VO$_2$ max assessment in athletes: A thorough method comparison study between Yo-Yo test and direct measurement

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Abstract

Introduction: Although different studies have reported limits of agreement in assessing VO$_2$ max between the Yo-Yo test and the direct measurement, the precision of these limits in general has not been considered. The aim of this study was to examine the extent of agreement in the assessment of VO$_2$ max in athletes between the Yo-Yo endurance test (YET) and the direct measurement (DM), and to quantify the precision of the estimated limits of agreement.

Material and methods: Data were obtained from a group of 11 male field hockey players (Age = 22.2 ± 3.6 yrs, BMI = 22.1 ± 2.4 kg m$^{-2}$). DM was performed using an incremental treadmill running test. YET level 1 was used for indirect estimation of VO$_2$ max. Bland–Altman analysis was employed for assessing agreement between the two methods. The acceptable 95% limits of agreement were set a priori at ±5 ml kg$^{-1}$ min$^{-1}$.

Results: A non-statistically significant bias was observed between YET and DM (50.78 vs. 51.09 ml kg$^{-1}$ min$^{-1}$, P > .05). The estimates of the 95% limits of agreement were −4.34 and 3.72 ml kg$^{-1}$ min$^{-1}$. And the 95% confidence intervals for these limits were from −6.78 to −1.90 ml kg$^{-1}$ min$^{-1}$, and from 1.29 to 6.16 ml kg$^{-1}$ min$^{-1}$, respectively. The difference between methods did not appear to be correlated to the magnitude of measurement.

Conclusions: A reasonably good agreement was found between YET and DM. However, the large variance of the limits of agreement due to the small sample size means these results should be treated with caution.

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Introduction

The maximal oxygen uptake (VO$_2$max) is a basic measure of physical fitness for athletes, mainly in the cases where the performance is influenced by the aerobic power. The direct measurement is considered the gold standard to assess it, but this is rather complex and expensive. In consequence, a variety of indirect tests have been developed to estimate VO$_2$max, such as Åstrand-Rhyming 6-minute cycle ergometer test, Balke 15-minute run, Cooper 12-minute run, Bruce treadmill test, the multistage 20-metre shuttle run tests of Léger and Lambert and Léger et al., 1-mile track jog and Yo-Yo endurance test. The Yo-Yo endurance test (YET) is a continuous multistage field test that is widely implemented to estimate VO$_2$max as an alternative to the direct laboratory measurement, because of its specificity, its practical and easy implementation and the simple testing environment required. It is one of the three Yo-Yo tests. The other ones are the Yo-Yo intermittent endurance test (YIET) and the Yo-Yo intermittent recovery test (YIRT), the last one also providing an estimation of VO$_2$max.

The Bland–Altman approach has been extensively applied to compare methods of measurement in diverse research areas. It allows to assess the degree of agreement between two measurement techniques, to determine if they can be used interchangeably. However, method comparison studies are sometimes analysed inappropriately, by comparing the mean responses, by using correlation coefficients or by testing the slope of the linear regression between the methods.

Different studies have compared the direct VO$_2$max measurement obtained through a treadmill exercise test with the outcomes of the Yo-Yo tests in athletes. In most cases the population under study was football players. In these works, the direct assessment of VO$_2$max was compared with the performance (distance covered) in the Yo-Yo tests, or with the indirect estimation of VO$_2$max obtained from YET or YIRT. Linear correlations were examined or mean responses were contrasted. Some of the studies that compared the VO$_2$max estimation given by the Yo-Yo test (YET or YIRT) with the direct measurement also reported Bland–Altman limits of agreement. However, confidence intervals for these limits were not included. Furthermore, it would be ideal to define the acceptable limits of agreement a priori. Although it may be difficult for physiologic variables, an attempt should be made; the opinion of experts may be used. Without a priori setting of limits of agreement, widely discrepant limits may be selected.

The uncertainty due to sampling error should be considered not only when estimating the difference between methods (bias), but also when estimating the limits of agreement. This issue is of crucial importance when the sample size is small. The Bland–Altman approach provides statistical methodology to quantify the precision of the estimated limits of agreement. Nevertheless, no method comparison studies were found between the direct measurement of VO$_2$max and the indirect estimation by the Yo-Yo test (YET or YIRT) that include confidence intervals for the limits of agreement. This study aimed to examine the extent of agreement in the assessment of VO$_2$max in athletes between
the Yo-Yo endurance test and the direct measurement performed in an incremental treadmill running test, and to quantify the precision of the estimated limits of agreement.

