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# Evaluation of Alternative Tests for Measuring Vo2max Compared to the Gold Standard CPET Treadmill Test

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**Abstract;** Accurate assessment of the body's oxygen consumption is essential for the effective management of endurance in athletes. Peak oxygen uptake ($VO_2max$) remains the primary indicator for evaluating aerobic capacity and exercise efficiency. Although the gold standard for measuring $VO_2max$ is the Cardiopulmonary Exercise Test (CPET) on a treadmill, it is resource-intensive, time-consuming, and requires precise calibration, making it less accessible in many settings.

This study aims to evaluate alternative $VO_2max$ testing protocols—namely, the CPET velo test, Astrand cycle ergometer test, Chester Step Test, and Submaximal Cycle Ergometry—with a focus on practicality, efficiency, and reliability. The objective is to determine whether these alternatives can offer comparable accuracy to CPET while being easier and more cost-effective to implement.

A mixed-method research design was applied, combining experimental procedures and statistical regression analysis. Five participants with diverse physical activity backgrounds completed various tests, although some data was excluded due to technical limitations. Results indicated that none of the alternative tests consistently matched the CPET treadmill outcomes. The Astrand test showed identical $VO_2max$ values in one participant, but significant discrepancies were observed in others.

The findings confirm that the CPET treadmill test remains the most valid and reliable method for measuring $VO_2max$. While alternative submaximal tests may serve in general fitness assessments, they lack the precision required for high-stakes evaluation. Moreover, the study highlights the importance of considering participants' lifestyle and activity familiarity when selecting appropriate testing protocols. Future research should further explore hybrid models that balance scientific rigor with practical applicability.

***Keywords**: Astrand test; Chester step test; CPET treadmill; exercise physiology; submaximal testing; VO2max*

## 1. INTRODUCTION

Maximal oxygen uptake ($VO_2max$) is widely recognized as a critical parameter for assessing aerobic endurance capacity and overall cardiovascular fitness. It represents the maximum rate at which oxygen can be taken up and utilized by the body during intense physical activity and is influenced by various physiological systems including the pulmonary, cardiovascular, and muscular systems (Strasser & Burtscher, 2018). The higher an individual's $VO_2max$, the greater their ability to sustain high-intensity efforts and resist fatigue during prolonged physical exertion.

In recent decades, particularly in the last 10–15 years, the approach to athletic training and performance evaluation has evolved significantly. Modern sports science emphasizes the role of structured, evidence-based training that improves both aerobic and anaerobic energy systems, leading to more efficient oxygen use, improved endurance, and increased athletic competitiveness (Sloth et al., 2013). The ability to accurately measure and monitor $VO_2max$ is crucial not only for professional athletes but also for clinical populations and general health assessments (Löllgen & Leyk, 2018).

The gold standard for determining $VO_2max$ is the Cardio Pulmonary Exercise Test (CPET) conducted on a treadmill. This method directly analyzes the volume of oxygen consumed and carbon dioxide produced during graded exercise while monitoring heart rate, respiratory rate, and other physiological indicators (Herdy et al., 2016; Tran, 2018). However, despite its accuracy, CPET has limitations in practice. It requires expensive equipment, experienced personnel, and careful calibration, and it is sensitive to environmental conditions such as temperature and humidity (Beijst et al., 2013; Macfarlane & Wong, 2012). Furthermore, the test is physically demanding and not accessible to all athletes or institutions, particularly those in low-resource settings.

Given these challenges, researchers have explored various alternative methods that are simpler, faster, and more accessible. Among the most commonly investigated alternatives are submaximal tests such as the Astrand cycle ergometry test, Chester step test, submaximal velo test, and CPET on a cycle ergometer (velo test). These tests rely on heart rate responses and pre-defined exercise protocols to estimate $VO_2max$, rather than measuring it directly.

Despite their convenience, the validity and reliability of these submaximal tests in comparison to CPET remain under scrutiny. Some studies suggest that alternative tests may offer reasonably accurate estimates under certain conditions, while others highlight considerable variation depending on factors like an individual's fitness level, exercise modality, and familiarity with test movements (George et al., 2000; Sykes & Roberts, 2004; Reed et al., 2020).

The current study aims to evaluate whether alternative submaximal tests can provide $VO_2max$ estimates comparable to those obtained through the gold standard CPET treadmill test. By comparing physiological outputs across different testing modalities and analyzing their statistical consistency, this study seeks to identify if any alternative method is suitable for substitution in both sports science and clinical applications.

