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Review Article

Physiological Responses to Repeated Running Sprint Ability Tests: A Systematic Review

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ABSTRACT

International Journal of Exercise Science 13(4): 1190-1205, 2020. The purpose of this study was to review acute physiological responses induced by repeated running sprint ability (RRSA) tests that could serve as references for practitioners utilising repeated sprints as a performance measure with athletes. This research was conducted following the PRISMA methodology. The systematic search was conducted in November 2019 and yielded 26 different scientific articles. Only peer-reviewed full-text article were included as abstracts are too short to allow proper explanation of the RRSAT methodology that was employed. According to the present literature, practitioners should use the following assessments: the 6x40m RRSA protocol with one Change of Direction (COD) (20+20 m with a 180° COD) and 25s of passive recovery between sprints with soccer players; the Intensive Repeated Sprint Ability (IRSA) test with men basketball players; the Futsal Intermittent Endurance Test (FIET) with futsal players; the Repeated Shuttle Sprint Test (RSST) with men handball players; and the Multiple Repeated Sprint Ability test for Badminton players (MRSAB). The present review should serve as a reference standard for RRSA tests. Further research should be directed towards creating and validating more specific RRSA tests protocols to each sports physiological and physical demands.

KEY WORDS: Maximal heart rate, blood lactate threshold, rated perceived exertion, VO2, running-based anaerobic sprint test, sport performance

INTRODUCTION

During the last century, several fitness assessments have been developed to measure the physical abilities of trained individuals. Some of the tests commonly used in sports field testing are: the 40-yard sprint (13, 15, 24, 32, 34, 47), the 5-10-5 also known as the pro agility (25, 50, 70), the vertical jump (40, 47), and the broad jump (40, 47). However, many of these tests are not specific to the physiology of the sports in which they are used. In modern sport strength and conditioning interventions, it is essential to properly select physical fitness assessments that meet the physiological demands of the activity. Tests like the Peterson's hockey test (62), the

NFL's 40 yards dash (13, 15, 24, 32, 34, 47) or the soccer's repeated-shuttle-sprint ability (41) are good examples of sport specific tests.

Repeated sprints are part of several sports, including soccer (10, 24, 31, 41, 51, 69), rugby (8, 26, 28, 30, 39, 42, 44), basketball (2, 11, 12, 14, 17, 22, 45, 52, 71, 72), lacrosse (65, 75), and football (24). Therefore, practitioners should train athletes to improve Repeated Running Sprint Ability (RRSA) as it plays an important role on performance. Consequently, practitioners will need a valid test that is specific to their sports in order to achieve that goal.

The purpose of this study was to review measurements taken on acute physiological responses (heart rate, blood lactate accumulation, oxygen consumption, rate of perceived exertion, etc.) induced from repeated running sprints and to regroup them in this article in order to guide practitioners in their future assessments. The hypothesis of this theoretical research is that a systematic approach will allow to regroup only peer reviewed scientific articles that present the different acute physiological responses to repeated running sprint tests and are summarized herein in Tables 1-4 of physiological outcomes. The overall goal of the present review is to serve as a reference standard for practitioners assessing repeated sprints performance with athletes.

METHODS

Experimental Approach to the Problem

Data Source and Search Strategy: This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method presented in Liberati *et al.*'s article (48). The databases used were three of the four proposed by the University of Québec in Montréal (UQÀM) library services: Pubmed, Scopus and SPORTDiscus. ERIC (ProQuest) was discarded due to its education focus. The systematic search started in November 2019 using the following search strategy in titles, abstracts and key words: (Physiology OR physiological response OR Heart Rate OR HR OR RPE OR rating of perceived exertion OR Borg Scale OR oxygen uptake OR VO2 OR Oxygen consumption OR oxygen deficit OR gas exchange OR Respiratory quotient OR Ventilatory threshold OR Lactate Threshold OR Respiratory Exchange Ratio OR Metabolic response OR Energy Expenditure OR Metabolic Cost OR running economy OR Muscle oxygenation OR NIRS OR portable metabolic analyzer OR Portamon OR Artinis OR Moxy OR Cosmed OR Medgraphics OR Jaeger) AND (repeated sprint* OR "Intermittent sport"). To be included, articles needed to be peer-reviewed. No restrictions were set on publication date as we wanted to be able to present data over a wider pool of pertinent articles. All search results were extracted into EndNote X9.

