Validity and reliability of a unique aerobic field test for estimating VO$_{2\text{max}}$ among basketball players

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ABSTRACT

This study aimed at developing and validating an innovative field test for measuring the aerobic capacity of basketball players during games. Such capacity is necessary for recovering from high frequency anaerobic actions such as sprinting and continuing to perform well. To recover, the body must rebuild its creatine phosphate reserve and emit accumulated phosphate in very short periods of time. The participants included 21 male basketball players on an elite youth league in Israel, aged 16.4 years on average. In addition to participating in the proposed test (Yo-Yo Recovery Test for Basketball Players) twice (test/re-test), the players also performed three previously validated tests (Bruce Protocol Stress Test, Yo-Yo Intermittent Recovery Level 1 Test, and Yo-Yo Endurance Test). For each test, the players’ time and distance covered were documented, as were their maximum oxygen consumption and heartrate during recovery, and their perceived level of exertion. Our findings indicate the validity and reliability of the proposed aerobic field test for basketball players. Moreover, the test requires shorter times and distances for obtaining results than the other three tests. As such, this tool could be highly beneficial for basketball coaches in creating optimal training programs and game plans for each individual player and for the entire team.

Keywords: Performance analysis of sport, Fitness field test, Maximal aerobic capacity, Anaerobic activities, Yo-Yo Test.
INTRODUCTION

Team sport games in general, and basketball in particular, are characterized by short intense activities that are repeatedly carried out throughout the game (Petway et al., 2021). These include short intense activities such as jumping, sprinting, change of direction, and agility, as well as moderate-intensity exercises that last up to 60 seconds (Stolen, 2005). In addition, basketball players also need to present aerobic capabilities (Mancha et al., 2019) during games and practices (Castagna et al., 2008), and as such, need to also develop strong aerobic capacities (Padulo et al., 2016). Due to their importance to the players’ performance, a range of methods for testing aerobic and anaerobic athletic capabilities have been developed over the past two decades (Petway et al., 2020).

After performing intense activities during practices and games, the athlete’s body needs to produce adenosine triphosphate (ATP), creatine phosphate (CP), and glycolysis (Gastin, 1993). Rebuilding CP requires the use of blood lactate concentrations and the removal of phosphate that accumulates in the cells (Wragg, 2000). Yet short recovery periods while playing basketball and other ball games are not always sufficient for refilling these resources after high intensity activities, and it is therefore difficult for players to consistently achieve the same level of performance throughout the game (Meckel, 2009a). In other words, the players’ ability to continuously play well over time throughout the practice or game depends on the rebuilding of their CP reserves and removal of waste products (Meckel, 2009b). Moreover, since the introduction of the 24-second shot clock (Abdelkrim et al., 2007), the concept of playing quickly has become even more crucial among players (Petway et al., 2020). In turn, this has led to even higher physical demand on players, increasing the importance of explosive strength (Stojanovic et al., 2012). As a result, fitness professionals strive to develop effective training methods for promoting and developing the physical abilities of basketball players (Freitas et al., 2017), as well as optimal techniques for monitoring and evaluating various fitness components (Edward, 2018) as a means for enhancing the players’ ability to perform at their optimal and maximum capacity (Freitas et al., 2019).

While basketball is considered an anaerobic-dominated game (with actions including jumping, changing direction, and footwork), these activities occur with such high frequency that they take their toll on the players (Castagna, 2008). During a game, a basketball player performs an average of 105 intense movements (each lasting two-six seconds) every 21 seconds while the clock is running. These movements lead to the consumption of 60%-75% of the body’s maximum oxygen consumption (VO2max); the players’ heart rate reaches 70%-90% of their maximum heart rate (Meckel, 2009a). While the overall distance that a player sprints during the game accounts for less than 10% of the overall distance that an athlete moves throughout the game, these infrequent sprints have a significant impact on the players’ athletic capabilities and performance during a game (Wragg, 2000). Moreover, the ability to recover from these activities and repeat them without fatigue is based on the fast renewal of CP stores and the fast removal of lactic acid from the muscle. Research indicates that a high aerobic capacity (measured via the player’s VO2max) may enhance this recovery process, enabling the player to perform high intensity actions throughout the basketball game (Glaister, 2005). The VO2max measure relates to the maximum rate at which the body can inhale, distribute, and use VO2 while performing physical activity (Akalan et al., 2004). For basketball players, optimal VO2max is 55 ml/kg/min (Marinkovic, & Pavlović, 2013).

