Maximal Aerobic Power versus Performance in Two Aerobic Endurance Tests among Young and Old Adults

Eva A. Andersson, Gunilla Lundahl, Liliane Wecke, Ida Lindblom, Johnny Nilsson

The Swedish School of Sport and Health Sciences, Department of Neuroscience, Karolinska Institutet, Stockholm; Ortivus AB, Danderyd; Department of Cardiology, Karolinska Institutet at Karolinska University Hospital Solna, Solna, Sweden; The Norwegian School of Sport Sciences, Oslo, Norway

Key Words
Physical fitness • Maximal oxygen uptake • Six-minute walk test • Exercise

Abstract
Background: Aerobic fitness is of great value for reducing risk of mortality and cardiovascular diseases. Objective: This study evaluated the performance in and correlations between a new test (five-minute pyramid test, 5MPT), the six-minute walk-test (6MWT) and maximal oxygen uptake (VO\textsubscript{2}\text{max}) among old and young adults. Methods: Forty-four habitually active adults (females and males), 23 old (64–79 years) and 21 young (20–32 years) participated. In the 5MPT, the participants moved back and forth along a short walkway (5.5 m) over boxes (height: ‘old people’ 0.42 m, ‘young people’ 0.62 m) arranged like an elongated step pyramid for 5 min. Power in the pyramid test (5MPT\textsubscript{power}) was calculated as the product of numbers of laps, body weight, gravity and highest box level divided by time. A 6MWT and a maximal cycle ergometer test for direct measurements of VO\textsubscript{2}\text{max} were also performed. In all tests heart rate, with on-line electrocardiography, and perceived exertion were recorded. Results: There was a strong correlation between the 5MPT\textsubscript{power} and VO\textsubscript{2}\text{max} for the entire group studied (r = 0.98), and each of the four subgroups old and young females and males separately (r = 0.78–0.98). Contrary to several earlier studies, especially involving people with various diseases, the present data showed that 6MWT cannot be used to predict VO\textsubscript{2}\text{max} among old females and young adults. The correlation with VO\textsubscript{2}\text{max} was weaker for the 6MWT than for the 5MPT\textsubscript{power}. The relative performance values for the old compared to the young (ratio old/young × 100) were considerably lower in 5MPT\textsubscript{power} and VO\textsubscript{2}\text{max} (47–55%) than in distance and ‘work’ in the 6MWT (82–86%). Conclusions: The results, with age and gender variations, can be valuable information in health-fitness contexts, since measuring physical aerobic capacity is very significant in connection with risk evaluations of mortality and various diseases. The 5MPT is a rapid, functional, easy and inexpensive tool for predicting assessed maximal aerobic power.

Introduction

There are strong indications that the risk of cardiovascular death and all-cause mortality for a person of higher weight with good cardiorespiratory fitness is smaller than that for a person of recommended weight but who is less fit [1]. A review study by Williams [2] showed a stronger association to cardiorespiratory fitness than to physical ac-
Aerobic Tests for Young and Old Adults

**Methods**

**Participants**

Forty-four females and males (23 old, 64–79 years; and 21 young, 20–32 years) volunteered to participate (Table 1). The participants received no financial compensation for taking part in the study. Inclusion criteria among the healthy young adults were that they should be students of physical education or health promotion; among the old adults that they should be active twice a week in supervised physical exercises. The elderly people were apparently healthy, although some had diabetes (n = 2), mild hypertension (n = 6) or hypercholesterolemia (n = 6). Exclusion criteria were intake of β-blockers or a history of ischemic heart disease, heart failure, chronic obstructive pulmonary disease or severe joint problems. Two other older individuals were excluded based on the exclusion criteria mentioned. All signed an informed consent form, a health declaration and an activity report before participating. The mean values from these self-reports showed 30 min of physical activity (at moderate or high intensity) at least three times/week for the elderly and at least five times/week for the young adults. The corresponding values for 60-min physical activity (at moderate or high intensity) were once-twice/week for the old and three times/week for the young group. Regarding medication intake among the elderly people, some were being treated for high blood lipids (n = 6), thrombocyte aggregation (n = 2), hyperuricemia (n = 1), thyroid disorder (n = 1), glaucoma (n = 1) and insomnia (n = 2). Some were receiving angiotensin II antagonist (n = 3), calcium antagonist (n = 1), diabetic medicine (n = 2), asthma aerosol (n = 1), folacin (n = 1), B12 vitamin (n = 1), or cytostatics for psoriasis (n = 1). The ambient conditions (like temperature, humidity, light and noise) during the three tests (cf. below) were controlled and comparable. The investigation was approved by the ethical committee of the Karolinska Institutet.

