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CONCURRENT VALIDITY OF THE 5-MINUTE PYRAMID TEST FOR VO_2MAX ESTIMATION IN HEALTHY YOUNG ADULTS

original paper
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ABSTRACT
Purpose. Maximal oxygen uptake (VO_2max) is an important physiological parameter related to sports performance and chronic disease risk. Many field tests have been developed to estimate VO_2max at reduced cost, time, and energy demands compared with laboratory measurement. The purpose of this investigation is to assess the concurrent validity of the 5-minute pyramid test (5MPT).
Methods. Overall, 14 young (21.1 ± 2.1 years) adult male (n = 7) and female (n = 7) participants completed 5MPT for VO_2max estimation, and a criterion measurement of VO_2max by using indirect calorimetry with the Bruce treadmill protocol.
Results. A strong positive correlation (r = 0.86, p < 0.0001) was observed between the estimated and measured VO_2max for the entire sample. The group mean VO_2max of 5MPT ($3.08 \pm 0.84\ l \cdot min^{-1}$) was significantly lower (p < 0.001, Cohen's d = 0.65) than the measured value of the Bruce protocol ($3.68 \pm 0.99\ l \cdot min^{-1}$). This difference was also observed when analysing VO_2max in $ml \cdot kg^{-1} \cdot min^{-1}$ ($37.87 \pm 5.43\ ml \cdot kg^{-1} \cdot min^{-1}$ vs. $46.76 \pm 9.23\ ml \cdot kg^{-1} \cdot min^{-1}$, p < 0.001, Cohen's d = 1.17), indicating a tendency to underestimate VO_2max.
Conclusions. 5MPT was designed to estimate VO_2max with a submaximal, field-test approach. It may underestimate VO2max when compared with treadmill derived maximal values in healthy young adults. Additional investigations are warranted to further test the validity and reliability of 5MPT in a variety of populations.
Key words: 5-minute pyramid test, submaximal exercise testing, VO_2max

Introduction

Cardiorespiratory fitness (CRF) is considered one of the most important components of physical fitness and has demonstrated a strong relationship with performance in several athletic modalities [1–3]. Additionally, maintaining adequate CRF has been linked to a reduction in chronic degenerative disease risk [4–6]. The measure of maximal oxygen consumption (VO_2max) is often obtained via indirect calorimetry during maximal exertion, graded exercise testing (GXT). This method has long been the standard laboratory measurement of aerobic capacity and has demonstrated adequate validity and reliability in many populations [7].

Several barriers exist for obtaining laboratory-based VO_2max or CRF, such as the need for specialized laboratory equipment, personnel, time, money, and other resources. Additionally, maximal exertion testing exposes participants to greater physical risk, cardiorespiratory strain compared with submaximal assessments. Therefore, field-based submaximal tests have been developed to estimate CRF, providing alternatives to the expensive and time-consuming process of VO_2max measurement by using indirect calorimetry. One of the first submaximal tests developed to estimate VO_2max was the 1954 Astrand-Ryhming test [8]. It extrapolates the predicted maximal heart rate achieved from submaximal power output as its method of prediction [9]. However, the Astrand-Ryhming tests was still designed to be conducted in a laboratory. Finally, the 1968 work of Cooper [10] led to the development of walk/run tests for time or distance, and provided non-laboratory estimates of CRF.

The test of interest to this study is the 5-minute pyramid test (5MPT), developed by Andersson et al. in 2011 [11]. It was created to provide an alternative to

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the previously designed 6-minute walk test (6MWT) [10]. One of the many benefits to the 6MWT is its short duration, achieved by shortening the original 12-minute walk test [12]. While the 6MWT demonstrates adequate validity and reliability when estimating CRF, it lacks sufficient demand to adequately tax the cardiorespiratory system among all levels of fitness [11, 13]. The design of the 5MPT requires participants to walk or run back and forth up and over a set of 3 boxes, the middle being higher than the 2 end boxes, as fast as possible. This design is more taxing on the aerobic system in more fit individuals than the walking would be in the 6MWT, while also decreasing the needed test time from 6 to 5 minutes. This higher intensity test may allow for more accurate estimations of VO_2max in younger, healthier populations compared with lower intensity walking-based tests. The test has potential to be a useful tool for clinicians, coaches, and athletes who would benefit from knowing their estimated VO_2max without the use of specialized laboratory equipment.

