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ORIGINAL ARTICLE

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Walking velocity measured over 5 m as a basis of exercise prescription for the elderly: preliminary data from the Nakanojo Study

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Abstract Moderate-intensity physical activity is recommended to promote health, and augment peak oxygen transport, thus reducing the risk of chronic disease, and delaying functional loss in the elderly. The optimal method of prescribing the recommended intensity of effort [approximately 50% of oxygen intake reserve ($\dot{V}O_{2reserve}$) or heart rate reserve ($HR_{reserve}$)] remains unclear for this age group. Our aim was to develop a new field-method of prescribing exercise for the elderly, based on walking velocity measured over a 5-m distance. Walking velocities were calculated from the time taken to move from the 3-m to the 8-m mark on an 11-m, straight, flat walkway. Interrelationships of preferred and maximal walking velocities with traditional laboratory measurements [peak isometric knee-extension strength and maximal oxygen intake ($\dot{V}O_{2max}$)] were examined in 10 healthy male and 13 healthy female volunteers, aged 65–74 years. Percentages of oxygen intake reserve ($\%\dot{V}O_{2reserve}$) and heart rate reserve ($\%HR_{reserve}$) were also determined when walking at 30–70% of maximal velocity. Preferred and maximal walking velocities were significantly correlated ($r > 0.60$; $P < 0.05$), the former corresponding to an average of 53–54% of the latter in both men and women. Maximal walking velocity was significantly correlated with both peak knee-extension torque ($r > 0.90$; $P < 0.05$) and $\dot{V}O_{2max}$ ($r > 0.80$; $P < 0.05$). As a result, the $\%\dot{V}O_{2reserve}$ and $\%HR_{reserve}$ showed a regular and linear relationship to various submaximal walking velocities. For both men and women, 40–60% of the maximal walking velocity corresponded to about 30–50% of $\dot{V}O_{2reserve}$ and $HR_{reserve}$. Approximately 60% of the maximal walking velocity (or 110–115% of the preferred walking velocity) represents an appropriate intensity of moderate exercise for the typical elderly person. Our preliminary data suggest that a prescription based on walking velocity over the 5-m distance allows the healthy elderly to exercise simply, safely, and effectively.

Keywords Maximal walking velocity · Peak knee-extension strength · Maximal oxygen intake · Oxygen intake reserve · Heart rate reserve

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Introduction

The directly measured maximal oxygen intake ($\dot{V}O_{2max}$) is correlated with the incidence of lifestyle-related diseases (Kurl et al. 2003; LaMonte et al. 2000; Oliveria et al. 1996; Wei et al. 1999a), all-cause (primarily cardiovascular disease and cancer) mortality (Blair et al. 1996; Church et al. 2001; Laukkanen et al. 2001; Lee and Blair 2002a, b; Wei et al. 1999b, 2000), and ability to perform aerobic activities (Aoyagi 1996; Aoyagi et al. 1997; McArdle et al. 1991; Shephard 1997). The increase of $\dot{V}O_{2max}$ by regular moderate-intensity physical activity is thus recommended for health promotion, disease prevention, and especially as a means of delaying functional loss in the elderly. In older individuals, the usual recommended intensity of activity corresponds to approximately 50% of the individual's oxygen intake reserve ($\dot{V}O_{2reserve}$) or heart rate reserve ($HR_{reserve}$) [50–60% of $\dot{V}O_{2max}$ or 60–70% of maximal heart rate (HR_{max})] (American College of Sports Medicine

1998a, b). However, the optimal method of regulating the intensity of effort in this age group remains unclear. In many settings, it is not feasible for older adults to perform a maximal exercise test, and the HR_{max} is estimated using the simple equation: $HR_{max} = 220-$age (in years). But neither a measured nor a predicted HR_{max} can be used in situations where the heart rate (HR) fails to show the anticipated increase with exercise (e.g., following cardiac transplantation, pacemaker implantation, treatment with beta-blocking drugs, or atrial fibrillation) (Shephard 1997). Ratings of perceived exertion (RPE) are also unsatisfactory because of the large variance in perceptions of a given intensity of effort in older persons (Shephard 1997).