Material and methods

Participants

Data were obtained from a group of 11 competitive male field hockey players. All subjects or their guardians gave consent to participate in the study after being informed of the aims and procedures. The study was conducted based on the ethical principles of the Declaration of Helsinki of the World Medical Association. Each participant underwent a physical examination before the testing sessions. Table 1 displays a statistical summary of the kinanthropometric characteristics of the athletes. Age was calculated in decimal years, by subtracting the date of birth from the date of assessment. Percentages of fat mass and muscle mass were estimated using the four-compartment model based on the strategy of De Rose and Guimaraes. This model was adapted using the simple regression equation for male athletes developed by Withers et al., which was cited by Norton, to estimate body density, and Siri formula to calculate the percentage of fat mass.

Study design

The present research is a study of simple cross-over design, in order to evaluate agreement in assessing \( V_{O2max} \) in ml kg\(^{-1}\) min\(^{-1}\) between the Yo-Yo endurance test and the direct measurement; a special focus is on the interval estimation of the limits of agreement. The direct measurement of \( V_{O2max} \) (DM) was conducted in the Exercise Physiology Laboratory of the National Center of High Performance Athletics (CeNARD, Buenos Aires, Argentina), using an incremental running test on a motorized treadmill (Technogym Excite Run 700i; Technogym SpA, Gambettola, Italy). Breath-by-breath data collection was obtained by means of a computerized open-circuit metabolic system (Medgraphics Cardiopulmonary Exercise System CPX/D, Breeze Ex v3.06 software; Medical Graphics Corporation, St. Paul, MN, USA). Increments in treadmill speed of 1 km h\(^{-1}\) every minute were stipulated until volitional exhaustion (initial speed = 9 km h\(^{-1}\)). Heart rate was controlled with a heart rate monitor (Polar 610i; Polar Electro Oy, Kempele, Finland). \( V_{O2} \) plateau (change in \( V_{O2} \) difference less than 2.1 ml kg\(^{-1}\) min\(^{-1}\) with a further increase in workload) was the primary criterion for the attainment of \( V_{O2max} \);

### Table 1

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<th>Kinanthropometric characteristics of the athletes.</th>
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<td>Age (yrs)</td>
<td>22.19 ± 3.60</td>
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<td>Weight (kg)</td>
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<td>BMI (kg m(^{-2}))</td>
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<td>Fat mass (%)</td>
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Statistical analysis

The kinanthropometric characteristics of the athletes and the heart rate and respiratory exchange ratio values reached when achieving \( V_{O2max} \) were reported as mean ± standard deviation (SD). Summary statistics were produced to describe the \( V_{O2max} \) values obtained by means of YET and DM. Bland–Altman analysis was employed for assessing agreement between the two methods of measurement. In accordance to Bland, the acceptable 95% limits of agreement were established on the basis of experience, and were set a priori at ±5 ml kg\(^{-1}\) min\(^{-1}\). The 95% confidence intervals for the limits of agreement were also computed. In view of the small sample size, they were estimated using the exact expression for the estimator of the variance of the limits of agreement instead of the approximate one:

\[
\text{Var} \left( \bar{d} ± 1.96s_d \right) = \left( \frac{1}{n} + \frac{1.96^2}{2(n-1)} \right) s_d^2.
\]

where \( \bar{d} \) is the mean difference between methods and \( s_d \) is the standard deviation of the differences. Pearson’s and Spearman’s correlation tests were implemented to evaluate possible associations of the difference between YET and DM with the magnitude of the measurement. Statistical significance was set at the 0.05 probability level. All analyses were performed using the R software environment, version 3.2.0 (R Core Team, Vienna, Austria).

Results

The \( V_{O2max} \) values obtained for each individual using the two methods of measurement were quite similar. The \( V_{O2max} \) values estimated by YET were, on average, only 0.6% lower than those determined by DM. Table 2 presents a descriptive summary of the outcomes of YET and DM and of the differences between them. The heart rate and respiratory exchange ratio values reached when achieving \( V_{O2max} \) are summarized in Table 3.

A non-statistically significant bias was found between YET and DM (−0.31 ml kg\(^{-1}\) min\(^{-1}\); 95% confidence interval:

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the estimated 95% limits of agreement was narrower than
of agreement between methods is shown in Fig. 1, while
the region bounded by the acceptable limits defined
a priori. However, the total region covered when considering the
variance of these limits (Eq. (1)). The region determined by
the estimated 95% limits of agreement was narrower than
the region bounded by the acceptable limits defined a priori. However, the total region covered when considering the
95% confidence intervals for the 95% limits of agreement
was wider than the 95% confidence intervals for the 95% limits of agreement were con-
structed using the exact expression for the estimator of the
classical Bland–Altman plot with estimated bias and 95% limits
was wider than the
the region bounded by the acceptable limits defined a priori. However, the total region covered when considering the
95% confidence intervals for the 95% limits of agreement
was wider than the a priori acceptable limits. The typical Bland–Altman plot with estimated bias and 95% limits of agreement between methods is shown in Fig. 1, while

difference between methods with 95% confidence intervals.