Inclusion and Exclusion Criteria

Duplicates: The articles' titles were placed in alphabetical order in EndNote X9 and duplicates were manually discarded. If an article was presented twice but with a different year of publication or in a different journal, it was considered as different and was not discarded.

Titles and Abstracts: An article was discarded if the authors could clearly identify, by reading the title or the abstract, that it did not present any of the following criteria: an evaluation of acute physiological responses to a repeated running sprints test executed on a level non-motorized and non-machined surfaces (grass, gymnasium, etc.); and that the evaluation was measured on elite team sports athletes (two or more), members of a professional, national, collegiate team, or part of developmental academy related to a professional team, of age 12 or older. If the research protocol presented a bias or interference (meaning that an activity was performed before or after the test), the article was discarded.

Text and Language: When screening texts, the authors first confirmed that the subjects were elite team sports athletes of 12 years old and older. Secondly, the authors screened for descriptive quantitative physiological values measured in direct response to a repeated running sprint test directed on a hard non-motorized and non-machine surface. If an article presented pre and post intervention testing results, post intervention results were retained as subjects were more accustomed to the test, therefore assuming greater homogeneity of the results within the group (eliminating the learning bias of the test). If tests were performed on the same day, results of the first test were retained as fatigue would affect the results of the second one. Physiological responses needed to come from homogeneous groups of elite athletes of the same level, gender and sport and be presented as group means accompanied with their respective standard deviations. If the text was not written in English, the article was discarded. Only peer-reviewed full-text article were included as abstracts are too short to allow proper explanation of the RRSAT methodology that was employed.

Contacting Authors: When clarification was needed to ensure that the retained article met all of the inclusion criteria, the corresponding author of the article was contacted twice by e-mail. If the corresponding author did not respond to both e-mails, other participating authors whose email were found through a Google search were contacted once. If no response was received by any of the authors contacted, the article was discarded.

Manual Search: A manual search was performed throughout the reference list of all articles retained for the systematic review and through all references of the systematic reviews and literature reviews retained for the full-text criteria.

Procedures

Classification: As defined per Girard *et al.* a test was only considered a repeated sprint ability evaluation if intensity and recovery were both less than 10 and 60 seconds respectively (38). Subjects were considered as professional athletes when they practiced their sport as a career or referred as such by authors. Subjects were considered as national level athletes when they competed at national level competitions. Subjects were considered collegiate/university athletes when they played for their college/university. Subjects that where part of an academy had to be affiliated to the developmental team of a professional one.

