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Effects of sprint distance and repetition number on energy system contributions in soccer players

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ABSTRACT

Background/objective: This study aims to compare the effect of sprint distance and repetition number on performance, physiological responses, and energy systems contributions.
Methods: Eighteen male university league soccer players (age: 19.9 ± 1.6 years, height: 177.9 ± 4.7 cm, body mass: 72.4 ± 6.3 kg, percentage body fat: 8.9 ± 1.8, training experience: 7.4 ± 1.6 years) completed two different repeated sprint protocols: 20 × 20 m (20 × 20) and 10 × 40 m (10 × 40) with 15s and 30s rest intervals, respectively. Oxygen uptake (VO_2) were measured during the rest, exercise, and recovery phases. Rest and peak blood lactate concentrations were determined. Using VO_2 and lactate values, the energy system contributions were calculated using a mono-exponential model and mathematical calculations. Energy systems contributions and total energy expenditure (TEE) were calculated both for the entire protocol (overall) and for the sprints only.
Results: Ratings of perceived exertion (RPE), peak and mean heart rate (HR) responses were significantly higher in the 20 × 20 whereas lactate response was higher in the 10 × 40. TEE was similar between the 10 × 40 (586.3 ± 60.8 kJ) and 20 × 20 (595.6 ± 57.5 kJ). For overall estimations, the 10 × 40 and 20 × 20 presented similar results of oxidative (47.5 ± 5.4 vs 45.7 ± 5.1 kJ min^{-1}) and phosphagen (44.7 ± 5.4 vs (42.9 ± 4.8 kJ min^{-1}) systems contributions whereas glycolytic contribution was higher in the 10 × 40 (15.5 ± 2.2 vs 12.8 ± 2.3 kJ min^{-1}). For sprints only estimation, the phosphagen (257.6 ± 31.5 vs 225.2 ± 28.2 kJ min^{-1}), glycolytic (89.4 ± 13.4 vs 67.3 ± 12.5 kJ min^{-1}), and oxidative (76.9 ± 6.9 vs 72.0 ± 7.9 2 kJ min^{-1}) systems contributions were higher in the 10 × 40.
Conclusions: Although HR and RPE responses were higher in the 20 × 20, phosphagen (during sprints) and glycolytic (during both sprints and overall protocol) were higher in the 10 × 40 protocol. Therefore, the 10 × 40 protocol seems more reasonable for developing or evaluating the anaerobic systems.

Introduction

Although soccer is a team sport that involves low-intensity efforts throughout most of the match, short-duration and high-intensity bouts are the main determinants that directly affect the decisive actions during the match.[1–3] Sprints are interspersed by numerous low-intensity actions, such as walking, standing, and jogging, that take place during a soccer match.[4] A single sprint performance is related to the ability to deplete large amounts of high-energy phosphates at a fast rate.[5] On the other hand, repeated sprint ability, which is considered a key attribute for team sports, refers to an athlete's ability to recover during short rest intervals and maintain maximal performance during consecutive sprint bouts.[5,6] Hence, due to the requirement for short-term high-power

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outputs, a fast rate of energy release and the ability to replenish high-energy phosphate stores are critical to success in soccer.[7]

The evaluation of the energy demands of different exercises or metabolic energy profiles of soccer players can help to formulate requirements related to their training.[4] Three energy systems, which use distinct metabolic pathways but are closely integrated to satisfy the energy requirements of the muscles, contribute at different levels depending essentially on the exercise intensity and duration.[7] During a single 3s and 6s maximal sprint activity, the phosphagen system (ATP–PCr) contributes approximately 65%[8] and 50%,[9] of the necessary energy provision, respectively, after which the glycolytic system becomes more dominant. However, when sprint bouts are repeated with sufficient rest intervals, the ATP-PCr relative contribution increases.[9–11] The contributions of the anaerobic (both ATP-PCr and glycolytic) and oxidative energy systems during an exhaustive exercise bout of 10 s are 94% and 6% respectively, but these values change to approximately 20% and 80% respectively during a maximal exercise bout of 4–5 min.[7] Conversely, following a repeated sprint protocol in which 9 × 6 s sprints are applied with a 30-s rest interval, giving a total period of 294 s (approximately 5 min), the contribution of the anaerobic and aerobic energy systems in the 10th sprint are indicated as 60% and 40%, respectively.[9] Therefore, in a ~5-min exercise design aimed at improving the anaerobic characteristics of soccer players, repeated protocols with optimum repetitions, sprint distances, and rest intervals seem more reasonable than maximal exercises which no resting intervals.

