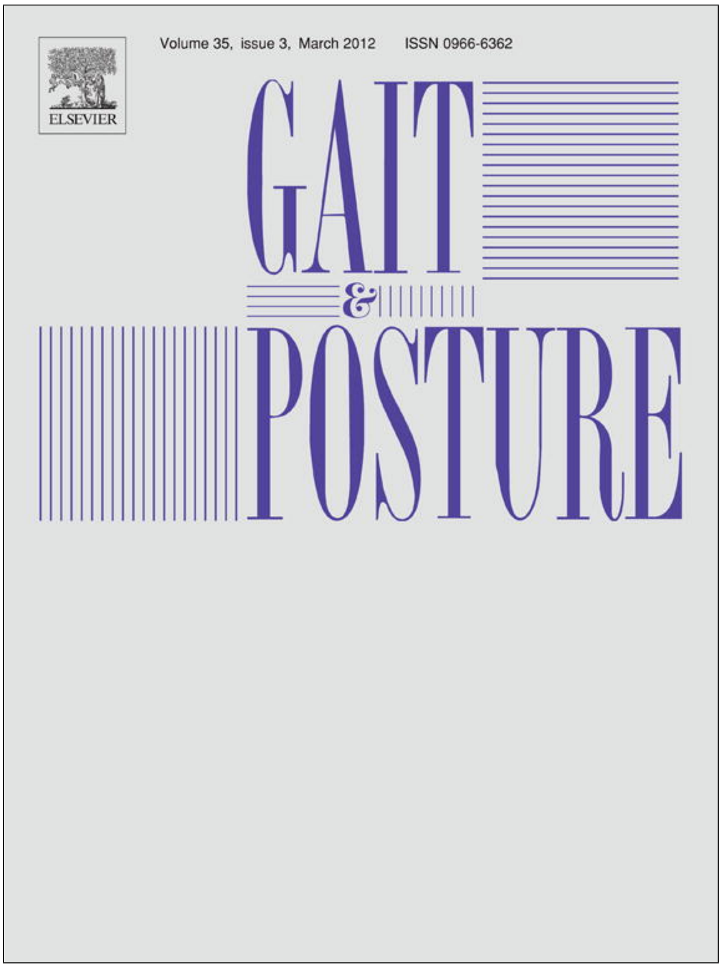
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The improvement of walking speed after cardiac rehabilitation is associated with the reduction in the metabolic cost of walking in older persons

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ABSTRACT

Background: To walk a given distance older persons consume more metabolic energy than younger adults across all speeds. As physical activity interventions improve a variety of physical performance measures in older persons, including walking speed, in this study we hypothesized that the improvement of walking speed might be associated with the reduction of the metabolic cost of walking and we tested our hypothesis in a selected sample of older patients receiving cardiac rehabilitation.
Methods: In 120 patients (88 men and 32 women, mean age 74.1 years ± SD 5.0) we assessed energy expenditure during the 6-min Walk Test (6mWT) before and after the rehabilitation using a portable system for direct calorimetry.
Results: On the 6mWT performed after the rehabilitation patients significantly increased total energy expenditure (28.0 kcal ± SD 8.3 vs. 25.7 kcal ± SD 7.6, $p < 0.001$), the distance walked (398 m ± SD 93 vs. 343 m ± SD 95, $p < 0.001$) and, consequently, walking speed (1.11 m/s ± SD 0.26 vs. 0.95 m/s ± SD 0.26, $p < 0.001$) while the metabolic cost of walking, i.e. the amount of energy used to move a body mass of 1 kg for a distance of 1 m, was significantly reduced (1.00 cal/kg/m ± SD 0.19 vs. 1.11 cal/kg/m ± SD 0.32, $p < 0.001$).
Conclusions: In older patients receiving cardiac rehabilitation the improvement of walking speed is associated with the improvement of walking economy. This might be a contributory factor to the favourable effects of physical activity interventions on physical performance measures.

