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Aerobic reserve and physical functional performance in older adults

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Abstract

Background: older adults can be limited in their performance of daily tasks due to an inadequate aerobic capacity. Aerobic capacity below minimum physiological thresholds required to maintain independence leaves older adults with little, or no, aerobic reserve.

Objective: the aim of this study was to measure functional performance and aerobic reserve in older adults during the serial performance of daily tasks.

Subjects: twenty-nine ($n = 29$) men and women ($n = 23$females) 70−92 years of age participated in this study.

Methods: performance based physical function was assessed using the Continuous-Scale Physical Functional Performance test (CS-PFP). A Cosmed K4b$^{2\text{TM}}$ portable metabolic system was used to measure VO_{2PEAK} and oxygen uptake during the serial performance of a battery of daily tasks (VO_{2PFP}). Aerobic reserve was calculated as the difference between VO_{2PEAK} and VO_{2PFP}.

Results: the correlation coefficient between aerobic reserve and functional performance was $r = 0.50 (P = 0.006)$. Participants utilized 32.2 ± 8.1%, 42.7 ± 10.8%, and 50.3 ± 12.3% of VO_{2PEAK} for the low, moderate, and high workloads of the CS-PFP, respectively.

Conclusions: light housework and carrying groceries require 40 to 50% of peak oxygen consumption. This information can be used by clinicians and health professionals working with older adults as a guide to how much aerobic fitness is needed to perform ADLs and maintain independence. These can then be used as guides for assessment and for setting training goals in older adults.

Keywords: *VO_{2PEAK}, CS-PFP, threshold, daily tasks, elderly*

Aerobic capacity between 18 and 20 ml/kg/min [1–3] has been defined as an aerobic threshold below which there is a reduced probability of living independently [1]. For each milliliter of oxygen uptake below the threshold, there is an associated 8-fold decline in physical function [1]. Once above the threshold, higher aerobic capacity provides an aerobic reserve, and thus a margin of safety for discretionary activities such as active leisure activities [4]. Older adults with little or no aerobic reserve may be perilously close to, or fall below, minimum physiological thresholds required to perform daily tasks [5].

It is more practical and sensible to measure the work of intermittent activities rather than single, isolated activities [6]. To sustain daily function, particularly by those with limited aerobic capacity, tasks are punctuated by rest breaks [6]. The continuous-scale physical functional performance (CS-PFP) test mimicking the performance of functional tasks in daily life is associated with the probability of living independently [1]. Understanding the aerobic cost of serial performances of daily tasks mimicking real-life situations relative to aerobic capacity may provide insights into the importance of an individual's aerobic capacity and reserves for independent living.

The purpose of this article was to determine (i) the oxygen cost of physical function, (ii) aerobic reserve, and (iii) capacity of physical functional performance. We hypothesised that older adults with higher aerobic reserves will have a higher physical functional performance capacity.

Methods

Participants

Participants were recruited from local social groups, assisted living facilities and using public service announcements on the radio. Forty-four older men and women were recruited to participate in this study of which seven were not medically cleared and seven chose not to participate for personal reasons. One participant's data file was eliminated due to data corruption, resulting in a final sample of 29 participants (23 females), representing 66% of the original sample. Testing was conducted on three separate days with a minimum of two rest days between each day of testing. Exclusion criteria were evaluated by their personal physician based on the following criteria: uncontrolled cardiovascular disease; uncontrolled diabetes; vigorous, aerobic exercise more than 3 days/week, 30 min/session; recent bone fracture or joint replacement; diseases with a variable course (e.g. rheumatoid arthritis); severe osteopenia; cardiovascular intolerance to exercise; severe psychiatric illness; and severe hypertension. This study was approved by the Institutional Review Board of the University of Georgia and all participants provided written informed consent.