| Table 1. Mean values ± SD (range) for age, body height, weight and BMI of the participants |
|---------------------------------------------------------------|
| OF (n = 12) | OM (n = 11) | YF (n = 11) | YM (n = 10) |
| Age, years  | 68.9 ± 4.6 (64–77) | 69.6 ± 4.4 (65–79) | 23.3 ± 3.2 (20–30) | 27.0 ± 3.0 (23–32) |
| Height, m  | 1.64 ± 0.04 (1.58–1.71) | 1.77 ± 0.06 (1.70–1.88) | 1.66 ± 0.04 (1.58–1.73) | 1.80 ± 0.06 (1.73–1.89) |
| Weight, kg | 65.2 ± 6.2 (52.4–73.0) | 82.4 ± 14.5 (62.8–115.5) | 63.6 ± 9.7 (48.5–85.7) | 81.6 ± 7.1 (72.5–93.0) |
| BMI       | 24.3 ± 2.6 (20.5–27.8) | 26.1 ± 3.16 (21.7–32.7) | 23.1 ± 3.0 (19.4–29.7) | 25.1 ± 2.0 (22.6–28.3) |

**Table 1.** Mean values ± SD (range) for age, body height, weight and BMI of the participants.
Test of Maximal Oxygen Uptake, VO\(_{2\text{max}}\)

The participants performed three submaximal bouts of 4 min on a cycle ergometer (Monark 839E, Monark AB, Vansbro, Sweden) followed by a 2-min rest and a test of maximal oxygen uptake (VO\(_{2\text{max}}\)). The latter test started at a submaximal power level which was increased stepwise each minute until exhaustion. The starting load for the old females, old males, young females and young males was 75, 75, 125 and 175 W, respectively. Corresponding increases each minute were 15, 15, 20 and 25 W, respectively. Common criteria for reaching maximal oxygen uptake are: respiratory exchange ratio >1.1, leveling-off or reduction in oxygen uptake, and/or rated perceived exertion (RPE) >17 [17]. Here Borg [17] clarifies that with RPE the participants express the level of experienced increased effort (graded between 6 and 20). The participants chose their own pedaling rates, which in our experience is more effective for reaching absolute maximal capacity. Three initial submaximal levels were chosen to follow how HR progressively increased at steady state before we conducted the test of VO\(_{2\text{max}}\). Oxygen uptake was recorded online with an automatic ergo-spirometric device (OxyconPro, Jaeger GmbH, Hoechberg, Germany). HR was recorded with electrocardiography (ECG; see below) and an HR monitor (RS800, Polar Electro OY, Kampele, Finland) together with RPE and rated chest pain below) and an HR monitor (RS800, Polar Electro OY, Kampele, Germany). HR was recorded with electrocardiography (ECG; see below) and an HR monitor (RS800, Polar Electro OY, Kampele, Finland) together with RPE and rated chest pain below). Continuous visual inspection of the airways for any individual. The test persons. Our participants were instructed to move back and forth along the walkway as fast as possible. The 6 min and at every 100 m walked, one experimenter noted the RPE ratings, chest pain, HR and number of shuttles the participant had performed. The total distance walked was registered (6MWT\(_{\text{distance}}\)). The subjects were consistently told how much of

\[
P = \frac{(m\cdot g)\cdot (n \cdot h)}{t},
\]

where \(P\) = mean power (W), \(m\) = body mass (kg), \(g\) = gravity constant (= 9.81 m/s\(^2\)), \(n\) = number of laps, \(h\) = height of the highest box (m) and \(t\) = duration of the test(s). A calculated example of mean power during the 5MPT for an old female participant is:

\[
\text{mean power} = \frac{[(72.5 \text{ kg} \cdot 9.81 \text{ m/s}^2) \cdot (76 \cdot 0.42 \text{ m})]{300 \text{ s} = 75.7 \text{ W}}.
\]

Thus, in the 5MPT a mean value for the number of laps (5MPT\(_{\text{laps}}\)) and also power (5MPT\(_{\text{power}}\)) was quantified for the whole 5 min of the test. Mean power was further calculated up to each minute, i.e. up to the 1st, 2nd, 3rd and 4th minute. Finally, power for each separate minute was quantified.

The Six-Minute Walk Test

The 6MWT is a shuttle walk test [19]. Each end of the 50-meter shuttle walkway is marked with a plastic cone, to be rounded by the test persons. Our participants were instructed to move back and forth along the walkway as fast as possible. After the 6 min and at every 100 m walked, one experimenter noted the RPE ratings, chest pain, HR and number of shuttles the participant had performed. The total distance walked was registered (6MWT\(_{\text{distance}}\)). The subjects were consistently told how much of
the 6 min had elapsed and/or how much time remained. Also, mean velocity was calculated based on the values at the 100-meter interval closest to each minute. The product of body mass (kg) times walking distance (m; 6MWT_{body mass-distance}) for separate age and gender groups was also analyzed to reflect the ‘work’ performed according to previous studies [c.f. 10, 12].

**ECG and HR Recordings**

For analysis and security reasons, continuous ECG was measured online with a vectorcardiography recording system (Corotron system, Ortivus Medical, AB, Danderyd, Sweden) in all three tests. This company contributed to the test design with ECG equipment and computer programs for ECG analyses, including HR measurements. The study was not sponsored by other means by this or any other industry. Vectorcardiography was recorded continuously from eight electrodes positioned according to the Frank orthogonal lead system, and a conventional 12-lead ECG was calculated and displayed in real time as described in detail elsewhere [20]. The on-line HR signals (in beats per minute, bpm) were averaged every 10 s. The ECG made it possible to observe whether pathological changes (e.g. ST shift or pathological arrhythmia) occurred during the tests. HR was, in addition to ECG, generally also recorded with HR monitors in the three tests. In the analysis procedure, the listed HR recordings from the various tests were also checked manually by an experimenter so as to eliminate movement artifacts and other disturbances. Such occurred during the 5MPT, but to some extent also during the 6MWT. In the three tests, the maximum HR value (HR_{max}) during 1 min was registered. In addition, for the 5MPT the HR for each separate minute (1–5) was calculated (based on number of heart beats during the last 10 s of each minute). ECG and chest pain permit early discovery of unknown ischemic heart disease.