1. Introduction

Walking is the most natural form of physical activity. It is critical to maintain independence in activities of daily living, to enjoy social relationships and to retain good emotional vitality, all of which are main determinants of quality of life, particularly in older persons [1]. Further, this natural form of physical activity also provides older persons with extensive benefits in terms of morbidity and mortality [2]. However, people walk progressively less with advancing age, even in the absence of chronic functional impairments [1].

In terms of kinematics, older persons, as younger adults, also tend to select a preferred speed of walking at or near the speed at which energy expenditure is minimized. However, the preferred speed of walking tends to decline with advancing age and to walk a given distance older persons consume more metabolic energy than younger adults across all speeds [3–5].

Fiser et al. [6] have recently shown a strong association between maximal aerobic capacity and self-selected walking speed, suggesting that the age-associated reduction of maximal aerobic capacity, most of which is explained by the loss of skeletal muscle mass [7], results in an increased perception of exertion during habitual walking that, in turn, results in a slowing of walking speed in an effort to reduce fatigue.As physical activity interventions improve a variety of physical performance measures in older persons, including walking speed [8,9], in this study we hypothesized that the improvement of walking speed after physical activity interventions might be associated with the reduction of the metabolic cost of walking and we tested our hypothesis in a selected sample of older patients receiving cardiac rehabilitation.

2. Methods

2.1. Study sample

Participants were enrolled among 297 consecutive patients admitted as inpatients to our rehabilitation centre from December 2008 to November 2009 for an intensive postacute three-week rehabilitation after cardiac surgery (mean time interval between surgery and admission to the rehabilitation centre was 7.3

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days ± SD 2.7). All patients aged 65 years and over who had undergone elective cardiac surgery were considered eligible for the study. Patients showing cognitive deterioration (corrected Mini Mental State Examination score < 21) or relevant functional impairment due to previous stroke, peripheral artery disease, severe osteoarthritis of weight bearing joints or other chronic diseases able to remarkably limit physical activity, such as chronic heart failure or chronic obstructive pulmonary disease, were excluded from the study. Further, patients with postoperative "sequelae", such as chest-wall or diaphragm mobility impairment, bronchial atelectasias and posture or walking impairment, that were not resolved by intensive individual physiotherapy within the first week after admission, were also excluded to obtain a group of patients fit enough to ensure at least two weeks of physical training.

The final study sample was represented by 120 patients, 88 men and 32 women. The Institutional Review Board approved the study protocol and all enrolled patients signed their informed consent form to be included in the study.

2.2. Rehabilitation program

A detailed description of the rehabilitation program has been reported elsewhere [10–12]. Briefly, the physical training component of the rehabilitation program was based on two 1-h sessions per day on 5 days each week that included:

(1) 20 min of aerobic exercise at cycle ergometry, to improve aerobic capacity;
(2) gentle low-level (around 25 W) and short-lasting (1–2 min) calisthenic exercises, to improve muscle strength (in these exercises the resistance needed to train muscles was sequentially provided by the weight of single body segments without any added weight);
(3) gentle passive stretching involving the main weight bearing joints, to improve flexibility;
(4) specific exercises for balance and coordination.

2.3. Assessment of the metabolic cost of walking

The metabolic cost of walking was assessed using a portable system for direct calorimetry (SenseWear Armband, from BodyMedia Inc., Pittsburgh, PA, USA). The system, by using a set of built-in sensors that also includes a two-axis accelerometer, continuously gathers information on movement, heat flux, near body temperature, skin temperature and galvanic skin response. An algorithm developed by the manufacturer (SenseWear Professional software, release 6.1) allows the measurement of wearer's caloric expenditure, number of steps and duration of physical activity, rest and sleep. Previous studies have confirmed the validity and reproducibility of the measures provided by the SenseWear Armband [13,14]. Further, in a subset of 64 patients that had also been enrolled in a study on oxygen uptake kinetics during the 6mWT, we performed a double measurement of energy expenditure using both the SenseWear Armband and the Oxycon Mobile apparatus (a portable gas analyzer from Jaeger, Germany, that provides energy expenditure based on oxygen uptake). Using a linear regression based model we found an $r^2 > 0.95$ both before and after the rehabilitation.

