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Comparison Between Direct and Predicted Maximal Oxygen Uptake Measurement During Cycling

LTC Matti Santtila, FDF*; Keijo Häkkinen, PhD†; Kai Pihlainen, MSc*; Heikki Kyröläinen, PhD†‡

ABSTRACT Predicted maximal oxygen uptake (VO_2max) measurements are based on the assumption of linear relationship between heart rate or power output and oxygen consumption during various intensities. To develop more reliable predicted test for soldiers, the purpose of the present study was to compare the results of direct measurements of VO_2max to respective predicted values in cycling (Military Fitness Test). The predicted mean (±SD) peak oxygen uptake (VO_2peak) value was 45.2 ± 7.7 mL kg^{-1} min^{-1} during first week, whereas the respective direct value was 44.8 ± 8.5 mL kg^{-1} min^{-1}. During the ninth week, the predicted and measured mean (±SD) VO_2max values were 47.4 ± 6.7 mL kg^{-1} min^{-1} and 48.7 ± 7.3 mL kg^{-1} min^{-1}, respectively. The absolute differences between the methods were −0.42 mL kg^{-1} min^{-1} (p = 0.46) and 1.28 mL kg^{-1} min^{-1} ($p < 0.05$), which correspond to relative values of 0.9% and 2.7%, respectively. A Bland–Altman plot of measured VO_2max and predicted VO_2max showed no significant trend between the mean and the difference of the 2 methods either before (r = 0.14, p = 0.24) or after the basic military training period (r = 0.11, p = 0.36). Intraclass correlation coefficient varied between r = 0.82 to 0.94. In conclusion, the predicted protocol is fairly accurate (±3 %) and reliable to predict VO_2max values in male soldiers but the use for clinical purposes should be considered individually.

INTRODUCTION

It is generally well known that adequate aerobic capacity and muscle strength are important elements of capable soldiers in several military duties as well as in human daily life. Good aerobic capacity and muscle strength are needed both in professional soldiers attempting to optimize their peak performance and in adolescents and elderly people carrying out their daily activities. Aerobic and muscle fitness, regular physical activity, and proper health-related behaviors are also essential factors for mental well-being, sufficient functional capacity, and the prevention of overweight/obesity and musculoskeletal injuries.[1–4]

Regular endurance training induces major adaptations in cardiorespiratory functions. Therefore, the aim of endurance training is not only to improve oxygen uptake and transportation but also the oxidative capacity and lipid utilization of specific muscle groups. Long-term endurance training improves maximal oxygen uptake (VO_2max) by improving cardiac output, increasing aerobic enzyme activity in the muscles, and by improving intramuscular glycogen stores. VO_2max is generally accepted as a measure of cardiorespiratory endurance, although several other factors also affect it.[5]

Direct measurement on VO_2max has been used as the gold standard method for determination of aerobic capacity. However, along with direct measurements, indirect field tests have been developed during last decades. For example, running tests from 20-m multiple-repetition shuttles to 2 miles or 12 minutes are widely used aerobic capacity measurements, especially, among army forces around the world to monitor performance of the military personnel.[6–9]

Several predicted VO_2max or peak oxygen uptake (VO_2peak) measurements, which are based on the assumption that there is a linear relationship between heart rate and oxygen consumption during various intensities, have been developed since the 1950s.[10,11] However, the validity and reliability of such protocols have been criticized. On the other hand, validity and reliability of the incremental submaximal bicycle ergometer have been widely investigated. Correlation coefficients between the measured and predicted VO_2max tests have been reported to vary between r = 0.59 to 0.95.[2,10,12]

A cross-validation of the VO_2max prediction equations by Malek et al[3] revealed that the use of age, body weight, and the power output achieved at VO_2 as predictor variables resulted in the lowest standard error of estimate and total error values. Therefore, they are recommended variables for estimating VO_2max in aerobically trained males and females. For predicting aerobic capacity of the soldiers in military environment, incremental bicycle ergometer tests are useful. A predicted maximal bicycle ergometer Military Fitness Test (MILFIT) has also been used in the Finnish Defence Forces to measure aerobic capacity of the soldiers aged over 40 years and civilian employees but its validity and reliability have not been studied. Development of more accurate, reliable, and easier indirect methods to measure VO_2max is still needed.