Of the 44 participants, one old and one young female performed only one of the tests, the VO_{2max}. Another old female and a young female did not perform the 5MPT. They chose, or were unable to take part in every test.

For each participant, the three tests were performed mostly within 10 days, each on a separate day. The mean aggregate values for the whole period of the three tests were 6.5 (±3.8) days. The mean duration was 4.2 (±3.3) days between the first and the second test and 2.2 (±1.8) days between the second and the third, for the whole group. The VO_{2max} test on the cycle ergometer was generally, but not always, performed first, followed by the 6MWT and finally the 5MPT. None of the persons performed the two maximal tests (VO_{2max} and 5MPT) on 2 consecutive days. None reported any chest pain during the tests. However, one old man performed only the 6MWT, and not the other two tests, due to an ECG finding of a wide QRS complex. This person had no symptoms or signs of coronary heart disease at rest or during the 6MWT, so his values were included in the study.

**Statistics**

Statistical calculations were performed with the SPSS Inc. (Chicago, Ill., USA) Statistics 17.0 software package. All data are reported as mean, range and standard deviation (±SD). Associations between the parameters investigated were analyzed with Pearson product-moment correlation. To evaluate possible differences between age and gender groups, independent samples, Student’s t test was used. One-way ANOVA, with a Tukey post-hoc test, was applied to detect significant differences between values in various time intervals within a test and for HR_{max} and RPE values between the three main aerobic tests. The significance level was set at p < 0.05.

**Results**

For analysis, the participants were divided into four subgroups, old females (OF), old males (OM), young females (YF) and young males (YM).

**Power at Maximal Oxygen Uptake**

For mean values in the VO_{2max} test for the different subgroups, see table 2. The mean values for maximal power obtained at the end of the maximal cycle ergometer test for the four subgroups OF, OM, YF and YM were 124 ± 20, 181 ± 36, 239 ± 22 and 355 ± 33 W, respectively.

**Correlations between 5MPT, 6MWT and VO_{2max}**

A significant correlation was observed between the end power results of the new 5MPT_{power} and VO_{2max} (l/min) for all subjects together (r = 0.98; fig. 2a). This was also true for the four subgroups (OF 0.78; OM 0.98; YF 0.82; YM 0.78), as well as for the old (r = 0.97) and the young (r = 0.96) participants separately.

A significant, but much weaker, correlation was seen between the 6MWT_{distance} and VO_{2max} tests for the en-

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**Table 2. Mean values ± SD (range) for VO_{2max} among old and young adult females and males**

| Group  | VO_{2max} l/min | VO_{2max} ml·kg^{-1}·min^{-1} |
|--------|----------------|-----------------------------|
| OF     | 1.51 ± 0.18 (1.18–1.76) | 22.9 ± 2.0 (19.5–26.5) |
| OM     | 2.19 ± 0.45 (1.40–2.91)  | 26.8 ± 4.6 (18.8–32.7)  |
| YF     | 2.73 ± 0.26 (2.12–3.07)  | 43.4 ± 4.9 (35.2–51.6)  |
| YM     | 4.23 ± 0.47 (3.53–4.87)  | 51.9 ± 4.0 (44.0–58.6)  |
tire group (l/min: r = 0.61; ml·kg⁻¹·min⁻¹: r = 0.69; fig. 2b). However, between these tests, and also between 6MWTbody mass distance and VO₂max (both units), there was no significant correlation for any of the four age and gender subgroups separately, except for OM between the 6MWTdistance and VO₂max (ml·kg⁻¹·min⁻¹: r = 0.80) and for OM between 6MWTbody mass distance and VO₂max (l/min: r = 0.88).

Performance in the 5MPT and 6MWT
The 5MPTpower end results are shown in figure 3a. The mean values were lower among the old adults (OF: 63 ± 9, range 44–71 W; OM: 87 ± 19, range 57–122 W) than among the young (YF: 124 ± 13, range 101–143 W; YM: 185 ± 18, range 164–213 W). In contrast, the 6MWTdistance for the old adults was only somewhat lower (OF: 660 ± 25, range 623–711 m; OM: 714 ± 88, range 586–850 m) than that for the young (YF: 810 ± 104, range 672–980 m; YM: 833 ± 93, range 715–1,000 m; fig. 3b). There were also fewer laps in the 5MPTlaps for the old (OF: 70 ± 6, range 56–76; OM: 78 ± 13, range 56–99) than for the young (YF: 96 ± 8, range 82–110; YM: 112 ± 4, range 106–119).
Parameter Changes within the 5MPT and 6MWT