Patients performed the 6mWT, according to the recommendations of the American Thoracic Society [15], before and after the rehabilitation. The SenseWear Armband was positioned on the right arm, over the triceps muscle halfway between the acromion and the olecranon processes, as suggested by the manufacturer. We measured the distance walked, total energy expenditure and number of steps. Then, we calculated walking speed (distance walked divided by the duration of the 6mWT, in seconds), stride length (distance walked divided by the number of steps) and the energy cost of walking, defined as the amount of energy used to move a body mass of 1 kg for a distance of 1 m.

3. Other variables

Family history of cardiovascular diseases was ascertained based upon the report of death or morbidity for angina, myocardial infarction, stroke or peripheral artery disease in one or both parents, or in one or more siblings, under the age of 65. Modifiable cardiovascular risk factors, such as smoking habit, hypertension, diabetes and dyslipidemia were considered categorical variables and ascertained using standard criteria [16]. The level of regular physical activity performed by patients in the year preceding the operation was assessed by using a questionnaire that has been described elsewhere [12]. Briefly, we classified as "low-intensity" preoperative physical activity those patients who were sedentary or who performed at most 4 h/week of light (<3 metabolic equivalent, METs) physical activity. On the contrary, we classified as "moderate-intensity" preoperative physical activity those patients who performed more than 4 h/week of light physical activity or at least 1–2 h/week of moderate (3–6 METs) physical activity. All patients underwent echocardiography, using a My Lab 30 apparatus (ESAOTE, Genoa, Italy) equipped with a 2.5 MHz imaging transducer and left ventricular ejection fraction was assessed using standardized criteria [17]. Information on medications was gathered from medical records. The use of β-blockers [18] and ACE-inhibitors [19] was considered as categorical variables.

3.1. Statistics

Data are reported as mean ± SD or as absolute value along with the percentage in brackets. Statistical analysis was performed using the STATA 7.0 software, from Stata Corporation (College Station, TX, USA). Differences between the 6mWT before and after the rehabilitation were tested using the paired Student's *t* test. Independent predictors of changes in the energy cost of waking were identified using a multivariable regression with backward selection. Type 1 error was set at the two-sided 0.05 level.

4. Results

All the 120 enrolled patients (88 men and 32 women, mean age 74.1 years ± SD 5.0) completed the scheduled two-week physical training program and no clinically relevant adverse event occurred.

Table 1 shows the characteristics of the study sample. Table 2 shows data from the 6mWTs before and after the rehabilitation. The distance walked and, consequently, walking speed significantly increased (+16%). The increase of the distance walked was associated with the increase of the number of steps rather than with the increase of stride length. Total energy expenditure also significantly increased (+9%), while the energy cost of walking was significantly reduced (−11%). Table 3 shows the multivariable backward regression predicting the energy cost of walking after physical training. Age, sex, left ventricular ejection fraction, reported level of physical activity in the year prior to surgery and distance walked before physical training were removed from the model by backward selection. On the contrary, higher energy cost of walking before the rehabilitation and greater increase of the distance walked after the rehabilitation remained independent predictors of the reduction of the energy cost of walking.

5. Discussion

In this study we tested the hypothesis that the improvement of walking speed after physical activity interventions might be

Table 1
Characteristics of the study sample ($n = 120$).

