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

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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_{2max}) 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 ($5MPT_{power}$) 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_{2max} 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 $5MPT_{power}$ and VO_{2max} 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_{2max} among old females and young adults. The correlation with VO_{2max} was weaker for the 6MWT than for the $5MPT_{power}$. The relative performance values for the old compared to the young (ratio old/young × 100) were considerably lower in $5MPT_{power}$ and VO_{2max} (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-

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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)

tivity habits for lowering the risk of coronary heart and other cardiovascular diseases, for example stroke. Here, aerobic fitness was recorded either in treadmill or cycle ergometer tests, including both maximal and submaximal measurements for indirect estimates of VO_{2max} [3, 4]. Facts concerning whether aerobic endurance tests show a significant correlation with VO_{2max} in an adult population are relevant in several public health-assessing contexts. Thus, measuring and evaluating fitness is of great importance for risk evaluations of cardiovascular and other diseases. Such fitness tests can be done in many ways.

The gold standard for studying aerobic power is direct measurement of oxygen uptake in a maximal test, for example on a cycle ergometer or a treadmill. However, such testing is time-consuming, not widely available and expensive. From an epidemiological perspective, these types of expensive tests are unrealistic to perform, which is why simpler and cheaper tests have been developed. The six-minute walk test (6MWT) is easy to administer and has been widely used for e.g. fitness evaluation of cardiovascular and respiratory patients [5–15]. However, reported outcome has varied regarding performance in and correlations between the 6MWT and VO_{2max} depending on the population studied.

The 6MWT with horizontal walking only is insufficient to tax the aerobic system for predicting maximal aerobic power among all levels of fitness [16]. For this reason, we designed a test in which the participants had to move backwards and forwards for 5 min along a short track (5.5 m) over boxes arranged like an elongated step pyramid, thus taxing the aerobic system more substantially. We wanted to investigate how calculated power in this new test (the five-minute pyramid test, 5MPT), and the distance covered or 'work' performed in a conventional 6MWT, correlated with maximum oxygen uptake (VO_{2max}) over a large performance range in both old and young adults. Our hypothesis was that the 5MPT would show a stronger correlation with VO_{2max} than the 6MWT does. If so, the 5MPT could be preferable in various health-assessing contexts. Variations of heart rate (HR) and perceived exertion in the tests were also of interest. To our knowledge, no study has been made on such test equipment and compared results and correlations between 6MWT and VO_{2max} both for habitually active old and young adults. Thus, the present purpose was to investigate the performance in and the correlation between the new 5MPT and a conventional 6MWT versus maximum oxygen uptake.

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), trombocyte 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), B_{12} 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.

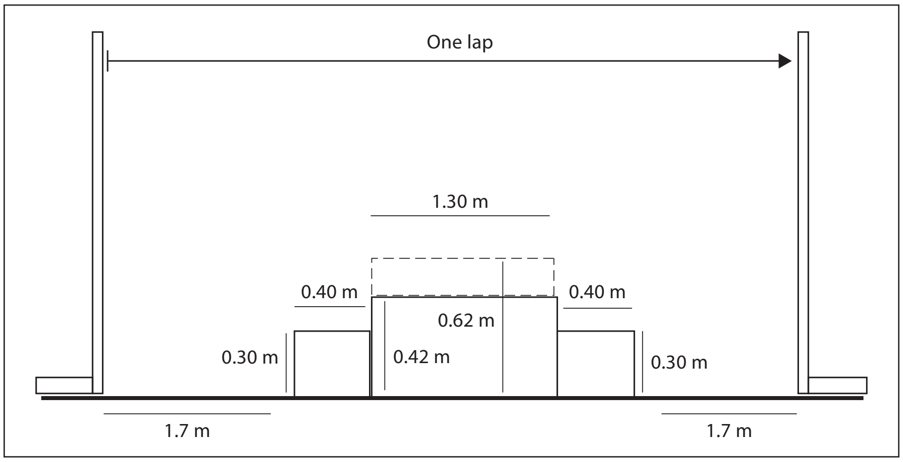

Fig. 1. Set-up equipment for the 5MPT. The height of the central box for the old adults was 0.42 m and for the young adults 0.62 m. The total lap distance was 5.5 m.