Repeated sprint exercises lead to a decline in sprint performance because of limitations at the muscular level, which reduce the energy available from phosphocreatine hydrolysis and involve the intramuscular accumulation of metabolic by-products such as hydrogen ions and inorganic phosphate induced by increased glycolysis.[1,9,10,12] On the other hand, increased energy contribution via the aerobic system is considered to reduce ATP production rates and sprint performance.[5,9,10] However, during a repeated sprint exercise, the essential function of the oxidative system is to resynthesize phosphocreatine (PCr), remove accumulated inorganic phosphate (Pi), and oxidize lactate during short rest periods.[5,9] Briefly, it seems that the most reasonable approach is to ensure circumstances where the oxidative system is active at a minimum level during sprint bouts and at a maximum level during rest periods to maintain high performance.

Previous studies have also investigated the effects of a range of repeated-sprint exercises, including variations of distance, number of repetitions, and rest intervals on performance and physiological characteristics.[5,13–15] However, the effect of the number of repetitions or single sprint distance on the contribution of the energy systems in repeated sprint protocols with equal total distance and similar total rest time is as yet unknown. Therefore, the aim of the present study was to compare the effect of sprint distance and repetition number on performance, physiological responses, and energy system contributions during repeated sprints.

Methods

Participants

Eighteen male soccer players who compete in the National University League (age: 19.9 ± 1.6 years, height: 177.9 ± 4.7 cm, body mass: 72.4 ± 6.3 kg, percentage body fat: 8.9 ± 1.8, training experience: 7.4 ± 1.6 years) volunteered to participate in this study. Participants were chosen from soccer teams according to experience and training frequency (each athlete selected had at least five years' experience and trained at least three times per week) and free of drugs or ingestion of nutritional supplements during the period of the study. Soccer players were tested as part of their athletic training program of a pre-season in a total of 1 month. The participants were instructed not to perform any strenuous exercise for 24 h before the tests. All participants provided written consent after being informed of all processes related to the study. All procedures were approved by the local university ethics committee.

Experimental protocol

To assess the effect of number of repetitions, the subjects completed two different repeated-sprint protocols: 20 × 20 m with 15 s rest intervals (20 × 20), and 10 × 40 m with 30 s rest intervals (10 × 40). Thus, work-rest ratio in the repeated sprint exercises was 1:5.3 for the 10 × 40 protocol and 1:4.5 for the 20 × 20 protocol. The reason we used standard rest times instead of the work:rest ratio was to test a design that a soccer team could train together. Because determining the individual resting rate of each player according to their sprint durations means a different protocol for each player. Although repeated sprint protocols including work:rest ratio can be applied for individual trainings, they are not reasonable for a training which whole team players perform at the same time. The experimental sessions were performed in a randomized order. Six players performed both protocols at 48 h intervals, while 12 players performed the protocols at 72 h intervals. The participants attended familiarization session before the tests, where they were allowed to try the mask used to measure their oxygen consumption, and were submitted to the blood lactate concentration measurement process. All tests were conducted 2–4 weeks before the start of the regular soccer season, under standardized environmental conditions (18–21 °C, 45%–55% humidity), 3–4 h after the participants had consumed a light meal. We did not apply a nutrition intervention to the participants, but since all participants were in the pre-season period, they followed a similar diet program recommended by their dietician. The tests were performed with the participants wearing training shorts, t-shirt, and shoes, on an outdoor soccer turf field, and the athletes were provided with verbal encouragement to maximize their performance.

Repeated-sprint performance

The participants performed a 5-min warm-up composed of exercises with various intensities, dynamic stretches, and short-duration maximal running before the tests.[16] Both tests of each participants were followed by 3 evaluators as well as using a photocell system (Smart Speed electronic system, Fusion Sport, Cooper Plains, Australia) simultaneously. Lighted photocell gates were used during the tests, and the athletes were instructed to watch the lights indicating a 3-s countdown and then start sprinting once the last light (green) was turned on. The participants were also instructed to restart from the finish gate for the next sprint after passing over it. The sprints started 50 cm behind the photocell gate. Participants completed a single-criterion sprint 3 min after the warm-up. The participants were instructed that they needed to achieve at least 95% of criterion sprint score during the first sprint. The test was terminated when they failed and restarted after another 5-min break.[8] In terms of repeated-sprint performance indices, the total time, best time, mean time, and percentage of time decrement were calculated according to the formulas proposed by Glaister et al. (2008).[17]

