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Original article

Changes in balance ability, power output, and stretch-shortening cycle utilisation after two high-intensity intermittent training protocols in endurance runners

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Abstract

Purpose: This study aimed to describe the acute effects of 2 different high-intensity intermittent trainings (HIITs) on postural control, countermovement jump (CMJ), squat jump (SJ), and stretch-shortening cycle (SSC) utilisation, and to compare the changes induced by both protocols in those variables in endurance runners.
Methods: Eighteen recreationally trained endurance runners participated in this study and were tested on 2 occasions: 10 runs of 400 m with 90 s recovery between running bouts (10 × 400 m), and 40 runs of 100 m with 30 s recovery between runs (40 × 100 m). Heart rate was monitored during both HIITs; blood lactate accumulation and rate of perceived exertion were recorded after both protocols. Vertical jump ability (CMJ and SJ) and SSC together with postural control were also controlled during both HIITs.
Results: Repeated measures analysis revealed a significant improvement in CMJ and SJ during 10 × 400 m ($p < 0.05$), whilst no significant changes were observed during 40 × 100 m. Indexes related to SSC did not experience significant changes during any of the protocols. As for postural control, no significant changes were observed in the 40 × 100 m protocol, whilst significant impairments were observed during the 10 × 400 m protocol ($p < 0.05$).
Conclusion: A protocol with a higher number of shorter runs (40 × 100 m) induced different changes in those neuromuscular parameters than those with fewer and longer runs (10 × 400 m). Whereas the 40 × 100 m protocol did not cause any significant changes in vertical jump ability, postural control or SSC utilisation, the 10 × 400 m protocol impaired postural control and caused improvements in vertical jumping tests.
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Keywords: Long-distance runner; Postural control; Reactive strength; Training prescription; Vertical jump

1. Introduction

High-intensity intermittent training (HIIT) involves repeated short to long bouts of rather high-intensity exercise interspersed with recovery periods and has been used by athletes for almost a century now.[1] In fact, it is today considered one of the most effective forms of exercise for improving physical performance in athletes.[1,2] Traditionally, this type of training has been associated with sports modalities with high power requirements, although in recent years, a growing body of literature has focused on the benefits of fast intermittent exercises for endurance athletes.[1–3] This fact has enabled both endurance athletes and coaches to realise that both low-intensity training performed at high volumes and high-intensity training of short durations must be part of the training programs for endurance athletes, and previous papers have shown the effectiveness of training programs based on both methods.[4,5]

To date, most of research considering HIIT in endurance runners has been focused on the acute physiological and neuromuscular response.[3,6–8] However, surprisingly, little attention has been given to parameters such as balance ability and stretch-shortening cycle (SSC) utilisation, which have been associated with both athletic performance and injury risk.[9–13] Indeed, to the best of the researchers' knowledge, no previous study has focused on determining the effect of HIITs performed in a real situation—a field study—on postural control and SSC

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utilisation in endurance runners. Therefore, the aims of this study were (1) to describe the acute effects of 2 different HIITs on postural control, countermovement jump (CMJ), squat jump (SJ), and SSC utilisation, and (2) to compare the changes induced by both HIIT protocols in the aforementioned variables in endurance runners.

2. Materials and methods

2.1. Subjects

A group of 18 recreationally trained endurance runners (age = 30.89 ± 11.69 years, body mass index (BMI) = 22.08 ± 2.17 kg/m^2, and velocity associated with maximal oxygen uptake ($v\mathrm{VO}_{2max}$) = 17.24 ± 1.37 km/h), comprising 16 males and 2 females, voluntarily participated in this study. No general clinical examination was carried out; however, all subjects are medically examined annually. The subjects had trained for about 1–3 h a day, 4–6 days a week all year around, for a minimum of 4 years and had no history of injury in the 3 months before the study, which might have limited training. The study was conducted in November 2014 during cross-country season and during the competition phase of their yearly program at a time when most of the athletes were at a high level of competitive fitness. At the time of these observations, the athletes had completed between 2 and 4 months of training.

