Performance and metabolic demand of a new repeated-sprint ability test in basketball players

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Performance and metabolic demand of a new repeated-sprint ability test in basketball players: does the number of changes of direction matter?

Abstract

This study compared two repeated-sprint ability tests in basketball players. Both tests included 10×30-m sprints, with the difference that the previously validated test (RSA_{2COD}) featured two changes of direction (COD) *per sprint*, while the experimental test (RSA_{5COD}) featured five CODs *per sprint*. Tests` performances and metabolic demands were specifically assessed in 20 basketball players. Firstly, RSA_{5COD} test-retest reliability was investigated. Then RSA_{2COD}, RSA_{5COD} sprint times, peak speeds, oxygen uptake (VO_2) and post-test blood lactate concentration [La^-] were measured. RSA_{5COD} results showed to be reliable. RSA_{2COD} performance resulted better than the RSA_{5COD} version ($P<0.01$), with shorter sprint times and higher peak speeds. Over sprints, the tests did not differ from each other in terms of VO_2 ($P>0.05$). Over whole bout, the RSA_{2COD} was more demanding than the RSA_{5COD}, considering overall metabolic power requirement (i.e., VO_2-driven+[La^-]-driven components). Given that 1) RSA_{5COD} mimics real game-play as sprint distance and action change frequency/direction and 2) has the same metabolic expenditure *per* task completion as metabolic cost, RSA_{5COD} is a valuable option for players and coaches for training basketball-specific agility and assessing bioenergetic demands.

Key Words: action change; energy expenditure; game-play; shuttle sprints; team sport.

INTRODUCTION

Basketball players are commonly required to perform several efforts of high intensity during a game, generally of short-lasting (11) duration up to 20 s (23). In addition, these actions often require a variety of multidirectional movements, such as jumping, running, dribbling, sprinting, and shuffling, performed at different speeds and intensities (29). It has previously been reported that an average of 168 high-intensity actions (i.e., running, sprinting, high-intensity shuffling, and jumping) occur during a game, and that they represent 21% of the total game movements (21).

In the last decade the repeated-sprint ability (RSA) test, which is mostly operated as straight-line sprinting mode (8), has been proved to evaluate high-intensity actions in sports such as rugby, football, and basketball (34). However, considering the variety of multidirectional movements involved in basketball, Castagna et al. (10) suggested an RSA test consisting of 10×30-m maximal shuttle sprints with one 180° change of direction (COD; i.e., with two-section, 15 m+15 m, repetitions), interspersed by 30 s of passive recovery. Such an RSA test with one single COD (10) has shown to be valid for basketball players, requiring different mechanical and metabolic energy demands compared to straight-line sprinting (34).

To investigate this matter in greater depth, Padulo et al. (29) and Attene et al. (2) recently investigated validity, accuracy and precision of an RSA test similar to that described by Castagna et al. (10). The authors asked the athletes to perform 10 repetitions of 30 m with 30 s of recovery, as in the Castagna et al. study (10). However, each repetition was performed with two 180° CODs (i.e., three sections: 10 m+10 m+10 m). Padulo et al. (29) found good test-retest accuracy (with intra-class correlation coefficient (ICC) between 0.74 to 1.00 and no significant differences).

Considering the performance model of the basketball play, wherein action changes occur on average every ≈2 s (5,22) and many of them consist of frequent changes in direction (i.e., laterally) with rapid deceleration and acceleration of the body (18), we hypothesized that a 10×30-m RSA test designed with several left and right CODs would more closely replicate real game-play and consequently demand a metabolic expenditure similar to real game-play (29). Moreover, while it is clear today that straight-line sprinting and COD ability are separate physical qualities when considering isolated sprints (31,33), the ability to repeat sprints with multiple COD should be suggested to profile a more specific athletic quality (3). In this regard, Scanlan et al. (32) showed that in elite and sub-elite basketball players, the mean distances covered by jogging, running, and sprinting during a basketball game are shorter than 10 m, i.e., about 2.5 m jogging, 6 m running, and 4 to 9 m sprinting. Therefore we proposed to administer a game-profile based RSA test including running sections shorter than those featuring Padulo et al. test (29), namely 5-m sections, and five CODs *per* sprint. Given that the inclusion of additional CODs to a standard RSA protocol could both affect activity profile and metabolic demand of this specific task and, in turn, better replicates real game-play situations of professional basketball players (9), the investigation of different RSA tests' performance and metabolic energy requirement could be useful in providing better and evidence-based insights. Therefore, the main study aim was to compare the two different RSA tests, an already validated test and a new version including multiple CODs, in terms of performance and metabolic demand. The outcomes of the study could also help researchers in determining which RSA test is the most appropriate for basketball players in terms of metabolic demand similar to real game-play.