Therefore, the purpose of the present study was to compare in the cross-sectional design the results of the direct measurements of VO_2max to respective predicted values during a maximal bicycle ergometer test. The second aim was to examine how similar the changes, in VO_2max induced by an 8-week basic military training (BT), are in the direct and predicted measurements.

*Finnish Defence Forces, Personnel Division of Defence Command, 00130 Helsinki, Finland.

†Department of Biology of Physical Activity, University of Jyväskylä 40014, Finland.

‡National Defence University, 00861 Helsinki, Finland.

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METHODS

Subjects

A total sample size was 68 healthy male soldiers, whose mean age was 19.2 ± 0.9 years, body height 1.79 ± 0.06 m, body mass 73.8 ± 12.4 kg, and body mass index 23.0 ± 3.8. The subjects voluntarily participated in the study after passing a medical examination. They were carefully informed about the design of the study with special information on possible risks and discomfort of the tests. Subsequently, they signed informed consent before the experiment. The present study was conducted according to the declaration of Helsinki 1975. The study was also approved by the Ethical Committee of the Central Finland Health Care District and the University of Jyväskylä (Jyväskylä, Finland).

Experimental Design

The VO_2max of the subjects was tested twice: in the beginning of their military service and after 8 weeks of BT, which included a total of 300 hours of military training. The BT program consisted of military-related physical training, sport-related physical training, and other military activities. During marching and combat training, the subjects carried a combat gear weighing 15 to 25 kg. BT also contained field exercises lasting from 4 hours up to 3 days for a total of 1 to 2 weeks. The BT program was mainly performed within low intensity aerobic limits. The overall amount of the sport-related physical training was planned to be 50 hours during BT.

Measurements

Direct and predicted VO_2max was measured/predicted by using a bicycle ergometer (Ergoline GmbH, Ergoline, Germany). The initial work load of the test was 50 W, and it was increased by 25 W every 2 minutes until exhaustion (Fitware Oy, Mikkeli, Finland). The pedaling rate (between 60 and 80 rpm) and a height of the saddle were instructed and adjusted individually.

Direct oxygen uptake (VO_2) was measured continuously using a gas analyzer (SensorMedics Vmax, Yorba Linda, California), which has been shown to be the most valid instrument for measuring respiratory gases.[13]

Predicted VO_2max (MILFIT/FitWare, Mikkeli, Finland), based on maximal power produced in the end of the test, was determined simultaneously with the direct VO_2max measurements according to the following equation:

$$VO_2\text{max}\ (\text{mL kg}^{-1}\,\text{min}^{-1}) = 12.35{*}P\text{max}/\text{kg} + 3.5.$$

Pmax = highest work rate (power) achieved during the test as watts.

Body mass as kilograms.

Heart rate was recorded continuously using a heart rate monitor (Polar Electro, Kempele, Finland).

Volitional exhaustion was the main criterion indicating that VO_2max was achieved, and the highest mean VO_2 over 1-minute period was set as VO_2max. Exhaustion was ensured by a respiratory exchange ratio above 1.05 and the rate of perceived exertion[14] more than 17 on a 6 to 20 scale or a decrease of the pedaling rate below 50 rpm.

Statistical Analysis

Standard statistical methods were used for the calculation of means, standard deviations, and Pearson product moment correlation coefficients. The data were then analyzed using multivariate analysis of variance with repeated measures. t–Tests were used for pairwise comparisons to study changes in VO_2max induced by the BT training. The Bland–Altman procedure was used to calculate the mean difference of direct and predicted VO_2max measurements, and 95% limits of agreement from the mean difference.[15] Intracorrelation coefficients (ICC) were calculated to further study the reliability of the two simultaneous measures. The criterion for statistical significance was set at $p < 0.05$.