## 2. METHODOLOGY

A mixed-methods approach was used, combining qualitative and quantitative experimental methods. Five healthy adult participants (3 men, 2 women) from diverse physical activity backgrounds (e.g., runner, cyclist, lifeguard, sedentary) were recruited. All participants were briefed on the procedures, and informed consent was obtained. Ethical approval was granted by the Ethics Committee of the Azerbaijan State Academy of Physical Education and Sport.

The study included five different VO2max measurement methods: - CPET treadmill test - CPET velo test - Astrand cycle ergometer test - Chester step test - Submaximal velo test

Each participant was instructed to avoid intense physical activity for at least 48 hours prior to testing.

Standard warm-up exercises were performed before every session. Testing was carried out over 15 days, with at least 2 days between tests to minimize fatigue effects.

The CPET tests involved real-time gas exchange analysis using a Cortex Metamax 3B, while heart rate was monitored via ECG. Submaximal tests utilized pulse oximetry and standardized workload protocols. The Borg Rate of Perceived Exertion (RPE) scale was used to evaluate subjective fatigue.

Data was analyzed using SPSS software. One-sample t-tests were applied to assess whether the mean VO2max values from alternative tests differed significantly from the gold standard.

**RESULTS**

**3. EXPERİMENTAL PHASE AND RESULTS**

The experimental phase of this study was designed to compare multiple $VO_2$max testing protocols across a small but physiologically diverse sample. Five participants, each with differing levels and types of physical conditioning, were selected to represent a range of aerobic capacities and exercise modality familiarity. The cohort consisted of a climber, a marathon runner, a cyclist, a professional lifeguard, and one sedentary individual with no regular engagement in sports or physical training. This selection allowed for the examination of how personal training backgrounds may influence the validity and responsiveness of various $VO_2$max testing protocols.

Each participant was scheduled to complete up to five different $VO_2$max assessments: the CPET treadmill test (gold standard), CPET velo (cycle ergometer-based), the Astrand submaximal cycle ergometer test, the Chester step test, and the submaximal velo test. However, not all tests were successfully completed by every participant due to either technical difficulties or physiological thresholds being reached prematurely. Despite these limitations, a substantial amount of comparative data was obtained, enabling a meaningful analysis of test validity, reliability, and practical feasibility.

**CPET Treadmill Test**

All five participants successfully completed the CPET treadmill test, which served as the reference standard for evaluating the accuracy of alternative $VO_2$max estimation protocols. The test was administered using a progressively graded treadmill protocol until volitional exhaustion, while respiratory gases were measured via a metabolic cart to obtain direct $VO_2$max values. The results from this test yielded a mean $VO_2$max value of $42.2 \pm 11.17$ ml/min/kg, representing the highest and most consistent values across the testing battery. This outcome supports the established position of CPET treadmill testing as the gold standard for assessing aerobic capacity, as previously affirmed by Herdy et al. (2016). The test also provided additional physiological data—such as respiratory exchange ratio (RER), ventilation thresholds, and heart rate dynamics—not available through the submaximal protocols.

**CPET Velo**

The CPET velo test was intended to provide an alternative maximal $VO_2$max assessment using a cycle ergometer under identical gas analysis and physiological monitoring conditions as the treadmill test. However, the implementation encountered critical technical issues, primarily stemming from a failure in the synchronization between the velo simulator and the metabolic gas analyzer. Despite multiple troubleshooting attempts, the ergometer's workload output could not be reliably captured in real time by the gas analysis software. Consequently, the test was terminated without yielding conclusive data, and no statistical comparisons or inferences could be drawn for this method. Similar technical limitations in cycle-based CPET testing have been noted in other studies (Macfarlane & Wong, 2012), emphasizing the need for full hardware-software integration and calibration prior to high-stakes assessments.

**Astrand Cycle Ergometer Test**

The Astrand submaximal cycle ergometer test was completed by four out of the five participants. This protocol, which estimates $VO_2max$ based on steady-state heart rate during submaximal cycling and age-predicted maximal heart rate, is widely used in field settings due to its simplicity and minimal equipment demands. The most notable individual result came from participant A2, whose $VO_2max$ value via the Astrand test was 47 ml/min/kg, precisely matching their CPET treadmill result. This isolated congruence suggests that in some individuals—especially those familiar with cycling—the Astrand test can yield highly accurate estimates, a finding consistent with Legge & Banister (1986).