After receiving detailed information on the objectives and procedures of the study, each subject signed an informed consent form to participate, which complied with the ethical standards of the World Medical Association Declaration of Helsinki (2013) and which made it clear that they were free to leave the study if they saw fit. The study was approved by the Ethics Committee of the University of Jaén (Spain).

2.2. Procedures

The participants were asked not to engage in any heavy intensity exercise for 72 h prior to the experiment and to have a meal at least 2 h before beginning warming up. All athletes had experience with the exercises analysed. All training sessions were carried out between 17:00 and 21:00 hours on an outdoor 400 m synthetic track. Before the running exercises, the athletes performed a warm-up, which consisted of 10 min of continuous running and 10 min general exercises (high skipping, leg flexion, jumping exercises, and short bursts of acceleration).

Each athlete was tested on 2 occasions separated by 7 days: first, 10 runs of 400 m with 90 s recovery between running bouts (10 × 400 m); second, 40 runs of 100 m with 30 s recovery between runs (40 × 100 m). Athletes underwent a passive recovery between runs (just standing, in a vertical position). Both HIIT protocols were carried out above the $v\mathrm{VO}_{2max}$, indirectly measured through the velocity of a 3000 m race.[14] Data about each athlete's best time in a 3000 m race the month prior to the test were supplied by their coaches. Participants are experienced athletes who perform these types of workouts in their training program. So the only instructions were to finish the protocols as fast as they could, maintaining a constant speed as much as possible. No more guidelines were provided as to exercise intensity, apart from the participants being informed that they were to exercise at an intensity of their own choice. Physiological and neuromuscular responses were monitored during both running protocols. The performance in every single run was also recorded (time spent: T400 m and T100 m, respectively, in seconds).

2.3. Materials and testing

2.3.1. Anthropometric variables

Height (m) and body mass (kg) were measured at the beginning of the first testing session; BMI was calculated by means of the following equation: body mass (kg)/height^2 (m). A stadiometer (Seca 222; SECA Corp., Hamburg, Germany) and a calibrated bascule (Seca 634; SECA Corp.) were used for this purpose.

2.3.2. Metabolic variables

Blood lactate accumulation (BLa) was recorded during the recovery period, after the last run of each running protocol (BLa at 1 min post-test). For this purpose, fingertip blood samples were analysed with a portable Scout Lactate analyser (SensLab GmbH, Leipzig, Germany). The blood lactate analyser was checked for accuracy according to the manufacturer's instructions prior to every testing session.

2.3.3. Physiological variables

Cardiovascular response was also monitored (Garmin Forerunner 405; Garmin International Inc., Olathe, KS, USA) throughout both 10 × 400 m and 40 × 100 m protocols. Peak heart rate reached (HR_{peak}), average heart rate (HR_{mean}), and heart rate at the end of recovery periods (heart rate recovery, HR_{rec}) were recorded for both running protocols. Moreover, as indicated by Daanen et al.,[15] although HR_{rec} is generally expressed in absolute terms (bpm), it can be useful to express it relative to the HR_{peak} (i.e., the difference between the resting and maximal heart rate) to minimise interpersonal differences. Based on this, the difference between HR_{peak} and HR_{rec} was calculated and was called the heart rate reserve (HRR, measured in bpm). Because the resting periods in both HIIT protocols differed, comparing the absolute values of the HR_{rec} and HRR would not be appropriate. Thus, in an attempt to control the impairment of cardiac recovery capacity throughout both running protocols, the difference between the first and the last run (increase, Δ) was used for the statistical analysis. Moreover, in order to obtain further information about the perceived exertion, the rate of perceived exertion (RPE) was recorded on the 6–20 Borg Scale[16] immediately after the last run in both protocols.