Performance-based physical function

Physical function was assessed during the first visit using the CS-PFP test, which has established validity and reliability [7]. The CS-PFP protocol and scoring system have been published elsewhere [8] and on the Web at http://www.coe.uga.edu/cs-pfp/. A brief description is included here for the reader's convenience. The CS-PFP protocol includes a standard dialogue and environment for the administration of 16 daily life tasks, quantified by time, distance and weight. Participants were instructed to perform the test at maximal effort within the bounds of safety and comfort. Tasks reflective of the domains of upper body strength (UBS), upper body flexibility (UBF), lower body strength (LBS), balance and coordination (BALC), and endurance (END), as determined using a modified Delphi procedure [8], are scaled from 0 to 100 and averaged to provide domain scores. The CS-PFP yields a total summary score (CS-PFP total), which is the average of all variables [8]. The sum of time taken to complete all timed tasks was PFP-TIME. Performance data were scored using the Web-based data reduction program at http://www.coe.uga.edu/cs-pfp. The CS-PFP tasks are separated into workload categories based on the difficulty of each task as shown in Table 3. On a separate visit, participants performed a modified version of the CS-PFP (CS-PFP$_{MOD}$) in order to measure oxygen uptake while performing activities of daily living. The CS-PFP$_{MOD}$ protocol is described in the section Oxygen Cost of Standardised Load Physical Functional Performance (VO_{2PFP}), below.

Peak oxygen uptake (VO_{2PEAK})

During the second visit, VO_{2PEAK} was measured with a Cosmed K4b^2 portable metabolic system (Cosmed S.R.L., Rome, Italy) during a modified Balke continuous, incremental treadmill protocol [9]. The Cosmed K4b^2 portable metabolic system was used to collect continuous, breath-by-breath values for oxygen uptake through indirect calorimetry. At rest and over a range of exercise intensities, the Cosmed K4b^2 has been shown to provide similar values of oxygen uptake, carbon dioxide production, minute ventilation and respiratory exchange ratio (RER) as those obtained by the Douglas bag method or a metabolic unit [10, 11]. Calibration of the Cosmed K4b^2 was conducted prior to each test following the manufacturer's guidelines [12].

Participants were familiarised with the face mask and walking on the treadmill, separately, prior to the VO_{2PEAK} test. To determine the pace for the test, participants were instructed to walk at their fastest, comfortable pace during a 2 min warm-up. The treadmill grade was increased 2–3% every 2 min while speed remained at the participants' fastest, comfortable pace (range $= 1.2–4.0$ mph, mean $\pm$ SD $= 2.5 \pm 0.7$ mph). A 12-lead Quinton 4000 (Quinton 4000, Bothell, WA) electrocardiogram was monitored by a cardiologist, and heart rate, blood pressure and rating of perceived exertion (RPE) (Borg scale 6–20) were collected at the end of each 2 min stage. Test termination occurred when participants reached volitional fatigue or demonstrated symptoms of cardiovascular incompetence according to ACSM guidelines [13]. The highest 30 s average VO_2 achieved during the treadmill test was considered VO_{2PEAK}. The value was determined by calculating the average of all breaths during the last 30 s period of a stage. Two of the following three criteria are often used to establish maximal effort: (i) a maximum heart rate within ± 10 beats of age-predicted maximum heart rate [14], (ii) an respiratory exchange ratio (RER) value >1.0 [15], and/or (iii) a RPE of 18 or higher on the Borg 6–20 scale [14, 16]. VO_{2PEAK} was used as none of the participants in this study demonstrated a plateau in oxygen uptake during the test. However, 69% ($n = 20$) achieved the maximal heart rate criterion, 55% ($n = 16$) achieved the RER criterion, and 79% ($n = 23$) achieved the RPE criterion with 93% ($n = 27$) of all participants meeting at least one criterion.

Oxygen cost of standardised load physical functional performance (VO_{2PFP})

During the third visit, the Cosmed K4b^2 measured oxygen uptake during performance of the CS-PFP$_{MOD}$. CS-PFP$_{MOD}$ is used to distinguish the administration of the modified version of the CS-PFP used during assessment of oxygen uptake during performance of functional tasks from the original CS-PFP [8]. To standardise the workload across subjects, a standardised weight was used for the three tasks labelled 'b' in Table 3. The weight was determined by taking the lowest quartile of weight carried by older adults in previous research [7]. A 3 min walk at the participant's usual pace was substituted for the 6 min walk as normal pace is the most efficient (lowest oxygen uptake), reproducible, and individualised [17]. Donning and removing a jacket was omitted because the Cosmed K4b^2 unit was worn on the torso. Collection and analyses of gas volumes and composition were carried out using the same procedures previously described for the VO_{2PEAK} test.