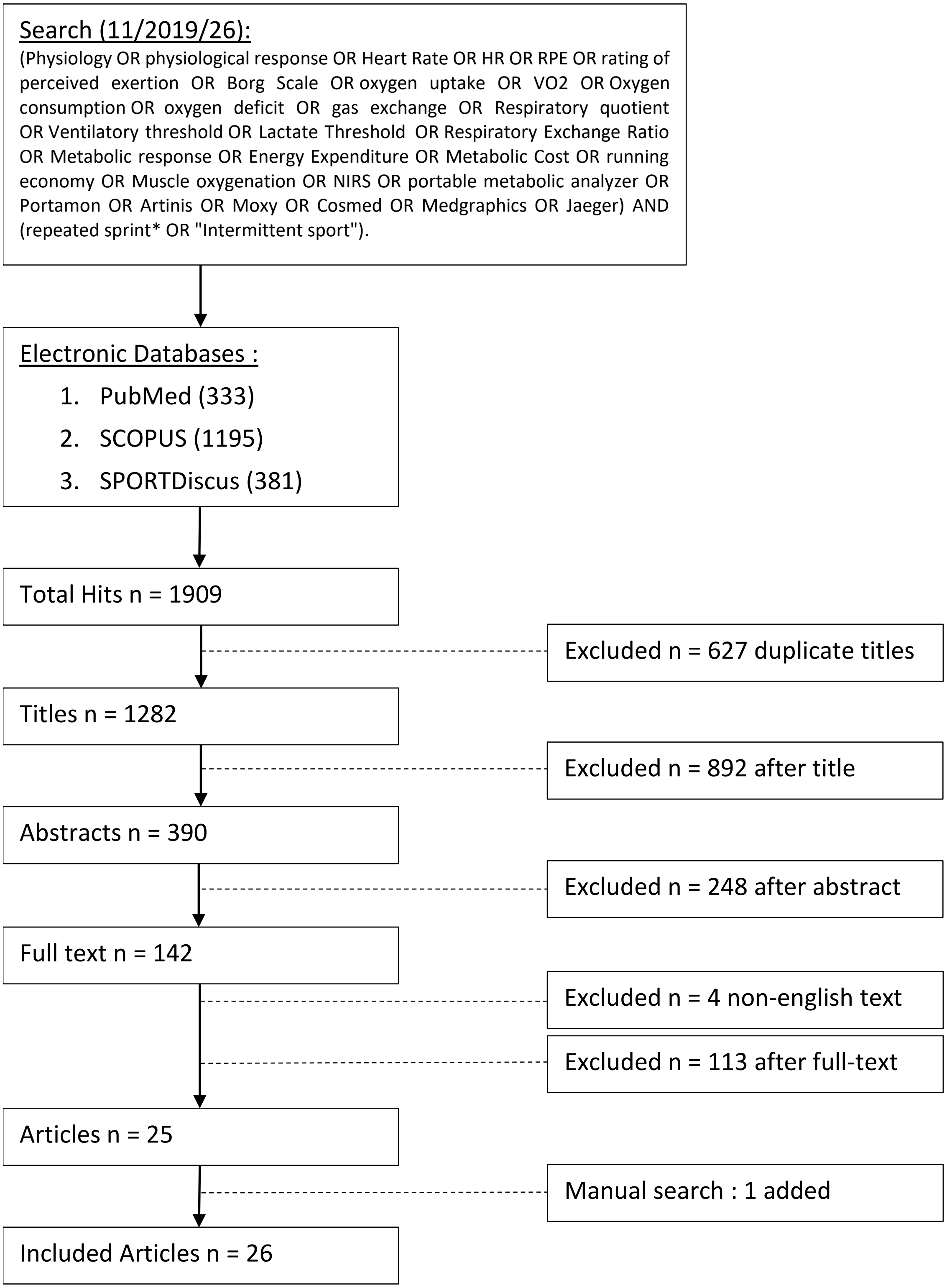

Figure 1. Flow diagram of the search strategy and article selection process.

Exportation: Results were exported to different Excel spreadsheets and classified by sport. In each of those spreadsheets the means were grouped by gender and then classified by level and year.

Verification Methods: The article selection process was entirely repeated by a second author to ensure its reliability.

Acknowledgement
This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (58).

RESULTS

The systematic search and the manual search yielded a total of 32 peer-reviewed publications containing relevant data. Out of those 32, one was discarded due to the poor quality of data presentation, one was discarded due to lack of clarity in classification and four were discarded due to no answer from authors. Consequently, 26 different scientific articles were retained from 22 different first authors from all articles published in mentioned databases until November 2019. Out of those 26 articles, 25 (3, 5-7, 9, 18, 19, 23, 27, 29, 33, 36, 37, 43, 49, 53-55, 59, 60, 63, 67, 73, 74, 76) were scientific articles resulting from the systematic search and one (61) was a scientific article resulting from the manual search (view figure 1). For the retained articles, the term Repeated Sprint Ability (RSA) was replaced by Repeated Running Sprint Ability (RRSA) as the articles presenting non-running repeated sprint ability test results were discarded. Result tables 1-4 display the physiological responses present in the retained articles.