The measurement of walking velocity (typically over <20-m distances or during a 6-min interval) has previously been suggested as a useful functional test in clinical settings. Numerous studies (Fiatarone et al. 1994; Hageman and Thomas 2002; Nagasaki et al. 1995a, b; Nelson et al. 1994) have reported that in the elderly the preferred or the maximal walking velocity is associated with performance on standardized tests of physical function, including strength and balance of the lower extremities, and perhaps less closely with $\dot{V}O_{2max}$. Many other investigations (Guralnik et al. 1995, 2000; Ostir et al. 1998; Penninx et al. 2000; Shinkai et al. 2000; Woo et al. 1999) have shown that lower-extremity function, including walking velocity, is a predictor for the subsequent development of disability, dependence in activities of daily living, institutionalization or hospitalization, and/or mortality in initially nondisabled older people.

The major purposes of this pilot research were: (1) to determine the relationships between preferred and maximal walking velocities as measured by our test and $\dot{V}O_{2max}$ in an elderly population, and (2) based on these results, to develop a new field-method of prescribing exercise for the elderly.

Methods

Subjects

Ten male and 13 female volunteers aged 65–74 years, members of the Tokyo Metropolitan Health Promotion Center, followed a protocol established and approved by the Human Ethics Committee of the Tokyo Metropolitan Institute of Gerontology. None of the participants had played sport or taken exercise on a regular basis, but all had been adequately habituated to the several tests of physical fitness (including walking on a treadmill) undertaken in the present study. A health history and clinical examination ensured that there were no medical contraindications to their participation. They were then informed of potential risks and discomfort, and signed a statement of informed consent. The experiments complied with the current laws of Japan in which they were performed.

Experimental protocol

Three separate laboratory visits were made under the same controlled conditions (time 1400–1500 hours; ambient temperature 20–22°C), with an interexperimental interval of 3 or more days.

On visit 1, measurements were made of preferred and maximal walking velocities over a 5-m distance, and peak isometric knee-extension strength. Subjects were asked to walk along an 11-m, straight, flat walkway, first at their usual, comfortable pace, and then as fast as possible. There were three trials for each type of walk, with 30-s intervening rest periods. The time taken to walk from the 3-m to the 8-m mark on the walkway was determined by electronic phototubes (Hamamatsu Photonics, Shizuoka, Japan); the averaged and the highest velocities were accepted as values for preferred and maximal walking velocities, respectively. Peak isometric knee-extension torque was determined on the dominant limb, at a joint angle of 90°, using a wire-strain-gauge dynamometer (μTas MF-01, Anima, Chofu, Tokyo, Japan), which had been extensively modified to ensure body stabilization and minimize synkinetic movements. Subjects kept their hands in their laps during measurements. They were allowed several submaximal familiarizing contractions, and then three definitive determinations of peak torque were made, with a 1-min rest between contractions. Torque was calculated as the product of force and the distance between the lateral malleolus (dynamometer) and the center of the knee joint.