METHODS

Experimental Approach to the Problem

This experimental study was approached through a “cross-over” observational design. As independent variable, we used RSA test type (i.e., validated or newly proposed). As dependent variables, we used specific RSA test’s performance and metabolic demand variables.

Subjects

Twenty male basketball players (age: 17±1 y [16-18 y], height: 1.91±0.08 m, body mass: 84.5±12.3 kg, body mass index: 23.0±2.1 kg·m^2, training experience 6±1 y with ≈5 hr training per week) were recruited from a Brazilian basketball team. All the participants competed in the Under 19 Brazilian National Basketball Championship 2013-2014. All tests were performed on a regular indoor basketball court during the preseason period. The parents/guardians of the participants under the age of 18 years and the participants over the age of 18 years gave written consent after being thoroughly informed of the study design, in conformity with the Code of Ethics of the World Medical Association (Declaration of Helsinki). The university human ethics committee followed the ethical standards for human studies and approved all experimental procedures.

Procedures

Athletes performed three randomized testing sessions: i) RSA test with two CODs (RSA_{2COD}), and ii) RSA test with five CODs (RSA_{5COD}, twice). To verify the RSA_{5COD} test-retest reliability, a second RSA_{5COD} was administered four days after the first RSA_{5COD} assessment. The three running tests were therefore separated from one another by either two days or four days (i.e., RSA_{2COD}-two days-first RSA_{5COD}-four days-second RSA_{5COD} or first

RSA_{5COD}-two days-RSA_{2COD}-two days-second RSA_{5COD}). All the tests were completed at the same time of the day (i.e., from 5:00 p.m. until 8:00 p.m.) and in randomized order. Environmental conditions were: temperature 27±2 °C, relative humidity 50±1%, low noise (i.e., typical indoor court level). Athletes were required to avoid strenuous activity on the day prior to testing, and all followed the same controlled dietary regimen during the testing sessions.

RSA_{2COD} (29) consisted of 10×30-m shuttle sprints with two changes of direction of 180° separated by 30 s of passive recovery. The participants started from the starting line, and running as fast as possible ran straight for 10 m, touched the second line with one foot, went back to the starting line, touched it with the other foot, turned back again, and ran back to the second/finish line.

RSA_{5COD} consisted of 10×30-m shuttle sprints with three changes of direction of 180° and two changes of direction of 90° separated by 30 s of passive recovery (i.e., walking back to starting line and standing). A schematic representation of the protocol circuit is shown in Figure 1. The participants started from the starting line and, as fast as possible, ran straight for 5 m and touched the second line with one foot, turned back and ran back to the starting line, turned right, ran for 5 m and touched the third line with a foot, turned back and ran back to the starting line, turned right, ran for 5 m and touched the fourth line with a foot and turned back again before running back to the starting/finish line (i.e., along a “T” letter shaped circuit). This protocol was re-administered four days later for test-retest reliability. To balance the physical effort of the legs during both tests’ CODs, the participants were instructed to alternate the braking legs.