DISCUSSION

Men's Soccer: Several protocols were used to measure RRSA in men's soccer players. When observing the data presented in each study, the following observation were made: the more repetitions added, the slower the sprint became (49). This is most likely explained by the accumulation of fatigue, an explanation supported by Angius *et al.* (6). Furthermore, Abt *et al.* observed that the speed decrement in the last 15 min of a soccer game was of 7.9%; therefore, a RRSA test should try to mimic the same level of speed decrement to be as close to game conditions as possible (1). Studies presented in this review observed speed decrements (Mean±SD) of 6.68%±3.08%, 4.79%±1.98%, 9.5±2.4%, 4.4%±3.8%, 3.2%±2.1%, 3.5%, 4.0±1.9%, 7.5% and between 4.0±1.0% and 5.5±2.1% depending on age level (3, 18, 19, 23, 27, 49, 54). The RRSAT closest to the 7.9% speed decrement of a game is the 40x15m sprint with a work:rest ratio of 1:6 (49). Additionally, Selmi *et al.* also observed an increase in the fatigue index (FI) between the first and the second half of a soccer game (74). This element could be used as an indicator of fatigue, however it should be carefully interpreted because speed decrement becomes less significant with familiarization of the test (54). In soccer, average sprint time was reported to be between 1-7s and more frequently, 2-3s over a 10-20m distance (43, 53); therefore, a RRSA test with a longer time or distance will perhaps not properly reproduce game conditions.

Table 1. RRSA Results from Men Soccer Players.

Level	n	Age	Surface	Method	Sets (Reps x Distance (m))	Rest (s)	Peak HR	BLa	RPE
Pro	6	18-27	Turf	Linear	40x15	15.6		8.8±1.1	17.3±0.5
Pro	6	18-27	Turf	Linear	40x15	10.4		13.0±1.7	18.8±0.4
Pro	18	26.8±3.6	Track	Linear	12x30	30		9.6±2.3	
Pro	8	27.8±5.0	Turf	Linear	6x35	10		10.5±2.0	15.9±0.9
Pro	6	18-27	Turf	Linear	15x40	33.6		9.6 ± 0.6	14.4±1.0
Pro	6	18-27	Turf	Linear	15x40	22.4		14.1±1.0	17.1±0.4
Nat	18	16±0		1 COD	6(2x20)	20		11.3±2.0	
Nat	17	16±0	Turf	1 COD	6(2x20)	15		14.5±0.4	
Nat	17	16±0	Turf	1 COD	6(2x20)	20		12.7±1.2	
Nat	17	16±0	Turf	1 COD	6(2x20)	25		8.0±1.5	
Nat	29	17.9±1.0		1 COD	7x34.2	25		15.4±2.2	
Nat	17	16±0.35	Turf	Linear	6x40	20	185±6	11.6±1.2	13.9±1.8
Nat	17	16±0.35	Turf	4 COD	6(4x10)	20	195±8	12.9±1.5	15.2±1.6
Coll	26	22.5±3.6	Grass	1 COD	6(2x20)	20		17.6±2.6	
Coll	7	20 ± 2		Linear	6x30	30	179±20	10.0±1.6	
Coll	8	20.8±1.5		Linear	6x35	10		14.8±2.8	
Coll	12	20.9±1.1	Artificial Lanes	Linear	6x20	20	171	9.8	15.0
Aca	24	17.4±0.3	Turf	Linear	2(5x20)	15	186±14	8.12±2.2	
Aca	14	15.9±0.3	Field	1 COD	6(2x20)	20		12	
Aca	29	14.8±0.3	Turf	Linear	10x20	20	179±6.8	9.5±2.1	
Aca	11	13.7±1.1	Turf	Linear	10x30	30	180±12	7.1±2.2	12.8±1
Aca	14	14±0.5	Turf	Linear	10x30	30	179±8		
Aca	14	14±0.5	Turf	Linear	10x30	Self Selected	187±7		
Aca	17	14.9±0.6	Turf	Linear	12x30	30		9.6±1.1	
Aca	17	U12	Turf	Linear	6x30	30		7.0±1.7	
Aca	15	U13	Turf	Linear	6x30	30		7.4±1.4	
Aca	16	U14	Turf	Linear	6x30	30		7.0±2.2	
Aca	19	U15	Turf	Linear	6x30	30		7.2±1.7	
Aca	17	U16	Turf	Linear	6x30	30		7.9±2.8	
Aca	17	U17	Turf	Linear	6x30	30		8.7±2.4	
Aca	11	U18	Turf	Linear	6x30	30		9.2±2.4	

RRSA: Repeated Running Sprint Ability, **Pro**: Professional, **Nat**: National, **Coll**: College, **Aca**: Academy, **n**: number of subjects, **COD**: Change Of Direction, **HR**: Heart Rate, **BLa**: Blood Lactate, **RPE**: Rated Perceived Exertion based on Borg scale

Table 2. RRSA Results from Women Soccer Players.