On visit 2, resting oxygen intake ($\dot{V}O_{2rest}$), resting heart rate (HR_{rest}), $\dot{V}O_{2max}$, HR_{max}, and RPE at peak effort (RPE_{peak}) were determined. The oxygen consumption ($\dot{V}O_2$) was measured using a breath-by-breath system (Minato Medical Science, Osaka, Japan). HR was recorded continuously by means of a bipolar chest electrocardiogram (Fukuda Denshi, Bunkyo, Tokyo, Japan). Subjects sat for 30 min prior to maximal testing, and averaged values of $\dot{V}O_2$ and HR at minutes 27–30 were taken as $\dot{V}O_{2rest}$ and HR_{rest}, respectively. $\dot{V}O_{2max}$ and HR_{max} were determined by an incremental treadmill protocol (modified Harbor ramp test). Subjects began walking at an incline of 0% and their preferred walking velocity (1.13–1.57 $m\ s^{-1}$) as determined on visit 1. After 3 min, the treadmill grade was increased at first by 2% min^{-1}, decreasing to 1% min^{-1} as exhaustion was approached, normally attained within 12–15 min. $\dot{V}O_{2max}$ and HR_{max} were defined as the highest observed 10-s averages, based on attainment of a $\dot{V}O_2$ plateau (failure of $\dot{V}O_2$ to increase by 2 ml kg^{-1} min^{-1} with an increase in work rate), attainment of a respiratory exchange ratio >1.00, and/or the subject attaining the age-predicted HR_{max} (220−age); all 23 subjects achieved a true $\dot{V}O_{2max}$. A rating of overall perceived exertion (6–20 RPE units) was taken in the final minute of the test, this value being adopted as the RPE_{peak}.

On visit 3, $\dot{V}O_2$, HR, and RPE were tested during level treadmill walking at speeds increasing by 10%

every 3 min from 30% to 70% of the individual's maximal walking velocity (2.00–3.13 m s^{-1}), as determined on visit 1. $\dot{V}O_2$ and HR were monitored throughout the submaximal test, and values were averaged for the last 30 s of each 3-min submaximal period. RPE was reported immediately before each increase in treadmill speed. Relative work intensities were calculated: $\%\dot{V}O_{2max}$ as $\dot{V}O_2\ \dot{V}O_{2max}^{-1}$ (×100), $\%HR_{max}$ as HR HR_{max}^{-1} (×100), $\%\dot{V}O_{2reserve}$ as $(\dot{V}O_2-\dot{V}O_{2rest})\ (\dot{V}O_{2max}-\dot{V}O_{2rest})^{-1}$ (×100), and $\%HR_{reserve}$ as $(HR-HR_{rest})\ (HR_{max}-HR_{rest})^{-1}$ (×100).

Statistical analyses

Data are presented as means and standard deviations (SD). Paired or nonpaired *t*-tests were used as appropriate to compare the measured and age-predicted values of HR_{max}, and to analyze differences in measured variables between men and women. Interrelationships between anthropometric (age, height, and body mass), kinesiological (preferred and maximal walking velocities, and peak knee-extension torque), and physiological measures ($\dot{V}O_{2max}$, the measured and age-predicted values of HR_{max}) were tested by simple Pearson's correlation coefficients and least-squares linear regression analyses. All statistical contrasts were made at the 0.05 level of significance (Statistical Analysis System, SAS Institute, Cary, N.C.).

Results

Subject characteristics, physical fitness, and maximal treadmill data

Appropriate *t*-tests showed the anticipated differences in height and body mass between men and women ($P < 0.05$), but age and body mass index did not differ significantly between sexes (Table 1). Average values of preferred and maximal walking velocities, and $\dot{V}O_{2max}$ were significantly greater in men than in women (Table 1). The measured HR_{max} was significantly higher than values estimated by the commonly adopted age-prediction equation [by 12 (9) beats min^{-1} in men and 9 (6) beats min^{-1} in women; Table 1].

Correlation analyses

Significant, positive correlations were observed among walking velocities, measures of maximal strength and $\dot{V}O_{2max}$, with the exception of preferred walking velocity versus peak knee-extension torque (Table 2). $\dot{V}O_{2max}$ and HR_{max} were significantly and positively correlated only in men ($r = 0.838$). None of these five variables showed significant correlations with age in either men or women (all $|r| < 0.50$). Moreover, relationships between measured and age-predicted HR_{max} values were not statistically significant ($r = 0.150$ for men; $r = 0.267$ for women). Body mass was significantly and positively correlated with nonstandardized values of $\dot{V}O_{2max}$ expressed in liters per minute and peak knee-extension torque in newton meters (all $r > 0.80$), but relationships between height and preferred or maximal walking velocities were very weak, even when data for men and women were analyzed jointly (all $|r| < 0.20$).