Figure 1 about here

The sprinting time, speed, and acceleration for each single sprint were recorded using a reliable approach (4,27,28) employing three cameras (60 Hz, Handycam DCR-SR21, Sony, Tokio, Japan,) placed 6 m from the three 5-m running sections, halfway and perpendicular with respect to the three athletes' sagittal planes (Figure 1). The three cameras were synchronized to capture 5 m of each running section during both RSA_{2COD} and RSA_{5COD}. DVIDEOW software (Digital Video for Biomechanics for Windows 32 bits, Campinas, Brazil; 15) was used for the calibration (by the mean of a calibration frame), measurement, synchronization and 2D reconstruction of the image sequences. The following variables for each sprint were calculated using Matlab software (version 7.10, Mathworks Inc., Natick, MA, USA): duration, average and peak (on a 1-m displacement basis) speed, and acceleration over each running section. For both RSA tests (RSA_{2COD} and RSA_{5COD}) the performance percent decrease ($DEC_{\%}$) was calculated according to Fitzsimons formula ($100\times(T_T/(B_T\times10))$–100, 16), where T_T corresponds to total time and B_T to best sprint time.

Breath-by-breath oxygen uptake (VO_2, $mL\cdot kg^{-1}\cdot min^{-1}$) was measured during both RSA tests using a portable gas analyzer ($K4b^2$, COSMED, Rome, Italy). Data were then linearly interpolated into 1-s intervals and time averaged into 5-s bins. The data were also time aligned, such that time corresponding to 0 s occurred at the onset of the test. Over the sprints, heart rate (HR, bpm; T31, Polar, Electro, Kempele, Finland) and VO_2 values were identified as the highest 5-s bin per sprint (20). Over the test, VO_2 was assessed as the test final 2-min average (36).

A micro sample of arterialized blood from the ear lobe was taken 5 and 7 min after the end of RSA_{2COD} and RSA_{5COD} for measurement of blood lactate concentration ($[La^-]$, $mmol\cdot L^{-1}$), and namely for measuring its post-test peak value ($[La^-]_{PEAK}$) with an electrochemical lactate analyzer (Yellow Spring Instruments – 2300 Stat, Yellow Springs, OH, USA).

To estimate the metabolic power and cost during the RSA tests, the methods described by Zamparo et al. (36) for shuttle sprint efforts with changes of direction were used. The total exercise metabolic power during each running bout (E'bout, $mL \cdot kg^{-1} \cdot min^{-1}$) was calculated on the basis of the VO_2 measured over the last 2 min of exercise as suggested by Zamparo et al. (36) and net [La^-] ([La^-]$_{NET}$). Net VO_2 (nVO_2) was also calculated by subtracting the resting standard metabolic rate (i.e., 3.5 $mL \cdot kg \cdot min^{-1}$) from the VO_2 measured over the last 2 min of exercise. [La^-]$_{NET}$ was calculated assuming that [La^-] at rest was equal to 1 $mmol \cdot L^{-1}$ (36). The bout metabolic power derived from the aerobic source ($E'O_2$, $mL \cdot kg^{-1} \cdot min^{-1}$) can be calculated as $E'O2 = VO_2 \times t_{tot}/t_e$, where t_{tot} (min) is the total duration of the test (i.e., effort period *plus* recovery period) and t_e is the duration of the exercise bout (36). Given the "10×30-m sprints w/9×30 s recoveries" test structure specifically used with both tests, their (constant) total distance (d) amounts to 300 m and total rest duration amounts to 270 s=4.5 min. Therefore $t_e = t_{tot} – 4.5$. The bout metabolic power derived from the anaerobic lactic source ($E'La$, $mL \cdot kg^{-1} \cdot min^{-1}$) can be calculated by dividing [La^-]$_{NET}$ by t_e, assuming an energy equivalent of 3.3 $mL \cdot kg^{-1} \cdot mM^{-1}$ (13): $E'La = ([La^-]_{NET}/t_e) \times 3.3$. Thereafter, the E'bout, can be calculated as $E'bout = E'O_2 + E'La$.

The bout net metabolic power derived from the aerobic source ($E'O_{2NET}$) can be calculated as $E'O2_{NET} = nVO_2 \times t_{tot}/t_e$. Then, the net exercise metabolic power during each running bout ($E'bout_{NET}$) can be calculated as $E'bout_{NET} = E'O_{2NET} + E'La$. Therefore, the net metabolic energy expenditure during the bout ($Ebout_{NET}$, $mL \cdot kg^{-1}$) can be calculated as $Ebout_{NET} = E'bout_{NET} \times t_e$. Finally, the metabolic cost of running during the intermittent exercise (C) can be calculated as the *ratio* of $E\text{bout}_{NET}$ to d (13,36 12,34): $C=E\text{bout}_{NET}/d$. C was expressed in $J \cdot kg^{-1} \cdot m^{-1}$ using an energy equivalent of 20.9 $J \cdot mL^{-1}$ O_2 (12,14,36).