Physiological measurements

VO_2 levels were monitored during the rest (10 min), exercise, and recovery (15 min) phases using a COSMED K5 (Rome, Italy) portable gas-exchange system in breath-by-breath mode. Prior to

each test, the portable metabolic gas analyzer was calibrated using a sample of known gases (5.0% CO_2 and 16.0% O_2). Blood lactate concentrations were measured from the earlobe using a Lactate Plus hand-held portable analyzer (Nova Biomedical, USA), at rest (to determine baseline value), and first, three, five, seven, and 10 min after the tests (to determine peak value). One measurement was taken at each time point and the coefficients of variation of lactate measures were 13.2% for 20 × 20 protocol and 11.5% for 10 × 40 protocol. Athletes' beat-to-beat heart rates (HR) were measured using a HR monitor (Polar 810i, Kempele, Finland). The highest HR that an athlete reached during an exercise session was accepted as their HRpeak. To determine ratings of perceived exertion, a Borg scale, consisting of numbered categories ranging from 6 to 20, and verbal cues from "very very light" to "very very hard," were shown to athletes immediately after their final repetition of each test, and their answers were recorded.

Calculations of the contributions of metabolic energy systems

Calculation of oxidative, glycolytic, and ATP-PCr energy system contribution were generated through VO2, delta of blood lactate concentration, and the fast component of excess post-exercise oxygen consumption (EPOC), respectively. Total energy expenditure (TEE) during the repeated-sprint exercises was calculated as the sum of energy derived from ATP-PCr, glycolytic, and oxidative systems.[18–20] The caloric quotient of 20.92 kJ was used in the three different energy systems. The ATP-PCr contribution was calculated using the fast component of EPOC following the final sprint and the sum of VO_2-time integral during the rest intervals among the sprints.[18,21] A mono-exponential model was fitted to observe the kinetics of EPOC using OriginPro 8.0 software (OriginLab Corp., Northampton, USA)[11,18,22] The model presented a time constant of 66.8 ± 8.5 s and an amplitude of 2467.9 ± 294.7 mL min^{-1} for the 10 × 40; a time constant of 70.8 ± 3.1 s and an amplitude of 2600.1 ± 286.7 mL min^{-1} for the 20 × 20. Thus, ATP-PCr contribution during the fast component of EPOC kinetic was calculated by multiplying the amplitude by time constant of the mono-exponential model.

To estimate the glycolytic system contribution, a value of 1 $mmol.L^{-1}$ delta lactate value (peak blood lactate after a test minus baseline value) was considered to be equivalent to 3 mL $O_2.kg^{-1}$ body mass.[23] Net energy derived from the oxidative system was estimated by subtracting resting VO_2 (measured for a 10-min period while the athletes were in a stationary standing position, but with only the last 5 min being analyzed) from the VO_2 area integrated over time during the test using the trapezoidal method. The oxidative contribution was calculated for both the entire test (oxidative $contribution_{OVERALL}$) and sprints only (oxidative $contribution_{SPRINTS}$).[11,18,21,22]

Statistical analysis

Data-processing procedures were conducted using SPSS 21.0 (IBM Corp, Armonk, NY, USA) and OriginPro 8.0 software (OriginLab Corp., Northampton, USA). The measures are reported as means and standard deviations. Normality of distribution was verified using the Shapiro-Wilk test. Differences between variables were calculated using the paired Student t-test. In addition, effect sizes for the paired Student t-test were calculated by Cohen's d[24] and were classified according to Hopkins.[25] The assumptions of sphericity were assessed by Mauchly's test. Assumptions of sphericity were controlled by Mauchly's test. Whenever an assumption was violated, Greenhouse-Geisser correction if epsilon (ε) value was <0.75 and Huynh-Feldt correction if ε was >0.75 were applied on the degree of freedom. For comparisons of sprints values within a protocol, a one-way analysis of variance with repeated measurements was used. A two-way analysis of variance with repeated measures was used to compare the variables related to the energy system contributions (energy systems − 3 levels × protocols − 2 levels), followed by multiple comparisons.

Results

Concerning physiological responses and performance variables (Table 1), total sprint time and percentage of sprint decrement were significantly higher in the 20 × 20 than 10 × 40. Delta lactate was significantly higher in the 10 × 40. VO_2 during the fast phase of EPOC was significantly higher in the 20 × 20 whereas VO_2 during the rest intervals was similar. HRpeak, HRmean, and RPE were significantly higher in the 20 × 20.