Table 1 Physical, physiological, and psychological characteristics of subjects. Values are means (SD). *BMI* Body mass index, *$\dot{V}O_{2max}$* maximal oxygen intake, *HR_{max}* maximal heart rate, *RPE_{peak}* peak rating of perceived exertion; $n = 10$ and $n = 13$ for each variable in men and women, respectively, except for RPE_{peak} in men ($n = 9$) and women ($n = 12$)

	Men	Women
Age (years)	69 (3)	68 (3)
Height (m)	1.64 (0.05)	1.50 (0.05)*
Body mass (kg)	63.2 (7.1)	49.3 (5.2)*
BMI (kg m^{-2})	23.4 (1.9)	22.0 (2.2)
Preferred walking velocity (m s^{-1})	1.36 (0.14)	1.24 (0.08)*
Maximal walking velocity (m s^{-1})	2.62 (0.39)	2.29 (0.18)*
Preferred/maximal walking velocities (%)	52.6 (5.3)	54.4 (4.1)
Peak knee-extension torque (N m kg^{-1})	1.53 (0.43)	1.36 (0.23)
$\dot{V}O_{2max}$(ml kg^{-1} min^{-1})	35.8 (5.2)	30.5 (4.6)*
HR_{max}		
Measured (beats min^{-1})	163 (9)	161 (6)
Age-predicted (beats min^{-1})	151 (3)**	152 (3)**
RPE_{peak}	17 (2)	16 (1)

*Significantly different from male value ($P < 0.05$)
**Significantly different from measured value ($P < 0.05$)

Regression analyses

Neither the intercept nor the slope of the positive regression lines relating peak knee-extension torque to maximal walking velocity differed significantly between men and women. Thus, this relationship remained unchanged when data for men and women were analyzed jointly (Fig. 1). On the other hand, the slope of the positive regression line of $\dot{V}O_{2max}$ versus maximal walking velocity was twice as large in women as in men.

Table 2 Pearson's correlation coefficients between preferred and maximal walking velocities, peak knee-extension torque, and $\dot{V}O_2$max. *Lower-left values* Men ($n = 10$), *upper-right values* women ($n = 13$)

	1	2	3	4
1. Preferred walking velocity	–	0.637*	0.448	0.655*
2. Maximal walking velocity	0.727*	–	0.901*	0.873*
3. Peak knee-extension torque	0.495	0.924*	–	0.790*
4. $\dot{V}O_{2max}$	0.750*	0.808*	0.744*	–

*Significant value ($P < 0.05$)

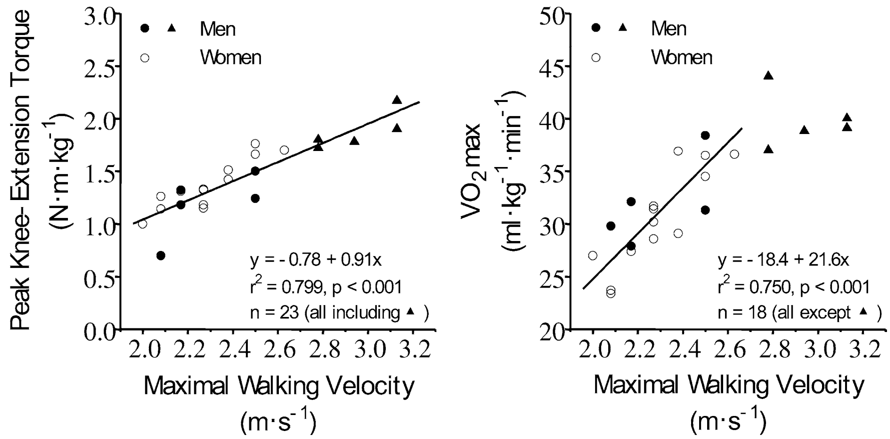

Fig. 1 Relationships between maximal walking velocity and peak knee-extension torque or maximal oxygen intake ($\dot{V}O_{2max}$). Combined data for men ($n = 10$) and women ($n = 13$). ▲; Data from five men who had both a maximal walking velocity ≥2.78 m s^{-1} and a $\dot{V}O_{2max}$ ≥37.0 ml kg^{-1} min^{-1}