Test of Maximal Oxygen Uptake, VO_{2max}

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_{2max}). 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_{2max}. 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 [18]. Encouragement was given primarily in the very last part of the test.

Except for resting ECG (cf. below), HR and blood pressure measurements, no other cardiovascular or pulmonary function evaluation, such as FEV1 and MVV, was performed before the tests. However, no serious cardiovascular or ventilator disease symptoms were present before or during the tests among the participants (cf. described illnesses and exclusion criteria above). Thus, it is reasonable to assume that no diseases of the cardiovascular and ventilator systems affected the gas exchange pattern in the airways for any individual. Continuous visual inspection of physiological parameters such as breathing frequency, tidal volume and ventilation supports this assumption.

The Five-Minute Pyramid Test

The 5MPT is a shuttle test in which numbers of laps back and forth are counted. Each lap starts and ends at floor level. The middle part includes steps up and down on the elongated 'pyramid', i.e. a box (0.30 m high) on each side of a higher central box (0.42 m high for the old and 0.62 m for the young adults; fig. 1). The central box was 1.30 m long in order to assure that the test person took a full step on it, thus raising their body centre of mass to its full height. The test person merely touched the standing pole when turning to start the next lap, so the body centre of mass did not move fully 5.5 m in the horizontal direction. The boxes were covered with 3 cm of soft material to minimize injury in case of falls. Hand rails were placed beside the pyramid to help balance if needed, but not for regular grabbing. The participants were instructed to walk or run as fast as they could over the track with steps up and along the pyramid, and after touching the pole from floor level, to turn round for another lap of 5.5 m. Every fourth lap, HR, RPE, rated chest pain and split times (in seconds) were registered. Encouragement was given primarily during the very last part of the test. Power was calculated from the formula:

$$P = [(m \cdot g) \cdot (n \cdot h)]/t,$$

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:

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

Thus, in the 5MPT a mean value for the number of laps ($5MPT_{laps}$) and also power ($5MPT_{power}$) 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 ($6MWT_{distance}$). The subjects were consistently told how much of

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)

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 (Coronet 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-

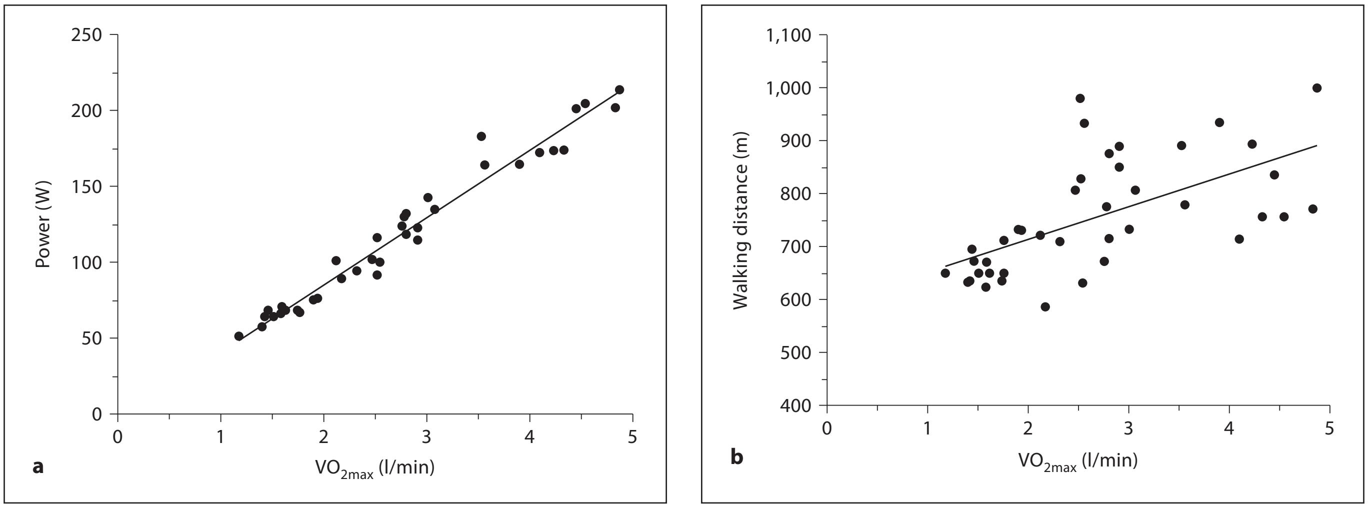

Fig. 2. Correlation between VO_{2max} and power in the 5MPT (**a**) and walking distance in the 6MWT (**b**).