Mean power values up to each minute in the 5MPT for each subgroup are presented in figure 4a. Here, the mean power is shown during the intervals 0–1, 0–2, 0–3, 0–4 and 0–5 min. At the end of the test, a tendency towards a small (not significant) drop in mean power was observed. Further, in a comparison between each separate 60-second interval, again no significant differences in power occurred for any subgroup (except for young men who showed significantly lower results only in the 3rd and 4th min compared to the 1st). In all subgroups, there was a significant correlation between VO$_{2\text{max}}$ (l/min) and mean power in the 5MPT already after the 3rd and 4th min (r for the four subgroups varied between 0.69–0.95 and 0.73–0.96, respectively). In the 6MWT, no significant differences were seen in mean speed during the test for any age or gender subgroup (fig. 4b).

Age and Gender Differences

The relative performance values for the old compared to the young (ratio old/young · 100 for each gender) were considerably lower in 5MPT$_{\text{power}}$ and VO$_{2\text{max}}$ (47–55%).
Higher values were seen in the VO$_{2\text{max}}$ test and 5MPT and 80–172 (l/min and ml·min$^{-1}$) and 92% for the 6MWT distance. The young relative to HR$_{\text{max}}$ in the VO$_{2\text{max}}$ test (percentage values of 85% for the VO$_{2\text{max}}$ (ml·kg$^{-1}$·min$^{-1}$) and 97% for 6MWT distance. A significant gender difference was noted for both age groups in 5MPT power, VO$_{2\text{max}}$ (l/min), 67% for 5MPT power, 75% for 6MWT$_{\text{body mass distance}}$ and 84% for VO$_{2\text{max}}$ (ml·kg$^{-1}$·min$^{-1}$) and 97% for 6MWT$_{\text{distance}}$. A significant gender difference was noted for both age groups in 5MPT power, VO$_{2\text{max}}$ (l/min and ml·kg$^{-1}$·min$^{-1}$) and 6MWT$_{\text{body mass distance}}$. In contrast, there was no significant gender difference, for any age group, in 6MWT$_{\text{distance}}$. Thus, the gender differences were most noticeable in VO$_{2\text{max}}$ (l/min) and 5MPT power and least in 6MWT$_{\text{distance}}$ for both age groups.

**HR and Rated Perceived Exertion**

The HR$_{\text{max}}$ (bpm; fig. 5) was significantly lower during the 6MWT for all four subgroups OF, OM, YF and YM relative to HR$_{\text{max}}$ in the VO$_{2\text{max}}$ test (percentage values of 91, 91, 86 and 79%, respectively) and relative to HR$_{\text{max}}$ in the 5MPT (88, 90, 86 and 79%, respectively). In the 5MPT, the HR in the last (i.e. 5th) minute was significantly higher than in the first minute for all subgroups, whereas no significant variations in HR were present between minute intervals 2–5. HR in the 5MPT increased relatively rapidly early in the test, and somewhat more each consecutive minute. The HR values (bpm) in the 1st, in the 2nd and the 5th min were: 143 ± 10, 154 ± 9 and 162 ± 9 for OF; 142 ± 14, 155 ± 16 and 165 ± 13 for OM; 165 ± 11, 172 ± 9 and 181 ± 10 for YF; 170 ± 9, 176 ± 11 and 185 ± 11 for YM, respectively. Also in RPE, significantly higher values were seen in the VO$_{2\text{max}}$ test and 5MPT than in the 6MWT (fig. 5b). No significant gender differences occurred for HR$_{\text{max}}$ and RPE in the respective test for any age group. A significant age difference was observed for HR$_{\text{max}}$ in the VO$_{2\text{max}}$ test and 5MPT, but not in the 6MWT, for both gender groups. The HR$_{\text{max}}$ mean values (SD) for subgroups OF/YF and OM/YM were in the VO$_{2\text{max}}$ test 155 (9)/185 (11) and 165 (11)/188 (12), in the 5MPT 161 (9)/180 (10) and 167 (16)/184 (11), and in the 6MWT 142 (13)/155 (23) and 150 (17)/145 (19), respectively (cf. also fig. 5a). A significant correlation was seen between HR$_{\text{max}}$ in the VO$_{2\text{max}}$ test and VO$_{2\text{max}}$ (ml·kg$^{-1}$·min$^{-1}$) for older and younger males. Further, a significant correlation between HR$_{\text{max}}$ in 5MPT and VO$_{2\text{max}}$ (ml·kg$^{-1}$·min$^{-1}$) was noted only for younger men. Apart from that, no significant correlations were present for any subgroup between absolute VO$_{2\text{max}}$ values (in both units) and HR$_{\text{max}}$ or RPE (in all the three tests 5MPT, 6MWT and VO$_{2\text{max}}$).