Aerobic capacity assessments
A range of tests have been developed for evaluating aerobic capacity and determining the physical capabilities and limitations of basketball players (Mancha et al., 2019). These can be used by professionals to design physical training programs that fit the players’ level, track the players’ fitness levels over time, and...
create goals for the players. This is especially important, as different sports require players to exert different types and degrees of efforts and present different physical capabilities. For example, basketball players need different levels of VO₂max than players of other team sports. As such, the demand for accurate and applicable field testing is of great importance and value (Stone, 2007).

Compared to laboratory tests, field tests have many advantages (Meckel, 2009a). For example, they can be conducted on a large number of players simultaneously (such as an entire basketball team), and they convey a more complete picture of the athletes’ coping mechanisms for dealing with physiological, technical, tactical, and mental obstacles during a game – thereby reflecting the true nature of the field in a more accurate manner. In other words, while running on a treadmill in a laboratory may provide researchers with important data and insights, this is not the same as actually running in the field, changing directions (Mancha-Triguero et al., 2019).

As such, aerobic conditioning, which relates to sport-specific adaptation training and incorporates skills and movements that are specific to the sport (Stone, 2007) and at intensities that are sufficient for promoting aerobic adaptation, has been increasingly implemented in professional team sports, including basketball. Specifically with basketball, aerobic capacity assessments are important for evaluating players’ recovery abilities from both aerobic and anaerobic activities, and they can provide a strong baseline for conducting professional conditioning (Stone 2007), while offering indications about planning and future training, and allowing coaches to understand which factors could assist in improving, maintaining, or increasing players’ fitness levels while performing at their optimal levels, given that few specific tests are used to assess this quality in athletes (Mancha-Triguero et al., 2019).

While observing 20 basketball games in the Israeli Premier League, the authors of this study observed that basketball players have incomplete recovery times, which only last between 10 seconds (with fouls that do not require free throws) to 30 seconds (with fouls that result in two free throws) during the game, about a minute during timeout, and longer than two minutes between quarters. On average, recovery times were observed approximately every three possessions. Due to the flow of the game of basketball, it is important to develop a unique aerobic test which can predict players’ VO₂max that is needed for recovery, based on movements such as running, changing directions, and defensive strides (Manch et al., 2019), according to the frequencies and durations of recovery during games (Calleja-Gonzalez et al., 2016; Calleja-González et al., 2018). The VO₂max is measured as millilitres of oxygen per kilogram of body mass per minute (ml/kg/min), and could depict high fitness levels (Figueira et al., 2008). Moreover, VO₂max is considered an optimal index for measuring aerobic capacity and maximal cardiorespiratory function (Hawkins et al., 2007). To the best of our knowledge, the literature lacks input regarding aerobic tests that examine activity/rest ratios, as well as related physiological aspects, among players during a basketball game.

The main aim of this study, therefore, was to develop and check the validity and reliability of a unique basketball field test that measures the aerobic capacity of basketball players during the game, while accurately replicating players’ movements observed during basketball games. Such a tool could be beneficial to basketball coaches and trainers for designing and strategizing optimal game plays for the team as a whole and for the individual players.
MATERIAL AND METHODS

Participants
A total of 21 basketball players on an elite youth league in Israel participated in this study. On average, these male participants were aged 16.4 years (±0.5) with height = 180 cm (±5.5), body mass = 72 kg (±4.9), and body fat = 10.8% (±1.9%). They had been playing basketball for eight years, and their weekly routine included five basketball practices, two fitness practices, and one league game per week. Four inclusion criteria were applied in this study, whereby the player had: (a) participated in at least 90% of the weekly training sessions during the 10-month season leading up to the research; (b) regularly participated in the previous competitive season; (c) had a clean bill of health; and (iv) had not incurred injuries or pain and were not administering medication.

To reduce interference in the experiment, the participants were asked to refrain from consuming stimulants (e.g., caffeine) or depressants (e.g., alcohol) for 24 hours prior to the testing, and to refrain from eating for about 3 hours prior to the testing. They were also asked to avoid strenuous activity for at least 24 hours before the testing. As the participants were minors, their parents signed an informed written consent form. Although anonymity could not be assured due to the nature of the study, all data obtained were treated with the utmost confidentiality and scientific rigor and were used solely for the purpose of this research project. The study was conducted in compliance with the Organic Law 15/1999 of December 13 on the Protection of Personal Data and the 2008 Helsinki Statement, updated in Fortaleza (World Medical Association, 2013).