VO_{2PFP} and aerobic reserve analysis

Erratic zero values within the VO_2 data were replaced with the average of the data point immediately before and after each zero, and a moving window average (window size = 11 data points) was used to smooth the VO_2 data. Group analysis of VO_2 data was performed utilising three methods: (i) VO_{2PFP} was determined by averaging VO_2 from the first task until completion of the last task, including VO_2, between tasks of the $CS\text{-}PFP_{MOD}$; (ii) low, moderate, and high was determined by averaging VO_2 measured from the beginning of the first task for each workload to the beginning of the first task of the next workload of the $CS\text{-}PFP_{MOD}$; and (iii) average VO_2 for each task was determined where VO_2 was averaged from the beginning of one task to the beginning of the next task of the $CS\text{-}PFP_{MOD}$. VO_{2PFP} and the average VO_2 of each workload (low, moderate and high) were calculated as a percentage of VO_{2PEAK}. Aerobic reserve PFP (AR-PFP) was determined by subtracting VO_{2PFP} from VO_{2PEAK} (VO_{2PEAK}—VO_{2PFP}).

Statistical analysis

Analyses were performed using SPSS for Windows (Version 14.0, SPSS Inc., Chicago, IL). Independent samples t-test were used to determine differences between males and females on selected characteristics and physiological and functional performance variables. Levene's and Bonferroni adjustments ($\alpha = 0.005$) were used when necessary. VO_{2PEAK}, VO_{2PFP} and CS-PFP total data were evaluated for normality. Pearson's product moment correlation was calculated to evaluate the association between age and VO_{2PEAK} and CS-PFP total and the association of AR-PFP and the following variables: END, CS-PFP total, and PFP-TIME. A point biserial correlation coefficient (r_{pb}) was calculated to evaluate the relationships between living status and the variables mentioned previously. An α level of 0.05 was used to denote significance on correlation analyses.

Results

Selected characteristics of the participants are reported in Table 1. The age of the participants in this study ranged from 70 to 92 years. Females represented 79% ($n = 23$) of the sample, and 17.2% were residents of a retirement community. The sample was generally free of prescribed medications (76.6%) or on one medication (23.4%). CS-PFP total and domain scores are reported in Table 1. Except for height (men = 175.1 ± 9.2 cm; women = 160.5 ± 7.5 cm; $P<0.001$), data from men ($n = 6$) and women ($n = 23$) were not statistically different. All means, standard deviations and correlations reported include data from both males and females.

Table 1. Means ± SD of selected characteristics and continuous-scale physical functional performance characteristics

	Mean ± SD
Age (years)	76.2 ± 6.2
Height (cm)	163.5 ± 9.8
Weight (kg)	70.8 ± 10.8
BMI	26.55 ± 4.1
Independent	82.8%
CS-PFP total	52.1 ± 12.7
UBS	60.8 ± 11.1
LBS	44.6 ± 12.8
UBF	70.1 ± 11.9
BALC	47.5 ± 15.0
END	53.1 ± 14.3

SD, standard deviation; independent, detached single-family dwelling or apartment; CS-PFP total, continuous-scale physical functional performance total score; UBS, upper body strength; LBS, lower body strength; UBF, upper body flexibility; BALC, balance/coordination; END, endurance; CS-PFP total, UBS, LBS, UBF, BALC, and END are scored out of a total 100 possible points.

The data appeared to have normal distributions for VO_{2PEAK}, VO_{2PFP}, and CS-PFP. Selected physiologic characteristics of the group are listed in Table 2. Average oxygen uptake and the percent of VO_{2PEAK} increased with the workload level of the $CS\text{-}PFP_{MOD}$. The oxygen uptakes of individual tasks performed during the $CS\text{-}PFP_{MOD}$ protocol are presented in Table 3.

Correlations between AR-PFP and END, CS-PFP total, and PFP-TIME were $r = 0.45$ ($P<0.05$), $r = 0.50$ ($P<0.01$), and $r = -0.43$ ($P<0.05$), respectively. The correlation between living status (living status -1 = assisted living, 2 = community dweller) and CS-PFP total was $r_{pb} = 0.52$ ($P<0.01$). Age was significantly related to both VO_{2PEAK} and CS-PFP total, $r = -0.62$ and -0.50, respectively.