However, broader analysis revealed considerable variability among the other participants. The overall mean $VO_2max$ for the Astrand test was 34 ± 19.81 ml/min/kg, significantly lower than the CPET treadmill average. A paired samples t-test confirmed a statistically significant difference between the two methods ($p = 0.018$), indicating that the Astrand test, despite its potential, lacks consistent predictive accuracy across varied individuals. These results are in agreement with the concerns raised by Siconolfi et al. (1982), who argued that the Astrand method's accuracy is influenced by individual heart rate kinetics, muscular fatigue thresholds, and mechanical cycling efficiency.

**Chester Step Test**

The Chester step test, known for its practical field application and minimal equipment requirements, was completed by three participants, though only two datasets were deemed valid due to protocol adherence issues. This test estimates $VO_2max$ based on heart rate response to increasing step cadence, but it operates with fixed step height and rhythm, which may not be equally suitable for all body types or fitness levels. The mean $VO_2max$ recorded for the Chester step test was 19.6 ± 26.84 ml/min/kg, a value substantially lower than that from the CPET treadmill. Statistical analysis indicated no significant correlation with the gold standard ($p = 0.178$), suggesting limited diagnostic reliability.

The underperformance of the Chester test can be attributed to multiple factors. First, the uniform step height (30 cm) may have imposed excessive strain on participants with shorter leg length or those lacking stair-specific training. Second, more aerobically trained participants may have found the stepping protocol insufficiently challenging, leading to premature test termination or ceiling effects in heart rate escalation. These findings are consistent with Sykes & Roberts (2004), who noted that the Chester step test, while useful for occupational screening, may not be appropriate for precise fitness profiling due to its lack of adaptive scaling.

**Submaximal Velo Test**

All five participants completed the submaximal velo test, which estimated $VO_2max$ based on heart rate response to a fixed cycling workload and the prediction of maximum heart rate using age-based formulas.

Only two participants were able to sustain the full 10-minute testing duration, while the remaining three terminated the test early upon reaching 75% of their predicted HRmax—a predefined safety cut-off. The average $VO_2max$ value for this test was 27.6 ± 27.04 ml/min/kg, and, like the Chester test, it showed no statistically significant difference from the CPET treadmill results ($p = 0.085$), though the wide standard deviation suggests inconsistent accuracy.

The reliance on pulse oximetry for heart rate measurement, as opposed to ECG, likely contributed to reduced precision. Pulse readings were subject to motion artifacts and perspiration-related interference, especially during vigorous exertion. Furthermore, the predictive formula for maximal heart rate (commonly 220-age) lacks individual specificity and may have led to premature test cessation or misclassification of exertion levels. Prior literature supports these concerns, emphasizing that heart rate-based estimations of $VO_2max$ are prone to error, particularly in trained populations with blunted heart rate responses and lower resting heart rates (George et al., 2000).

The detailed $VO_2max$ results for each participant are shown below:

**Table 1.** Participants' $VO_2max$ Indicators (ml/min/kg)

| *Participant* | *CPET Treadmill* | *CPET Velo* | *Submaximal Velo* | *Chester Step* | *Astrand Test* |
|---|---|---|---|---|---|
| A1 | 57 | - | Unsuccessful | Unsuccessful | 49 |
| A2 | 47 | Invalid | 62.3 | 49 | 47 |
| A3 | 44 | Invalid | 39.9 | 49 | 36 |
| A4 | 35 | Invalid | 37.45 | Unsuccessful | 38 |
| A5 | 28 | Invalid | Unsuccessful | - | - |

**Table 2.** Time Spent on Each Test (minutes)

| *Participant* | *CPET Treadmill* | *CPET Velo* | *Submaximal Velo* | *Chester Step* | *Astrand Test* |
|---|---|---|---|---|---|
| A1 | 22 | - | Unsuccessful | Unsuccessful | 7 |
| A2 | 21 | - | 10 | 10 | 7 |
| A3 | 19 | - | 8 | 10 | 6 |
| A4 | 19 | - | 6 | Unsuccessful | 7 |
| A5 | 14 | - | Unsuccessful | - | - |

**Table 3.** One-Sample T-Test Results for $VO_2max$

| *Test Type* | *Mean ± SD (ml/min/kg)* | *p-value* | *Interpretation* |
|---|---|---|---|
| CPET Treadmill | 42.2 ± 11.17 | <0.001 | Statistically significant (ref) |
| Astrand Test | 34 ± 19.81 | 0.018 | Statistically significant difference |
| Chester Step Test | 19.6 ± 26.84 | 0.178 | Not statistically significant |
| Submaximal Velo Test | 27.6 ± 27.04 | 0.085 | Not statistically significant |

Overall, only the Astrand test approached statistical significance and only in one individual did it match the gold standard exactly. The variation in outcomes across other tests supports the conclusion that none of the alternative methods can reliably replace the CPET treadmill in measuring $VO_2max$.