Statistical Analyses

The normality of the data was confirmed by the Shapiro-Wilk test, which permitted the use of parametric analysis and mean±standard deviation to present the results. The reliability of RSA_{5COD} (test and retest conditions) was verified using the paired-sample *t*-test, ICC (17,25,35), Standard Error of the Measurement (SEM, 35), effect size (ES), and the 95% limits of agreement (LoA, 24). In addition, two-way analysis of variance (ANOVA, tests×sprints) for repeated measures was used to compare the values measured in the test and retest. In addition, Mauchly sphericity test was applied to the data, and the sphericity was assumed to be violated when the F test was significant. In case of sphericity violation, the Greenhouse-Geisser Epsilon correction was used. The analysis was completed using the "Bonferroni" *post hoc* test. For comparison between RSA_{2COD} and RSA_{5COD}, the paired-sample *t*-test was used. The ESs obtained in each statistical analysis were shown and interpreted as proposed by Hopkins (www.sportsci.org/resource/stats), with ES<0.2 considered as trivial, 0.2-0.5 small, 0.6-1.1 moderate, 1.2-1.9 large, and >2 very large. In all cases, statistical significance was set at $P<0.05$. Statistical analyses were performed using the software package SPSS, version 16.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

The means and standard deviations (*s*) of sprinting time, mean speed, peak speed and acceleration, and oxygen uptake for each sprint in RSA_{5COD} are shown in Figures 2 and 3, and highlight test-retest reliability of RSA_{5COD}. No significant differences were found between each sprinting time (Figure 2A) and peak acceleration (Figure 2D) over the two RSA_{5COD}s. The mean speed (Figure 2B) showed significant decreases (*P*<0.001) over the first test, while peak speed (Figure 2C) and oxygen uptake (Figure 3) over both tests showed significant decreases and increases (*P*<0.001), respectively. The best, worst, and mean sprint time, speed and acceleration, total test time, and percent sprint time decrease are shown in Table 1. Only the worst speed (W_{MS}) was statistically different (*P*<0.05), but with a trivial effect size (test value lower than retest one). Overall, the ES showed to be trivial or small, and SEM resulted small. In addition, significant ICCs (*P*<0.005) were found for sprint and total test times, $[La^-]_{PEAK}$, worst and mean sprint speed, and worst sprint acceleration (W_{ACCEL}, Table 1).

Figure 2 about here

Figure 3 about here

Table 1 about here

Overall, the performance outcomes featuring RSA_{2COD} were statistically faster than the ones featuring RSA_{5COD} (Table 2**)**, with the exception of W_{ACCEL} (similar values). During RSA_{2COD}, CODs occurred less frequently than during RSA_{5COD}**,** both considering t_e (every 3.42±0.15 *vs.* 1.68±0.07 s, -50.8±2.6%, *P*<0.001) and t_{tot} (every 16.92±0.15 *vs.* 7.08±0.07 s, -58.2±2.6%, *P*<0.001). The VO_2 response was higher in RSA_{2COD} over each sprint but statistically different (*P*<0.05) only in the fourth sprint (Figure 4A). The HR response (Figure 4B) was similar in both tests**.** The variables featuring the bioenergetics approach regarding both tests are shown in Table 3. *C* did not differ between RSA_{2COD} and RSA_{5COD}, and showed a small effect size. In contrast, *E′*bout showed a very large effect size with the RSA_{5COD} values statistically (P<0.001) lower than the RSA_{2COD} ones (-18.5±5.6%).