2.3.4. Neuromuscular variables

CMJ and SJ tests were performed before (pre-test, unfatigued condition), in the middle of the training session (intermediate test), and after each running workout (post-test, fatigued condition). Participants were experienced athletes who perform different plyometric exercises in their daily training sessions. Moreover, to make sure the execution of the test conducted was correct, a familiarisation session had previously been carried out. The CMJ and SJ were recorded using the OptoGait system (Microgate, Bolzano, Italy), which has been

previously used in similar studies.[17] This device measures the contact time on the floor and the flight time using photoelectric cells. Flight time was used to calculate the height of the rise using the body's centre of gravity. Subjects performed 2 trials of every test, with a 15 s recovery period between them with the best trial being used for the statistical analysis. In all tests performed—CMJ, SJ—the pre-intermediate and pre-post differences (increase, Δ) were also calculated and used for the subsequent analysis. Participants were encouraged to achieve maximum performance throughout both running protocols.

Both CMJ and SJ tests are commonly used to discriminate between the effects of the SSC in various athletic populations.[9,18] Performance of the SSC is commonly measured using an added pre-stretch to a movement, such as comparing CMJ performance with SJ performance.[9,18] Researchers have measured SSC performance from CMJ and SJ jump heights as an augmentation of a prior stretch.[19] Pre-stretch augmentation (PSA) can be calculated as a percentage with PSA (%) = ((CMJ − SJ)/SJ) × 100. Another approach is to measure reactive strength (reactive strength index (RSI) calculated as CMJ–SJ height).[20] This is considered to be a measure of the ability to utilise the muscle pre-stretching during the CMJ.[18,20] Intermediate-pre and post-pre differences (Δ) were also calculated for PSA and RSI.

2.3.5. Postural control variables

A FreeMed© BASE model baropodometric platform was used for the stabilometric measurements (Sensormédica, Rome, Italy). The platform's surface is 555 × 420 mm, with an active surface of 400 × 400 mm and 8 mm thickness manufactured by Sensormédica. The reliability of this baropodometric platform has been shown in previous studies.[21] Calculations of centre of pressure (CoP) movements were performed with the FreeStep© Standard 3.0 software (Sensormédica). A monopodal stabilometry test was performed before and immediately after (pre- and post-test, respectively) every training session (10 × 400 m and 40 × 100 m). Athletes stood on each of their lower limbs for 10 s (left leg first) at the centre of the platform according to the manufacturer's instructions and following the procedure of previous studies.[22,23] The following parameters were recorded for the left- and right-leg monopodal tests: length (Length) and area (Area) of the path described by the CoP and the speed for the CoP movement (Velocity). The average for both the left- and right-leg was calculated and used for the subsequent analysis.

2.4. Statistical analysis

Descriptive statistics are represented as mean ± SD. Tests of normal distribution and homogeneity (Kolmogorov–Smirnov and Levene's) were conducted on all data before analysis. A repeated measures analysis (ANOVA) (pre-, intermediate-, and post-test) was performed for CMJ, SJ, and SSC utilisation variables in both HIITs—10 × 400 m and 40 × 100 m—whilst a pre-post comparison was performed by Student's *t* test in variables related to postural control. The level of significance was $p < 0.05$. Data analysis was performed using SPSS (Version 21; IBM, Armonk, NY, USA).

Table 1
HRR, RPE average running pace, and BLa accumulation during 2 high-intensity intermittent trainings (mean ± SD).

Variable	Protocol		*p* value
	10 × 400 m	40 × 100 m	
HR_{peak} (bpm)	179.00 ± 9.07	176.25 ± 9.64	0.067
HR_{mean} (bpm)	144.12 ± 14.29	160.60 ± 12.64	<0.001
ΔHR_{rec} (bpm)	31.00 ± 14.09	22.88 ± 14.23	0.091
ΔHRR (bpm)	−13.80 ± 16.55	−3.00 ± 14.36	0.067
RPE (6–20)	16.00 ± 1.24	15.11 ± 1.13	0.019
Running pace (km/h)	18.47 ± 1.51*	21.60 ± 1.72*	<0.001
$\%v\,VO_{2max}$	107.17 ± 2.83	125.40 ± 4.89	<0.001
BLa (mmol/L)	12.87 ± 3.21	12.40 ± 4.14	0.670

Note: * indicates no significant differences in intra-running protocols, constant speed.
Abbreviations: BLa = blood lactate at 1 min post-test; ΔHR_{rec} = heart rate recovery in the last run minus HR_{rec} in the first one; ΔHRR = heart rate reserve in the last run minus HRR in the first one; HR_{mean} = mean heart rate; HR_{peak} = peak heart rate; HRR = heart rate response; RPE = rate of perceived exertion; RPE = rate of perceived exertion in a 6–20 scale; $\%v\,VO_{2max}$ = percentage of velocity associated with maximal oxygen uptake.