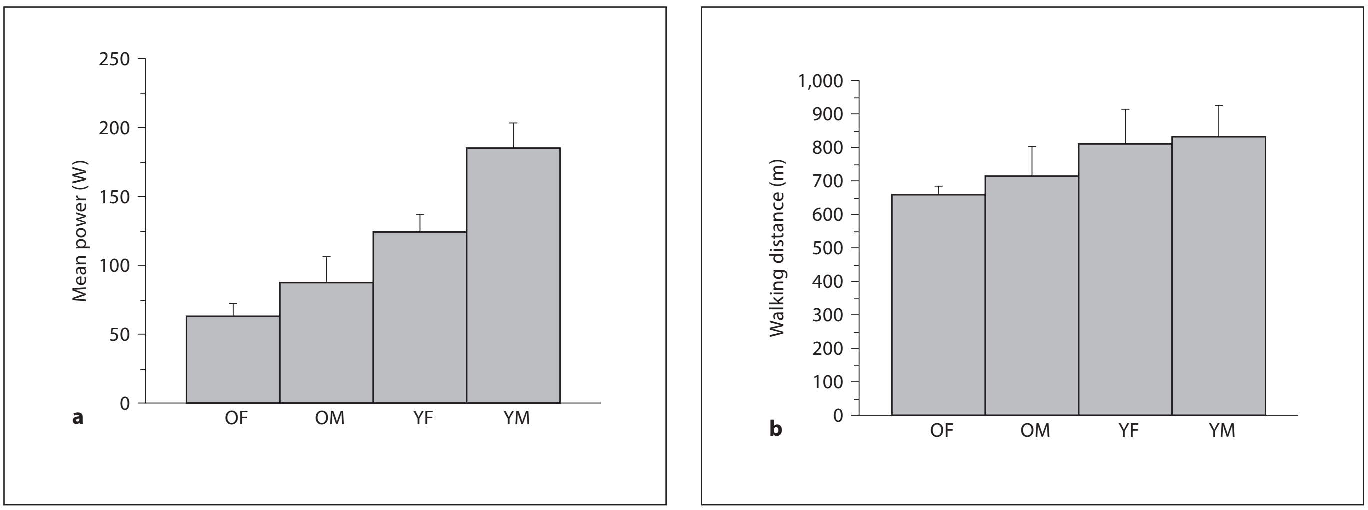

Fig. 3. Mean power (±SD) in the 5MPT (**a**) and walking distance (±SD) in the 6MWT (**b**) for OF, OM, YF and YM.

tire group (l/min: r = 0.61; ml•kg^{-1}•min^{-1}: r = 0.69; fig. 2b). However, between these tests, and also between $6MWT_{body\ mass•distance}$ and VO_{2max} (both units), there was no significant correlation for any of the four age and gender subgroups separately, except for OM between the $6MWT_{distance}$ and VO_{2max} (ml•kg^{-1}•min^{-1}: r = 0.80) and for OM between $6MWT_{body\ mass•distance}$ and VO_{2max} (l/min: r = 0.88).

Performance in the 5MPT and 6MWT

The $5MPT_{power}$ 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 $6MWT_{distance}$ 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 $5MPT_{laps}$ 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).