Nevertheless, when data for men and women were pooled, no sex difference in the relationship between dependent and predictor variables was found, at least within the range (2.00–2.63 m s^{-1}) of maximal walking velocities common to male and female subjects (Fig. 1).

Submaximal treadmill data

Over the range from 40% to 60% of maximal walking velocity, each of the cardiovascular variables tested (%$\dot{V}O_{2reserve}$, %$HR_{reserve}$, %$\dot{V}O_{2max}$, and %HR_{max}) increased linearly with relative intensity of effort, almost all values at a given velocity being within < ± 5% of the mean (Table 3 and Fig. 2). On the other hand, when walking at 30% and 70% of maximal velocity, each of the cardiovascular variables showed a relatively large variance (Table 3 and Fig. 2). Furthermore, values for these variables tended to be smaller in men than in women at low relative walking velocities, and to be larger in males at high relative walking velocities. The RPE also showed large interindividual differences, especially in women (Table 3 and Fig. 2).

Table 3 Percentages of $\dot{V}O_{2max}$ (%$\dot{V}O_{2max}$), HR_{max} (%HR_{max}), oxygen intake reserve (%$\dot{V}O_{2reserve}$), and heart rate reserve (%$HR_{reserve}$), and RPE when exercising at 30–70% of maximal walking velocity. Values are means (SD), $n = 10$ for each variable in both men and women, except for RPE in women ($n = 12$)

	Percentage of maximal walking velocity (men)				
	30	40	50	60	70
	Percentage of maximal walking velocity (women)				
	30	40	50	60	70
%$\dot{V}O_{2max}$	33 (5)	37 (3)	45 (3)	56 (3)	68 (4)
%HR_{max}	53 (6)	57 (5)	63 (4)	70 (3)	83 (6)
%$\dot{V}O_{2reserve}$	24 (5)	29 (3)	38 (3)	48 (4)	64 (5)
%$HR_{reserve}$	22 (6)	28 (4)	39 (3)	49 (4)	70 (11)
RPE	8 (1)	9 (1)	10 (1)	12 (1)	14 (2)
%$\dot{V}O_{2max}$	38 (4)	42 (4)	50 (3)	56 (3)	68 (5)
%HR_{max}	59 (3)	62 (3)	67 (2)	71 (2)	79 (4)
%$\dot{V}O_{2reserve}$	29 (4)	33 (3)	42 (3)	50 (3)	63 (5)
%$HR_{reserve}$	28 (6)	33 (5)	42 (5)	50 (3)	64 (7)
RPE	9 (2)	9 (2)	10 (2)	10 (1)	12 (2)

Discussion

The intent of this pilot research was to explore relationships between preferred and maximal walking velocities as measured over a short (5 m) distance and