3. Results

HRR, RPE, average running pace, and BLa during both HIITs (10 × 400 m *vs.* 40 × 100 m) are shown in Table 1. No significant differences were found between running protocols in the HR_{peak}, whilst the HR_{mean} was significantly higher ($p < 0.001$) in the 40 × 100 m protocol. No significant differences between HIITs were found in either the ΔHR_{rec} or the ΔHRR. Significant differences between both HIITs were found in the RPE ($p = 0.019$), with lower values in the 40 × 100 m protocol. Running pace and $\%v\,VO_{2max}$ were significantly ($p < 0.001$) faster during 40 × 100 m, and no significant changes were observed in pace throughout both running protocols. The speed maintained during each HIIT protocol is shown in Fig. 1. No significant differences in 10 × 400 m or in 40 × 100 m were found. Finally, no significant differences were found in BLa.

Data from the ANOVA of CMJ, SJ, and SSC utilisation throughout both HIITs are reported in Table 2. No significant changes were found during the 40 × 100 m protocol, whilst significant improvements in CMJ and SJ ($p = 0.008$ and 0.002, respectively) were found in the 10 × 400 m protocol. Indexes related to SSC utilisation (PSA and RSI) did not experience significant changes during any of the protocols.

A pre-post comparison regarding CoP movement (Area, Length, and Velocity) in monopodal support during both HIIT protocols is shown in Table 3. No significant changes were observed in the 40 × 100 m protocol, whilst significant impairments were observed in Area ($p = 0.006$), Length ($p = 0.001$), and Velocity ($p = 0.004$) during the 10 × 400 m protocol.

4. Discussion

The main purpose of this study was to describe the acute effects of 2 different HIITs on postural control, CMJ, SJ, and SSC utilisation in endurance runners, as well as determining whether a protocol with a higher number of shorter runs

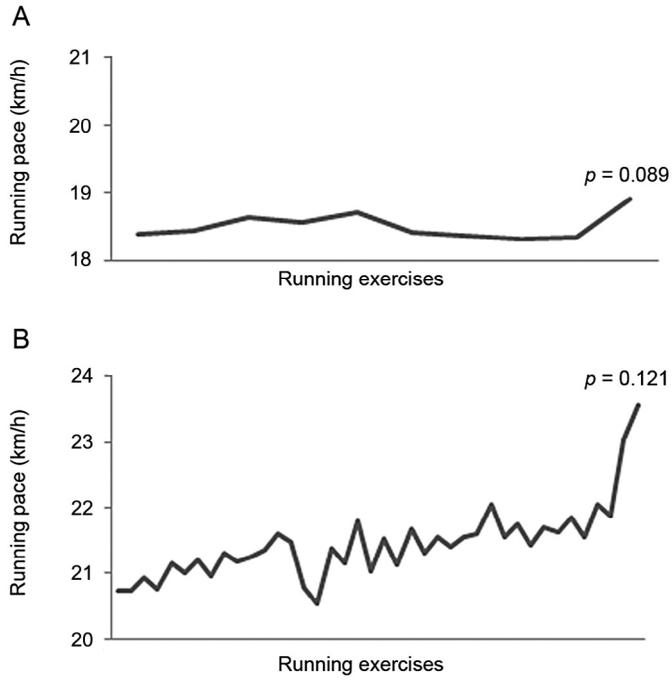

Fig. 1. Running pace during both high-intensity intermittent training protocols: 10 × 400 m (A) and 40 × 100 m (B).