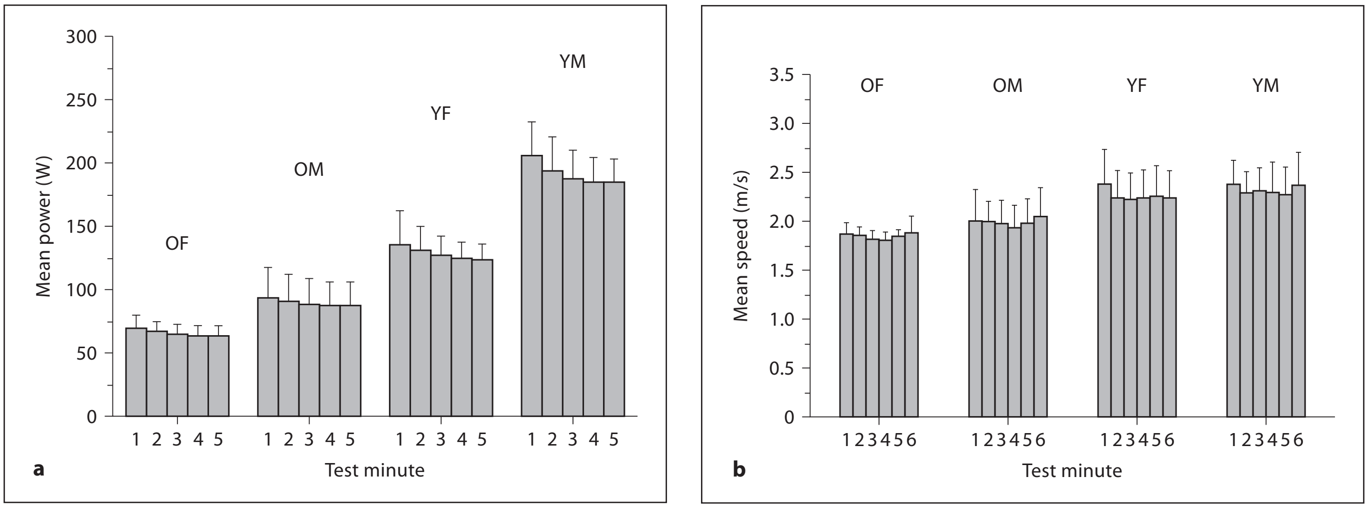

Fig. 4. Mean power (± SD) up to test minutes 1–5 in the pyramid test (**a**) and mean speed (± SD) during each separate test minute, 1–6, in the 6MWT (**b**) for OF, OM, YF and YM.

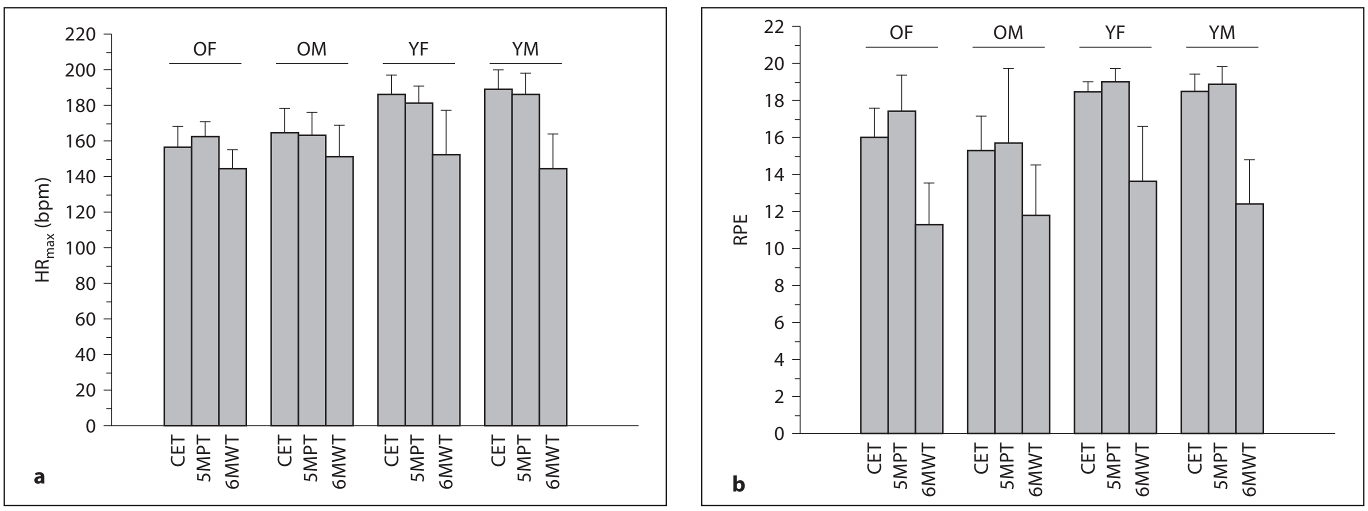

Fig. 5. HR_{max} ± SD (**a**) and RPE ± SD (**b**) at the termination of three tests: CET (cycle ergometer test to maximum; i.e. VO_{2max} test), 5MPT and 6MWT.