Regarding the energy provisions (Table 2), total energy contribution and total energy demand were similar between the 10 × 40 than 20 × 20. For sprints only estimations, the phosphagen, glycolytic, and oxidative contribution were significantly higher in the 10 × 40. For overall estimations, the glycolytic contribution was higher in the 10 × 40 whereas phosphagen and oxidative contributions were similar between protocols.

Fig. 1 shows that the times of sprints 4–10 were significantly higher than the time of first sprint ($p < .001$; $d = 0.42–2.52$, small − large effect) during the 10 × 40 (left panel) and the times of sprints 5–20 were significantly higher than the time of first sprint ($p < .001$; $d = 0.53–1.93$, small − large effect) during the 20 × 20 (right panel).

Fig. 2A shows that the oxidative contribution of sprint 1 was significantly lower than the oxidative contribution of sprints 2–10 ($p < .001$; $d = 1.03–1.82$, moderate − large effect) and the oxidative contribution of sprint 2 was significantly lower than the oxidative contribution of sprints 8–10 ($p < .020$; $d = 0.62–0.92$, moderate effect) during the 10 × 40. Fig. 2B presents that the oxidative contribution of sprint 1 was significantly lower than the oxidative contribution of sprints 2–20 ($p < .001$; $d = 1.35–2.32$, large − very large effect) during the 20 × 20.

Fig. 2C presents that the oxygen uptake of rest interval 1 was significantly lower than the oxygen uptake of rest intervals 2–9 ($p < .001$; $d = 1.13–2.90$, moderate − very large effect); the oxygen uptake of rest interval 2 was significantly lower than the oxygen uptake of rest intervals 5–9 ($p < .034$; $d = 0.54–1.91$, small − large effect) and the oxygen uptake of rest interval 3 was significantly lower than the oxygen uptake of rest intervals 8 and 9 ($p < .009$; $d = 0.75–1.39$, moderate − large effect) during the 10 × 40. Fig. 2D shows that the oxygen uptake of rest interval 1 was significantly lower than the oxygen uptake of rest intervals 2–19 ($p < .001$; $d = 0.71–1.44$, moderate − large effect); the oxygen uptake of rest interval 2 was significantly lower than the oxygen uptake of rest intervals 14–19 ($p < .021$; $d = 0.49–0.92$, small − moderate) and the oxygen uptake of rest interval 3 was significantly lower than the oxygen uptake of rest intervals 17–19 ($p < .012$; $d = 0.44–0.77$, small − moderate) during the 20 × 20.

Fig. 3 shows that higher values were found for the oxidative system compared to the glycolytic ($p < .001$; $d = 13.43$, nearly perfect effect for the 10 × 40 and $p < .001$; $d = 15.34$, nearly perfect effect for the 20 × 20) and phosphagen ($p < .001$; $d = 1.77$, large effect for the 10 × 40 and $p < .001$; $d = 1.95$, large effect for the 20 × 00) systems for both protocols. Moreover, from the two-way analysis of variance, there was also an interaction for energy system and protocol ($p = .004$; $\eta^2 = 0.347$).

Discussion

The present study indicated that percentage of phosphagen,

Table 1
The physiological responses and performance outputs of repeated sprint exercise forms.

	10 × 40 m	20 × 20 m	t	p	d
Total sprint time (s)	56.7 ± 1.6	67.3 ± 3.0	16.016	<.001	4.41 (nearly perfect)
Sprint decrement (%)	4.8 ± 1.7	6.9 ± 2.8	2.755	.014	0.91 (moderate)
Delta lactate (mmol.L^{-1})	18.6 ± 2.1	16.6 ± 2.2	2.978	.008	0.93 (moderate)
$VO_{2[EPOCfast]}$ (L)	2.7 ± 0.5	3.1 ± 0.3	3.366	.004	0.74 (moderate)
$VO_{2[REST]}$ (L)	8.9 ± 1.2	9.0 ± 1.1	0.382	.707	0.07 (trivial)
HRpeak	184 ± 8	188 ± 8	2.415	.027	0.44 (small)
HRmean	164 ± 7	168 ± 9	2.204	.042	0.50 (small)
RPE	17 ± 1	19 ± 1	6.985	<.001	1.23 (large)

Note: $VO_{2[EPOCfast]}$ = oxygen consumption during the fast phase of EPOC; $VO_{2[REST]}$ = oxygen consumption during the rest intervals; HR = heart rate; RPE = rating of perceived exertion.

Table 2
Energy demand and energy system contributions during repeated sprint exercise forms.