While Andersson et al. [11] found a strong correlation (r = 0.98) between VO_2max ($l \cdot min^{-1}$) and the end power results of the 5MPT, there have been no other studies performed to validate the 5MPT as an estimator of VO_2max. Additionally, the study by Andersson et al. [11] included 44 participants, 21 of which were young (20–32 years) and 23 of which were old (64–79 years). The 5MPT shows promise as a potentially valid predictor of VO_2max but a thorough search of the literature only reveals a single validation study available [11]. Therefore, the purpose of this investigation is to assess the concurrent validity of the 5MPT VO_2max estimation among young (18–25 years) healthy individuals. It was hypothesized that a significant correlation would exist between the estimation of VO_2max by using the 5MPT and the VO_2max measured via indirect calorimetry during the Bruce treadmill test.

Material and methods

Participants

A total of 14 healthy young adult males (n = 7) and females (n = 7) participated in this investigation. Their demographic characteristics are reported in Table 1. All subjects were screened for cardiopulmonary, orthopaedic, and metabolic disorders and reported no recent injuries that would limit their ability to run or exert maximal effort.

Table 1. Participant characteristics

Characteristics	Males (n = 7)	Females (n = 7)	Total (n = 14)
Age (age)	20.9 ± 2.3	21.4 ± 1.9	21.1 ± 2.1
Height (cm)	180.0 ± 6.6	166.3 ± 4.3	173.1 ± 8.9
Weight (kg)	84.9 ± 12.6	73.7 ± 21.8	79.3 ± 18.1
BMI ($kg \cdot m^{-2}$)	27.2 ± 3.5	26.5 ± 6.6	26.9 ± 5.1

Procedure

Upon completion of the Physical Activity Readiness Questionnaire (PAR-Q), baseline measures of height and weight were obtained by using a stadiometer and standard balance scales, respectively. The participants then accomplished one of the two exercise protocols (5MPT or Bruce GXT) in a counterbalanced testing order. The second exercise test was performed on a separate day, with at least 24 hours in between sessions. The subjects were instructed to limit vigorous physical activity prior to testing as well as between testing days. The Bruce protocol utilized a Trackmaster TMX425C treadmill (Full Vision, Newton, KS, USA) with variable speed and incline. The Cosmed Fitmate Pro metabolic testing system (Cosmed, Rome, Italy) was used to assess oxygen consumption during the treadmill test. Additionally, 3 previously constructed boxes and 2 marker cones were used to complete the 5MPT.

The 5MPT is a shuttle test that requires the number of laps back and forth to be counted. Each lap is defined as starting on floor level and ending on floor level. The middle portion of the lap contains 3 different sized boxes, the 2 end boxes being the same dimension (0.30 m high, 0.40 m long) and the middle box being taller and longer than the 2 end boxes (0.62 m high and 1.30 m long) to create the 'pyramid'. An image of the box configuration has been previously published by Andersson et al. [11]. The total distance of the course is 5.5 m, which is indicated by one 1.2-m high cone at each end. The participants were instructed to start by touching the cone, go up and over the boxes (walking or running as fast as possible), touch the other cone, and repeat the 5.5-m lap until the 5-minute time was up. They were to complete as many laps as possible during the 5 minutes. Each subject received verbal encouragement throughout the test. Laps were counted for each minute separately in order to eventually calculate the power output for each minute. There were 2 lab technicians timing each participant as well as recording the number of laps in order to ensure accuracy. Total laps completed were used to estimate VO_2max with the Andersson equation [11].

The Bruce treadmill protocol is a graded treadmill test with progressively increasing work rate [14]. Participants start the test at a walking pace (2.7 km · h^{-1}), on a 10% grade. Speed and grade increase in 3-minute stages until the participant can no longer tolerate the pace. Prior to the start of the test, the subjects attached a Polar A300 heart rate monitor (Polar Electro Oy, Kempele, Finland) to their chest. Following resting heart rate, the technician described the protocol, and fit the participant with a Cosmed facemask (Cosmed, Rome, Italy) to collect the oxygen consumption data. Heart rate and rating of perceived exertion (RPE) (Borg RPE 6–20 scale) [15] were recorded every minute, and oxygen consumption (l · min^{-1}) was collected continuously during the Bruce test. The participants were asked to stay on the treadmill as long as possible, stopping from volitional fatigue.

