






Validity and reliability of a unique aerobic field test for estimating VO_{2max} among basketball players

-  **Roni Gottlieb** . School of Human Movement and Sport Sciences. The Academic College at Wingate. Wingate Institute. Israel.
-  **Asaf Shalom**. Physical Education in High School. Naharia city, Israel.
-  **Pedro Emilio Alcaraz**. UCAM Research Center for High Performance Sport. The Faculty of Sport Science. Catholic University of Saint Anthony (UCAM). Murcia, Spain.
-  **Julio Calleja-González**. Physical Education and Sport Department. Faculty of Education and Sport University of the Basque Country. University of the Basque Country (UPV/EHU). Vitoria-Gasteiz, Spain.

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.

Cite this article as:

Gottlieb, R., Shalom, A., Alcaraz, P.E., & Calleja-González, J. (2022). Validity and reliability of a unique aerobic field test for estimating VO_{2max} among basketball players. *Scientific Journal of Sport and Performance*, 1(2), 112-123. <https://doi.org/10.55860/TRMF2461>

 **Corresponding author.** School of Human Movement and Sport Sciences. The Academic College at Wingate. Wingate Institute. Israel.

E-mail: ronigot23@gmail.com

Submitted for publication May 09, 2022.

Accepted for publication May 23, 2022.

Published June 01, 2022.

[Scientific Journal of Sport and Performance](#). ISSN 2794-0586.

©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.

doi: <https://doi.org/10.55860/TRMF2461>

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 ($VO_{2\max}$); the players' heartrate reaches 70%-90% of their maximum heartrate (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 $VO_{2\max}$) may enhance this recovery process, enabling the player to perform high intensity actions throughout the basketball game (Glaister, 2005). The $VO_{2\max}$ measure relates to the maximum rate at which the body can inhale, distribute, and use VO_2 while performing physical activity (Akalan et al., 2004). For basketball players, optimal $VO_{2\max}$ 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 $VO_{2\max}$ 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' $VO_{2\max}$ 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 $VO_{2\max}$ 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, $VO_{2\max}$ 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% ($\pm 1.9\%$). 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 $20.2 \pm 0.5^\circ\text{C}$ and relative humidity of $65.3\% \pm 3.5\%$. The tests were conducted in indoor laboratories and on regular indoor official basketball courts; the participants wore basketball shoes and appropriate sportswear.

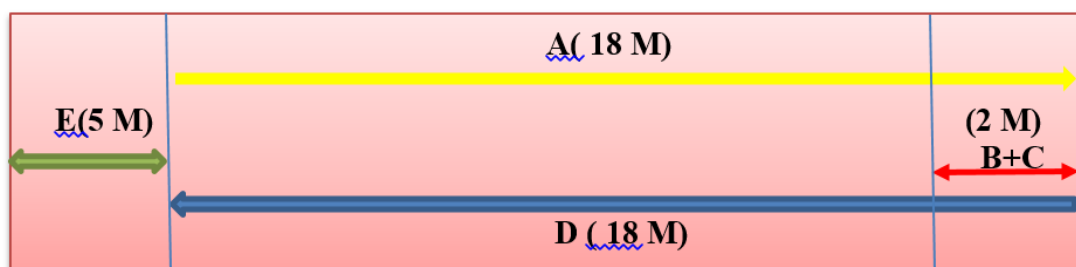
Each participant participated in 4 tests: one laboratory test and three field tests, within three days of each other.

Measures

To measure VO_{2max} 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_{2max}, 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_{2max} 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_{2max} 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.



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_{2Max} , we also measured their maximum heart rate (HRmax) 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 \pm 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® v17.0 (SPSS®, 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 HR_{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 VO₂max (mL x kg⁻¹ x min⁻¹) and YYRECB ($r = .769$; 95% 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 HR_{max} and distances covered. Internal correlation between repetitions was .971 (Table 1).

Table 1. Descriptive statistics (Test/Re-Test) for the New YYRECB test.