Discussion
The indirect measurement of $\dot{V}O_2_{max}$ is frequently performed in sport evaluation. Maximal and submaximal effort protocols have been proposed to estimate the maximal aerobic power of an individual. Good agreement with the direct measurement should be the main objective of these tests. The Yo-Yo endurance test is a continuous multistage field test broadly used to indirectly assess $\dot{V}O_2_{max}$. Its mechanical characteristics make it suitable for athletes participating in sports that involve stop, start and change of direction movement patterns.

Diverse studies have been conducted to compare the outputs provided by the Yo-Yo tests with the $\dot{V}O_2_{max}$ obtained by direct measurement in an incremental running test on treadmill. The comparisons involved contrasting the $\dot{V}O_2_{max}$ values or testing the correlation between directly measured $\dot{V}O_2_{max}$ values and distances covered in the Yo-Yo tests. Some of the studies that compared the $\dot{V}O_2_{max}$ estimations given by YET level 1 with the $\dot{V}O_2_{max}$ obtained by DM in either a continuous or an intermittent running protocol on a treadmill (YET level 1 values lower than DM values by 11.4% and 13.4%, respectively). Castagna et al. contrasted the $\dot{V}O_2_{max}$ results of YET level 2 with the ones of DM in male football players ($n = 24$), evidencing a non-statistically significant bias ($p = 0.10$) of 1.17 ml kg$^{-1}$ min$^{-1}$, and 95% limits of agreement of $-5.44$ and $7.79$ ml kg$^{-1}$ min$^{-1}$. Nazarali et al. reported a higher mean for the $\dot{V}O_2_{max}$ values provided by YIRT level

\begin{table}[h]
\centering
\caption{Table 2: $\dot{V}O_2_{max}$ assessment: comparative summary of both methods of measurement.}
\begin{tabular}{|l|c|c|}
\hline
Method & Mean $\pm$ SD & Minimum & Maximum \\
\hline
Yo-Yo endurance test (YET) & 50.78 $\pm$ 4.44 & 45.00 & 58.70 \\
Direct measurement (DM) & 51.09 $\pm$ 4.41 & 45.00 & 59.70 \\
Difference (YET-DM) & $-0.31 \pm 2.06$ & -3.50 & 3.00 \\
\hline
\end{tabular}
\end{table}

\begin{table}[h]
\centering
\caption{Table 3: Heart rate and respiratory exchange ratio values reached when achieving $\dot{V}O_2_{max}$.}
\begin{tabular}{|l|c|}
\hline
Parameter & Mean $\pm$ SD \\
\hline
Heart rate (beats min$^{-1}$) & 197.9 $\pm$ 8.2 \\
Respiratory exchange ratio & 1.1 $\pm$ 0.08 \\
\hline
\end{tabular}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1}
\caption{Fig. 1 $\dot{V}O_2_{max}$: Difference between methods against the average measurement with bias and 95% limits of agreement.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Fig. 2 $\dot{V}O_2_{max}$: Mean and 95% limits of agreement of the difference between methods with 95% confidence intervals.}
\end{figure}
the sample size. The smaller is the number of observations
study between the direct assessment of \( \dot{V}O_2 \) max in labora-
differences between methods.
mean difference and that of the limits of agreement
reporting method comparison studies by using Bland-Altman
limits of agreement are inversely proportional to the sample size.
meaningful estimates it must be assumed that they are constant
the corresponding confidence intervals are wide when the
This research presents a thorough method comparison
indirect estimation by means of the
football and rugby players. Estimates of bias and 95% limits
bias was observed between the two tech-
mean difference and the standard
deviation of the differences appeared not to depend on the
It is worth emphasizing that the mean difference and the standard
differences of the appearances not to depend on the
The point estimates of the 95% limits of agreement were
within \( \pm 5 \) ml kg\(^{-1}\) min\(^{-1}\), satisfying the \textit{a priori} requirement
based on experience. Thus, a reasonable good agreement
was found between the Yo-Yo endurance test and the direct
laboratory measurement for the assessment of \( \dot{V}O_2 \) max in ath-
interchangeably. Nevertheless, the need for caution in inter-
interpreting this result solely is further emphasized by the finding
that the region covered when considering the 95% confidence
intervals for the 95% limits of agreement was wider than the
acceptable region of agreement defined \textit{a priori}. Hence, although the estimated 95% limits of agreement
do not discredit the Yo-Yo endurance test as an alternative
method to measure \( \dot{V}O_2 \) max in athletes, the present study
is limited in precision because of the small sample size and
does not allow definitive conclusions.

Conflict of interests

Authors declare that they do not have any conflict of inter-

Acknowledgments

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Arango, Enrique D. Balardini, Claudio A. Gillone, Cristina
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