	10 × 40 m	20 × 20 m	t	p	d
Total energy contribution (kJ)	586.3 ± 60.8	595.6 ± 57.5	0.894	.384	0.15 (trivial)
Total energy demand (L of O_2)	28.0 ± 2.9	28.5 ± 2.7	0.895	.383	0.17 (trivial)
$Oxidative_{OVERALL}$ (kJ.min^{-1})	47.5 ± 5.4	45.7 ± 5.1	1.933	.070	0.35 (small)
$Oxidative_{SPRINTS}$ (kJ.min^{-1})	76.9 ± 6.9	72.0 ± 7.9	3.515	.003	0.66 (moderate)
$Glycolytic_{OVERALL}$ (kJ.min^{-1})	15.5 ± 2.2	12.8 ± 2.3	4.982	<.001	1.16 (moderate)
$Glycolytic_{SPRINTS}$ (kJ.min^{-1})	89.4 ± 13.4	67.3 ± 12.5	6.947	<.001	1.71 (large)
$Phosphagen_{OVERALL}$ (kJ.min^{-1})	44.7 ± 5.4	42.9 ± 4.7	1.690	.109	0.36 (small)
$Phosphagen_{SPRINTS}$ (kJ.min^{-1})	257.6 ± 31.5	225.2 ± 28.7	4.746	<.001	1.08 (large)

Note: OVERALL = estimated during the entire test (sprints + rest intervals); SPRINTS = estimated during the sprints only.

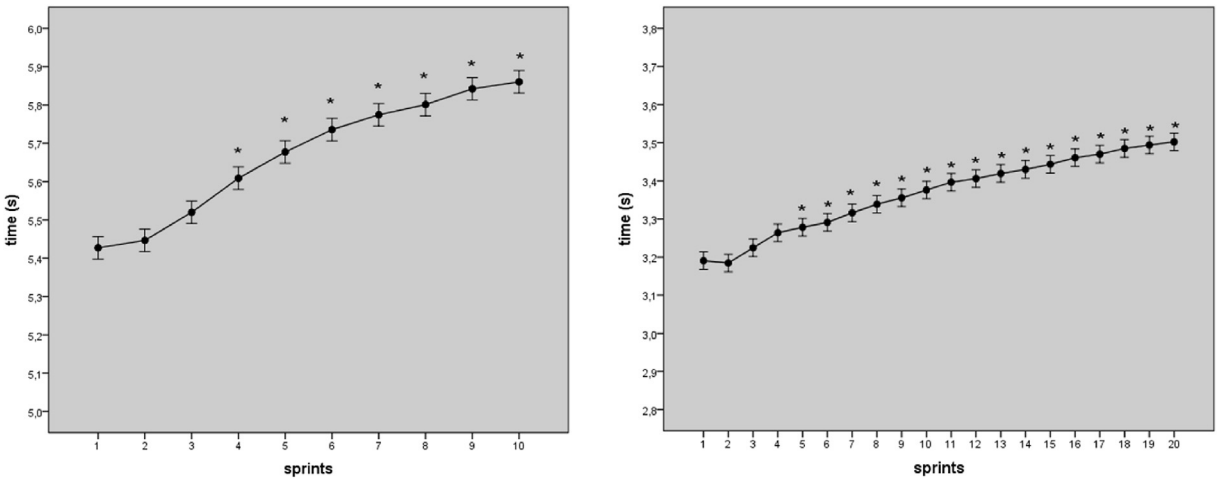

Fig. 1. Time measured during 10 × 40 m (left panel) and 20 × 20 m (right panel) repeated sprint exercise forms. Note: * significantly different from sprint 1. p < .05. d = 0.42–2.52 for 10 × 40 m d = 0.53–1.93 for 20 × 20 m.

glycolytic, and oxidative systems contributions were 41.4 ± 1.4%, 14.5 ± 2.3%, and 44.1 ± 1.5%, respectively, for the $10 \times 40_{OVERALL}$, and 42.3 ± 1.1%, 12.7 ± 2.4%, and 45.0 ± 1.5%, respectively, for the $20 \times 20_{OVERALL}$. In addition, TEE was similar between the 10 × 40 and 20 × 20. For overall estimations, the 10 × 40 and 20 × 20 presented similar results of oxidative and phosphagen systems contributions whereas glycolytic contribution was higher in the 10 × 40. However, for sprints only estimation, the phosphagen, glycolytic, and oxidative systems contributions were higher in the 10 × 40. Hence, considering that the anaerobic contributions are critical for many team athletes' decisive actions, the 10 × 40 protocol may be a more appropriate training or test protocol, since the contribution of both the phosphagen (during sprints) and glycolytic system (during both sprints and overall) are significantly higher than 20 × 20 protocol.