Variable		Mean	SD	Coefficient of Variable
Level	Test	10.94	0.14	5.95
	Re-test	11.02	0.13	5.48
VO ₂ 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. HR end = Heart Rate at the end of the test. RPE = Rate Perceived Extortion. VO₂max = 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 VO₂max. As shown in Table 2, when tested against the VO₂max, 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 VO₂max in the YYRECB resulted in zero, indicating complete agreement and lack of bias (Giavarina, 2015). The formula for estimating VO₂max in the YYRECB test is: $VO_{2max} = 0.0146x + 32.078$ (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 VO₂max 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 VO₂max 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	YYRECB				
	ICC	SD	Bland-Altman	VO ₂ max (lower)	VO ₂ max (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).

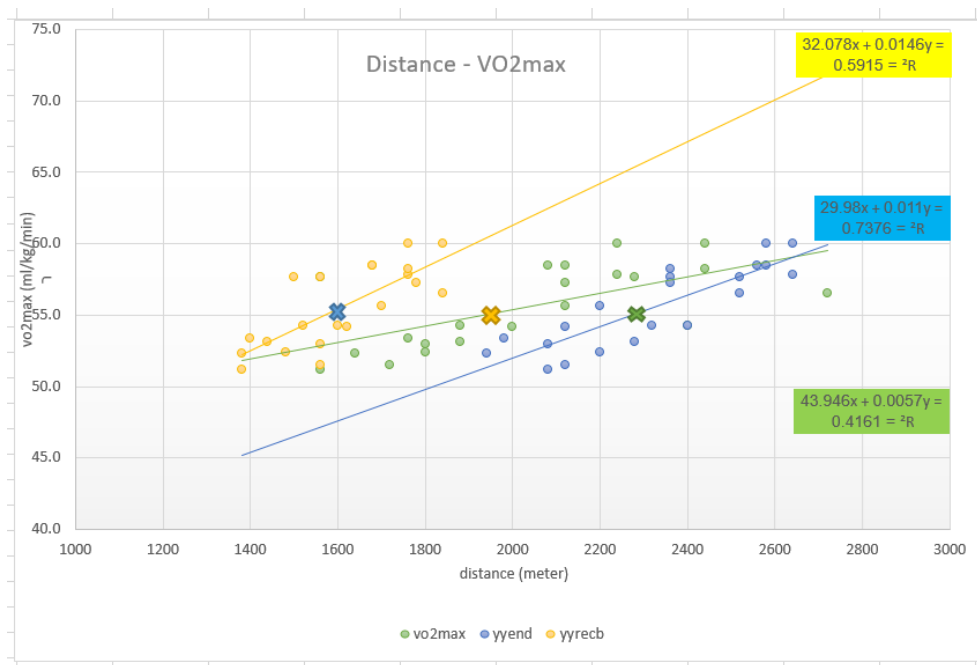


Figure 2. Formula for estimating VO₂max.

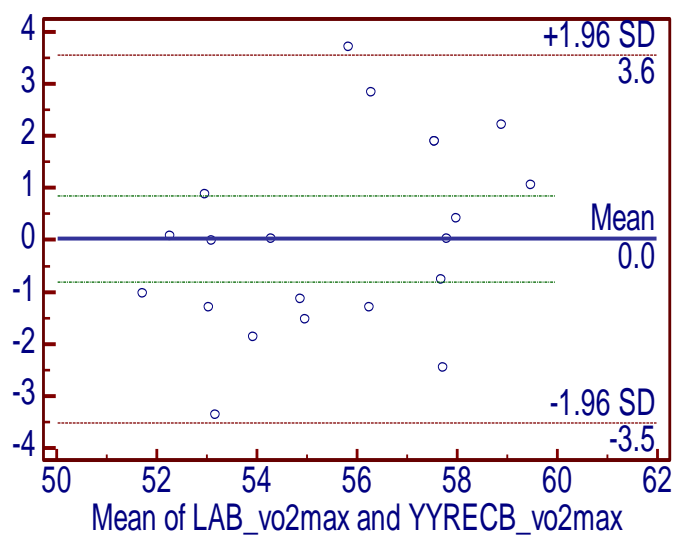


Figure 3. Bland-Altman Plot for VO₂max laboratory and YYRECB tests.