**Linear Regression Equation**

Based on the present 5MPT$_{\text{power}}$ results for all persons in each age group, we developed, from linear regression analyses, an equation for calculation among the old participants:

$$\text{VO}_{2\text{max}} \text{in l/min} = (5\text{MPT}_{\text{power}} - 7.9398)/36.637.$$  

The corresponding equation for the young adults was:

$$\text{VO}_{2\text{max}} \text{in l/min} = (5\text{MPT}_{\text{power}} - 16.37)/39.5.$$  

No significant difference occurred for any subgroup between VO$_{2\text{max}}$ values in l/min obtained from direct measurements on the cycle ergometer and those from the equation (mean values for OF 1.51 and 1.51; OM 2.19 and 2.17; YF 2.73 and 2.71; YM 4.23 and 4.27 l/min, respectively). Directly measured VO$_{2\text{max}}$ results in l/min and results calculated with this formula correlated significantly with all participants together ($r = 0.98$) and for all subgroups ($r = 0.78–0.98$).

In the unit ml·kg$^{-1}$·min$^{-1}$, apart from YM, the other subgroups correlated significantly ($0.73–0.95$) and also the entire group ($0.98$) in a comparison between directly measured and calculated VO$_{2\text{max}}$ results. Here again, no significant variation appeared between directly measured VO$_{2\text{max}}$ values and those calculated from the formula for all four subgroups (mean values for OF 22.9 and 22.7; OM 26.8 and 26.5; YF 43.4 and 42.8; YM 51.9 and 52.3 ml·kg$^{-1}$·min$^{-1}$, respectively).

Linear regression equations for calculating VO$_{2\text{max}}$ levels, based on the results for each age group in 6MWT$_{\text{distance}}$ and 6MWT$_{\text{body mass distance}}$, were performed as well. No significant correlation, with simultaneous absence of significant difference of mean values, was then found for any subgroup between directly measured and calculated VO$_{2\text{max}}$ results (in ml·kg$^{-1}$·min$^{-1}$ or l/min). The only exception was for old males ($r = 0.80$ for VO$_{2\text{max}}$ values in ml·kg$^{-1}$·min$^{-1}$ based on 6MWT$_{\text{distance}}$).
Aerobic Tests for Young and Old Adults

Discussion

The newly developed five-minute pyramid test (5MPT<sub>power</sub>) showed a very strong (0.98) and significant correlation with VO<sub>2max</sub> (l/min) determined in a maximal cycle ergometer test. 5MPT<sub>power</sub> was the only one of the present assessments which resulted in the overall strongest correlation with VO<sub>2max</sub> (l/min). Neither 6MWT<sub>distance</sub>, 6MWT body mass<sub>distance</sub> nor number of laps in the 5MPT showed such strong correlation with VO<sub>2max</sub> among either old or young, females and males. Thus, the 5MPT<sub>power</sub> can be useful in various public-health areas to predict maximal aerobic power in both old and young adults. The 5MPT<sub>power</sub> test is much easier and more cost-effective than the maximal VO<sub>2max</sub> test. Thus, advantages of the 5MPT<sub>power</sub> test include short test duration, no expensive equipment and no need for HR measurements. Due to the proper length (1.30 m), the central box has to be passed with full elevation of the centre of mass. This is not always achieved in regular step test measurements [see 23]. Further, in the 5MPT no fixed pace has to be followed like in the incremental walking shuttle [8, 11, 14, 21, 22] or in step tests [23].

The 6MWT has been properly and widely used for categories of less healthy persons. But we found for the old females and both habitually active young gender groups that 6MWT demonstrated no significant correlation with – and thus cannot generally be used to predict – maximal oxygen uptake in these populations. The present results for the 6MWT may be related to the low potential of walking to tax the cardio-respiratory system sufficiently for these groups. Our results contrast with those in several prior studies, especially involving people with various diseases. This observation is supported by a study [16] of young adults using the 6MWT. Thus, the 6MWT is not valid for estimating VO<sub>2max</sub> in physically active young men and women [16], which was also the case for ‘our’ physically active old females. Significant correlations between VO<sub>2max</sub> and 6MWT<sub>distance</sub> have been reported extensively for elderly people with diverse cardiopulmonary disorders, in mixed gender or male groups (generally with mean ages 51–67 years) with correlation coefficients varying between 0.21 and 0.76 [6, 8, 10, 12–15]. Conversely, for elderly people with chronic obstructive pulmonary disease, no significant correlation reportedly appeared between VO<sub>2max</sub> and 6MWT<sub>distance</sub> among men [11] and women [12].

However, we found a significant correlation with VO<sub>2max</sub> for 6MWT<sub>distance</sub> (0.80) and 6MWT body mass<sub>distance</sub> (0.88) only among OM. Thus, these two 6MWT assessments can be used for reflecting aerobic capacity in various contexts only for this category. That 6MWT body mass<sub>distance</sub> showed stronger correlation than 6MWT<sub>distance</sub> with VO<sub>2max</sub> has earlier been reported for chronic obstructive pulmonary disease groups (mean age 65–67 years) of men [10] and mixed genders [12]. However, we found that significant correlation levels between 5MPT<sub>power</sub> and VO<sub>2max</sub> were even stronger (cf. above).

