characteristics are presented in Table 1. The data for the functional, systemic, and muscle imaging variables are presented in Table 2. There were no significant time-effect or time vs. group interactions ($p > 0.05$) in PT, RTDs, SJ and CMJ performance, biceps femoris or quadriceps femoris muscle echo intensity, and CK activity (Table 2). Neither sprint protocol resulted in any significant effects on the assessed variables.

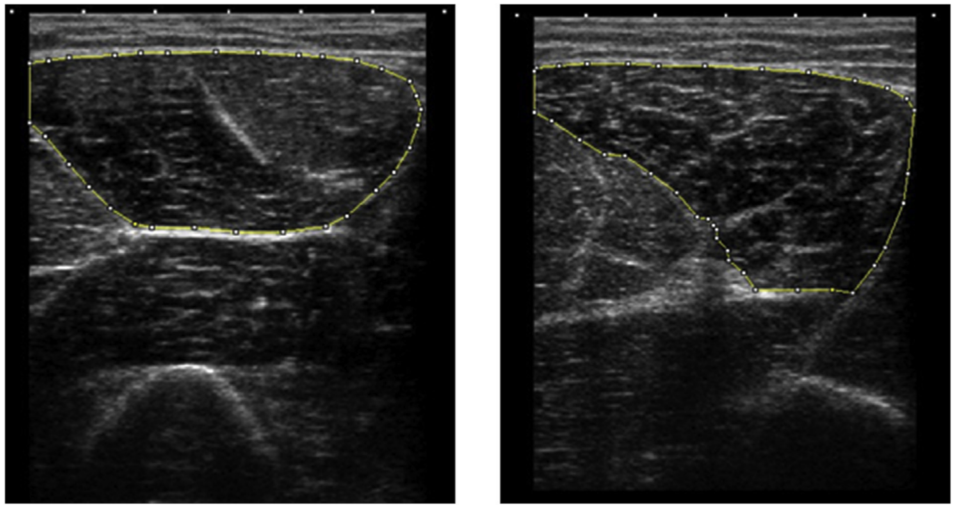

Fig. 2. Rectus femoris (left) and biceps femoris (right) images.

Table 1
Physical characteristics. Mean ± SD.

	Change of direction group (CODG), n = 15	Straight line group (SLG), n = 11
Age (years)	22.5 ± 3.4	22.1 ± 3.2
Body mass (kg)	81.6 ± 9.8	83.2 ± 12.2
Height (cm)	182.9 ± 8.5	180.9 ± 7.3

Table 2
Neuromuscular and physiological data. Mean ± SD.

Change of direction group (CODG), n = 15	Pre	0 h	24 h	48 h	72 h
Quadriceps Echo Intensity	38.7 ± 7.1	43.5 ± 8.3	38.8 ± 7.8	41.0 ± 6.1	39.0 ± 6.5
Biceps Femoris Echo Intensity	46.2 ± 13.1	49.6 ± 10.9	47.9 ± 10.2	47.3 ± 12.0	48.5 ± 10.0
MRTD (N.m/s)	285.5 ± 55.1	275.2 ± 58.5	282.8 ± 56.2	266.3 ± 52.2	281.7 ± 51.6
RTD 0–50 ms (N.m/s)	1270.5 ± 448.6	1280.0 ± 406.3	1275.6 ± 364.4	1146.0 ± 305.4	1251.9 ± 413.0
RTD 0–100 ms (N.m/s)	1248.4 ± 394.1	1249.6 ± 356.1	1227.4 ± 317.5	1132.1 ± 286.2	1223.4 ± 352.1
RTD 0–300 ms (N.m/s)	714.1 ± 166.8	709.3 ± 167.2	706.3 ± 155.4	661.9 ± 143.8	699.4 ± 145.0
Peak Torque (N.m)	315.5 ± 70.8	301.1 ± 60.3	309.5 ± 54.4	292.1 ± 55.2	305.2 ± 61.3
CMJ (cm)	39.2 ± 6.5	39.1 ± 6.4	39.7 ± 6.8	39.0 ± 6.6	39.7 ± 6.9
SJ (cm)	36.3 ± 6.9	35.3 ± 6.0	36.6 ± 7.0	35.9 ± 7.0	36.0 ± 5.8
CK (U/L)	321.8 ± 268.0	335.0 ± 289.6	286.4 ± 140.7	222.8 ± 98.9	171.2 ± 63.0
Straight line group (SLG), n = 11					
Quadriceps Echo Intensity	39. ± 6.6	42.9 ± 6.8	40.0 ± 5.1	40.0 ± 6.2	40.0 ± 6.3
Biceps Femoris Echo Intensity	44.6 ± 8.4	46.9 ± 8.3	42.4 ± 6.5	42.6 ± 7.8	45.0 ± 9.3
MRTD (N.m/s)	257.0 ± 41.7	248.6 ± 38.3	253.9 ± 43.7	248.6 ± 41.7	247.7 ± 38.5
RTD 0–50 ms (N.m/s)	1308.4 ± 276.4	1315.7 ± 363.0	1246.8 ± 271.2	1192.1 ± 328.7	1120.0 ± 165.4
RTD 0–100 ms (N.m/s)	1263.0 ± 222.0	1240.0 ± 229.7	1189.6 ± 254.2	1143.4 ± 185.3	1077.4 ± 143.9
RTD 0–300 ms (N.m/s)	645.9 ± 105.3	630.2 ± 85.4	631.9 ± 115.5	601.3 ± 72.0	593.6 ± 83.0
Peak Torque (N.m)	281.5 ± 46.6	264.3 ± 47.7	266.3 ± 55.4	260.2 ± 47.7	265.2 ± 44.4
CMJ (cm)	34.6 ± 5.7	34.5 ± 5.8	34.5 ± 6.4	35.4 ± 7.0	36.1 ± 6.2
SJ (cm)	32.4 ± 5.7	32.9 ± 5.4	32.8 ± 5.0	33.0 ± 5.9	33.1 ± 5.9
CK (U/L)	491.6 ± 535.2	583.0 ± 715.6	476.2 ± 357.0	348.7 ± 292.7	281.2 ± 224.3

