European Journal of Sport Sciences
Vol 3 | Issue 1 | April 2024
ISSN 2796-0048

RESEARCH ARTICLE

A Validation Study to Assess the Concurrent Validity of the Beep Test as a Proxy for Cardiopulmonary Endurance, Using VO_2 Max as the Criterion Standard

Sameera Peumal Senanayake[1,*], Prasangi Dabare[2], Athige Rajith Nelosan Silva[1], Sujani Pushpika[1], and Ridmi Maddumage[1]

ABSTRACT

Rowing, characterized as a "velocity-centric sport," demands high physical and physiological performance. Cardiorespiratory endurance, an integral component of physical fitness, plays a vital role in rowing performance. Optimal physical fitness is essential for injury prevention and success in international competitions. Cardiopulmonary exercise testing (CPET) is the gold standard for assessing maximal oxygen uptake (VO_2 max), a crucial indicator of cardiopulmonary endurance. The considerable expense and specialized expertise required for CPET have prompted the utilization of field tests, such as the beep test. The current study aims to validate the accuracy of the beep test in measuring VO_2 max uptake as the gold standard. The present cross-sectional observational study involved 16 participants from the national rowing pool of Sri Lanka (11 males, 5 females). The study adhered to the Bruce protocol for implementing CPET to measure VO_2 max. Concurrently, the standardized beep test, encompassing 21 progressively challenging levels, was administered to assess the VO_2 max of participants. The number of shuttles completed during the beep test underwent meticulous conversion into corresponding VO_2 max values, facilitating a comparative analysis with the VO_2 max values derived from CPET. Among the key findings, the CPET among Sri Lankan rowers, male rowers exhibited statistically significant disparities across several vital physiological parameters, including VO_2 max, VO_2 max at anaerobic threshold (VO_2 max AT), maximum heart rate (HR max), and minute ventilation (VE), against their female counterparts. A statistically significant and positive correlation was discerned among female rowers between the VO_2 max values obtained through the gold standard CPET and those derived from the beep test. However, a consistent trend emerged, revealing that the beep test consistently overestimated VO_2 max in both male and female rowers compared to the gold standard CPET method. The study underscores the importance of considering population-specific factors and advocates for developing refined equations to enhance the accuracy of field tests in predicting cardiopulmonary endurance.

Keywords: Beep Test, Cardiopulmonary Exercise Testing (CPET), Cardiovascular Endurance, Maximal Oxygen Uptake (VO_2 max).

Submitted: January 13, 2024

Published: April 16, 2024

10.24018/ejsport.2024.3.1.131

[1] Department of Basic Sciences, Faculty of Allied Health Sciences, Kotelawala Defence University, Sri Lanka.
[2] Department of Physiotherapy, Faculty of Allied Health Sciences, Kotelawala Defence University, Sri Lanka.

** Corresponding Author:*
e-mail: sp.senanayake@kdu.ac.lk

1. Introduction

Rowing, a "velocity-centric sport," is known for demanding physical and physiological requirements. Rower performance relies on various factors, including cardiovascular endurance, motor coordination, technical skills, and aerobic and anaerobic fitness. Achieving optimal physical fitness is crucial for injury prevention and success in international competitions (DeBlauw *et al.*, 2023).

Cardiorespiratory endurance, a key component of health-related physical fitness (Cheng *et al*., 2019), entails the efficient supply of oxygen to skeletal muscles during physical activity (Raghuveer *et al*., 2020). Endurance training is vital for athletes across various sports, not just long-distance disciplines. It aims to enhance parameters like VO_2 max, which reflects maximal oxygen consumption during exercise (Joyner & Coyle, 2008).

Cardiorespiratory endurance is typically assessed using gas-analyzed and non-gas-analyzed tests (Raghuveer *et al*., 2020), with direct measurement of VO_2 max considered the gold standard (Dalui & Bandyopadhyay, 2017). However, this method requires specialized facilities and can be resource-intensive.

In contrast, the beep test offers a cost-effective and scalable alternative. It can be administered to large groups simultaneously. This study aims to validate the beep test for assessing cardiorespiratory endurance by comparing it to the gold-standard Cardiopulmonary Exercise Test (CPET). The research focuses on evaluating the predictive accuracy of the beep test formula for assessing cardiovascular endurance.

2. Methodology

2.1. Participants

This study employed a comprehensive total population sampling approach, incorporating the complete cohort of male (n = 11) and female (n = 5) rowing athletes within the national pool of Sri Lanka. Exclusion criteria were rigorously applied to non-consenting participants, those with recent musculoskeletal, neurological, or other injuries within the prior month, athletes who had undergone surgery in the preceding six months, and individuals medically contraindicated for vigorous physical activities. Additionally, participants with documented cardiorespiratory conditions, confirmed by medical diagnoses, such as exercise-induced asthma and asthmatic attacks, were excluded. Data collection spanned from July 2021 to March 2022, encompassing a comprehensive examination of the selected athletes.