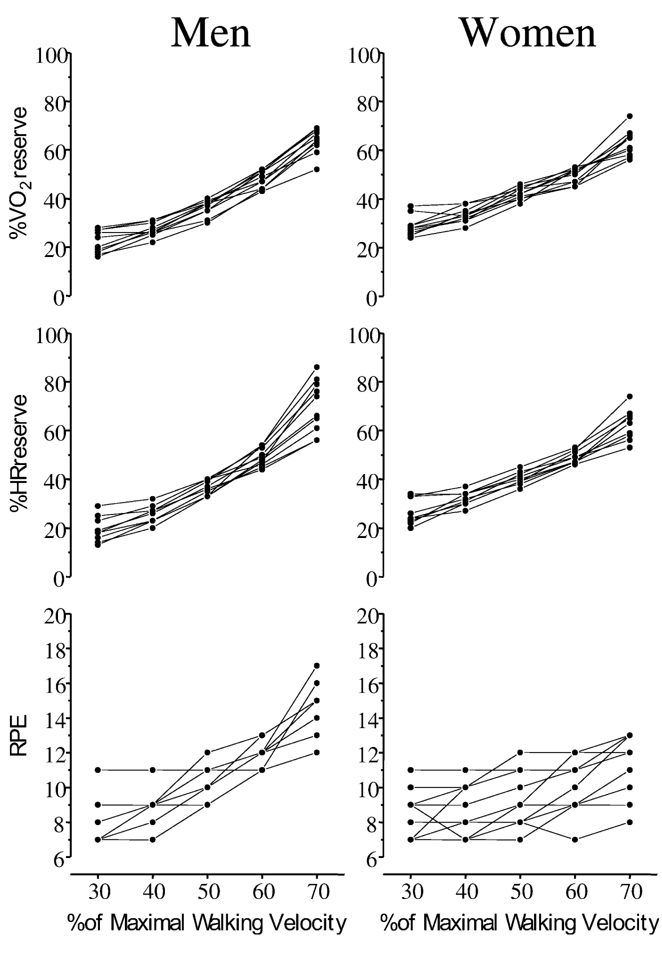

Fig. 2 Percentages of oxygen intake reserve (%$\dot{V}O_{2reserve}$) and heart rate reserve (%$HR_{reserve}$), and rating of perceived exertion (*RPE*) when exercising at 30–70% of maximal walking velocity. Individual data for both sexes, $n = 10$ for each variable in both men and women, except for RPE in women ($n = 12$)

$\dot{V}O_{2max}$ in an elderly population, and based on the findings, to develop a new field-method of prescribing exercise for this age group. The data from our pilot trial suggest that either maximal or preferred walking velocity offers a simple, safe, and effective method to regulate the intensity of aerobic exercise.

Walking velocity and $\dot{V}O_{2max}$

Muscle strength and cardiorespiratory endurance cannot normally be evaluated by any single common test, since the physiological factors limiting the two components of physical fitness usually differ (Aoyagi 1996; Aoyagi and Katsuta 1990; Aoyagi and Shephard 1992; Aoyagi et al. 1997). However, the present results demonstrate that in older people, maximal walking velocity is an indicator of both peak knee-extension torque and $\dot{V}O_{2max}$. This is in keeping with earlier work by Nagasaki et al. (1995a, b), who noted significant correlations between walking and several physical-performance measures (strength, balance, flexibility, and/or stamina) in Japanese people aged 61–89 years. The maximal walking velocity of our subjects over the 5-m distance was higher than would be tolerated in the traditional 6-min walk. Nevertheless, our observations show a statistically significant correlation between preferred and maximal walking velocities, the former corresponding to 53–54% of the latter, irrespective of the individual's sex. Since the maximal walking velocity is correlated with $\dot{V}O_{2max}$, our subjects may have chosen to walk at a speed determined by their physical fitness. Thus, if a person's preferred walking velocity is low, it is likely that his or her physical fitness also is poor.

Determination of an appropriate intensity of exercise on the basis of walking velocity

The present data highlight problems associated with the development of exercise prescriptions based on predicted HR_{max} values in the elderly. The commonly accepted formula often underestimates the true HR_{max} by a substantial margin, and the prescribed intensity of effort is thus too low for health benefit. Mazzeo and Tanaka (2001) have suggested that the regression equation $HR_{max} = 208-(0.7\times age)$ may be more appropriate for apparently healthy elderly individuals; however, their equation would again underestimate the true HR_{max} in our subjects. There are also problems in basing a prescription upon RPE. In our study, despite the subject's exhaustion and/or the fact that $\dot{V}O_2$ and HR had reached a steady state at the end of the maximal treadmill test, the average RPE_{peak} was only 17 for men and 16 for women. The gap between physiological indices of exercise intensity and reported perceptions was also seen during submaximal exercise.