(40 × 100 m) induced different changes in those neuromuscular parameters than those with fewer and longer runs (10 × 400 m). The results obtained showed that despite maintaining the same training volume (4 km), the difference in training structure enabled runners to train at a higher running pace (+3.13 km/h) during the 40 × 100 m protocol. Additionally, the acute effect of both HIITs on postural control and power output differed, whilst SSC utilisation remained unchanged throughout both HIITs. Whereas the 40 × 100 m protocol did not cause any significant changes in vertical jump ability, postural control or SSC utilisation, the 10 × 400 m protocol impaired postural control (from 18.33% to 40.83% impairment in CoP movement) and caused improvements in CMJ (+5.18%) and SJ (+6.43%). Moreover, the evolution of the cardiovascular response (HR_{peak}, 10 × 400 m: 179.00 bpm; 40 × 100 m: 176.25 bpm) and lactate accumulation levels (BLa, 10 × 400 m: 12.87 mmol/L; 40 × 100 m: 12.40 mmol/L) during both HIIT protocols indicate that high exhaustion levels were reached with no significant differences between both HIITs. This fact eliminates and negates the possibility that acute response differences in both HIITs might be due to athletes' levels of involvement or exhaustion levels induced by both HIITs. It is also worth noting that athletic performance in terms of running pace was not impaired during any of HIITs, so athletes followed the instructions given by coaches and they were able to maintain the speed and to be regular during both protocols.

Both metabolic markers and vertical jumping height are of interest because they are considered to indirectly reflect the

Table 2
Repeated measures analysis of CMJ, SJ, and SSC utilisation in both high-intensity intermittent protocols (mean ± SD).

Variable	Protocol	Pre-test	Intermediate test	Post-test	Intermediate-pre difference (Δ, %)	Post-pre difference (Δ, %)	*p* value
CMJ (cm)	10 × 400 m	27.11 ± 4.56[a]	27.99 ± 3.44	28.59 ± 4.84[a]	0.88 (3.14)	1.48 (5.18)	0.008
	40 × 100 m	28.25 ± 4.23	28.32 ± 4.80	27.91 ± 4.64	0.07 (0.25)	−0.34 (−1.20)	0.581
SJ (cm)	10 × 400 m	25.60 ± 4.51[b]	26.76 ± 4.20	27.36 ± 4.54[b]	1.16 (4.33)	1.76 (6.43)	0.002
	40 × 100 m	27.87 ± 4.21	28.02 ± 3.89	27.47 ± 4.21	0.15 (0.54)	−0.40 (−1.44)	0.374
PSA (%)	10 × 400 m	6.19 ± 5.51	5.36 ± 8.32	4.65 ± 7.92	−0.83 (−13.41)	−1.54 (−24.88)	0.638
	40 × 100 m	3.41 ± 5.16	0.90 ± 7.29	1.48 ± 4.29	−2.51 (−73.61)	−1.93 (−56.60)	0.484
RSI (cm)	10 × 400 m	1.51 ± 1.34	1.24 ± 2.24	1.23 ± 1.99	−0.27 (−17.88)	−0.28 (−18.54)	0.721
	40 × 100 m	0.85 ± 1.24	0.30 ± 2.07	0.44 ± 1.21	−0.55 (−64.71)	−0.41 (−48.24)	0.592

Note: *p* value indicates differences within protocols.
[a,b] The same superscript letter indicates significant differences within protocol (repeated measures analysis).
Abbreviations: CMJ = countermovement jump; PSA = pre-stretch augmentation; RSI = reactive strength index; SJ = squat jump; SSC = stretch-shortening cycle utilisation.

Table 3
Pre-post comparison regarding CoP movement in monopodal support (average from both the left and the right sides) during high-intensity intermittent protocols (mean ± SD).