Balsom et al.[26] reported that VO_2 during 30 s rest periods during before the sprints 3–5, 5–7, 9–11, and 15 of 15 × 40 m protocol were 2.85, 3.07, 3.11, and 3.09 L min^{-1}, respectively. Milioni et al.[11] indicated the VO_2 during the sprint bouts of 6 × 35 m protocol ranged from approximately 0.12–0.28 L and reported that sprints 1 and 2 were lower than others. Our study found that the VO_2 during the sprint bouts of 10 × 40 and 20 × 20 protocols ranged from 0.23 to 0.38 L and 0.09–0.21 L, respectively. Furthermore, initial sprints (sprints 1 or 2) were lower than next sprints whereas there was no increase later period in both protocols. Similarly, VO_2 during the rest intervals of 10 × 40 and 20 × 20 protocols ranged from 0.8 to 0.11 L (1.6–2.2 L min$^{-1)}$ and 0.43–0.51 L (1.72–2.4 L min^{-1}), respectively. Moreover, rest intervals 1–3 were lower than next rest intervals whereas there was no increase among the subsequent rest intervals for both protocols. It is known that, there is an exponential rise at the onset of the heavy exercises since the respiratory and cardiovascular systems do not supply enough oxygen, then VO_2

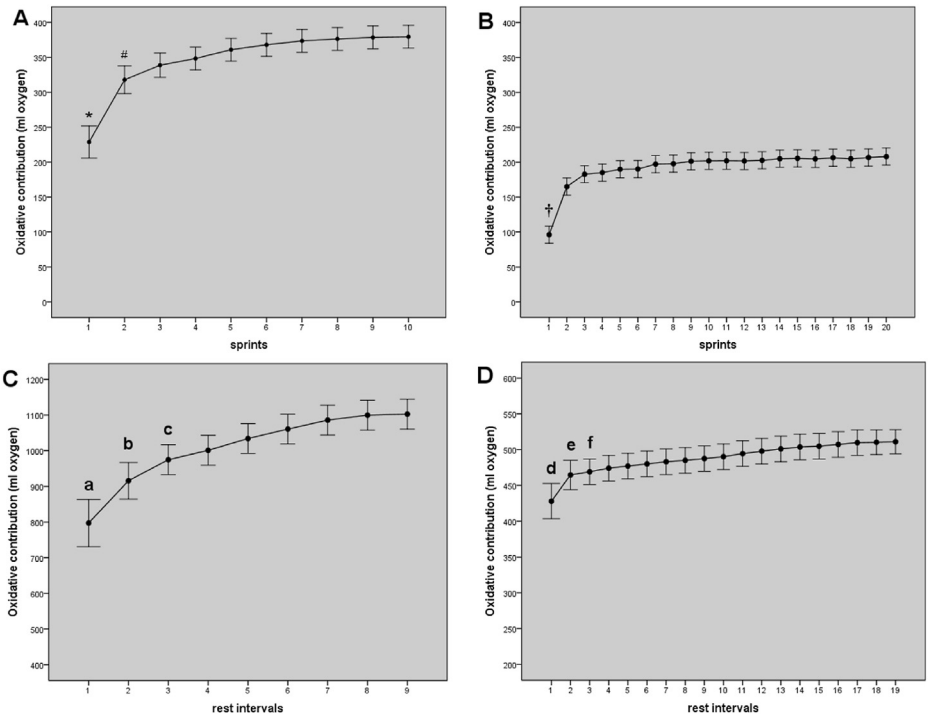

Fig. 2. Oxidative contribution during the sprint efforts and the rest intervals. Note: Panel A shows that *sprint 1< sprints 2–10 (d = 1.03–1.82); #sprint 2< sprints 8–10 (d = 0.62–0.92). Panel B shows that †sprint 1< sprints 2–20 (d = 1.35–2.32). Panel C shows that [a]rest interval 1< rest intervals 2–9 (d = 1.13–2.90); [b]rest interval 2< rest intervals 5–9 (d = 0.54–1.91); [c]rest interval 3< rest intervals 8 and 9 (d = 0.75–1.39). Panel D shows that [d]rest interval 1< rest intervals 2–19 (d = 0.71–1.44); [e]rest interval 2< rest intervals 14–19 (d = 0.49–0.92); [a]rest interval 3< rest intervals 17–19 (d = 0.44–0.77). $p < .05$.