Design and Procedure
To eliminate circadian variation, all participants completed the tests at the same time of day, at 4 pm, in normal ambient conditions, with a temperature of 20.2 ± 0.5°C and relative humidity of 65.3% ± 3.5%. The tests were conducted in indoor laboratories and on regular indoor official basketballs courts; the participants wore basketball shoes and appropriate sportswear.

Each participant participated in 4 tests: one laboratory test and three field tests, within three days of each other.

Measures
To measure VO$_{2\text{max}}$ specifically among basketball players, we developed the innovative Yo-Yo Recovery Test for Basketball Players. To test and validate this new field tool, the data achieved from the novel test was compared to three already-validated tests based on distance covered, VO$_{2\text{max}}$, heart rate, and perceived test difficulty.

1) Bruce Protocol Laboratory Stress Test (Bruce, 1949). Each participant was asked to continuously run on the treadmill, subject to gradually increasing intensity every three minutes (increased speed and inclination) for a total of seven times or until the subject was unable to continue to perform due to fatigue. This is considered the goal standard.

2) Yo-Yo Intermittent Recovery Level 1 (YYIR1). Previous assessments of this test (Bangsbo et al., 2012) show a correlation of $r = .77$ with VO$_{2\text{max}}$ values. Each test section is comprised of a 40-meter run (20 meters in one direction, 20 meters back to the starting point, and a 10-second recovery period). The test gradually increases from 10kph by 0.5 kph for each new 40-meter section, until the participant is unable to continue to perform due to fatigue. The version applied in this study was developed specifically for sports such as basketball, that require intense physical efforts separated by sections of incomplete recovery (Castagna, 2008).
3) **Yo-Yo Endurance (YYEND) Test.** Developed by Léger et al. (1988), this test requires participants to run back and forth in 20-meter sections with increased intensity effort until the participant is unable to continue due to fatigue. Previous assessments of this test show a very high correlation of \( r = .92 \) with VO\(_{2\text{max}}\) and is reliable and valid for predicting aerobic capacity among a range of populations (St. Clair Gibson et al., 1988). The sprints begin at a speed of 8 km/h and increase by 0.5 km/h approximately every minute, as dictated by an audio disc. The results are determined by the number of times the athlete is able to perform these sprints until overcome by fatigue. The test was chosen for this study due to its similarity to the activity patterns that are routinely performed by athletes every few months, as a means for evaluating their aerobic fitness.

4) **Yo-Yo Recovery Test for Basketball Players (YYRECB).** This unique test was developed to examine recovery specifically among basketball players and is comprised of movements from the game of basketball, including running, changing directions, and defensive strides – with short and intense discrete parts for recovery. The procedure includes running (18 meters) + defensive strides in one direction (2 meters) / defensive strides (2 meters) + running (18 meters) back to the starting point / recovery walking (five meters + five meters in both directions) for 10-20 seconds (Figure 1). Each participant performed this test twice for means of validation (i.e., test/re-test), while the previous three tests were only performed once.

![Diagram of YYRECB Test](image)

**Note.** A. Running forward (18 meters) – **Yellow line.** B. Defensive steps (2 meters) – **Red line.** C. Defensive steps (2 meters) – **Red line.** D. Running back to the starting line (18 meters)– **Blue line.** E. Recovery, 10-20 seconds walking (10 meters: 5 meters back and forth) – **Green line.**

Figure 1. Track for conducting new YYRECB Test.

In addition to documenting the distance covered in each test, the time it took to complete the tests, and the participants’ VO\(_{2\text{max}}\), we also measured their maximum heart rate (HR\(_{\text{max}}\)) towards the end of each test, based on the number of heartbeats (contractions) per minute (bpm) – using the Polar HR monitor and transmitter (Polar Electro, Lake Success, NY, USA) that was validated by Goodie et al. (2000). Finally, after each test, the participants were asked to rate the difficulty of the test using the Rated Perceived Exertion (RPE) Scale (Borg, 1998). The scale ranges from six (felt nothing at all [like sitting in a chair]) to 20 (felt very heavy [like at the end of an exercise stress test or other very difficult activity]).