Variable	Protocol	Pre-test	Post-test	Post-pre difference (Δ, %)	*p* value
Area (mm)	10 × 400 m	417.80 ± 201.47	706.10 ± 403.31	288.30 (40.83)	0.006
	40 × 100 m	835.30 ± 584.08	910.27 ± 1163.35	74.97 (8.24)	0.812
Length (mm)	10 × 400 m	338.72 ± 74.08	414.75 ± 116.85	76.03 (18.33)	0.001
	40 × 100 m	385.72 ± 103.67	436.30 ± 167.84	50.58 (11.59)	0.220
Velocity (mm/s)	10 × 400 m	24.02 ± 6.04	29.73 ± 10.63	5.71 (19.21)	0.004
	40 × 100 m	29.13 ± 9.25	33.43 ± 18.61	4.30 (12.86)	0.364

Abbreviations: Area = area of centre of pressure movement in monopodal support; CoP = centre of pressure; Length = length of centre of pressure movement in monopodal support; Velocity = velocity of center of pressure movement in monopodal support.

degree of anaerobic glycolysis activation (BLa),[24] as well as the capability of the leg extensor muscles to generate mechanical power (CMJ and SJ).[25] This study showed that in spite of the high level of fatigue reached—as demonstrated by cardiovascular response, BLa and RPE—the vertical jump ability was not impaired after HIITs in endurance runners. In the 40 × 100 m protocol the CMJ and SJ performance remained unchanged—there were no significant differences according to baseline values. Even more surprising was that the best values for CMJ and SJ performance for the 10 × 400 m protocol were obtained post-test. It might be expected that power performance after running exercises inducing high levels of fatigue would decreased. Nevertheless, some previous studies[6,7,26,27] found post-activation potentiation (PAP)—a significant improvement in muscular power as a result of previous muscular work[28,29]—after running exercises in endurance runners. These data show that, despite high levels of fatigue, trained subjects can maintain their strength and power levels, and therefore their work capacity in terms of running pace, during HIIT protocols performed above vVO_{2max}. Since fatigue level after both workouts was similar and pace was maintained over both HIITs, neither level of fatigue reached nor pacing strategy for each HIIT seems to be responsible for changes induced in jumping ability. The authors suggest that the running pace might be responsible for these muscle power output changes. A faster running pace during the 40 × 100 m protocol (faster average pace and higher $\%vVO_{2max}$) will recruit additional fast twitch motor units for relatively short durations.[30]

Data obtained from SSC utilisation support and reinforce that statement. It might be expected that SSC utilisation, indirectly measured by means of PSA and RSI, would decrease throughout both HIITs. Despite a trend towards lower SSC utilisation being observed in both HIITs, no significant changes were found in PSA or RSI during either running protocols. As far as the authors know, the information available about SSC utilisation in endurance athletes is limited[18,31,32] and no previous studies have analysed the fatigue-induced changes in SSC utilisation during running exercises so the comparison with previous studies is quite difficult. Padua et al.[33] concluded that some parameters associated with SSC utilisation were unaffected after fatigue, the opposite results found by Moritani et al.[34]

Basic muscle function is defined as the SSC, where the pre-activated muscle is first stretched (eccentric action) and then followed by the shortening (concentric) action.[35] However, neuromuscular fatigue has traditionally been examined using isolated forms of isometric, concentric or eccentric actions, whereas none of these actions are naturally occurring in human ground locomotion. Parameters related to SSC utilisation, such as PSA or RSI, have been used for monitoring training adaptations over a sport season[18] and have been associated with performance enhancement, injury prevention and fatigue mechanisms.[12,33,36] Based on the results obtained, the authors suggest that monitoring parameters such as RSI and PSA during running exercises might provide interesting information about acute responses to training sessions and about training adaptation throughout the season.

Postural control is a complex function that involves keeping the vertical projection of the centre of gravity within the base of support.[11] As indicated by Degache et al.[37] postural control is a permanent re-establishment process of balance, which depends on the orientation information derived from 3 independent sensory sources: somatosensory, vestibular, and visual inputs. Balance is actively controlled by the central nervous system, which calls into action various relevant postural muscles when they are required;[38] therefore, postural control is also dependent upon reflexive and voluntary muscle responses.[39] On the other hand, fatigue following physical exercise is caused by a combination of physiological processes, occurring at both central and peripheral levels, which mainly deal with the inability to produce an expected force or with the increase in the onset delay of movement.[30] It has been shown that exercises such as running, cycling, cycle ergometer, walking, ironman triathlon, or mountain ultra-marathon affect postural control.[22,37–39] This type of exercise involving the whole organism deteriorates the sensory proprioceptive and exteroceptive information and/or their integration, and/or decreases the muscular system efficiency.[38] It is therefore well documented that muscular exercise is a cause of aggravation of postural sway since the increase of energy needs amplifies liquid movements and cardiac and respiratory muscular contractions.[40] In addition, when muscular exercise generates fatigue, it affects the regulating system of postural control by its effects on the quality and treatment of sensory information, as well as motor command. Indeed, muscular exercise induces perturbations of the neuromuscular system that involve changes in muscle strength[7] and postural control.[22]