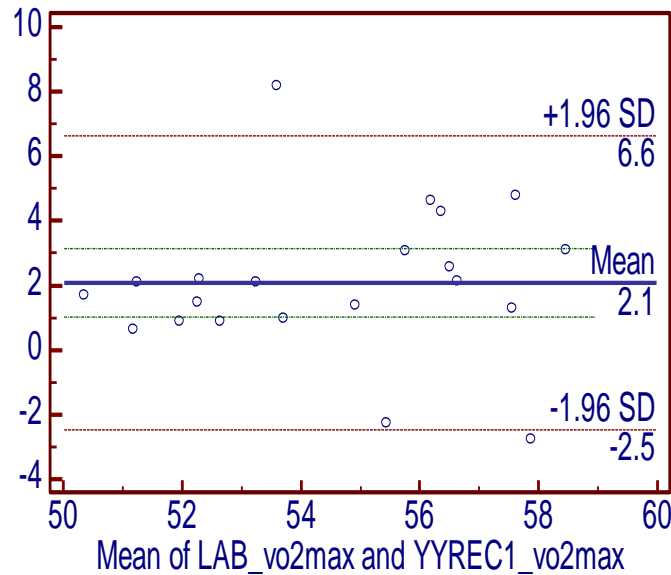


Figure 4. Bland-Altman Plot of VO_{2max} laboratory and YYRECB tests.

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_{2max}) 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 (Akanan et al., 2004). Moreover, measuring VO_{2max} 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_{2max} 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_{2max} 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_{2max} 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 (Krustrup 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_{2max}) 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.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ACKNOWLEDGMENTS

The authors would like to thank the Ramat Hasharon Basketball Club in Israel for their cooperation with the study. We would also like to thank the players and coaches for their efforts in completing the physical tasks required for the study.

REFERENCES

Abdelkrim, N. B., El Fazaa, S., & El Ati, J. (2007). Time motion analysis and physiological data of elite under 19 years old B players during competition. *British Journal of Sports Medicine*, 24, 2330-2342. <https://doi.org/10.1136/bjism.2006.032318>