**Statistical analysis**

Standard statistical parameters (mean ±SD) were calculated for the anthropometric data and physical performance test results. Normality was tested through analysis of the censored exposure data subject to the constrained maximization of the Shapiro-Wilk W statistics (<30). Reliability of the new test was measured via Intra-class Correlation Coefficient (ICC), and validity was measured using Pearson correlation tests. In line with Hopkins et al. (2009), correlation coefficients were considered trivial \( (r < .1) \), small \( (.1 < r < .3) \), moderate \( (.3 < r < .5) \), high \( (.5 < r < .7) \), very high \( (.7 < r < .9) \), nearly perfect \( (r > .9) \), or perfect \( (r = 1) \). Validity
and intra/inter-evaluator reproducibility were evaluated by the ICC as well. Finally, the analysis of the Bland-Altman concordance resulted in a variation coefficient of less than 10%. Significance levels were \( p < .05 \). SPSS\textsuperscript{®} v17.0 (SPSS\textsuperscript{®}, Inc., Chicago, IL) was used for conducting statistical analyses.

**RESULTS**

The test/re-test results showed the YYRECB to be very reliable (\( r = .97 \)). In particular, the \( \text{HR}_{\text{max}} \) during the distance covered during tests, time spent on each task, and RPE ratings did not present test/re-test differences (all variables = .971). Very high correlations were found between \( \text{VO}_{2\text{max}} \) (\( \text{ml kg}^{-1} \text{min}^{-1} \)) and YYRECB (\( r = .769; 95\% \text{ confidence interval [CI]}; p < .0001 \)). Besides, significant differences were also seen in distances covered in the YYRECB test compared to those covered in the YYREC1 and YYEND tests (\( r = .748 \) and \( r = .723 \), respectively; 95\% CI; \( p < .0001 \)). Pearson correlations were performed once for all measures and twice for the YYRECB (test/re-test), which was found to be reliable, without significant differences in \( \text{HR}_{\text{max}} \) and distances covered. Internal correlation between repetitions was .971 (Table 1).

| Variable                  | Mean    | SD      | Coefficient of Variable |
|---------------------------|---------|---------|-------------------------|
| Level                     | Test    | 10.94   | 0.14                    | 5.95 |
|                           | Re-test | 11.02   | 0.13                    | 5.48 |
| \( \text{VO}_{2\text{max}} \) (ml/kg/min) | Test    | 55.52   | 0.49                    | 4.07 |
|                           | Re-test | 55.63   | 0.45                    | 3.74 |
| HR (end)                  | Test    | 191     | 1.1                     | 2.64 |
|                           | Re-test | 191.57  | 1.11                    | 2.66 |
| Total Distance (min)      | Test    | 1605.71 | 34.62                   | 9.88 |
|                           | Re-test | 1613.33 | 31.99                   | 9.09 |
| Total Time (sec)          | Test    | 1006.9  | 18.02                   | 8.2  |
|                           | Re-test | 1009.48 | 16.53                   | 7.5  |
| RPE (6-20)                | Test    | 17.29   | 0.24                    | 6.37 |
|                           | Re-test | 17.29   | 0.22                    | 5.83 |

Note. \( \text{HR end} = \text{Heart Rate at the end of the test. RPE = Rate Perceived Extortion. VO}_{2\text{max}} = \text{Maximal aerobic capacity.} \)

Bland-Altman analysis of reliability is derived from agreement between measures (Lu Mj et al., 2016), enabling reporting of the mean bias and the upper/lower \( \text{VO}_{2\text{max}} \). As shown in Table 2, when tested against the \( \text{VO}_{2\text{max}} \), the innovative YYRECB demonstrated a high correlation for distance (\( r = .769 \)). When tested against YYREC1 and YYEND, the YYRECB demonstrated high correlations for distance (\( r = .723 \) and \( r = .748 \), respectively). The Bland-Altman Difference Plot for analysing \( \text{VO}_{2\text{max}} \) in the YYRECB resulted in zero, indicating complete agreement and lack of bias (Giavarina, 2015). The formula for estimating \( \text{VO}_{2\text{max}} \) in the YYRECB test is: \( \text{VO}_{2\text{max}} = 0.0146x + 32.078 \) (\( x = \) the distance covered during the test); mean = 0. Complete agreement was seen between the laboratory test and the YYRECB (CI 95\% -1: + 1, CI mean -3.5: +3.6), as well as a very good correlation up to 55 ml/kg/min (Figure 2).

For the Bland-Altman analysis of \( \text{VO}_{2\text{max}} \) and YYREC1, mean = 2.1 (Figure 3). As such, 2.1 must be added to the result to compare YYREC1 results to laboratory results (CI 95\% -0.5: + 3, CI mean -2.5: + 6.6).