Table 2 about here

Figure 4 about here

Table 3 about here

DISCUSSION

The present study aimed to compare the metabolic demands and performance outcomes of two RSA tests (RSA_{2COD} and RSA_{5COD}) in young basketball players. Firstly, the RSA_{5COD} reliability was assessed. No significant differences were found between test and retest concerning the RSA outcomes (e.g., best [B_T], worst [W_T] and mean sprint time [M_T], and total test time [T_T]). Most of the variables showed a good test-retest agreement in terms of ICC (≥0.67), and all of them featured small SEMs (≤2.10, Table 1). These results were similar to those found by Padulo et al. (29), who showed good test-retest agreement of the RSA outcomes during RSA_{2COD} (ICC>0.87). None of the investigated kinematic (best [B_{MS}], worst [W_{MS}], and mean sprint speed [M_{MS}], best [B_{PS}], worst [W_{PS}] and mean peak speed [M_{PS}], best [B_{ACCEL}], worst [W_{ACCEL}] and mean peak acceleration [M_{ACCEL}] included) or metabolic (i.e., blood lactate concentration post-test peak $[La^-]_{PEAK}$) variables resulted in significant test-retest differences. All these results confirm reliability of RSA_{5COD}. Considering that sensitivity of sportsmen is very high in different conditions as well (19), the reliability assessment was made to give strength to the present study. Given that test-retest studies should involve at least 50 participants to provide compelling evidence of reliability (1), peremptory RSA_{5COD} reliability has yet to be confirmed.

Overall, players revealed to be faster over RSA_{2COD} than over RSA_{5COD} (i.e., with shorter B_T, M_T, and T_T, and higher B_{MS}, M_{MS}, B_{PS}, M_{PS}, B_{ACCEL}, and M_{ACCEL}; Table 2). In addition, during RSA_{5COD} the metabolic power (*E′*bout) was significantly lower than during RSA_{2COD}. In contrast, the metabolic cost of running (*C*) values were similar.

All typical RSA outcomes (i.e., B_T, W_T, M_T, T_T, and $DEC_{\%}$) changed significantly from RSA_{2COD} to RSA_{5COD}, as a clear indication of the different mechanical output and metabolic input of the two protocols. The longer sprints featuring RSA_{2COD} allowed higher speeds with respect to RSA_{5COD}. The shorter sprints of RSA_{5COD} did not allow high accelerations, as already shown by Zamparo et al. (36). They showed that in young basketball players, shuttle sprinting with a COD of 180° both oxygen uptake and [La^-] (and therefore their resulting *E′*bout) increases with the shuttle distance, while *C* decreases. In the current study, during RSA_{5COD} (i.e., with shorter shuttles) in comparison to during RSA_{2COD} (i.e., with longer shuttles), lower *E′*bout (169.63±17.25 *vs.* 208.38±18.44 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$, -18.5%, $P < 0.001$) but similar *C* (15.06±1.38 *vs.* 15.20±1.31 $J \cdot kg^{-1} \cdot m^{-1}$, -0.8%, $P > 0.05$) was found. Therefore, our results largely confirm those of Zamparo et al. (36) regarding *E′*bout with shorter shuttles. The lower *E′*bout during RSA_{5COD} can be explained by the shorter distances run straight-line over each section during the test (i.e., 6×5-m) and the consequent inability of the athletes to have enough time to accelerate up to a higher speed, resulting in a lower metabolic power demand (36).

Unlike Zamparo et al. (36) we estimated similar *C* with longer and shorter shuttles, when it was indicated that decreased shuttle distance promotes increase in this estimate. *C* (decrease) substantially depends on the net metabolic energy expenditure during the bout ($E\text{bout}_{NET}$, decrease). Therefore we hypothesize that its difference over shuttle distance with respect to Zamparo et al.'s result (36) may be due to the different longer and shorter shuttles protocols used with 1) their protocols only 20 and 10 m long, and our ones both 300 m long. Furthermore, 2) our RSA_{5COD} was featured by a continuous change between 180° and 90° COD thus affecting (decreasing) less $E\text{bout}_{NET}$ than their standard 180° COD protocol (Tables 2 and 3). Actually, that was the case with us reporting only an only -0.3% $E\text{bout}_{NET}$ average decrease ([RSA_{5COD}-RSA_{2COD}]/RSA_{2COD} %) compared with the corresponding -27.7% ([shorter shuttles-longer shuttles]/longer shuttles %) reported by Zamparo et al. (36). Such a reduced change could be due to some extra metabolic expenditure required for some motor control purpose specifically required by RSA_{5COD} and yet to be specifically investigated.