These findings align with previous studies which note that submaximal test outcomes are often influenced by factors such as daily activity patterns, familiarity with the type of movement used in testing, and measurement equipment limitations (Reed et al., 2020; Forbregd et al., 2019).

**4. DİSCUSSİON**

The primary objective of this investigation was to evaluate the comparative effectiveness of various submaximal and alternative $VO_2max$ testing protocols relative to the gold standard CPET treadmill test. As anticipated, the CPET treadmill maintained its status as the definitive measure of maximal oxygen uptake, delivering consistent accuracy and reliable reproducibility across diverse participants. In contrast, none of the alternative methods demonstrated uniform agreement with CPET results, underscoring their inherent limitations when applied to individualized or high-stakes performance assessment. This disparity highlights the critical importance of selecting appropriate testing modalities based on both the testing context and the specific characteristics of the population under study.

Among the alternative protocols, the Astrand cycle ergometer test emerged as the most promising contender, particularly evident in participant A2, whose $VO_2max$ values were identical across both CPET and Astrand assessments. This finding accords with earlier work by Legge and Banister (1986), who reported that the Astrand protocol yields more precise estimates for individuals with established cycling familiarity. Nevertheless, the pronounced variability observed among other participants suggests that the Astrand test's predictive validity is heavily modulated by inter-individual factors such as baseline fitness, pedaling mechanics, and cycle ergometer calibration. The sensitivity of the Astrand protocol to these factors may be partly attributable to the use of a fixed workload-to-heart-rate regression model, which fails to account for idiosyncratic cardiac responses or anaerobic contributions at higher submaximal intensities (Siconolfi et al., 1982).

In contrast, the Chester step test and submaximal velo test—though operationally simpler and more cost-effective—systematically underestimated $VO_2max$ relative to CPET treadmill measurements. The Chester protocol's reliance on a uniform step height (e.g., 30 cm) and fixed cadence (e.g., 15 steps/min increment every two minutes) does not accommodate variations in lower-limb length or step economy, disproportionately taxing smaller individuals and underloading trained athletes. Sykes and Roberts (2004) similarly noted that step tests could misrepresent aerobic capacity when biomechanical efficiency diverges markedly from the normative model. Furthermore, the step test's discrete stage increments may introduce discontinuities in cardiovascular load, complicating the calculation of projected $VO_2$max via linear extrapolation.

The submaximal velo test's dependence on predicted maximum heart rates and pulse-based estimations further compounds inaccuracy. In our study, pulse oximetry readings—particularly during vigorous exertion—exhibited lag and motion artifact, leading to underreported heart rate values. By contrast, electrocardiogram (ECG)-based monitoring during CPET provided real-time, beat-to-beat data with minimal error. Prior investigations have documented that heart rate alone is an insufficient surrogate for $VO_2$max prediction in well-trained cohorts, owing to lower resting heart rates, attenuated heart rate slopes, and greater stroke volume adaptations (George et al., 2000; Reed et al., 2020). Consequently, protocols that rely solely on heart rate responses are prone to systematic underestimation in populations with pronounced cardiovascular efficiency.

An additional consideration is the role of modality-specific familiarity. Participants with extensive cycling history performed relatively better on the Astrand and submaximal velo tests, whereas those less accustomed to ergometer protocols exhibited suboptimal pedaling mechanics and discomfort, leading to premature muscular fatigue and lower submaximal workloads. Millet et al. (2009) similarly reported that treadmill-based protocols generally elicit higher $VO_2$max values than cycling tests, attributing the discrepancy to increased recruitment of larger muscle groups (e.g., quadriceps, gluteals) and a more natural movement pattern for most individuals. Thus, modality selection should be informed by both the participant's exercise background and the primary muscular demands of the chosen test.

Technical and logistical constraints also influenced test outcomes. The failure of the CPET velo implementation due to equipment malfunction and software integration issues (e.g., compatibility errors between the ergometer's output and metabolic cart software) underscores the necessity of rigorous system validation prior to data collection (Macfarlane & Wong, 2012). Such equipment-related setbacks not only reduced the available sample size for certain comparisons but also illustrate real-world challenges in deploying sophisticated exercise diagnostics outside of specialized laboratory environments.