It has been claimed that 6MWT<sub>distance</sub> can be valuable for testing persons with severe heart failure, but less useful for those with mild heart failure, for whom a maximal test may be more appropriate for determining aerobic power accurately [7]. Further, for persons with moderate-to-severe chronic heart failure, VO<sub>2max</sub> is associated with survival, which has not been shown with respect to distance in 6MWT or an incremental shuttle test (10-meter course with progressively increasing walking speed each minute [14]). When comparing HR<sub>max</sub> between the three main tests, no significant difference was noted between the 5MPT and the VO<sub>2max</sub> cycle ergometer test. Thus, the 5MPT can be considered a maximal aerobic test. For use with persons with moderate-to-severe cardiopulmonary diseases, supervision by staff in a clinic is preferable, as is generally the case during maximal VO<sub>2max</sub> tests. Given the very strong correlation between the 5MPT<sub>power</sub> and VO<sub>2max</sub>, the 5MPT can be used in field test contexts because it is simple and inexpensive. Regarding the parameter number of laps in the 5MPT, no significant correlation with VO<sub>2max</sub> was observed for the subgroup of YM. The other three subgroups had similar correlation coefficient levels (between 5MPT<sub>laps</sub> and VO<sub>2max</sub> in ml·kg<sup>−1</sup>·min<sup>−1</sup>) to those in the comparison of 5MPT<sub>power</sub> and VO<sub>2max</sub> (l/min). Thus, the 5MPT<sub>power</sub> assessment was the most prominent of our examinations, showing for all subgroups an overall high significant correlation with VO<sub>2max</sub>.

Interestingly, similar trends appeared for all subgroups in the pyramid test right from the 3rd and 4th min regarding: (a) a significant correlation between power versus VO<sub>2max</sub> and (b) a significantly high HR in the 5MPT (see ‘Results’). Thus, during the pyramid test, 3 or 4 min instead of 5 may suffice in certain situations.

Comparison with Previously Published Studies

A comparison of our data with previously published results for the 6MWT, VO<sub>2max</sub> and HR<sub>max</sub> provides information about the physical fitness of ‘our’ tested older and younger adults.
The Six-Minute Walk Test

The 6MWT\textsubscript{distance} assessment is also easy to administer. Our mean results for OF, OM, YF and YM (660, 714, 810 and 833 m, respectively) were higher than in previous studies. Earlier reported mean values vary between 294 and 558 m for those with cardiopulmonary diseases [5–8, 10, 11, 13–15] and 683 m for healthy mixed gender populations aged 36–68 years [7]. Other examples are 494 m for women and 576 m for men in a normal gender populations aged 36–68 years,

approximately 430–440 m for both genders aged 70 years [24]. A cardiac rehabilitation report showed 60- to 85-year-old men walking significantly further than women in the 6MWT (approximately 600 and 550 m, respectively) were higher than in a normal population study [25]. In contrast, we found no significant gender difference for the 6MWT\textsubscript{distance}, but did so for 5MPT\textsubscript{power} and \(\text{VO}_2\text{max}\).

Maximal Oxygen Uptake

We performed pre-pilot studies to develop the best progression of workload in the present cycle ergometer test. Here, adjustments were made with respect to age, sex and training status. Thus, in the selected workload structure, an optimal progression was found for these categories of participants (see ‘Methods’). After the three initially submaximal levels described, the total duration (with stepwise increase of workload each minute) was generally 5–10 min until exhaustion for all subjects, except for one old male (2 min) and 4 old females (3–4 min). Further, to reach their absolute \(\text{VO}_2\text{max}\), we used common criteria such as respiratory exchange >1.1, leveling-off or reduction in oxygen uptake, and/or perceived exertion (RPE) >17. Thus, with the methods we consider the participants most probably reached their predicted \(\text{VO}_2\text{max}\).

Compared to previous reports for groups aged 20–33 years, the mean values for our female and male young adults (43 and 52 ml·kg\(^{-1}\)·min\(^{-1}\), 2.7 and 4.2 l/min, respectively) were higher than in a normal population study (41 and 40 ml·kg\(^{-1}\)·min\(^{-1}\), respectively [25]), and higher than or similar to healthy people (40 and 52 ml·kg\(^{-1}\)·min\(^{-1}\), respectively [26]). Our results were somewhat lower than in well-trained people (48–49 and 59 ml·kg\(^{-1}\)·min\(^{-1}\), respectively [3, 27]).

The values we found for OF and OM were 23 and 27 ml·kg\(^{-1}\)·min\(^{-1}\) (1.5 and 2.2 l/min), respectively. Previous \(\text{VO}_2\text{max}\) data for apparently healthy elderly people with age ranges corresponding to our participants’ (64–79 years) are rare. Lower values for our old adults were noted compared to healthy somewhat younger people (28 and 31 ml·kg\(^{-1}\)·min\(^{-1}\) for women aged 50–65 years and men 60–69 years, respectively [26]). Our results were also lower than those for currently or previously active old male athletes (43 and 37 ml·kg\(^{-1}\)·min\(^{-1}\), respectively, aged 60–67 years [28]; 32 ml·kg\(^{-1}\)·min\(^{-1}\) for men with mean age 75 years [29]). Moreover, we found for the old somewhat lower or the same \(\text{VO}_2\text{max}\) levels than in a normal population (25 and 27 ml·kg\(^{-1}\)·min\(^{-1}\), for women and men, respectively, aged 60–65 years [25]).