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_{2max} (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 $5MPT_{power}$ and VO_{2max} (47–55%)

than in distance and ‘work’ in the 6MWT (82–86%). A significant age difference was observed for both genders in all the test assessments [$5MPT_{power}$, VO_{2max} (l/min), VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$), $6MWT_{distance}$ and $6MWT_{body\ mass \cdot distance}$], except for men in $6MWT_{body\ mass \cdot distance}$.

Gender differences as percentage values for the women compared to the men (mean values for women/men · 100) were also calculated for all tests. The gender difference was highest among the elderly, with 69% for the VO_{2max} (l/min) test. This subsequently decreased (i.e. enhanced percentage levels) for the other tests in the following order: 72% for the $5MPT_{power}$, 74% for the $6MWT_{body\ mass \cdot distance}$, 85% for the VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) and 92% for the $6MWT_{distance}$. The young adults showed a corresponding order between the tests, with similar gender percentage values: 64% for the VO_{2max} (l/min), 67% for $5MPT_{power}$, 75% for $6MWT_{body\ mass \cdot distance}$, 84% for VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) and 97% for $6MWT_{distance}$. A significant gender difference was noted for both age groups in $5MPT_{power}$, VO_{2max} (l/min and $ml \cdot kg^{-1} \cdot min^{-1}$) and $6MWT_{body\ mass \cdot distance}$. In contrast, there was no significant gender difference, for any age group, in $6MWT_{distance}$. Thus, the gender differences were most noticeable in VO_{2max} (l/min) and $5MPT_{power}$ and least in $6MWT_{distance}$ for both age groups.

HR and Rated Perceived Exertion

The HR_{max} (bpm; fig. 5) was significantly lower during the 6MWT for all four subgroups OF, OM, YF and YM relative to HR_{max} in the VO_{2max} test (percentage values of 91, 91, 84 and 77%, respectively) and relative to HR_{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_{2max} test and 5MPT than in the 6MWT (fig. 5b). No significant gender differences occurred for HR_{max} and RPE in the respective test for any age group. A significant age difference was observed for HR_{max} in the VO_{2max} test and 5MPT, but not in the 6MWT, for both gender groups. The HR_{max} mean values (SD) for subgroups OF/YF and OM/YM were in the VO_{2max} 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_{max} in the VO_{2max} test and VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) for older and younger males. Further, a significant correlation between HR_{max} in 5MPT and VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) was noted only for younger men. Apart from that, no significant correlations were present for any subgroup between absolute VO_{2max} values (in both units) and HR_{max} or RPE (in all the three tests 5MPT, 6MWT and VO_{2max}).

Linear Regression Equation

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

VO_{2max} in l/min = ($5MPT_{power}$ – 7.9398)/36.637.

The corresponding equation for the young adults was:

VO_{2max} in l/min = ($5MPT_{power}$ – 16.37)/39.5.

No significant difference occurred for any subgroup between VO_{2max} 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_{2max} 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 $ml \cdot kg^{-1} \cdot min^{-1}$, 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_{2max} results. Here again, no significant variation appeared between directly measured VO_{2max} 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 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively).

Linear regression equations for calculating VO_{2max} levels, based on the results for each age group in $6MWT_{distance}$ and $6MWT_{body\ mass \cdot distance}$, 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_{2max} results (in $ml \cdot kg^{-1} \cdot min^{-1}$ or l/min). The only exception was for old males (r = 0.80 for VO_{2max} values in $ml \cdot kg^{-1} \cdot min^{-1}$ based on $6MWT_{distance}$).