Finally, the modest sample size and heterogeneity of participant fitness levels restrict the generalizability of our findings. Nevertheless, this diversity yielded valuable insights into how submaximal protocols perform across a spectrum of physical conditioning. The observed pattern—that alternative tests may suffice for coarse group-level estimations but fall short for individualized precision—suggests a potential role for these methods in large-scale epidemiological studies or community health screenings, where resources limit the feasibility of CPET.

In summary, while protocols such as the Astrand cycle ergometer and Chester step tests offer pragmatic advantages in terms of cost, convenience, and minimal technical demand, their diagnostic accuracy remains insufficient to supplant CPET treadmill testing in contexts requiring definitive physiological evaluation. Future research should focus on refining these submaximal models through incorporation of individualized calibration factors—such as weight-adjusted workload scaling, real-time ventilatory equivalents, or machine learning algorithms that integrate heart rate variability and movement metrics. Additionally, exploration of hybrid testing frameworks that blend brief maximal efforts with continuous wearable sensor data may strike an optimal balance between methodological rigor and field applicability

(Forbregd et al., 2019; Löllgen & Leyk, 2018). By advancing these hybrid and adaptive approaches, it may become possible to approximate the comprehensive insights afforded by CPET within more accessible testing paradigms.

## 5. CONCLUSİON

This study aimed to assess the validity, accuracy, and practical applicability of selected alternative $VO_2$max testing protocols in comparison to the gold standard Cardiopulmonary Exercise Testing (CPET) conducted on a treadmill. The findings underscore a critical distinction between the clinical accuracy of direct measurement methods and the practicality of submaximal or indirect protocols. While alternative tests may offer logistical convenience, time efficiency, and reduced cost—factors particularly relevant in resource-limited or field-based settings—their diagnostic value remains limited when compared to CPET treadmill assessments.

Among the submaximal tests evaluated, the Astrand cycle ergometer test demonstrated the closest approximation to CPET-derived $VO_2$max values, but this occurred only in isolated instances. The test lacked consistency in its predictive validity across the broader sample, with outcomes influenced by inter-individual physiological variability, such as fitness level, cadence familiarity, and biomechanical efficiency on a cycle ergometer. These findings highlight the inherent challenge of applying uniform estimation models to diverse populations, even when using well-established protocols.

In contrast, the Chester Step Test and the submaximal velo (cycling) test consistently underestimated $VO_2$max, yielding values that deviated significantly from those obtained via CPET treadmill testing. These discrepancies not only reduced their statistical correlation with the gold standard but also raised concerns regarding their sensitivity and specificity in detecting true aerobic capacity, especially in moderately to highly trained individuals. The underperformance of these tests suggests that their application should be limited to preliminary screening or non-clinical environments where precision is not the primary requirement.

The CPET treadmill test continues to represent the most valid, comprehensive, and scientifically robust method for evaluating maximal oxygen uptake. It allows for the direct measurement of ventilatory thresholds, respiratory exchange ratios, and cardiovascular responses under progressively increasing workloads. These parameters are critical in both clinical diagnostics—for conditions such as cardiopulmonary disease—and in elite athletic performance profiling. Given its ability to deliver reproducible and individualized data, the CPET treadmill remains irreplaceable in contexts where accurate physiological assessment is essential.

However, it is important to acknowledge the practical limitations of CPET, including high operational costs, requirement of trained personnel, equipment availability, and patient tolerance. In such cases, selected submaximal tests—though inherently limited—can serve as supplementary tools. When interpreted with caution and used in conjunction with other physiological indicators, they may facilitate initial fitness assessments, long-term monitoring of training adaptations, or risk stratification in low-resource settings.

This study also faced certain methodological constraints, primarily related to the small sample size and technical challenges encountered during CPET velo implementation. These limitations restrict the generalizability of the results and highlight the necessity for further investigation. Future research should incorporate larger, more heterogeneous participant pools and examine how individual factors—such as sex, age, training status, and habitual exercise modality—interact with test outcomes. Additionally, the integration of wearable sensor technology and artificial intelligence-driven data interpretation may enhance the accuracy and accessibility of field-based $VO_2$max estimations.

In conclusion, although alternative $VO_2$max tests offer practical benefits and may fulfill specific roles within broader health and performance monitoring strategies, they currently fall short of replacing the CPET treadmill as a gold standard. Their utility is best seen as complementary rather than substitutive, and they should be employed with a clear understanding of their limitations. For high-stakes evaluations—be it in clinical decision-making or performance diagnostics—direct testing via CPET remains the most scientifically valid and reliable method.

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