Demographics	
Age (years, mean ± SD)	74.1 ± 5.0
Male gender, *n* (%)	88 (73)
Operation	
Coronary artery by-pass grafting (CABG), *n* (%)	52 (43)
Valve repair/replacement (VR), *n* (%)	46 (38)
Combined procedures, *n* (%)	23 (19)
Cardiovascular risk factors	
Family history of cardiovascular diseases, *n* (%)	35 (29)
Current smokers, *n* (%)	11 (9)
Hypertension, *n* (%)	71 (59)
Diabetes, *n* (%)	20 (17)
Dyslipidemia, *n* (%)	42 (35)
Body mass index > 25 kg/m^2, *n* (%)	49 (41)
Physical activity in the year prior to surgery	
Low-intensity, *n* (%)	73 (61)
Moderate-intensity, *n* (%)	47 (39)
Left ventricular ejection fraction (%, mean ± SD)	53 ± 10
Use of β-blockers, *n* (%)	67 (56)
Use of ACE-inhibitors, *n* (%)	71 (60)

Table 2
Data from the 6mWT performed before and after the rehabilitation ($n = 120$).

	Before rehabilitation	After rehabilitation	p^a
Measured variables			
Distance walked (m, mean ± SD)	343 ± 95	398 ± 93	<0.001
Total energy expenditure (kcal, mean ± SD)	25.7 ± 7.6	28.0 ± 8.3	<0.001
Number of steps (mean ± SD)	263 ± 62	296 ± 50	<0.001
Calculated variables			
Energy cost of walking (cal/kg/m, mean ± SD)[b]	1.11 ± 0.32	1.00 ± 0.19	<0.001
Walking speed (m/s, mean ± SD)	0.95 ± 0.26	1.11 ± 0.26	<0.001
Stride length (m, mean ± SD)	1.37 ± 0.24	1.40 ± 0.20	0.363

[a] From paired Student's t test.
[b] Amount of energy used to move a body mass of 1 kg for a distance of 1 m.

Table 3
Multivariable backward regression predicting the metabolic cost of walking after the rehabilitation.

Model: Obs = 120; $F = 110.80$; Prob > $F < 0.001$; $R^2 = 0.672$

Metabolic cost of walking after the rehabilitation (cal/kg/m)	β (SE of β)	p
Metabolic cost of walking before the rehabilitation (cal/kg/m)	0.5752 (0.0426)	<0.001
Increase of the distance walked after the rehabilitation (m)	0.0007 (0.0003)	0.019

The initial model also included age, sex, left ventricular ejection fraction, reported physical activity level in the year prior to surgery and distance walked before the rehabilitation, all of which were removed by backward selection ($p = 0.236$, 0.337, 0.355, 0.140 and 0.883, respectively).

associated with a reduction of the metabolic cost of walking. In a selected sample of older patients receiving cardiac rehabilitation we found that at the 6mWT performed after the rehabilitation total energy expenditure, the distance walked and, consequently, walking speed were significantly increased while the energy cost of walking was significantly reduced.

To the best of our knowledge, only two studies have investigated the effect of physical activity interventions on walking economy. Beneke and Meyer [20] reported, along with a remarkable increase of the walking speed at the 6mWT (70%), a great reduction of the metabolic cost of walking (30%) after three weeks of physical training. However, unlike our study, authors investigated a small sample of younger adults (16 men, mean age 52 years) with severe chronic heart failure, as documented by the poor left ventricular function (mean ejection fraction 21%). On the contrary, Mian et al. [21] found that a one-year physical conditioning program did not affect the metabolic cost of walking in healthy community-dwelling septuagenarians. However, the sample they investigated was quite small (25 subjects) and, possibly, statistically underpowered. Further, participants were extraordinarily fit, as documented by the long distance walked at the 6mWT before physical training (587 m, corresponding to a walking speed of 1.63 m/s), which was far away from the standards reported in the literature for healthy septuagenarians [22,23]. Finally, the magnitude of the increase of the distance walked at the 6mWT after one year of physical conditioning was quite small (7%), suggesting that either the intensity of physical training might have been inadequate to induce a conditioning effect in those participants or that a ceiling effect might have occurred, given the remarkably long distance walked before the physical training.

Understanding the mechanisms underlying the association between the improvement of gait speed after physical activity interventions and the reduction of the energy cost of walking is a difficult task and it was beyond the scope of this study: however, a few comments are warranted.