Discussion

The newly developed five-minute pyramid test ($5MPT_{power}$) showed a very strong (0.98) and significant correlation with VO_{2max} (l/min) determined in a maximal cycle ergometer test. $5MPT_{power}$ was the only one of the present assessments which resulted in the overall strongest correlation with VO_{2max} (l/min). Neither $6MWT_{distance}$, $6MWT_{body\ mass \bullet distance}$ nor number of laps in the 5MPT showed such strong correlation with VO_{2max} among either old or young, females and males. Thus, the $5MPT_{power}$ can be useful in various public-health areas to predict maximal aerobic power in both old and young adults. The $5MPT_{power}$ test is much easier and more cost-effective than the maximal VO_{2max} test. Thus, advantages of the $5MPT_{power}$ 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_{2max} in physically active young men and women [16], which was also the case for 'our' physically active old females. Significant correlations between VO_{2max} and $6MWT_{distance}$ 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_{2max} and $6MWT_{distance}$ among men [11] and women [12].

However, we found a significant correlation with VO_{2max} for $6MWT_{distance}$ (0.80) and $6MWT_{body\ mass \bullet distance}$ (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 $6MWT_{body\ mass \bullet distance}$ showed stronger correlation than $6MWT_{distance}$ with VO_{2max} 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 $5MPT_{power}$ and VO_{2max} were even stronger (cf. above).

It has been claimed that $6MWT_{distance}$ 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_{2max} 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_{max} between the three main tests, no significant difference was noted between the 5MPT and the VO_{2max} 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_{2max} tests. Given the very strong correlation between the $5MPT_{power}$ and VO_{2max}, 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_{2max} was observed for the subgroup of YM. The other three subgroups had similar correlation coefficient levels (between $5MPT_{laps}$ and VO_{2max} in $ml \cdot kg^{-1} \cdot min^{-1}$) to those in the comparison of $5MPT_{power}$ and VO_{2max} (l/min). Thus, the $5MPT_{power}$ assessment was the most prominent of our examinations, showing for all subgroups an overall high significant correlation with VO_{2max}.

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_{2max} 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_{2max} and HR_{max} provides information about the physical fitness of 'our' tested older and younger adults.

The Six-Minute Walk Test

The $6MWT_{distance}$ 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 group aged 40–80 years and, among these, 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 [9]). In contrast, we found no significant gender difference for the $6MWT_{distance}$, but did so for $5MPT_{power}$ and VO_{2max}.

Maximal Oxygen Uptake

We performed pre-pilot studies to develop the best progression of workload in the present maximal 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 VO_{2max}, 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 VO_{2max}.

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

The values we found for OF and OM were 23 and 27 $ml \cdot kg^{-1} \cdot min^{-1}$ (1.5 and 2.2 l/min), respectively. Previous VO_{2max} 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 $ml \cdot kg^{-1} \cdot min^{-1}$ 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 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, aged 60–67 years [28]; 32 $ml \cdot kg^{-1} \cdot min^{-1}$ for men with mean age 75 years [29]). Moreover, we found for the old somewhat lower or the same VO_{2max} levels than in a normal population (25 and 27 $ml \cdot kg^{-1} \cdot min^{-1}$, for women and men, respectively, aged 60–65 years [25]).

Our elderly VO_{2max} 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 $ml \cdot kg^{-1} \cdot min^{-1}$ [7, 8, 13–15]).

Maximum HR

As expected, our RPE and HR_{max} values were significantly higher for all subgroups in the 5MPT and the VO_{2max} test than in the 6MWT. Previously, a significant difference was also found for HR_{max} between the VO_{2max} 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_{max} values than our participants in the VO_{2max} test (OF 155 and OM 165). For younger females and males, earlier published mean HR_{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_{max} values in the VO_{2max} test tended to resemble the latter levels best (YF 185 and YM 188). Previously published HR_{max} values in VO_{2max} tests for old people of ages corresponding to our data (range 64–79 years) are scarce, but reportedly 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_{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 $HR_{max} = 220 - age$.

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 $5MPT_{power}$ fitness test showed a very strong correlation with directly measured VO_{2max} for the entire group as well as for subgroups of old and young, male and female. Further, we observed no significant correlation for any subgroup between 6MWT and VO_{2max} except for old males; but then with a lower r value than between the $5MPT_{power}$ and VO_{2max}. 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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