Our elderly \(\text{VO}_2\text{max}\) values turned out to be slightly lower or equal to those in studies with healthy or sedentary old people of similar ages [30–32]. On the other hand, our levels were somewhat higher than those in other reports with apparently healthy people, with mean ages between 69 and 75 years [33–36]. Finally, our values for the elderly were notably higher than for those with various cardiopulmonary diseases (10–18 ml·kg\(^{-1}\)·min\(^{-1}\) [7, 8, 13–15]).

Maximum HR

As expected, our RPE and HR\textsubscript{max} values were significantly higher for all subgroups in the 5MPT and the \(\text{VO}_2\text{max}\) test than in the 6MWT. Previously, a significant difference was also found for HR\textsubscript{max} between the \(\text{VO}_2\text{max}\) test (146) and 6MWT (131) for persons with moderate-to-severe heart failure (mean age 53 years, mostly men [8]). However, they had lower HR\textsubscript{max} values than our participants in the \(\text{VO}_2\text{max}\) test (OF 155 and OM 165). For younger females and males, earlier published mean HR\textsubscript{max} values in cycle ergometer tests are 199 and 195, respectively, among well-trained people, and 187 and 186, respectively, among healthy people aged 20–33 years [26]. Our HR\textsubscript{max} values in the \(\text{VO}_2\text{max}\) test tended to resemble the latter levels best (YF 185 and YM 188). Previously published HR\textsubscript{max} values in \(\text{VO}_2\text{max}\) tests for old people of ages corresponding to our data (range 64–79 years) are scarce, but reported are 151–163 for healthy females with a mean age of 69 years [30]. However, for somewhat younger people, the mean reported values are 170 for healthy females, 50–65 years, and 159 for healthy males, 60–69 years [26], 163 for males, 56–68 years [37], and 170 for former male athletes, 60–67 years [28]. Our overall HR\textsubscript{max} (seen in the 5MPT) for OF and OM (mean age 69 and 70 years, respectively) were higher (mean values 161 and 167, respectively) than expected, as calculated using the common equation HR\textsubscript{max} = 220 – age.
Conclusions

Aerobic fitness is of great health value [38, 39], and sometimes even better than physical activity habits, for reducing risk of mortality and cardiovascular disease [2, 40]. Measuring fitness is thus of great importance. The new 5MPT power and VO2max – The 5MPT is a short, functional, simple and inexpensive tool for evaluating maximal aerobic power among various groups. The present results can be of value when measuring physical fitness in various public health contexts.