MRTD – maximal rate of torque development; RTD – rate of torque development 0–50 ms, 0–100 ms and 0–300 ms; CMJ – countermovement jump; SJ – squat jump; CK – blood creatine kinase.

4. Discussion

The main findings of the present study were that a moderate volume of sprint bouts, with or without change of direction, did not induce significant decreases in the neuromuscular performance parameters such as maximal strength (i.e., PT), explosive strength (i.e., RTD), and vertical jump (i.e. SJ, CMJ). In addition, there were no detectable changes in the muscle damage-related variables assessed by plasma CK activity and EI (i.e., quadriceps femoris and hamstrings). These results suggest that, in well-trained athletes, a moderate volume of sprint bouts (i.e., 1 × 15 of 20 m), regardless of whether change-of-direction exercises are used, does not require a longer time of recovery, without decreasing neuromuscular performance in other types of interventions during 72 h post-exercise such as technical and tactical sessions or matches, optimizing training routines. This may reduce training staff's uneasiness concerning hamstring and quadriceps muscle damage.

Regarding neuromuscular performance, it has been shown that long-term SpT induces important adaptations, such as lower-limb muscle power output (Taylor et al., 2015). Nevertheless, the time needed to completely recover after a sprint session has been poorly investigated. In the present study, we aimed to investigate functional variables, such as jump performance (i.e., CMJ and SJ), explosive strength (i.e., RTD), and maximal strength (i.e., PT), which are strongly associated with the capacity to maintain the sprint performance during SpT (Ross and Leveritt, 2001; Mero et al., 1992; Keane et al., 2015). Thus, these variables could accurately identify a possible neuromuscular impairment induced by muscle mechanical stress and damage during SpT protocols. The chosen variables are largely used in literature for expressing muscle damage in response to different training protocols and they have demonstrated high sensitivity to even small changes in muscle performance (Keane et al., 2015; Chen et al., 2011; Cadore et al., 2013; Maffiuletti et al., 2016). The echo intensity and rate of torque development, for example, are able to assess tiny alterations in gray scale pixels and explosive force, respectively. In the same way, jump performance has been demonstrated as one of the best functional outcomes to assess fatigue and muscle damage induced by sprint protocols (Jiménez-Reyes et al., 2019).

Considering that change of direction requires a greater number of eccentric muscle actions to reduce the speed, we hypothesized that CODG would present greater muscle impairment in the days following the protocol. Nevertheless, this difference did not occur, and both sprint protocols showed similar responses. In this context, although there were more decelerations to change of direction in CODG when compared to SLG, one supposes that the athletes would achieve a higher maximal speed in straight line bouts. As a consequence, it is necessary to decelerate from a higher speed, which could explain the similar responses in both groups.