RESULTS

Before the BT period, the predicted mean (±SD) VO_2peak value was 45.2 ± 7.7 mL kg^{-1} min^{-1}, whereas the respective direct value was 44.8 ± 8.5 mL kg^{-1} min^{-1} (Fig. 1). The absolute difference between the methods was –0.42 mL kg^{-1} min^{-1} (p = 0.46), which corresponds to a relative value of 0.9% (Fig. 2). A significant Pearson's correlation (r = 0.84, $p < 0.001$) was found between the tests (Fig. 3). The 95% confidence interval for the mean values was 43.2 to 46.9 mL kg^{-1} min^{-1}, and ICC varied between r = 0.85 to 0.94.

After the BT period, the predicted and measured mean (±SD) VO_2max values were 47.4 ± 6.7 mL kg^{-1} min^{-1} and 48.7 ± 7.3 mL kg^{-1} min^{-1}, respectively (Fig. 1). The absolute and relative differences between the methods were 1.28 mL kg^{-1} min^{-1} ($p < 0.05$) and 2.7%, respectively (Fig. 2). A significant Pearson's correlation (r = 0.80, $p < 0.001$) was observed between the tests (Fig. 3). The 95% confidence interval for the mean values was 46.4 to 49.7 mL kg^{-1} min^{-1}, whereas ICC varied between 0.82 to 0.93.

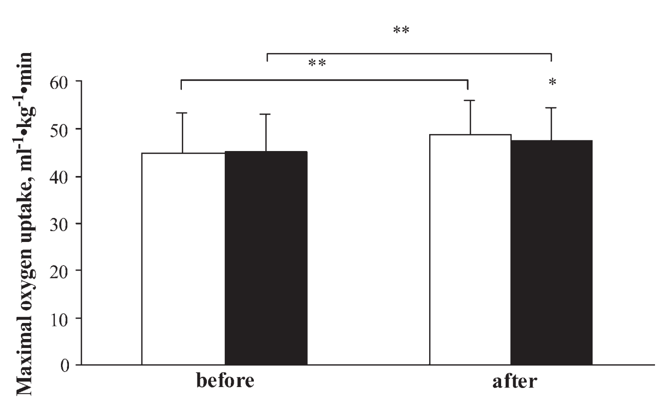

FIGURE 1. VO_2max measured by direct bicycle ergometer (white bar) and predicted MILFIT protocol (black bar) during the first (before) and ninth (after) training weeks (*$p < 0.05$) including changes in VO_2max induced by the 8-week BT period with a horizontal line (*$p < 0.05$; **$p < 0.01$).