- Akalan, C., Kravitz, L., & Robergs, R. (2004). VO₂max: Essentials of the most widely used test in exercise physiology. *ACSM's Health & Fitness Journal*, 8(3), 5-9. <https://doi.org/10.1097/00135124-200405000-00004>
- Bangsbo, J., Marcello, I., & Krstrup, P. (2012). The Yo-Yo Intermittent Recovery Test: A useful tool for evaluation of physical performance in intermittent sports. *Sports Medicine*, 38, 37–51. <https://doi.org/10.2165/00007256-200838010-00004>
- Borg, G. (1998). Borg's Perceived Exertion and Pain Scales. *Human Kinetics*.
- Bruce, R. A., Pearson, R., Lovejoy, F. W., Jr. Yu, P. N. G., & Brothers, G. B. (1949). Variability of respiratory and circulatory performance during standardized. *The Journal of Clinical Investigation*, 28(6), 1431-1438. <https://doi.org/10.1172/jci102208>
- Calleja-González, J., Terrados, N., Mielgo-Ayuso, J., Delextrat, A., Jukic, I., Vaquera, A., Torres, L., Schelling, X., Stojanovic, M., & Ostojic, S. M. (2016). Evidence-based post-exercise recovery strategies. *The Physician and Sports Medicine*, 44(1),74-78. <https://doi.org/10.1080/00913847.2016.1102033>
- Calleja-González J., Mielgo-Ayuso, J., Sampaio, J., Delextrat, A., Ostojic, SM., Marques-Jiménez, D., Arratibel, I., Sánchez-Ureña, B., Dupont, G., Schelling, X., Ter-rados N. (2018). Brief ideas about evidence-based recovery in team sports. *Journal of Exercise Rehabilitation*, Aug 24;14(4):545-550. <https://doi.org/10.12965/jer.1836244.122>
- Calleja-Gonzalez, J., Mielgo-Ayuso, J.M., Lekue, J.A., Leibar, X., Erauzkin, J., Jukic, I., Ostojic, S.M., Ponce González, J.G., Fuentes Azpiroz, M., Terrados, N. (2018). Anthropometry and performance of top youth international male basketball players in spanish national academy. *Nutrición Hospitalaria*, VOL 35, NÚM. 6, nov-dec, 1331-1331. <https://doi.org/10.20960/nh.1897>
- Castagna, C., Grant, A., Vincenzo, M., Giueseppe, A., Evira, P., & Stefano, D. (2008). Effect of recovery mode on repeated sprint ability in young basketball players. *Journal of Strength and Conditioning Research*, 22, 1-7. <https://doi.org/10.1519/jsc.0b013e31816a4281>
- Figueira, T. R., Caputo, F., Machado, C. E. P., & Denadai, J. B. S. (2008). Aerobic fitness level typical of elite athletes is not associated with even faster VO₂ kinetics during cycling exercise. *Journal of Sports Science & Medicine*, 7(1), 132-138.
- Freitas, T.T., Martinez-Rodriguez, A., Calleja-González, J., Alcaraz, P.E. (2017). Short-term adaptations following complex training in team-sports: A meta-analysis. *PLoS One*, 12(6), e0180223. <https://doi.org/10.1371/journal.pone.0180223>
- Freitas T.T., Calleja-González, J., Carlos-Vivas, J., Marín-Cascales, E., & Alcaraz, P. E. (2019). Short-term optimal load training vs a modified complex training in semi-professional basketball players. *Journal of Sports Sciences*, 37(4), 434-442. <https://doi.org/10.1080/02640414.2018.1504618>
- Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochemia Medica*, 25(2), 141-5. <https://doi.org/10.11613/bm.2015.015>
- Goodie, J. L., Larkin, K. T., & Schauss, S. (2000). Validation of the Polar Heart Rate Monitor for assessing heart rate during physical and mental stress. *Journal of Psychophysiology*, 14(3), 159-164. <https://doi.org/10.1027/0269-8803.14.3.159>
- Hawkins, M. N., Raven, P. B., Snell, P. G., Stray-Gundersen, J., & Levine, B. D. (2007). Maximal oxygen uptake as a parametric measure of cardiorespiratory capacity. *Medicine & Science in Sports & Exercise*, 38(11), 103-107. [https://doi.org/10.1016/s0162-0908\(08\)79148-7](https://doi.org/10.1016/s0162-0908(08)79148-7)
- Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J (2009). Progressive statistics for studies in sports medicine and exercise science *Medicine & Science in Sports & Exercise*, 41(1), 3-13. <https://doi.org/10.1249/mss.0b013e31818cb278>
- Krstrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P. K., & Bangsbo, J. (2003). The Yoyo Intermittent Recovery Test: Physiological response, reliability, and