We saw a strong correlation between maximal and preferred walking velocities, and $\dot{V}O_{2max}$ in both men and women. As a result, the $\%\dot{V}O_{2reserve}$ and $\%HR_{reserve}$ used by our subjects showed a consistent linear relationship to submaximal walking velocities over the central range. In both men and women, 40–60% of the maximal walking velocity corresponded to about 30–50% of $\dot{V}O_{2reserve}$ (around 40–60% of $\dot{V}O_{2max}$) and $HR_{reserve}$ (around 60-70% of HR_{max}). Thus, approximately 60% of the maximal walking velocity (or 110–115% of the preferred walking velocity) is an appropriate intensity of moderate exercise to prescribe for elderly individuals. When walking at 30% and 70% of maximal velocity, the relationships were less consistent; cardiovascular variables showed unacceptably large sex and interindividual differences, possibly reflecting differences in the mechanical efficiency of walking. It may be that 30% of maximal velocity was an uncomfortably slow speed of walking for some subjects, and that 70% of maximal speed was too fast for others, in both cases leading to exaggerated energy expenditures. We also noted relatively large interindividual differences in the relationship between submaximal walking velocities and RPE. Especially in women, a moderate rating (12 RPE units) underestimated the intensity of effort by $>10\%$ relative to physiological indicators. Therefore, considerable caution must be shown if attempts are made to use the RPE as a basis of prescribing exercise for the elderly.

The applicable range of the new method for determining exercise intensity

Maximal walking velocity and peak knee-extension torque were strongly correlated, whether data for men and women were examined separately or jointly. This observation supports previous studies (Fiatarone et al. 1994; Hageman and Thomas 2002; Nagasaki et al. 1995a; Nelson et al. 1994), which have suggested that the walking velocity of the elderly depends on lower-extremity muscle strength, irrespective of training status. There were some sex differences in the relationship between maximal walking velocity and $\dot{V}O_{2max}$. However, if data from all subjects except five men who had both a maximal walking velocity ≥ 2.78 m s^{-1} and a $\dot{V}O_{2max}$ ≥ 37.0 ml kg^{-1} min^{-1} were analyzed, the resulting correlation coefficient was similar to that obtained for women alone. Possibly a few of the fitter men retained the specificity of fitness (muscle strength vs cardiopulmonary function) typical of younger adults. Certainly, the present results suggest that either the maximal or the preferred walking velocity can provide an appropriate basis for exercise prescription in the large majority of elderly individuals whose maximal walking velocity is <2.78 m s^{-1} (10.0 km h^{-1}).

Possibility of sampling and measurement bias

A relatively small sample was tested in this pilot trial. Subjects were on the average in their late sixties, and were typical healthy elderly men and women with modest levels of physical fitness (Aoyagi and Katsuta 1990). Our observations should now be repeated, to cover a wider range of ages and physical condition. The energy cost of walking on a treadmill at the range of submaximal speeds examined in this study matches that of walking on a hard surface at the same speeds (McArdle et al. 1991), so we are confident that the present findings can be applied to the prescription of normal daily walking. Our results support the concept that laboratory data can be used to quantify human energy expenditures in normal daily walking.

Conclusions

The data from this pilot trial suggest that the use of either maximal or preferred walking velocity offers the healthy elderly person a simple, safe, and effective method to regulate the intensity of aerobic exercise. An appropriate intensity of moderate aerobic exercise for the average elderly individual is indicated by approximately 60% of maximal walking velocity (or 110–115% of preferred walking velocity). Further study is needed to increase subject number, and to examine how far these relationships are true for elderly individuals with exceptionally high levels of aerobic fitness and for those whose aerobic function is compromised by chronic disease or disability.

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