Table 2. Means ± SD of selected physiologic characteristics

($n = 29$)		VO_2 (ml/kg/min)	Percent of VO_{2PEAK} (%)
VO_{2PEAK}		19.8 ± 6.3	
VO_{2PFP}		7.5 ± 1.4	40.3 ± 9.8
AR-PFP		12.2 ± 5.7	
Workload	Low	6.0 ± 1.0	32.2 ± 8.1
	Moderate	8.0 ± 1.6	42.7 ± 10.8
	High	9.4 ± 1.8	50.3 ± 12.3

SD, standard deviation; VO_{2PEAK}, peak oxygen uptake; VO_{2PFP}, average oxygen uptake for all tasks of modified CS-PFP; percent of VO_{2PEAK}, VO_{2PFP} as percentage of VO_{2PEAK}; AR-PFP, VO_{2PEAK}—VO_{2PFP}; workload, average oxygen uptake for tasks of the low, moderate, and high workloads of the modified CS-PFP.

Table 3. Workload, task, and measurement categorisation of the CS-PFP* and average VO_2[a] during performance of the modified CS-PFP and values reported for specific tasks

Workload	Task	Measurement	VO_2 (ml/kg/min) MOD CS-PFP	VO_2 (ml/kg/min) Reported data
Low	Weight carrying	Weight[b], time	5.2 ± 1.2	
	Pouring	Time	5.9 ± 1.1	
	Shoe strapping	Time	5.6 ± 1.0	
	Scarves wrapping	Time	6.4 ± 1.2	
	Reaching	Distance	6.8 ± 1.4	
Moderate	Floor sweeping	Time	7.3 ± 1.6	8.8[c], 11.4[d], 11.7[g]
	Laundry 1	Time	8.2 ± 1.8	7.0[c]
	Laundry 2	Time	8.1 ± 1.7	
	Bed making	Time	10.0 ± 2.0	7.0[c]
	Vacuuming	Time	8.0 ± 1.6	12.3[c], 9.8[d], 10.4[g], 8.1–8.9[e]
	Floor down/up	Time	8.2 ± 1.4	
	Fire door	Time	6.8 ± 1.6	
High	Bus	Weight[b], time	9.2 ± 1.7	
	Groceries	weight[b], time	10.8 ± 2.4	8.8[c], 11.4[d], 11.7[g]
	Stair climbing	Time	9.6 ± 1.8	
	Usual pace walking (3 min)	Distance	8.3 ± 2.4	8.8[f]

* CS-PFP, continuous-scale physical functional performance test.
[a] VO_2 values include performance of the task and the time between tasks (generally standing, listening to instruction).
[b] $CS\text{-}PFP_{MOD}$, modified CS-PFP (weight standardised for each task using weight in the CS-PFP; weight carrying, 14.75 lbs; bus, 12 lbs; and groceries, 14 lbs), reported data from [c] [18, 19], [d] [20], [e] [21], [f] [17], and [g] [22]. Values for this study are reported as means ± standard deviation and means from reported literature are listed.

Discussion

The principle finding of this study was that higher aerobic capacity provided a greater aerobic reserve, which in turn, was associated with higher physical functional performance capacity in older adults. A higher aerobic reserve provides older adults with a larger margin of safety [4], which may ultimately attenuate functional decline, preserving independence.

A higher aerobic reserve allowed the older adults in this study to use a lower percentage of VO_{2PEAK} for functional performance (Table 2). The percentage of oxygen uptake elicited during the moderate and high workload levels (Table 2) are above the 40% intensity reported [6] as a sustainable workload throughout the day. Each workload, moderate and high, reflects an average oxygen uptake increase of 7.6–10.5% of VO_{2PEAK} (Table 2). A higher aerobic reserve allows older adults to do more throughout the day without encroaching upon their maximal aerobic capacity. These findings can be used to understand how changes in living status could affect the functional performance of older adults. For example, typical services provided by retirement communities range from weekly linen services to light housekeeping, eliminating the need to perform the moderate and high workload tasks included in the CS-PFP. Reducing the number of tasks that require strength can exacerbate declines in muscle mass and strength [3]. Without light housekeeping services the daily energy demand is lowered between 10 and 18% (from Table 2). Since the low workload tasks, on average, required only 6 ml/kg/min, or 32% of VO_{2PEAK}, older adults living in these facilities should be aware of the need to engage in moderate intensity activities to maintain minimum recommended aerobic activity levels. Moderate-intensity walking and resistance training programmes have led to improvements in VO_{2PEAK} [23] and physical function [8, 23–27]. Maintaining an aerobic reserve may decrease functional limitations and delay the onset of dependence. In older adults, a positive correlation exists between aerobic capacity and daily physical activity [28]. Thus, older adults with a large aerobic reserve are more likely to have discretionary energy, which may allow them to engage in activities of interest and perform tasks necessary to maintain independence.