- validity. *Medicine & Science in Sports & Exercise*, 35(4), 697-705. <https://doi.org/10.1249/01.mss.0000058441.94520.32>
- Léger, L. A., D Mercier, C Gadoury, (1988). The multistage 20 meter shuttle run test for aerobic fitness. *Journal of Sports Sciences*, 6(2), 93-101. <https://doi.org/10.1080/02640418808729800>
- Lu, M. J., Zhong, W. H., Liu, Y. X., Miao, H. Z., Li, Y. C., & Ji, M. H. (2016). Sample Size for Assessing Agreement between Two Methods of Measurement by Bland-Altman Method. *The International Journal of Biostatistics*, 12(2). <https://doi.org/10.1515/ijb-2015-0039>
- Mancha-Triguero, D., García-Rubio, J., Calleja-González, J., Ibáñez, S. J. (2019). Physical fitness in B players: A systematic review. *The Journal of Sports Medicine* 59(9), 1513-1525. <https://doi.org/10.23736/s0022-4707.19.09180-1>
- Marinkovic, & Pavlović. (2013). The differences in aerobic capacity of basketball players in different playing positions. *Physical Education and Sport*, 11(1), 73-80.
- Meckel, Y., Gottlieb, R., & Eliakim, A. (2009a). Repeated sprint tests in young basketball players at different game stages. *European Journal of Applied Physiology*, 107, 273-279. <https://doi.org/10.1007/s00421-009-1120-8>
- Meckel, Y., Machnai, O., & Eliakim, A. (2009b). Relationship among repeated sprint test, aerobic fitness and anaerobic fitness in elite adolescent soccer players. *Journal of Strength Conditioning Research*, 23, 163-169. <https://doi.org/10.1519/jsc.0b013e31818b9651>
- Padulo, J., Bragazzi, N. L., Nikolaidis, P. T., Dello Iacono, A., Attene, G., Pizzolato, F., Dal Pupo, J., Zagatto, A. M., Oggianu, M., & Migliaccio, G. M. (2016). Repeated sprint ability in young basketball players: Multi-direction vs. one-change of direction (Part 1). *Frontiers in Physiology*, 7(133), 1-12. <https://doi.org/10.3389/fphys.2016.00133>
- Petway, A. J., Freitas, T. T., Calleja-González, J., Leal, D. M., & Alcaraz P. E. (2020). Training load and match-play demands in basketball based on competition level: A systematic review. *PLoS One* 15(3):e0229212. <https://doi.org/10.1371/journal.pone.0229212>
- Petway, A. J., Freitas, T. T., Calleja-González, J., Torres-Ronda, L., & Alcaraz, P. E. (2021). Front sports act living. seasonal variations in game activity profiles and players' neuromuscular performance in collegiate Division I Basketball: Non-conference vs. conference tournament. *Frontiers in Sports and Active Living*, 21. <https://doi.org/10.3389/fspor.2020.592705>
- Gottlieb, R. Shalom, A., & Calleja-Gonzalez, J. (2021). Physiology of Basketball – Field Tests. Review Article. *Journal of Human Kinetics*, 77(1), 159-167. <https://doi.org/10.2478/hukin-2021-0018>
- Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). Physiology of Soccer: An update. *Sports Medicine*, 35, 501-536. <https://doi.org/10.2165/00007256-200535060-00004>
- Stone, N. (2007). Physiological response to sport-specific aerobic interval training in high school male basketball players. *Auckland University of Technology*.
- St. Clair Gibson, A., Broomhead, S., & Lambert, M. I. (1998). Prediction of maximal oxygen uptake from a 20 m shuttle run as measured directly in runners and squash players. *Journal of Sports Sciences*, 16(4), 331-335. <https://doi.org/10.1080/02640419808559361>
- Stojanovic, M. D., Ostojic, S.M., Calleja-González, J., Milosevic, Z., & Mikic, M. (2012). Correlation between explosive strength, aerobic power and repeated sprint ability in elite basketball players. *Journal of Sports Medicine and Physical Fitness*, 52(4), 375-81.
- World Medical Association. (2013). Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, 310(20), 2191-2194. <https://doi.org/10.1001/jama.2013.281053>
- Wragg, C. B., Maxwell, N. S., & Doust, J. H. (2000). Evaluation of the reliability and validity of a soccer specific field test of repeated sprint ability. *European Journal of Applied Physiology*, 83, 77-83. <https://doi.org/10.1007/s004210000246>



This work is licensed under a [Attribution-NonCommercial-ShareAlike 4.0 International](https://creativecommons.org/licenses/by-nc-sa/4.0/) (CC BY-NC-SA 4.0).