2.2. Ethical Considerations

This study meticulously obtained ethical clearance from the Ethical Review Committee of the Faculty of Medicine at General Sir John Kotelawala Defense University (RP/S/2021/33). Formal permissions were also diligently secured from the Institute of Sports Medicine under the Ministry of Sports and the Rowing Council of Sri Lanka, ensuring strict adherence to ethical and regulatory standards.

2.3. Procedure

2.3.1. The CPET Measures

Before the fitness assessments, verbal and written consent was obtained from the participants. All CPETs were conducted in the morning and in a temperature and humidity-controlled environment. Bruce protocol was used to carry out the CPET (Linder *et al*., 2006). Participants were instructed to adhere to specific guidelines, including abstaining from exercise, alcohol, and supplementation for 24 hours before testing. Additionally, they were required to fast for two hours before testing. Pre-CPET medical assessments were carried out by a qualified medical officer, followed by stretching sessions to prevent injuries. Resting blood pressure and blood oxygen saturation were checked to ensure eligibility. Participants wore Heart Rate monitors throughout the procedure. The CPET started with a warm-up on the rowing ergometer, followed by the attachment of electrodes to monitor cardiac activity. Participant demographics were recorded. CPET masks were fitted, and participants were briefed on the protocol. Oxygen consumption and heart rate were continuously monitored. The sports physician engaged in real-time ECG oversight for arrhythmias or anomalies, contemplating the termination of CPET upon detecting any abnormal indication. The ergometer's inclination increased gradually to introduce resistance.

Participants were encouraged to perform at their maximum, aiming for maximal oxygen consumption (VO_2 max). Breath-by-breath data analysis determined an experienced physiologist identified VO_2 max and the anaerobic threshold. After the test, participants cooled down, and post-test measurements were taken. ECG electrodes were removed, and participants were instructed to rest. CPET reports were provided. VO_2 max was measured using the Medgraphics Ultima CardiO2 sensor and the Concept II Model C rowing ergometer software.

2.3.2. Administering the Beep Test

The beep test was conducted in the Institute of Sports Medicine indoor gymnasium, concurrent with the preceding day's CPET. All Beep tests were conducted in the morning, and the temperature

was meticulously monitored during testing. Participants received detailed instructions and a practical demonstration from the same investigator.

The beep test consists of 21 levels, each with a specific number of shuttles. Participants ran back and forth on a 20-meter distance on a cemented floor, following a pre-recorded audio track of beeping signals. The number of shuttles completed by each participant was recorded until they couldn't maintain the required pace.

The test started at a slower speed and progressively increased with each beep. Up to five participants could perform the test together and were encouraged to push themselves to their limits. The total number of shuttles completed was noted, and it was then converted into a VO_2 max equivalent score using a specific mathematical equation provided by Purba *et al*. (2021), which is provided in Eq. (1):

$$CapVO_2max = 18.043461 + (0.3689295 \times TS) + (-0.000349 \times TS \times TS) \quad (1)$$

where TS refers to the total number of shuttles.

2.4. *Statistical Analysis*

Data analysis was performed using IBM Statistical Package for Social Science (SPSS) version 23, and the normality of the data was assessed using the Kolmogorov-Smirnov test.

3. Results

The anthropometric data obtained for both male and female rowers are given in Table I.

The CPET data of the National Rowers pool of Sri Lanka are presented in Table II. In the context of CPET among Sri Lankan rowers, it was observed that male rowers exhibited significant differences in VO_2 max, VO_2 max AT, HR max, and VE compared to their female counterparts.

Table III depicts the total number of shuttles executed by the subjects alongside their VO_2 max values derived from the beep test. In administering a beep test among Sri Lankan rowers, a noteworthy disparity was evident in the number of shuttle rowers performed, with males scoring significantly higher and their corresponding VO_2 max values between male and female participants.

The correlation between the total number of shuttles completed during the beep test and their corresponding VO_2 max values with the VO_2 max obtained during CPET are depicted in Tables IV and V, respectively. In the female rowers, a statistically significant and positive correlation was identified between the VO_2 max values obtained from the gold standard CPET and those derived from the beep test.