Finally, Bland-Altman analysis of \( \text{VO}_{2\text{max}} \) and YYEND presented mean = 0.7, as seen in Figure 4. Therefore, 0.7 must be added to YYEND results in order to compare to the innovative test to the laboratory test (CI 95\% 0: +1; CI mean -2.5: +4).
Table 2. Test/re-test reliability and agreement between Yo-Yo Tests.

| Variable | ICC        | SD   | Bias | VO_{2max} (lower) | VO_{2max} (upper) |
|----------|------------|------|------|-------------------|-------------------|
| YYIR1    | 0.645*     | 5.01 | 6.6  | -2.5              | 2.1               |
| YYEND    | 0.859*     | 5.66 | 3.9  | -2.4              | 0.7               |
| YYRECB   | 0.769*     | 3.81 | 3.6  | -3.5              | 0                 |

Note. *Correlation is significant at the .01 level (2-tailed).

Figure 2. Formula for estimating VO_{2max}.

Figure 3. Bland-Altman Plot for VO_{2max} laboratory and YYRECB tests.
DISCUSSION

Basketball involves specific movements on the field (Petway et al., 2021), including frequent changing of direction and repeated sprints with limited recovery time (Meckel, 2009a). Moreover, aerobic conditioning among basketball players is necessary for achieving desired outcomes in practices and games. The main aim of the study was to test the validity and reliability of a novel field test that measures the aerobic capacity of basketball players (i.e., VO$_{2\text{max}}$) based on movements that replicate those performed during games. As this test is also less time consuming and money draining than laboratory tests, and does not require specialized personnel and equipment, this test is more practical for basketball trainers and can be applied in the field (Akalan et al., 2004). Moreover, measuring VO$_{2\text{max}}$ in the field is expected to provide results that are more aligned with the players’ capabilities during a game (Gottlieb et al., 2021).

Our results indicate the validity and reliability of our proposed version of the Yo-Yo test (i.e., the YYRECB) for assessing basketball players’ endurance and fitness in the field, with no differences seen in the players’ RPE and heart rate between tests. The Bland-Altman analysis presented completed agreement between the VO$_{2\text{max}}$ measured in the laboratory and that measured in the YYRECB. Correlation and agreement were also found when compared to previously validated field tests (i.e., YYEND and YYREC1). Moreover, to achieve the target VO$_{2\text{max}}$ needed in basketball (about 55ml/kg/min, Marinkovic & Pavlović, 2013), the players needed to complete 1600 meter. Stopping the test at this level means they will be able to maintain this aerobic conditioning in basketball practices, although there are significant differences between U-14 and U-17, in the VO$_{2\text{max}}$ on court specific test (Calleja-Gonzalez et al., 2018).

The Yo-Yo test performances may vary greatly over the course of a season, as seen in the game of soccer, where peak performance is often demonstrated mid-season (Krstrup et al., 2003). Thus, to provide a more accurate indication of aerobic capability of players throughout the season, the YYRECB test should be conducted a minimum number of times a year. For example, one week into pre-season, three-four weeks into the pre-season, and then again mid-season. Based on these findings, future studies may modify the
YYRECB field test to suit other specific sports, especially where players are frequently required perform intermittent activities as with basketball.

Our research presents a number of limitations. First, only high school male basketball players participated in the study. Future studies could benefit from evaluating the test based on a larger range of gender and ages, to be able to generalize the findings. Moreover, participants must be motivated in order to optimally perform the test. Finally, gathering and deciphering the data was not simple, and required a range of technological means to do so.

**Limitations**

Despite its theoretical and practical contribution to the field, the current study has limitation, only youth male basketball players participated in the study. Future studies could benefit from evaluating the test based on a larger range of gender, ages, and positions, to enable generalization of the findings.

**CONCLUSIONS**

Field tests for examining basketball players’ aerobic capacity needed for recovery must be aligned with the unique components of the game. The proposed YYRECB test offers a valid and reliable field test for evaluating the recovery capabilities (VO\textsubscript{2\text{max}}) of basketball players that also requires less time and distances to achieve the required data. This test could be beneficial for basketball trainers in planning practices and games and achieving optimal outcomes.

**AUTHOR CONTRIBUTIONS**

Roni Gottlieb, Asaf Shalom, Dr. Pedro Emilio Alcaraz, and Dr. Julio Calleja-González conceived and designed the investigation tool, analysed and interpreted the data, drafted the manuscript, and approved the final version submitted.

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**DISCLOSURE STATEMENT**

No potential conflict of interest was reported by the authors.

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