The two tests were not statistically different from each other in terms of HR or oxygen uptake (VO_2) over the sprints (Figure 3). Yet, RSA_{5COD} was shown to be significantly lower in terms of post-test blood lactate concentration ($[La^-]_{PEAK}$, Table 3). Indeed, when comparing the two tests with each other as single bouts, RSA_{5COD} was shown to be significantly less metabolically demanding in terms of both the metabolic power derived from the aerobic source (i.e., VO_2-driven) and the metabolic power derived from the anaerobic lactic source (i.e., $[La^-]$-driven). The lower resulting E'bout suggests a lower RSA_{5COD} overall metabolic power demand. Buchheit et al. (6) found lower $[La^-]$ after some RSA tests with different COD angles (45º, 90º and 135º) in comparison with a straight-line RSA. In comparison with RSA_{2COD}, RSA_{5COD} lower running speed might have caused a diminished exploitation of the anaerobic lactic pathway, resulting in the detected lower $[La^-]$ values and consequent lower contribution to the overall metabolic power demand (6,7).

RSA_{5COD} was verified as a reliable method for assessing the sprint ability of basketball players. The RSA_{5COD} running section distance (i.e., 5 m) was specifically chosen to mimic real game-play mean covered distance (32). Our results showed that COD, a very common basketball action change, occured every ≈2 s and along different directions, similar to real game-play (5). Therefore we investigated both performance and anaerobic/aerobic demand of a test/training protocol miming basketball running, sprinting and high-intensity shuffling. In comparison with RSA_{2COD}, RSA_{5COD} required less metabolic power (*E′*bout) but the same metabolic expenditure per task completion (*C*, which relates to travelled distance).

For the above reasons, we believe that RSA_{5COD} is a proper tool to assess and train basketball-specific agility and the bioenergetics demand. Therefore, we suggest its use to players and coaches. A further improved RSA test specific for basketball players might include other general exercises, e.g., jumps (30), and/or fundamental skills, e.g., shooting (26), rebounding and/or passing.

PRACTICAL APPLICATIONS

The reliability of a 10×30 m sprints RSA test for basketball players with six 5-m running sections and five changes of direction per sprint, RSA_{5COD}, has been assessed. In comparison with another previously validated 10×30 m sprints RSA test for basketball, with three 10-m running sections and two changes of direction per sprint (RSA_{2COD}), RSA_{5COD} requires lower metabolic power (as witnessed by the lower bout total exercise metabolic power, *E′*bout, in Table 3) but the same metabolic expenditure (as witnessed by the same metabolic cost of running, *C*, in Table 3). Therefore, RSA_{5COD} should be included within basketball testing and training protocols.

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Table 1. Test-retest reliability for RSA_{5COD} (n=10).