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References

[1] Lee CD, Blair SN, Jackson S: Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. Am J Clin Nutr 1999;69:373–380.
[2] Williams PT: Physical fitness and activity as separate heart disease risk factors: a meta-analysis. Med Sci Sports Exer 2001;33:754–761.
[3] Åstrand P-O, Ryhming I: A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. J Appl Physiol 1954;7:218–221.
[4] Åstrand P-O, Rodahl K: Textbook of Work Physiology. New York, McGraw Hill, 1986, pp 363–366, 399–405.
[5] Butland RJA, Pang J, Gross ER, Woodstock AA, Geddes DM: Two-, six-, and twelve minute walking tests in respiratory disease. BMJ 1982;284:1607–1609.
[6] Guyatt GH, Sullivan MJ, Thompson PJ, Fall EL, Pugsley SO, Taylor DW, et al: The 6-minute walk: a new measure of exercise capacity in patients with chronic heart failure. Can Med Assoc J 1985;132:919–923.
[7] Lipkin DP, Scriver AJ, Crake T, Poole-Wilson PA: Six minute walking test for assessing exercise capacity in chronic heart failure. BMJ 1986;292:653–655.
[8] Morales F, Martinez A, Mendez M, Agarradó A, Ortega F, Fernández-Guerra J, Montemayor T, Burgos J: A shuttle walk test assessing functional capacity in chronic heart failure. Am Heart J 1999;138:291–298.
[9] Hamilton DM, Haenel RG: Validity and reliability of the 6-minute walk test in a cardiac rehabilitation population. J Cardiopulm Rehabil 2000;20:156–164.
[10] Chuang ML, Lin IF, Wasserman K: The body weight-walking distance product as related to lung function, anaerobic threshold and peak VO2 in COPD patients. Respir Med 2001;95:618–626.
[11] Onorati P, Antonucci R, Valli G, Bertoni E, De Marco F, Serra P, Palange P: Non-invasive evaluation of gas exchange during a shuttle walking test vs a 6-min walking test to assess exercise tolerance in COPD patients. Eur J Appl Physiol 2003;89:331–336.
[12] Carter R, Holiday DB, Stocks J, Grothues C, Tied B: Predicting oxygen uptake for men and women with moderate to severe chronic obstructive pulmonary disease. Arch Phys Med Rehabil 2003;84:1158–1164.
[13] Starobin D, Kramer MR, Yamolovsky A, Bendayan D, Rosenberg I, Sulkes J, Fink G: Assessment of functional capacity in patients with chronic obstructive pulmonary disease: correlation between cardiopulmonary exercise, 6 minute walk and 15 step exercise oximetry test. Isr Med Assoc J 2006;8:460–463.
[14] Puls C, Diniz RV, Alves ANF, Teixeiren AJ, Carvalho AC, de Paola A, Almeida R: Incremental shuttle and six-minute walking tests in the assessment of functional capacity in chronic heart failure. Can J Cardiol 2008;24:131–135.
[15] Ross RM, Murthy J, Wollak ID, Jackson AS: The six minute walk test accurately estimates mean peak oxygen uptake. BMC Pulm Med 2010;10:31.
[16] Andersson EA, Nilsson J: Can a six-minute shuttle walk test predict maximal oxygen uptake. Gazz Med Ital 2011;170:163–170.
[17] Borg GAV: Psychophysical bases of perceived exertion. Med Sci Sports Exer 1982;14:377–381.
[18] Sylvén C, Borg G, Brandt R, Beermann B, Jonzon B: Dose-effect relationship of adenosine provoked angina pectoris-like pain – a study of the psychophyical power function. Eur Heart J 1988;9:87–91.
[19] American Thoracic Society: ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med 2002;166:111–117.
[20] Wecke L: Cardiac memory studies in two human models; thesis, Karolinska Institutet, Stockholm, 2006.
[21] Sing SJ, Morgan MD, Scott S, Walters D, Hardman AE: Development of a shuttle walking test of disability patients with chronic airways obstruction. Thorax 1992;47:1019–1024.
[22] Singh SJ, Morgan MDL, Hardman AE, Rowe C, Bardsley PA: Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airflow limitation. Eur Respir J 1994;7:2016–2020.
[23] van Denderen JC, Boersma JW, Zeinstrap J, Hollander AP, van Neerbos BR: Physiological effects of exhaustive exercise in primary fibromyalgia syndrome (PFS): is PFS a disorder of neuroendocrine reactivity? Scand J Rheumatol 1992;21:35–37.
[24] Enright PL, Sherill DL: Reference equations for the six-minute walk in healthy adults. Am J Respir Crit Care Med 1998;158:1384–1387.
[25] Ekblom B, Engström L-M, Ekblom Ö: Secular trends of physical fitness in Swedish adults. Scand J Med Sci Sports 2007;17:267–273.
[26] Åstrand J: Aerobic work capacity in men and women with special reference to age. Acta Physiol Scand 1960;49(suppl 169):1–92.
[27] Åstrand P-O, Bergh U, Kilmel A: A 33-years follow-up of peak oxygen uptake and related variables of former physical education students. J Appl Physiol 1997;82:1844–1852.
[28] Saltin B, Grimaldy P: Physiological analysis of middle-aged and old former athletes. Circulation 1968;38:1104–1115.
[29] Bromar G, Johnson L, Kayser L: Golf: a high intensity interval activity for elderly men. Aging Clin Exp Res 2004;16:375–381.
30 Broman G, Quintana M, Lindberg T, Jansson E, Kaijser L: High intensity deep water training can improve aerobic power in elderly women. Eur J Appl Physiol 2006;98:117–123.

31 Farinatti PTV, Soares PPS: Cardiac output and oxygen uptake relationship during physical effort in men and women over 60 years old. Eur J Appl Physiol 2009;107:625–631.

32 Sasai H, Matsuo T, Fujita M, Saito M, Tanaka K: Effects of regular exercise combined with ingestion of vespa amino acid mixture on aerobic fitness and cardiovascular disease risk factors in sedentary older women: a preliminary study. Geriatr Gerontol Int 2010, Epub ahead of print.

33 Peterson MJ, Pieper CF, Morey MC: Accuracy of VO2max prediction equations in older adults. Med Sci Sports Exerc 2003;35:145–149.

34 Simonsick EM, Fan E, Fleg JF: Estimating cardiorespiratory fitness in well-functioning older adults: treadmill validation of the long distance corridor walk. J Am Geriatr Soc 2006;54:127–132.

35 Misic, MM, Rosengren KS, Woods JA, Evans EM: Muscle quality, aerobic fitness and fat mass predict lower-extremity physical function in community-dwelling older adults. Gerontology 2007;53:260–266.

36 Shvartz E, Reibold RC: Aerobic norms for males and females aged 6 to 75 years: a review. Aviat Space Environ Med 1990;61:3–11.

37 Åstrand I, Åstrand P-O, Rodahl K: Maximal heart rate during work in older men. J Appl Physiol 1959;14:562–566.

38 Blair SN, Kohl HW 3rd, Paffenbarger RS Jr, Clark DG, Cooper KH, Gibbons LW: Physical fitness and all-cause mortality. A prospective study of healthy men and women. JAMA 1989;262:2395–2401.

39 Ekblom-Bak E, Hellénius M-L, Ekblom O, Engström LM, Ekblom B: Independent associations of physical activity and cardiovascular fitness with cardiovascular risk in adults. Eur J Cardiovasc Prev Rehabil 2010;17:175–180.

40 Myers J, Kaykha A, George S, Abella J, Zaheer N, Lear S Yamazaki T, Froelicher V: Fitness versus physical activity patterns in predicting mortality in men. Am J Med 2004;117:912–918.