Recently published guidelines for physical activity for older adults recommend a systematic, well-rounded exercise programme in addition to routine activities of daily living that may include chores of light or moderate intensity [27]. Data presented here provide evidence that light household tasks and carrying groceries require moderate (40–60%) [13] aerobic intensity. The normal day consists of linking together multiple tasks and performing them consecutively while incorporating small intermittent breaks [6]. A systematic and scientific exercise programme where the heart rate is continuously elevated for thirty or more minutes a day could result in a significant increase in VO_{2PEAK}, and therefore, better aerobic reserve. In this way, the aerobic cost of household chores becomes a lower percentage of the overall aerobic capacity, and therefore, requires less effort.

Previously reported oxygen uptake values for performance of daily tasks are similar to those reported for the $CS\text{-}PFP_{MOD}$ (Table 3, marked) [18–22]. Average VO_2 of the five values for the tasks labelled ‘c’ in Table 3 (8.8 ± 2.2

ml/kg/min) appears to be similar to the average VO_2 for comparable tasks in the CS-PFP$_{MOD}$ (8.9 ± 1.5 ml/kg/min). Average oxygen uptake for tasks in the moderate workload (8.0 ± 1.6 ml/kg/min, Table 3) are slightly lower than the average for similar tasks reported in the literature (9.7 ± 0.7 ml/kg/min, Table 3), with high workload tasks (9.4 ± 1.8 ml/kg/min, Table 3) also slightly lower than tasks reported in the literature (Table 3) (11.2 ± 2.4 ml/kg/min). Differences in VO_2 values for individual tasks may be attributed to differences in task execution and administration (e.g. muscle group used; vacuum model). The CS-PFP$_{MOD}$ tasks are administered to reflect how tasks are performed in daily life, short, non-steady state activities. Rest periods between tasks of the CS-PFP$_{MOD}$ most likely decreased the average VO_2 value. However, the tasks labelled 'c' in Table 3, which had a higher average VO_2 value, were performed for three or more minutes in order to achieve steady state oxygen uptake. Understanding the aerobic cost of serially performed tasks can provide researchers with insight into how much aerobic fitness is needed to optimise the living arrangements for older adults as aerobic capacity wanes in the later years of life.

While the mechanisms for age-related decreases in aerobic capacity are not fully understood, evidence from animal [29] and human [30–32] research supported that muscle taken from older research subjects had the capacity to make large energetic changes in response to both endurance and resistance training. Peripheral oxygen carrying capacity is improved with increases in the capillary-to-fibre ratio [30, 32] and increased blood flow to the working muscle at both maximal and sub-maximal capacities [33] may account for the improved performance in those with adequate aerobic reserve.

Some of the limitations of this study include the mask of the Cosmed K4b^2 unit that may interfere with vision during tasks such as sweeping the floor or climbing the stairs, which can lengthen the time taken to complete the task. The ability to generalise this research is limited to the mostly Caucasian female sample used in this study. However, it should be noted that the CS-PFP scores of this group are comparable to scores from previous research samples [34, 35]. Future investigations could implement training interventions to determine the effect of increased physical activity on aerobic reserve, functional performance and discretionary energy in older adults.

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Key points

- In older adults, performance of daily tasks requires between 30 and 50% of aerobic capacity.
- Maintaining an aerobic capacity of 20 ml/kg/min allows for moderate and high workload tasks to be performed with 50% of aerobic capacity in reserve.
- Higher aerobic reserves may provide more discretionary energy for work and leisure over and above that required to perform household tasks.

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Conflict of interests

The authors of this article have no conflicts of interest in sources of funding or provenance of laboratory or biochemical equipment.

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