TABLE I: Anthropometric Measurements of the Subjects

	BMI (Kgm^{-2})	Age (years)
Total sample (N = 16)	22.77 ± 2.31	29.9 ± 3.4
Male (N = 11)	23.07 ± 2.38	28.2 ± 2.4
Female (N = 5)	22.12 ± 2.25	29.3 ± 3.1

TABLE II: CPET Data of the National Rowers Pool of Sri Lanka

	VO_2 max CPET ($mlKg^{-1}min^{-1}$)	VO_2 max AT. (ml/kg/min)	HR_{Max}	VE (ml/min)
Total	33.32 ± 6.69	27.12 ± 6.87	182.37 ± 7.28	133.63 ± 23.89
Male	33.01 ± 8.35	28.99 ± 5.91	181.82 ± 7.37	147.25 ± 12.76
Female	33.64 ± 6.27	23.16 ± 7.81	183.60 ± 7.76	103.68 ± 10.19

Note: VO_2 max AT-VO_2 max obtained at the anaerobic threshold (AT); HR_{Max}–Maximum heart rate of the participant recorded in the procedure; Minute ventilation of the participant (Volume of air inspired into or expired out of the lungs in one minute).

TABLE III: Total Number of Shuttles Performed by the Subjects and Their Respective VO_2 Max Values of the Beep Test

	Total number of shuttles	VO_2 max.Beep ($mlKg^{-1}min^{-1}$)
Total	99 ± 15	49.26 ± 7.94
Male	87 ± 18	50.75 ± 8.78
Female	81 ± 17	45.99 ± 4.88

TABLE IV: The Correlation between the Total Number of Shuttles and the CPET VO_2 Max Values

	R-value	P-value
Total sample	0.27	0.33
Male	0.34	0.30
Female	0.88	0.50

TABLE V: The Correlation between the VO_2 Max Values of the CPET and the Beep Test

	R-value	P-value
Total sample	0.3	0.39
Male	0.3	0.30
Female	0.9	0.05

Table VI presents the comparison between the mean VO_2 max values of CPET and the beep test. The beep test consistently overestimated VO_2 max compared to the gold standard CPET method in both male and female rowers.

TABLE VI: Comparison of the Mean VO_2 Max Values of CPET and the Beep Test

	Mean ± SD (ml/Kg/min^{-1}) VO_2 max gold standard CPET	Mean ± SD (ml/Kg/min^{-1}) VO_2 max beep test	Mean bias (ml/Kg/min^{-1}) Under/overestimation	P-value
Total sample	33.64 ± 6.69	49.26 ± 7.94	15.62 ± 1.25	0.001
Male	33.01 ± 8.35	50.75 ± 8.78	17.74 ± 0.43	0.006
Female	33.64 ± 6.27	45.99 ± 4.88	12.35 ± 1.39	0.043

4. Discussion

This study assessed the cardiopulmonary fitness of Sri Lankan Rowers using the gold standard CPET-VO_2 max and Beep test as a field assessment. In a similar vein, Magee *et al.* (2021) conducted an experimental study involving hockey players to assess the efficacy of the Beep test in predicting VO_2 max compared to the gold standard CPET (Magee *et al.*, 2021). Their findings and the beep test equation by Leger *et al.* (1988) have overestimated VO_2 max, consistent with the current study's finding.

As Magee *et al.* (2021) highlighted, fitness level is crucial when calculating VO_2 max using different equations. In our study, the participants' irregular training patterns due to the COVID-19 pandemic might have influenced the results due to reduced overall physical fitness.

Furthermore, a similar study was conducted by Chatterjee *et al.* (2007) to validate the Beep test against the gold standard CPET. Their findings showed no significant relationship between age. They revealed a statistically significant difference, with the average VO_2 max obtained from the treadmill test being higher than that acquired from the beep test, similar to the results of the current study. These consistencies suggest that the beep test may have limitations in accurately predicting VO_2 max, and these limitations persist across different studies and populations.

The present study observed a significant discrepancy between the VO_2 max values obtained from CPET and those from the Beep test. The Beep test significantly overestimated VO_2 max, with overestimations more pronounced in female participants than male participants (33.7% vs. 26.8%). The study by Aandstad *et al.* (2011) involving military home guard soldiers and air force cadets suggests that while the beep test demonstrates reliability, the validity is less confident due to variability between measured and estimated VO_2. Notably, running performance parameters, such as Shuttles Completed and Last Half Level (LHL) completed, contribute significantly to the equation, indicating the importance of these factors in beep test outcomes.

The study by Magee *et al.* (2021) on female field hockey participants highlights variations in VO_2 max predictions using different beep test equations. While some equations provide valid predictions, others, including the one used in the current study, overestimate VO_2 max. The differences in anthropometrics, age, and fitness levels between populations may contribute to discrepancies in results. This underscores the need for caution when applying beep test equations across diverse populations.