Level	n	Age	Surface	Method	Sets (Reps x Distance (m))	Rest (s)	Peak HR	BLa
Nat	19	18.1±2.9	-	Linear	6x20	15	182±6	9.3±2.0
Coll	8	19±2	-	Linear	4(6x30)	30	190±8	12.2±3.7

RRSA: Repeated Running Sprint Ability, **Nat**: National, **Coll**: College, **n**: number of subjects, **HR**: Heart Rate, **Bla**: Blood Lactate.
N.B. RPE are not presented because the two cited studies did not take this measure.

Table 3. RRSA Results from Men Basketball Players.

Level	n	Age	Surface	Method	Sets (Reps x Distance (m))	Rest (s)	BLa	RPE
Nat	20	17±1	Court	5 COD	10(6x5)	30	8.2±1.9	
Nat	20	17±1	Court	2 COD	10(3x10)	30	9.8±2.5	
Nat	18	16±1	Court	2 COD	10(3x10)	30	11.4±2.2	8.1±1.5
Nat	18	16±1	Court	2 COD	10(3x10)	30	10.4±2.5	
Nat	18	16±1	Court	1 COD	10(2x15)	30	11.5±2.6	
Nat	18	16±1	Court	1 COD	10(2x15)	30	11.9±2.1	8.0±1.2

RRSA: Repeated Running Sprint Ability, **Nat**: National, **n**: number of subjects, **COD**: Change Of Direction, **BLa**: Blood Lactate, **RPE**: Rated Perceived Exertion based on Borg scale, **VO2**: Oxygen uptake

Table 4. RRSA Results from Men of Other Sports.

Sport	Level	n	Age	Surface	Method	Sets (Reps x Distance (m))	Rest (s)	BLa	Peak HR
Bad	Nat	9	24.6±5.2	Court	4 COD	10(4x3)	30	10.7±2.1	
Fut	Pro	11	26±1.6	Gym	7 COD	8x35.6	10	14.8±0.4	171±7.1
Hand	Pro	21	25.2±5.1	Indoor	1 COD	6(2x15)	14		172±8
Hand	Nat	13	23.5±4.1	Gym	1 COD	6(2x15)	20	10.6±2.1	

RRSA: Repeated Running Sprint Ability, **Bad**: Badminton, **Fut**: Futsal, **Hand**: Handball **Pro**: Professional, **Nat**: National, **n**: number of subjects, **COD**: Change Of Direction, **HR**: Heart Rate, **BLa**: Blood Lactate, **RPE**: Rated Perceived Exertion based on Borg scale

A blood lactate (BLa) concentration of 7.9±0.7 mmol/L during gameplay has been reported by Krustrup *et al.* (46). On the other hand, physical tests that produced a similar accumulation of BLa were the 10x30 with 30s of recovery (7.1±2.2) (36); the two sets of 5x20m with 15s of recovery (8,12±2.2) (74); the 6x40 with 25s of recovery and one COD (8.0±1.5)(60); and the 40x15m with 15.6s of recovery (8.8±1.1) (49). As for recovery time, it was noted that soccer players have generally less than 60s rest between sprints (38). Padulo *et al.* noted that 25s seems to be the optimal time because it takes approximately 20 seconds for PCr re-synthesis, an important molecule for the anaerobic demands of sports (60). Brocherie *et al.* noted that 10s is insufficient for muscle re-oxygenation and will only lead to partial recovery that will alter the RRSA test performance considering that faster muscle re-oxygenation has been linked with better RRSA test performance (18).