	RSA test	RSA retest	ES	95% LoA	Magnitude-inference	SEM	ICC
B_T (s)	8.13±0.41 (7.84-8.43)	8.23±0.18 (8.10-8.36)	0.33	-0.52 – 0.71	Small effect	0.24	0.67* (-0.32-0.92)
W_T (s)	8.69±0.37 (8.43-8.95)	8.81±0.33 (8.48-8.95)	0.08	-0.47 – 0.51	Trivial effect	0.14	0.85* (0.46-0.96)
M_T (s)	8.39±0.41 (8.10-8.68)	8.46±0.24 (8.29-8.63)	0.22	-0.53 – 0.67	Small effect	0.21	0.73* (-0.08-0.93)
T_T (s)	83.86±4.05 (80.96-86.76)	84.57±2.37 (82.87-86.26)	0.23	-5.27 – 6.69	Small effect	2.10	0.73* (-0.08-0.93)
$DEC_{\%}$ (%)	3.1±0.8 (2.5-3.7)	2.7±0.7 (2.2-3.3)	-0.31	-2.7 – 2.0	Small effect	0.57	-0.49 (-0.71-0.63)
$[La^-]$ ($mmol \cdot L^{-1}$)	8.10±2.10 (6.60-7.60)	7.76±2.82 (5.75-9.78)	-0.15	-4.78 – 4.11	Trivial effect	1.07	0.74* (-0.06-0.93)
B_{MS} ($m \cdot s^{-1}$)	2.65±0.09 (2.58-2.71)	2.63±0.10 (2.56-2.71)	-0.18	-0.15 – 0.26	Trivial effect	0.06	0.59 (-0.63-0.90)
W_{MS} ($m \cdot s^{-1}$)	2.46±0.07 (2.41-2.51)	2.51±0.06* (2.46-2.55)	0.09	-0.41 – 0.24	Trivial effect	0.01	0.96* (0.54-0.96)
M_{MS} ($m \cdot s^{-1}$)	2.56±0.08 (2.50-2.61)	2.56±0.07 (2.51-2.61)	0.06	-0.22 – 0.23	Trivial effect	0.03	0.85* (0.43-0.96)
B_{PS} ($m \cdot s^{-1}$)	4.69±0.29 (4.48-4.89)	4.63±0.34 (4.38-4.87)	-0.15	-0.23 – 0.27	Trivial effect	0.23	0.35 (-1.60-0.84)
W_{PS} (s)	4.25±0.28 (4.04-4.45)	4.20±0.06 (4.16-4.25)	-0.15	-0.37 – 0.23	Trivial effect	0.25	0.20 (-2.20-0.80)
M_{PS} ($m \cdot s^{-1}$)	4.46±0.29 (4.25-4.66)	4.38±0.12 (4.29-4.46)	-0.27	-0.25 – 0.21	Small effect	0.25	0.26 (-0.50-0.82)

B_{ACCEL} (m·s^2)	7.90±1.32 (6.97-8.83)	8.34±0.65 (7.87-8.80)	0.33	-1.24 – 0.97	Small effect	1.06	0.35 (-1.65-0.84)
W_{ACCEL} (m·s^2)	6.51±0.91 (5.86-7.16)	6.38±0.48 (6.03-6.72)	-0.24	-2.11 – 2.98	Small effect	0.39	0.82* (0.29-0.96)
M_{ACCEL} (m·s^2)	7.14±1.14 (6.32-7.95)	7.18±0.39 (6.90-7.45)	0.04	-1.75 – 1.83	Trivial effect	0.73	0.59 (-0.63-0.90)

Data as mean, *s* and 95% confidence (in parentheses). Abbreviations: B_T: best sprint time; W_T: worst sprint time: M_T: mean sprint time; T_T: total test time; $DEC_{\%}$: percent sprint time decrease; $[La^-]_{PEAK}$: blood lactate concentration post-test peak value; B_{MS}: best sprint speed; W_{MS}: worst sprint speed; M_{MS}: mean sprint speed; B_{PS}: best sprint peak speed; W_{PS}: worst sprint peak speed; M_{PS}: mean sprint peak speed; B_{ACCEL}: best sprint acceleration; W_{ACCEL}: worst sprint acceleration; M_{ACCEL}: mean sprint acceleration. * $P<0.05$.

Table 2. Comparison of test performance variables between RSA_{2COD} and RSA_{5COD}.

	RSA_{2COD}	RSA_{5COD}	ES	Magnitude-inference
B_T (s)	6.56±0.30	8.14±0.36*	3.87	Very large effect
W_T (s)	7.24±0.49	8.71±0.37*	2.62	Very large effect
M_T (s)	6.84±0.30	8.39±0.36*	3.9	Very large effect
T_T (s)	68.4±2.91	83.99±3.60*	3.87	Very large Effect
$DEC_{\%}$ (%)	4.2±1.8	3.0±1.1*	-0.53	Small effect
B_{MS} ($m \cdot s^{-1}$)	4.21±0.23	2.65±0.08*	-7.43	Very large effect
W_{MS} ($m \cdot s^{-1}$)	3.76±0.25	2.47±0.09*	-5.37	Very large effect
M_{MS} ($m \cdot s^{-1}$)	3.99±0.18	2.56±0.08*	-8.94	Very large effect
B_{PS} ($m \cdot s^{-1}$)	7.56±0.58	4.78±0.41*	-3.09	Very large effect
W_{PS} (s)	5.48±1.26	4.26±0.35*	-0.95	Moderate effect
M_{PS} ($m \cdot s^{-1}$)	6.32±0.94	4.51±0.47*	-1.7	Large effect
B_{ACCEL} ($m \cdot s^2$)	11.2±2.98	7.76±1.04*	-1.24	Large effect
W_{ACCEL} ($m \cdot s^2$)	6.50±1.14	6.50±0.76	-0.01	Trivial effect
M_{ACCEL} ($m \cdot s^2$)	8.44±0.92	7.06±0.91*	-1.37	Large effect