The study by Purba *et al.* (2021) introduces a new predictive modeling formula, the Ruli formula, suggesting its utility in predicting VO_2 max from the beep test. The formula incorporates parameters

like Total Shuttles, Body Weight, HR Max in the field test, and Field Temperature. Internal validity and reliability tests support the formula's use, emphasizing the importance of considering multiple factors for accurate predictions.

In contrast, the study by Aziz *et al*. (2005) on young, trained soccer players emphasized the significant correlations between beep test performance and measured VO_2 max. However, differences in age, training schedules, and criteria for participant selection highlight potential influencing factors.

These findings emphasize the complexity of interpreting beep test results and the need to consider population-specific factors carefully when evaluating its validity and reliability. The current study's limitations, such as a small sample size and testing during off-seasons, should be acknowledged when interpreting the overestimated VO_2 max values obtained from the gold standard CPET.

5. Conclusion

In conclusion, our study underscores a notable overestimation of VO_2 max by the beep test compared to the gold standard CPET, particularly evident in females. Despite this overestimation, gender-specific differences in CPET-measured VO_2 max were insignificant, with male rowers exhibiting higher VO_2 max AT. The beep test demonstrated a positive correlation with CPET results in female rowers. Still, no significant correlation was observed between total shuttle completion and CPET-measured VO_2 max across the entire population and within gender subgroups. Male rowers demonstrated a significantly higher full shuttle completion during the beep test than females. These findings emphasize the caution needed when using beep test results as a substitute for CPET in assessing VO_2 max, especially considering gender-specific variations and potential limitations in predicting aerobic capacity.

6. Limitations of the Study

This study, characterized by a broad age range spanning from 24–33 years, and the age variability among participants could introduce confounding factors affecting results. Furthermore, the small sample size (16 participants) with a discernible gender imbalance limits statistical sensitivity and generalizability. Additionally, since the study occurred during the COVID-19 pandemic and the off-season regular training sessions had been disrupted, players tended to engage in separate fitness sessions. This resultant heterogeneity in fitness levels poses a notable consideration.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

References

Aandstad, A., Holme, I., Berntsen, S., & Anderssen, S. A. (2011). Validity and reliability of the 20 meter shuttle run test in military personnel. *Military Medicine*, *176*(5), 513–518.

Aziz, A. R., Tan, F. H., & Teh, K. C. (2005). A pilot study comparing two field tests with the treadmill run test in soccer players. *Journal of Sports Science & Medicine*, *4*(2), 105.

Chatterjee, P., Banerjee, A. K., Debnath, P., Bas, P., & Chatterjee, B. (2007). Validity of 20-metre multi stage shuttle run test for estimation of maximum oxygen uptake in Indian male university students promotion, fitness and wellness. *African Journal for Physical Health Education, Recreation and Dance*, *12*(4), 461–467.

Cheng, J. C., Chiu, C. Y., & Su, T. J. (2019). Training and evaluation of human cardiorespiratory endurance based on a fuzzy algorithm. *International Journal of Environmental Research and Public Health*, *16*(13), 1–20.

Dalui, R., & Bandyopadhyay, A. (2017). Pulmonary function of young Indian male judo and karate players. *Biology of Exercise*, *13*(1), 33–43.

DeBlauw, J. A., Stein, J. A., Blackman, C., Haas, M., Makle, S., Echevarria, I., *et al.* (2023). Heart rate variability of elite female rowers in preparation for and during the national selection regattas: A pilot study on the relation to on water performance. *Frontiers in Sports and Active Living*, *5*, 1–10.

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: The physiology of champions. *The Journal of Physiology*, *586*(1), 35–44.

Leger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences*, *6*(2), 93–101.

Linder, S. P., Wendelken, S., & Clayman, J. (2006, August). Detecting exercise induced stress using the photoplethysmogram. *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*, IEEE, 5109–5112.

Magee, M. K., White, J. B., Merrigan, J. J., & Jones, M. T. (2021). Does the multistage 20-m shuttle run test accurately predict VO_{2max} in NCAA division I women collegiate field hockey athletes? *Sports*, *9*(6), 1–11.

Purba, R. H., Tulaar, A. B., Yunus, F., Ibrahim, E. I., Abdullah, M., Tamin, T. Z., *et al.* (2021). Model prediction maximum oxygen intake (VO_{2max}) using the bleep test in male junior athletes. *Systematic Reviews in Pharmacy*, *12*(1), 1243–1247.

Raghuveer, G., Hartz, J., Lubans, D. R., Takken, T., Wiltz, J. L., Mietus-Snyder, M., *et al.* (2020). Cardiorespiratory fitness in youth: An important marker of health: A scientific statement from the American heart association. *Circulation*, *142*(7), e101–e118.