Statistical analysis

Descriptive statistics (means ± standard deviation [*SD*]) were used to report participant characteristics. Pearson product-moment correlation and standard errors of estimates were employed to assess the association between the 5MPT VO_2max estimation and the VO_2max measured from the Bruce protocol. Dependent *t*-tests were applied to assess differences between group mean VO_2max estimates, and Cohen's *d* served to determine the meaningfulness of differences observed. Statistical significance was accepted at $p < 0.05$.

Ethical approval

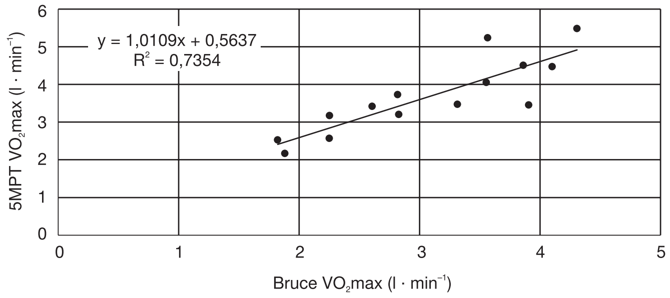
The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the authors' institutional review board.

Informed consent

Informed consent has been obtained from all individuals included in this study.

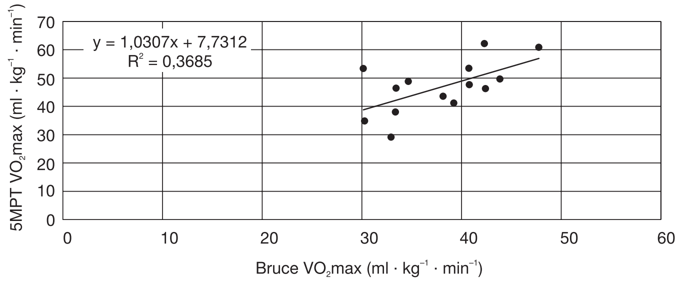
Results

The participants completed an average of 85.9 ± 9.2 laps during the 5MPT, which resulted in an average estimated VO_2max of 3.08 ± 0.84 l · min^{-1} or 37.87 ± 5.43 ml · kg^{-1} · min^{-1}. The number of laps and estimated VO_2max during the test ranged 71–102 laps, and 1.82–4.31 l · min^{-1} or 32.90–47.76 ml · kg^{-1} · min^{-1}, respectively. The Bruce test resulted in an average VO_2max of 3.68 ± 0.99 l · min^{-1} or 46.76 ± 9.23 ml · kg^{-1} · min^{-1}, maximal heart rate of 192.9 ± 10.7 beats · min^{-1}, and maximal RPE of 18.7 ± 1.0.



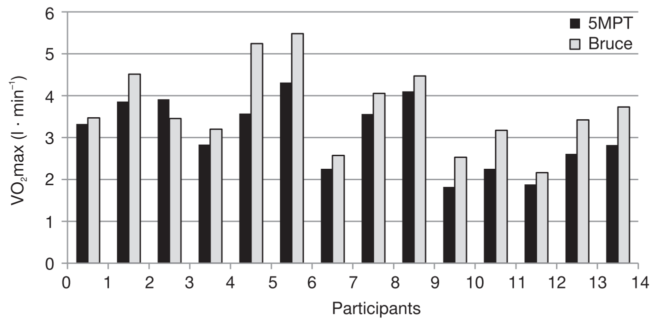
5MPT – 5-minute pyramid test, VO_2max – maximal oxygen uptake

Figure 1. Correlation between 5MPT-estimated and Bruce VO_2max (l · min^{-1})



5MPT – 5-minute pyramid test, VO_2max – maximal oxygen uptake

Figure 2. Correlation between 5MPT-estimated and Bruce VO_2max (ml · kg^{-1} · min^{-1})



VO_2max – maximal oxygen uptake, 5MPT – 5-minute pyramid test

Figure 3. Comparison of the 5MPT VO_2max estimations and the Bruce protocol VO_2max measurements

A strong positive correlation ($r = 0.86$, $p < 0.0001$, standard error of the estimate [*SEE*] = 0.53) was observed between the estimated and measured VO_2max in l · min^{-1} (Figure 1). A significant moderate-strong correlation was noted when analysing VO_2max in ml · kg^{-1} · min^{-1} ($r = 0.61$, $p < 0.01$, *SEE* = 7.6) (Figure 2).