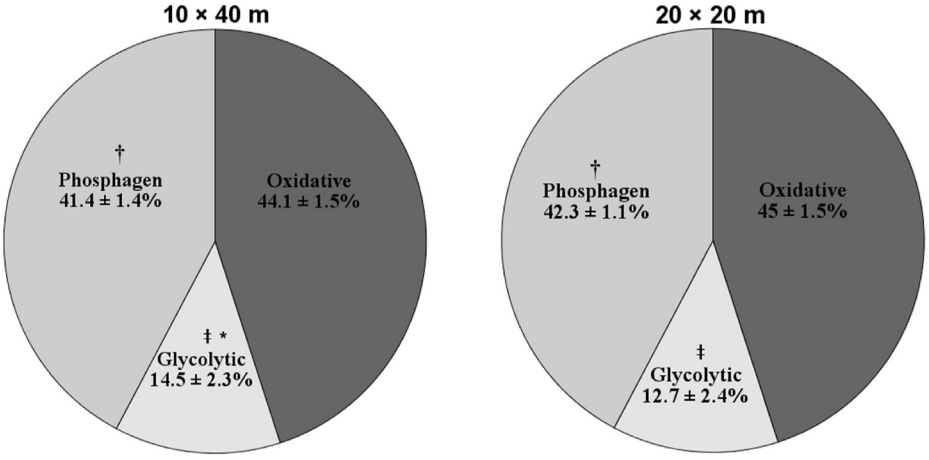

Fig. 3. Estimated relative energy contribution during 10 × 40 m and 20 × 20 m repeated sprint exercise forms. Note: † phosphagen different from oxidative and glycolytic; ‡ glycolytic different from oxidative; * 10 × 40 different from the 20 × 20. $p < .05$).

becomes more stable in a few minutes.[27,28] Similarly the aforementioned studies, the findings of this study showed that VO_2 during sprinting and rest intervals significantly increases in initial period, then VO_2 increases slightly.

Milioni et al.'s[11] calculations of energy demand in 6 × 35 m tests with a resting time of 10 s reported TEE of 199.6 kJ for the whole protocol and 156.2 kJ for sprints only. Additionally, these authors estimated the phosphagen, glycolytic, and oxidative systems contributions of 28.3%, 33.9%, and 37.8% for the entire period and, 36.2%, 43.7%, and 20.1% for sprints only, respectively. Gaitanos et al.[10] applied 10 × 6 s cycle sprint exercise with 30 s rest intervals and found a decrease of 43.6 mmol kg^{-1} dm (from 76.5 to 32.9) during the first sprint, whereas a decrease of 25.3 mmol kg^{-1} dm in the PCr stores (from 37.5 to 12.2) during the 10th sprint. Additionally, from conducting a range of estimations, Girard et al.[9] reported contributions of the phosphagen, glycolytic, and oxidative systems during a single sprint (6 s) of 52%, 40%, and 8%, whereas the values for the last sprint (10th sprint of a repeated sprint protocol with 30 s rest intervals) were 51%, 9%, and 40%, respectively. Therefore, it is clear that the relative contribution of the phosphagen system does not change expressively in this type of repeated sprint exercises, but the absolute contribution decreases. Hence, to improve repeated sprint performance, strategies that increase the absolute contribution of the phosphagen system either

providing more PCr available or increasing its re-synthesis may be reasonable.

Previous studies using the short (≤30 s) resting intervals have reported performance decrements around %9–10 during repeated-sprint exercises.[11,15] However, unlike the current research, these previous studies examined only a single protocol. Another previous study conducted four different repeated-sprint protocols with a total distance of 600 m, with rest periods chosen as four or six times the best sprint times. One of these protocols involved 15 × 40 m sprints with a rest interval of 33.6 s, while another involved 40 × 15 m sprints with a rest interval of 15.6 s. Speed decrement values in these two protocols were 4.1% and 7.5%, respectively.[13] The same study's third protocol involved 15 × 40 m sprints with a rest interval of 22.4 s, while the final protocol involved 40 × 15 m sprints with a rest interval of 10.4 s. The speed decrement values in these protocols were 11.1% and 15.9%, respectively. Similarly, in the present study, 10 × 40 and 20 × 20 protocols resulted in speed decrements of 4.8 and 6.9%, respectively. The aforementioned findings indicate that, in repeated-sprint exercises with equal total distance and rest rates, increasing the number of repetitions results in higher performance decrement.