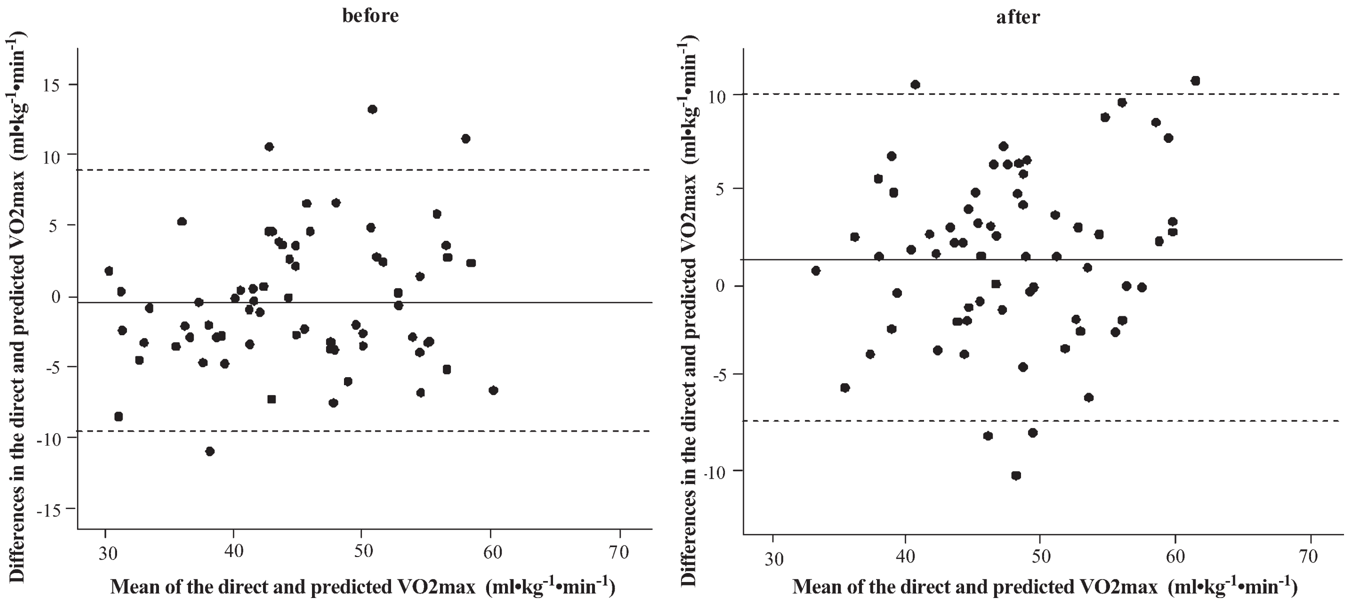

FIGURE 2. Bland–Altman plots with mean differences (solid lines) between direct and predicted VO_2max and 95% limits of agreements (dashed lines) before (left) and after (right) the training period.

The direct mean VO_2max values and differences of the predicted and direct VO_2max values were not significantly correlated either before (r = 0.14, p = 0.24) or after the BT period (r = 0.11, p = 0.36). In the total group of subjects, direct VO_2max improved by 10.5 % ($p < 0.01$) and predicted by 5.6 % ($p < 0.01$) during the 8-week training period (Fig. 1).

DISCUSSION

The present study demonstrated that predicted VO_2max measurements slightly overestimated at week 1 and underestimated at week 9 the VO_2max values of the direct measurements, demonstrating that MILFIT is a fairly reliable method to measure VO_2max in cycling.