As for HR_{max}, Krustrup *et al.* found that HR_{max} is usually 187±9 bpm during gameplay (46). From all selected articles, the closest to these data are; 185±6, 187±7 and 186±14 (3, 19, 74). Brownstein *et al.*'s 10x30m with self selected recovery is the closest to game reality with 187±7 bpm (19).

In terms of maximal oxygen consumption ($V0_2max$), results are mixed, some authors found no correlation between VO_2max and RRSA test performance (9, 27, 74), while others indicated strong relationships between VO_2max and the RRSA test performance in soccer players (41, 68).

Some authors believe sprint velocity at onset of blood lactate accumulation (vOBLA) would be a better predictive indicator of RRSA test performance (9, 27).

Finally, a RRSA test should include a final straight-line sprint considering it is frequently seen prior, for example, to a goal in soccer (31). Additionally, the RRSA test should include changes of direction considering that over 600 COD from 0-90 degrees per game have been observed in soccer (16).

In view of all the previously mentioned factors, authors recommend that practitioners intervening with men soccer players, use the 6x40m RRSA test protocol with one COD (20 + 20 m with a 180° COD) and 25s of passive recovery at the starting line in between each sprint, as this test includes: a change of direction, a BLa close to game level, optimal recovery and a sprint distance that is similar to game sprints.

Women's Soccer: Only two studies presented physiological responses to RRSA tests in women's soccer (29, 33). The study by Gabbett published in 2010 presented a mean sprint duration of 2.1s with a maximum sprint duration of 2.9s during a 6x30m RRSA test, while the study by Dent *et al.* (2015) using 6x30m sprints presented a sprint time average slightly under five seconds per sprint (29, 33). Therefore, both protocol sprint times appear similar to those performed during a soccer game as 90% of the sprints lasted less than five seconds (4). The study by Dent *et al.* showed a speed decrement from a sprint bout to another, showing an accumulation of fatigue (29). The accumulation of fatigue can be represented by the fatigue index and is measured by subtracting the slowest time to the fastest, then diving the result by the fastest time and finally multiplying this result by 100. Similar results in men have been reported by Abt *et al.*'s study on changes in peak sprint speed during prolonged high-intensity intermittent exercise with results showing a progressive speed decrement over the repetitions (1). RRSA protocols of both studies with women respect the soccer game sprint duration but none of them include any type of COD, an action that is observed roughly 600 times per game (16).

Considering all the previously mentioned factors, the authors recommend that practitioners working with women soccer players use the same test as men: the 6x40m RRSAT protocol with one COD (20+20m with a 180° COD) and 25s of passive recovery at the starting line in between each sprint.

Men's Futsal: Only one article presented physiological responses to a RRSA test in men futsal players (indoor soccer) (5). Angius *et al.* observed a progressive decrease in mean velocity during the test. When compared to runs #1-2, runs #5-8 had a lower mean velocity. This decrease was attributed to an accumulation of fatigue that appears specific to futsal considering many high-intensity actions, such as sprinting and changing directions are observed and where about 80% of the game time is spent playing at 80% or more of the players maximal heart rate (HR_{max}) (57). Angius *et al.*'s test also presented a mean BLa of 12.2 ± 0.72 mmol/L which is greater than what Naser *et al.* presented in their literature review (mean BLa of 5.3 mmol/L) directed on the physical and physiological demands of futsal (57). Naser *et al.*'s literature review suggested the futsal intermittent endurance test (FIET) (3x15m with 10-30s rest until exhaustion, including three COD) was a reliable and valid test (21). The FIET presented similar peak blood lactate (PeakBLa) to a futsal game situation (21).

We believe that both tests, the RRSA test by Angius *et al.*'s and the FIET, should be compared in order to evaluate which one recreates most accurately the physical and physiological demands of the sport. These demands are 8.6 activities/minute with low intensity effort every 14s, medium-intensity efforts every 37s, high-intensity efforts every 43s. and maximal intensity every 56s. The review by Naser *et al.* highlighted that the work:rest ratio in futsal should be around 1:1 (57). Changes of direction are also an important factor since it was shown that soccer has around 600 turns from 0-90 degrees and 95 turns of angles larger than 90 degrees during a regular field match and it is expected there are more in futsal (16, 57).