The group mean VO_2max of the 5MPT (3.08 ± 0.84 l · min^{-1}) was significantly lower ($p < 0.001$, Cohen's $d = 0.65$) than the measured value of the Bruce protocol (3.68 ± 0.99 l · min^{-1}). This difference was also observed when analysing VO_2max in ml · kg^{-1} · min^{-1} (37.87 ± 5.43 ml · kg^{-1} · min^{-1} vs. 46.76 ± 9.23 ml · kg^{-1} · min^{-1}, $p < 0.001$, Cohen's $d = 1.17$), which indicated a tendency to underestimate VO_2max in the sample population. Additionally, individual comparisons (Figure 3) demonstrated that all but one participant achieved a higher VO_2max during the Bruce test compared with the 5MPT.

Discussion

The 5MPT VO_2max estimations demonstrated positive (r = 0.86 and r = 0.61) correlations with VO_2max determined by the Bruce treadmill protocol. However, the 5MPT significantly underestimated VO_2max for the present sample. A comparison between the participants recruited for the present investigation and for the original study by Andersson et al. [11] may provide insight into some of the differences observed. The mean age of the young male (27.0 ± 3.0 years) and young female (23.3 ± 3.2 years) subgroups were higher in the Andersson et al.'s study [11] compared with the present investigation's male (20.9 ± 2.3 years) and female (21.4 ± 1.9 years) samples. The healthy young adult sample produced VO_2max values (3.68 ± 0.99 $l \cdot min^{-1}$ or 46.76 ± 9.23 $ml \cdot kg^{-1} \cdot min^{-1}$) comparable to the young adult male (4.23 ± 0.47 $l \cdot min^{-1}$ or 51.9 ± 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$) and female (2.73 ± 0.26 $l \cdot min^{-1}$ or 43.4 ± 4.9 $ml \cdot kg^{-1} \cdot min^{-1}$) samples from the original validation study. The present investigation also employed the Bruce treadmill protocol to elicit VO_2max values compared with the cycle protocol in previous investigations [11]. The Bruce-derived values are expected to be higher than the cycle test peak values, which possibly contributes to the underestimation of VO_2max by an average of 0.6 ± 0.51 $l \cdot min^{-1}$ or 8.89 ± 7.34 $ml \cdot kg^{-1} \cdot min^{-1}$. Additionally, the participants in the present investigation were highly fit, and when compared with CRF normative data, ranking in the 80th and 75th percentiles for male and female, respectively [16]. The 5MPT-estimated VO_2max values might prove to be more accurate in middle-aged or older adult populations, or in populations with lower CRF. Moreover, results may differ if the 5MPT results are compared against a different criterion treadmill or maximal cycling ergometer protocol.

Certain limitations in the present study, including the small sample size and the homogeneous nature of the young fit participants, may contribute to differences observed. While heart rate and perceived exertion were monitored during the criterion max test, researchers in the present study were also unable to control effort and assumed that all participants performed at maximal effort for both tests. Heart rate and RPE were not assessed during the 5MPT, which limited the ability to compare the intensity of effort between the two tests. The evaluation of heart rate and percent of age-predicted heart rate maximum achieved during the 5MPT could provide additional insight for future investigations. Additionally, the participants may have benefited from an orientation/familiarization trial for both tests. Practicing 5MPT would give them an opportunity to learn the proper pacing of the test to prevent premature fatigue, and prior fitting and practice with the indirect calorimetry equipment and facemask may have improved treadmill running performance. Finally, every effort was made to conduct all testing sessions at approximately the same time of day. However, this was not possible for all participants because of a scheduling conflict, which is recognized as a limitation when analysing the results of this investigation.

Future research could include validating the 5MPT within the young athletic population, as well as middle-aged and older adults of varying fitness levels and health status. Also, further investigations should attempt to validate the 5MPT against multiple maximum and peak exercise protocols that vary in modality. Test-retest reliability investigations would help to strengthen the merit of the 5MPT.

Conclusions

In conclusion, the 5MPT was designed to estimate VO_2max by using a submaximal, field-test approach. The results from the present investigation indicate that the 5MPT may underestimate VO_2max when compared with treadmill-derived maximal values in healthy young adults. Additional research is warranted to further test the validity and reliability of the 5MPT in a variety of populations.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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