Data as mean and *s*. Abbreviations: B_T: best sprint time; W_T: worst sprint time: M_T: mean sprint time; T_T: total test time; $DEC_{\%}$: percent sprint time decrease; [La^-]: peak of blood lactate concentration after sprints; B_{MS}: best sprint speed; W_{MS}: worst sprint speed; M_{MS}:

mean sprint speed; B_{PS}: best sprint peak speed; W_{PS}: worst sprint peak speed; M_{PS}: mean sprint peak speed; B_{ACCEL}: best sprint acceleration; W_{ACCEL}: worst sprint acceleration; M_{ACCEL}: mean sprint acceleration. * $P<0.05$.

Table 3. Variables featuring the bioenergetics approach in RSA_{2COD} and RSA_{5COD}.

	RSA_{2COD}	RSA_{5COD}	% Change	ES	Magnitude-inference
Speed ($m \cdot s^{-1}$)	0.89±0.01	0.85±0.01*	-4.39±1.11	-3.89	Very large effect
t_{tot} (s)	338.41±2.91	353.99±3.59*	4.61±1.21	3.87	Very large effect
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	37.0±2.9	36.1±3.2	-2.3±5.9	-0.31	Small effect
E'bout ($mL \cdot kg^{-1} \cdot min^{-1}$)	208.4±18.4	169.6±17.2*	-18.5±5.6	-3.07	Very large effect
$[La^-]_{PEAK}$ ($mmol \cdot L^{-1}$)	9.8±2.5	8.2±1.9*	-14.6±17.3	0.96	Moderate effect
$[La^-]_{NET}$ ($mmol \cdot L^{-1}$)	8.8±2.5	7.2±1.9*	-16.1±19.6	-0.96	Moderate effect
$E'O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	183.0±16.4	152.7±15.5*	-16.4±6.2	-2.50	Very large effect
E'La ($mL \cdot kg^{-1} \cdot min^{-1}$)	25.4±7.0	17.0±4.7*	-31.4±15.9	-1.81	Large effect
$Ebout_{NET}$ ($mL \cdot kg^{-1}$)	218.2±18.9	217.6±18.5*	-0.8±6.5	-0.11	Trivial effect

***C* (J·m^{-1}·kg^{-1})**	15.2±1.3	15.1±1.4	-0.8±6.5	0.25	Small effect

Data as mean and *s*. Abbreviations: Speed: test overall speed; t_{tot}: test overall duration; VO2: oxygen uptake; *E′*bout: bout total exercise metabolic power; $[La^-]_{PEAK}$: blood lactate concentration post-test peak value; $[La^-]_{NET}$: net blood lactate concentration; $E'O_2$: bout metabolic power derived from the aerobic source; *E′*La: bout metabolic power derived from the anaerobic lactic source; $E\text{bout}_{NET}$: bout net metabolic energy expenditure; *C*: metabolic cost of running. * $P<0.05$.

Figure captions

Figure 1. RSA_{5COD} schematic sketch of the test. The dashed lines indicate the running sections.

Figure 2. RSA_{5COD} measurements over sprints. A: time; B: mean speed; C: peak speed; D: peak acceleration (*n*=10).

Figure 3. RSA_{5COD} measurements over sprints. Oxygen uptake (*n*=10).

Figure 4. Comparison between RSA_{2COD} and RSA_{5COD} for oxygen uptake (A) and heart rate (B). (*n*=20). “*” $P<0.05$ compared to the other test and same sprint.