In light of these findings, the authors recommend that practitioners intervening with men futsal players use the FIET (Futsal Intermittent Endurance Test) which consists of shuttle-running bouts of 45 m (i.e., 3x15 m) performed at progressive speeds until exhaustion dictated by pre-recorded audio cues as it presents PeakBLa similar to game situations and includes three COD which are important in futsal. In this test, subjects can actively rest for 10 seconds every 45-m. After each 8x45 m bout, players passively rest for 30 s before continuing. The starting speed is set at 9 km/h, and speed increments during the first 8x45 m bouts are of 0.33 km/h , successively shifting to 0.20 km/h every 45 m until exhaustion (21).

Men's Basketball: Several protocols were used to measure RRSA in men's basketball players. Three studies presented physiological responses of the subject (7, 59, 76). Results showed that five COD resulted in lower peak values in BLa compared to two COD (8.2±1.9 mmol/L vs 9.8±2.5 mmol/L respectively) (76). Narazaki *et al.* proposed that the stop and go nature of basketball could limit the accumulation of blood lactate (56). This hypothesis was confirmed with Zagatto *et al.*'s study (76). A third study found BLa levels higher than those previously presented with 11.89±2.3 mmol/L for the one COD protocol and 11.35±2.5 for the two COD protocol (59). These values are similar to what was found in a game analysis with a peak BLa of 13.2 mmol/L (12). Zagatto *et al.*'s study also showed that players were faster with two COD vs five COD. The authors concluded that two COD might allow more time for acceleration than five COD (76).

The two-part study, stated that intensive repeated sprint ability (IRSA) (two COD) was closer to game demands than a RRSA test with one COD because time movement was 2.3s and 3s respectively which places IRSA closer to a basketball game reality (movements of 2s) (59). They also observed that FI and rate of perceived exertion were higher in the RRSA test compared to the IRSA with 3.528 FI and 3.296 FI respectively (59).

In view of all the previously mentioned factors, the authors recommend that practitioners intervening with men basketball players use the IRSA test which consists of 10x30m (10m + 10m + 10m) shuttle sprints with two COD of 180° and 30s of passive recovery (walking back to the starting line and waiting for the next sprint) as it is close to game reality with stops and go, similar BLa and is transferable to jump performance.

Men's Handball: Two studies presented RRSA test protocols that were used on men handball players (55, 73). Both investigations used a 6x30m (15+15m) repeated shuttle sprint test (RSST) but with different recovery times. The study by Nakamura *et al.* used a protocol that included 20s of passive recovery (55) in between sprints and the second one by Schwesig *et al.* used a protocol that included 14s of passive recovery in between sprints (73). Although, both protocols used passive recovery, a study directed by Povoas *et al.* presented an analysis of handball physical and physiological demands showing that handball players spend 44.9±23.03% of their recovery time standing still and 52.4% active (66). This observation seems to suggest that active recovery would be more representative of the sport's demand. In addition, the same study showed the time between high-intensity efforts was either less than 30s or more than 90s (the latter could be associated with time-outs or faults) (66). Furthermore, both testing protocols only included one COD, but the handball analysis revealed that 60% of the playing actions in handball are changes of directions that occur every 5.6±1.03s (66). Finally, results presented by Schwesig *et al.* show differences between players according to their position on the field, differences were found in their RRSA test results (73). The wings showed the best performance on the RRSA test because their position needs to cover the largest distance in the field and to repeat several sprints in order to create fast breaks (73).

Nakamura *et al.* compared a Repeated Shuttle-Sprint AbilityTest (RSST) with the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$). These tests presented peak heart rate (HR_{peak}) values of 180 and 191 beats per minutes (bpm) respectively (55). On the other hand, Schwesig *et al.* obtained a peak value of 172±8 bpm during their test (73). When comparing those results with the analysis produced by Povoas *et al.*, which presented a HR_{peak} of 185±6.6 bpm (66), we believe the assessment used by Nakamura and his colleagues was closer to game reality than the RSST used by Schwesig and his colleagues.