As for balance ability and fatigue-induced changes by 2 different HIITs in endurance runners, the data obtained in this study are partially consistent with previous works showing that CoP movements in monopodal support were greater—worse balance ability—after 2 different HIITs (10 × 400 m: 18.33%–40.83%, 40 × 100 m: 8.24%–12.86%) according to pre-test or baseline values. Nevertheless, despite no differences being found between fatigue levels induced by either HIIT protocols, reductions only were statistically significant after the 10 × 400 m protocol, whilst no significant reductions were seen in the 40 × 100 m protocol. To date, previous papers focused on checking the fatigue-induced changes after running exercises in balance ability reported impairment.[22,37,40] However, as indicated by Degache et al.,[37] the conditions under which the different exercises are performed influence postural control in different ways. As mentioned earlier, neither level of fatigue reached nor pacing strategy for each HIIT seems to be responsible for changes induced in balance ability. However, this study seems to indicate that short runs performed at high intensities (40 × 100 m) cause smaller impairments in postural control than longer runs performed at a slower pace (10 × 400 m). Anyway, more research is needed to highlight the physiological basis of that assumption.

Finally, the main limitation of this study was not to include more indications on a precise intensity to maintain. Despite that vVO_{2max} was reported, coaches usually prescribe in terms of $\%HR_{max}$ or best performance on a distance. Notwithstanding

this limitation, the study offers some insight into neuromuscular impact of HIIT in endurance runners and training method selection for endurance runners by comparing 2 running sessions of the same overall volume (4 km) but distributed differently (10 × 400 m or 40 × 100 m).

5. Conclusion

To sum up, the results obtained in this study showed that acute effects of both HIITs on postural control and power output differed, whilst SSC utilisation remained unchanged throughout both HIITs. Whereas the 40 × 100 m protocol did not cause any significant changes in vertical jump ability, postural control, or SSC utilisation, the 10 × 400 m protocol impaired postural control (in terms of CoP movement) and caused improvements in vertical jumping tests. Hence, a protocol with a higher number of shorter runs (40 × 100 m) induced different changes in those neuromuscular parameters than those with fewer and longer runs (10 × 400 m). Likewise, data showed that, despite maintaining the same training volume and inducing similar levels of fatigue, the difference in training structure enabled runners to train at a higher pace during the 40 × 100 m protocol. Based on this, the authors accentuate the importance of average running pace in every workout, leading to different fatigue-induced changes in power output and postural control despite maintaining the training volume and inducing similar levels of fatigue.

From a practical point of view, a further knowledge about the acute impact of different HIITs on the neuromuscular system of endurance runners might facilitate a higher accuracy in training prescription for coaches. Additionally, the fact that trained subjects can maintain their strength and power levels and, therefore, their work capacity during HIITs performed above vVO_{2max} and inducing high levels of fatigue, might provide useful and interesting information for coaches and athletes about training adaptations throughout the sport season. The authors therefore suggest that monitoring parameters such as CMJ, SJ, SSC utilisation, and balance ability during running exercises might provide practical information about both acute responses to training sessions and training adaptation.

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Authors' contributions

FGP participated in the data collection, performed the statistical analysis and drafted the manuscript; JAPM participated in the data collection and its design and revised the manuscript critically; VMSH participated in the data collection and its design and revised the manuscript critically; PALR participated in the data collection and its design and revised the manuscript critically. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

None of the authors declare competing financial interests.

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