Keane et al. (2015), who investigated the recovery time in response to 1 set of 15 repetitions of 30-meter straight sprints in collegiate female athletes (rugby, netball, and soccer players), observed significant changes in two functional variables (CMJ and 30-meter sprint time) after sprint exercises. As in the present study, Keane et al. (2015) did not observe significant decreases in PT, suggesting that even when a greater volume of SpT is performed, the maximal knee extension isometric force remains at the basal level. It should be noted that there are differences between our study and the study by Keane et al. (2015) that could explain the different results, such as the sex of individuals assessed, sports modalities, training level, and mainly, the sprint protocol volume. In the present study, we used a SpT volume of 300 m, which was 150 m lower than that used by their study (Keane et al., 2015). In the present investigation, we chose repetitions of 20-meter sprints to reflect the characteristics of our participants' sports modalities, in which 20-meter maximal sprints are mandatory and more common than longer sprints (Carling et al., 2008; Barros et al., 2007). To the best of our knowledge, no previous study has assessed quadriceps and biceps femoris muscle EI in response to sprint training bouts. The present study showed no significant changes in the muscle EI in response to both sprint protocols. An increase in the muscle EI after eccentric exercise bouts has been observed in different investigations (Chen et al., 2011; Cadore et al., 2014). Regarding biceps femoris EI, Chen et al. (2011) found significant increases in this muscle and no changes in quadriceps femoris in response to maximal eccentric contractions. However, it is difficult to compare their outcomes with the present results because they used pure eccentric muscle actions performed in isokinetic devices (Chen et al., 2011; Cadore et al., 2014) whereas in the present study we assessed the EI after a cyclic multi-joint ballistic exercise, such as running at maximal speed. The absence of changes in these variables in the present study may be due to the training background of our participants, who often perform sprint exercises during their regular workouts and during their games. Because the current study was the first to investigate the knee flexor and extensor EI in response to sprint protocols with and without change of direction, the exact sprint volume that could induce detectable muscle damage (i.e., echo intensity alterations) in this type of athlete remains to be elucidated. Future studies investigating different sprint volumes, distances and amounts of rest between repetitions and sets are required to identify the magnitude of muscle damage induced by this type of exercise.

In the present study, CK activity showed lower values at 72 h than at baseline evaluation. In contrast, the aforementioned study by Keane et al. (2015) found significant increases at 24 h, 48 h, and 72 h post-exercise (peak at 24 h). One possible explanation for the absence of changes and even a slight decrease at 72 h in the present study is that the participants' level of training (4–7 times per week, including strength, power, and technical/tactical sessions) and their sports modalities, which are characterized by high-intensity power exercises, may have influenced our results. Although we asked the participants to refrain from physical training for 48 h before the study protocol, the volume and intensity of training were not monitored in the week that preceded the assessments as well as the dietary routine. Thus, it is possible that during the week of assessment, the physical "inactivity" allowed better physiological recovery compared with their regular levels, which caused the slight decrease in the days following the sprint protocols. Taking together the CK and EI results, it should be pointed out that both sprint protocols characterized by moderate volume (i.e., 300 m) may be performed during the training program without generating detectable levels of muscle damage and performance impairment.

4.1. Limitations

The present study has some limitations. We did not assess the sprint time during each point (pre-, 0 h, 24 h, 48 h, and 72 h post-sprint bouts). However, to isolate the 72 h of recovery as much as possible, we decided to include only maximal isometric force and jump performance tests, thus avoiding the muscle mechanical stress imposed by sprint tasks (maximal running) at each time point. Furthermore, we did not evaluate velocity losses and time increases during our prescribed sprint bouts, which could have helped us to identify the exact fatigue and power leakage in relation to these sprint bouts and to inform conditioning coaches about fatigue index during these sprint protocols. It could be hypothesized that the training volume of the SpT protocols was not enough to elicit muscle damage. However, importantly, literature suggests that the SpT volume prescribed in the current cross-sectional study, which was considered moderate, induces relevant increases on neuromuscular performance when applied during longitudinal interventions in a population of athletes (Taylor et al., 2015; Haugen et al., 2015; Iaia et al., 2017; Wiewelhove et al., 2015). Taylor et al. (2015) reviewed 13 controlled and non-controlled experimental studies with different SpT protocols and concluded that moderate volume, as used in present study, induced significant effects on CMJ and sprints performance.

5. Conclusion

In summary, a moderate volume of SpT with and without change of direction did not induce decreases in maximal strength, RTD or jump performance up to 72 h post training. In addition, neither SpT protocol induced any detectable muscle damage assessed in thigh (quadriceps femoris and biceps femoris), EI muscles, or plasma CK values. Therefore, the current study fills a knowledge gap regarding the monitoring of recovery among athletes in different sports modalities. It is indispensable to carefully consider the organization of sprint training periodization along with other training components, such as technical and tactical exercises, as well as aerobic, strength, and plyometric training. In this context, it is important to know the time course of muscle performance and imaging recovery to any training bout in order to apply the sufficient rest interval between different training sessions. Taking together all analyzed variables of the present study, SpT protocols composed of 15 repetitions of 20 m with and without change of direction did not induce any decrease in the neuromuscular parameters assessed, or any detectable muscle damage in well-trained male collegiate athletes. Although SpT is widely used, the recovery after its sessions is poorly understood, and in this context, our results have important practical applications for qualifying SpT prescriptions by conditioning coaches.

Conflicts of interest

The authors declare no conflict of interest.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

The authors extend special thanks to CNPq and CAPES. Furthermore, they also gratefully acknowledge all the participants who participated in this research and made this project possible.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbmt.2019.05.019.

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