Considering all the previously mentioned factors, we recommend that practitioners intervening with men handball players use the RSST, which consists of 6x30m (15+15-m sprints with a 180° COD) with 20s of passive recovery at the starting line in between sprints. Although, a test more specific to physical and physiological demands of the sport could be created.

Men's Badminton: In badminton, only one study met our inclusion criteria and presented physiological responses to a RRSAT, the test presented was the multiple repeated sprint ability test for badminton players (MRSAB) (63). Results showed an average HR of 186.6 ± 5.1 bpm, which represents approximately 90% of maximal HR. This is similar to what the authors of the study had previously observed in another study during gameplay (64) but is different to what has been observed by other researchers, an average HR of 173.5 bpm (20). The VO_2max measures were different between these two studies; Phomsoupha and Laffaye (63) had an average of 54.6±5.5 ml/kg/min whereas Cabello-Manrique and Gonzalez-Badillo recorded 51.5 ml/kg/min (20). The mean BLa also differs, the first study (63) recorded a mean value of 10.8±2.2

mmol/L and the second (20) had a mean value of 3.8 mmol/L. However, a third study by Ghosh showed similar values to the one recorded by Phomsoupha and Laffaye with a mean BLa of 12.2±2.1 mmol/L (35). The 10(4x3m) (MRSAB) test used by Phomsoupha, Berger and Laffaye did recreate similar work:rest ratio as seen during game play. The study had a ratio of 18.1±2.8: 30.0±0.1s of work for rest time, respectively (63). Cabello-Manrique and Gonzalez-Badillo found several similar results with work:rest times of 8:16s, 12.3:20.4s, 6.4:12.9s and 5:10s (20), which are all around the same work:rest ratio of 1:2. The researchers found a strong correlation with a shared variance between $V0_2$max and mean time of 85% for the 10(4x3m) test (63) which indicates that an increase in aerobic capacity could be beneficial for badminton athletes. The test seems appropriate for badminton players, but further sports analysis should be made to compare average HR and mean BLa because of the large discrepancies reported in the literature. Considering all the previously mentioned factors, the authors of the current review recommend that practitioners working with badminton players should use the MRSAB (Multiple Repeated Sprint Ability test for Badminton players) which consists of 10x12m (4x3m with COD) with 30s of passive recovery in between sprints as its work:rest ratio is similar to game situation.

The overall purpose of this review was to help guide practitioners in their future assessments. Ultimately, by using a systematic approach, the authors were able to review the different acute physiological responses to repeated running sprint tests and present them into result tables in a brief review. Therefore, the hypothesis is accepted. The present review could serve as reference for professionals using repeated running sprints as part of their physical testing battery.

Nevertheless, the present work was limited by the current body of literature. Future publications should focus on presenting clear information about the competitive level of the subjects and the protocol utilized. Further research should be directed towards creating RRSA tests more specific to the physical and physiological demands of each sport presented in this study (soccer, futsal, basketball, handball, badminton).

The authors recommend the following tests to practitioners. Practitioners intervening with soccer players should use the 6x40m RRSA protocol with one COD (20+20 m with a 180° COD) and 25s of passive recovery at the starting line in between each sprint. When intervening with men basketball players, practitioners should use the IRSA (Intensive Repeated Sprint Ability) test which consists of 10x30m (10m+10m+10m) shuttle sprint with two COD of 180° and 30s of passive recovery (walking back to the starting line and waiting for the next sprint). When intervening with men futsal players, practitioners should use the FIET (Futsal Intermittent Endurance Test) which consists of shuttle-running bouts of 45 m (i.e., 3x15 m) performed at progressive speeds until exhaustion dictated by pre-recorded audio cues. When intervening with men handball players, practitioners should use the RSST (Repeated Shuttle Running Test) which consists of 6x30m (15+15m sprints with a 180° COD) with 14s of passive recovery at the starting line in between sprints. Finally, when intervening with men badminton players, practitioners should use the MRSAB (Multiple Repeated Sprint Ability test for Badminton players) which consist of 10x12m (4x3m with COD) with 30s of passive recovery at the starting line in between sprints.

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