On the other hand, performance decrement in repeated-sprint designs seems to be independent of lactate accumulation. Little et al.[13] report a greater response of blood lactate in the 15 × 40 m protocol despite a higher performance decrement in the 40 × 15 m protocol. Similarly, our results showed that higher blood lactate concentration in the 10 × 40 protocol despite higher performance decrement in the 20 × 20 protocol. In repeated sprints with a very short resting interval (~15 s or fewer), deceleration and rapid movements are required for participants to return to the starting line as soon as possible for the next sprint. In addition, considering that using forceful eccentric contractions to decelerate may cause muscle damage, the contradictory findings of less accumulation of lactate but more performance decrement may be acceptable.[29] Moreover, RPE responses in the present study support this probability since RPE is higher in the 20 × 20 protocol.

Previous studies have shown that protocols with repeated-sprint bouts of distances of 30 m and longer (or longer than 5 s) lead to high blood lactate values.[13,14,26] For example, studies have reported that 5 × 6 s cycling exercise,[15] 6 × 35 m sprint running,[11] 10 × 30 m sprint running (15 + 15 m) with 180° change of direction,[30] and 7 × 34.2 m sprint[31] exercises increase blood lactate concentration to 12.0, 15.5, 12.7, and 15.4 mmol L^{-1}, respectively. Padulo et al.[14] applied 6 × 40 m shuttle sprints (20 + 20 m with 180° change of direction) separated by 15, 20, and 25 s recovery in male soccer players and reported blood lactate concentrations of 14.5, 12.7, and 8.0 mmol L^{-1}, respectively. Similarly, Balsom et al.[26] applied 15 × 40 m repeated sprint exercise with separated by 30, 60, and 120 s rest intervals and indicated that blood lactate responses of 17.2, 13.9, and 12.1 mmol L^{-1}, respectively. Little et al.[13] applied different protocols with equal total distance, and their results show the highest blood lactate value (14.1 mmol L^{-1}) in the protocol containing the combination of long distance (40 m) and short rest (22.4 s). In the current study, the blood lactate levels were higher in the 10 × 40 protocol than 20 × 20 protocol. Hence, it seems that when other variables are kept constant, increasing the sprint distance or reducing the rest interval results in increased lactate responses. The fact that peak glycolytic activation occurs around 5s[7] and the time in sprints longer than 40 m last more than this period is a possible explanation for higher blood lactate in our longer protocol. Moreover, the shorter intervals are likely decreasing the PCr re-synthesis, which makes the effort be supported by a higher glycolytic contribution, up to the point that hydrogen ions negatively affect the phosphofructokinase activation, decreasing the glycolytic rate.[10]

Standard rest times were used in this study instead of the work: rest ratio to test a design that a soccer team could train together. Because using the individual resting rate of each athlete according to their sprint durations means a different protocol for each athlete. Although repeated sprint protocols including work: rest ratio can be applied for individual trainings, they are not reasonable for a training which whole team players perform at the same time. The present study showed the performance and physiological responses between two repeated sprint protocols. First protocol included 20 m distance with of 15 s rest intervals whereas second protocol doubled the distance and rest time variables but halving the repetition number. Therefore, this study can provide practical findings for field professionals to standardize or modify repeated sprint components for all team players.

Conclusions

Repeated-sprint exercises should be designed to reflect the actual performance of the sport. In this study, football-specific sprint distances, repetition numbers and rest intervals were applied. Unlike cycling sprints, the present study showed that deceleration and jogging activities performed to return to the next start line reduced the participants' full rest periods when the rest periods were too short and the repetition number was high in the running sprint exercises. Moreover, these findings were supported with the results of physiological responses and energy systems contributions were higher in the 10 × 40 but RPE was higher in the 20 × 20 protocol.

This study revealed detailed information on the energy demand and the contribution of the energy systems of two different protocols in which many variables such as total distance, total exercise and rest time were similar. The findings showed that there was a rapid increase in VO_2 during the initial sprints during the sprint efforts or rest intervals, then increased slightly. This study also draws attention to the fact that the estimation of overall or during the efforts may highly change the energy proportions in repeated sprints. The contribution of the oxidative system seems superior because of the inclusion of VO_2 in rest intervals in the estimations of overall. Consequently, this study indicated that 10 × 40 protocol seems more reasonable to improve the anaerobic contribution during repeated sprint performance which is critical in the soccer and many team sports, as the phosphagen and glycolytic system contribution is higher than 20 × 20 protocol. Thus, the findings may provide evidence to allow soccer coaches and sports scientists to more effectively evaluate athletes' performance and prescribe optimal training exercises.

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Declaration of competing interest

We have no conflicts of interest to disclose.

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