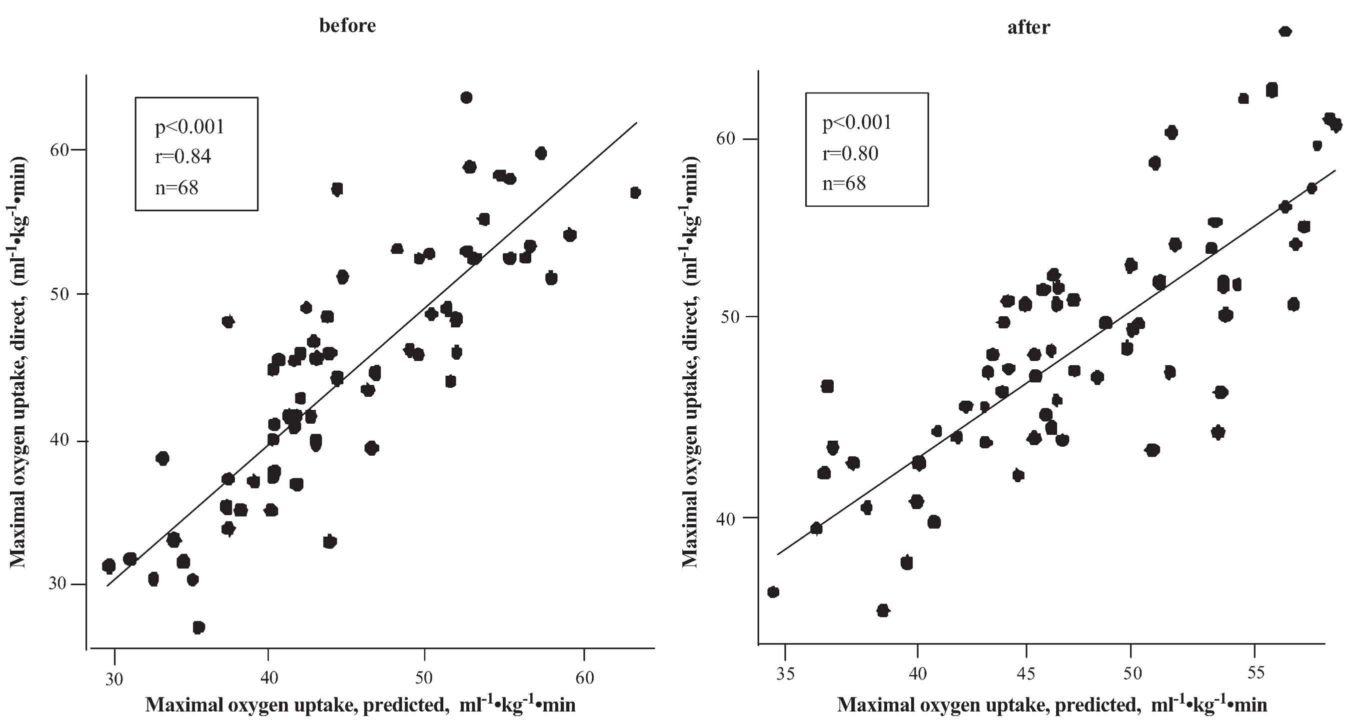

FIGURE 3. Relationship by Pearson correlation between the direct VO_2max and predicted VO_2max (MILFIT,) during the first (before) and ninth (after) week bicycle ergometer tests.

However, the present study revealed high interindividual differences in the accuracy of the predicted VO_2max values measured during bicycle ergometer tests, which can be seen as a weakness of the MILFIT protocol. This has also been the case in previous studies.[16–18] In addition, Greiwe et al[19] have reported that the American College of Sports Medicine submaximal cycle ergometer test protocol significantly overestimates VO_2max. They found that the standard error of estimated VO_2max varied between ±15 and 16% including large interindividual differences (±15%). Therefore, when an accurate assessment of VO_2max is required, a maximal test should be performed instead of a submaximal test. As figure 2 demonstrates, a value of the predicted VO_2max can be 10 mL kg^{-1} min^{-1} above or 7.5 mL kg^{-1} min^{-1} below the respective, directly measured VO_2max. This can be considered as a weakness of the use of MILFIT protocol for clinical purposes. For example, in the Finnish Defence Forces the minimum requirement for the aerobic capacity of professional soldiers is 42 mL kg^{-1} min^{-1}. In that case, his or her VO_2max values can vary between 34.5 and 52.0 mL kg^{-1} min^{-1} when using the MILFIT protocol.

In the present study, the pedaling rate was instructed to maintain between 60 and 80 rpm. Swain and Wright[18] have announced that the pedaling rate from 50 to 80 rpm has a similar validity in cycle ergometry for predicting VO_2max in individuals with or without cycling experience. In the present study, all of the subjects were more or less experienced with cycling as a part of their combat and marching training during BT.

As earlier mentioned, a wide selection of field tests has been used for assessing aerobic fitness in military personnel. For example, Aandstad et al[20] found a correlation of 0.69 (ICC $r = 0.62$) between estimated VO_2max in a 20-m shuttle run test and directly measured VO_2max in a treadmill test in male military personnel. Santtila et al[21] have found a negative correlation between the measured VO_2max values during cycling ergometer test and field running times in 3 K with combat gear ($r = -0.66$, $p < 0.001$). Williford et al[22] and Lockwood et al[23] have earlier stated that 4 different predicted models of cycle ergometer tests (Air Force Cycle Ergometry Tests 1-3 and Progressive Cycle Ergometer Test) underestimated true VO_2max by 15% to 17%. Their "true VO_2max" was measured during a treadmill test. The data from Londeree et al[24] suggest that there are differences in %VO_2max and %HRmax (percent of maximal heart rate) regressions between weight bearing (treadmill, stepper etc.) and weight-supported (cycle, rowing etc.) modes. This is mainly because of an amount of active muscles contributing to muscle actions. Therefore, a real VO_2max can only be measured when all major muscle groups are active such as during Nordic walking or running uphill.

In conclusion, based on the data of the present study, MILFIT protocol is fairly accurate and valid to predict VO_2max of male soldiers as a group level. Accuracy of the MILFIT bicycle ergometer test seems to be the same or a little better than the other predicted VO_2max measurements used in military settings. However, the use of MILFIT protocol for clinical purposes should be considered individually. The present study group included young and relatively fit male soldiers. Therefore, the results cannot be generalized to females or elderly persons, which can be seen as a limitation of the study and needs further investigations.

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