First, in terms of kinematics, walking speed and metabolic demand are related to each other according to a U-shaped curve, whose central region is the region in which the metabolic cost of walking is minimized [3,5]. As our patients, according to the recommendations of the American Thoracic Society [15], performed the 6mWT over ground at their individually selected maximal speed, for each patient we were able to assess only one point of the speed–metabolic demand curve before and after the rehabilitation. Thus, we do not know whether the physical training component of our cardiac rehabilitation program has actually shifted the whole curve downward [5] or whether the decrease of the energy cost of walking was accounted for simply by a shift away from an uneconomical towards a more economical region of the same speed–metabolic demand curve [21].

Second, an intriguing approach might be to interpret our results within the context of the various mechanisms suggested to explain the increase of the energy cost of walking that occurs with advancing age. The increase in gait instability [24,25] or the increase in the cost of balance maintenance [24], and the impairment of the pendulum like interchange of mechanical energies at the centre of mass [26] or the increase in individual limb work on the centre of mass [27], have been, in turn, proposed as potential mechanisms for the age-related increase of the energy cost of walking. However, conflicting results have been reported and no conclusive evidence has yet been achieved. Further, the greater co-contraction of antagonist muscle pairs has also been suggested as a potential mechanism for the age-related increase of the energy cost of walking [26,28]. Although this strategy is uneconomical because each agonist muscle must produce an extra force to offset the opposing force of the antagonist muscle [25,26,28], it actually stiffens weight-bearing joints and maintains stability, which is a crucial factor to avoid falls in older persons, despite the deterioration in sensory input and processing ability [26,29]. However, the two studies that addressed this issue, reported conflicting results. Greater co-contraction at the thigh level, which increases knee stability, was correlated with the increased metabolic cost of walking in the study of Mian et al. [26] but it was not in the study of Peterson and Martin [28]. Finally, as aging is associated with a progressive loss of muscle mass and strength [30], to perform a given task older persons likely have to recruit more motor units or to increase the level of activation of already recruited muscle fibres, both of which are detrimental to muscle efficiency [21]. So, the greater cost of generating muscle force has also been proposed as a potential mechanism for the age-related increase of the metabolic cost of walking [5,24,25]. However, even in this case, the two studies that addressed this issue reported conflicting results. Malatesta et al. [24] reported a significant inverse relationship between the maximal isometric strength of knee extensor muscles and the metabolic cost of walking, while Mian et al. [21] found no relationship.

Contrary to previous studies, in which energy expenditure was assessed in participants walking on a treadmill at pre-established speeds, in this study we assessed the energy expenditure in patients freely walking over ground along a corridor at their self-selected speed, which is more natural especially for older persons. Further, in previous studies energy expenditure was measured using indirect calorimetry, based upon oxygen consumption, while in this study we used a system for direct calorimetry. Both these aspects represent the strength of the study. However, some inherent limitations need to be considered. First, the absence of a control group does not allow claiming with certainty a cause–effect relationship between the physical training component of our rehabilitation program and the reduction of the metabolic cost of walking. Actually, the control group should be represented by elderly patients who have undergone cardiac surgery and who do not receive cardiac rehabilitation. Since cardiac rehabilitation is strongly recommended for these patients [16], ethical reasons forbade us to propose a study project in which randomly selected patients did not receive a recommended treatment and the Institutional Review Board would never approve such a study protocol. Second, to obtain a group of patients fit enough to ensure at least two weeks of physical training we introduced a wide series of exclusion criteria, so that our patients represent a quite selected sample of patients who receive rehabilitation after cardiac surgery.

In conclusion, our findings show that the improvement of walking speed observed in older patients after cardiac rehabilitation is associated with the improvement of walking economy, suggesting that the reduction of the metabolic cost of walking might be a contributory factor to the favourable effects of physical activity interventions on physical performance measures. Interestingly, the reduction of the metabolic cost of walking after the rehabilitation was significantly related to higher metabolic cost of walking before the rehabilitation and to greater increase of the distance walked after the rehabilitation, both of which are markers of poor physical conditioning.

Future studies are needed to confirm our results on a broader scale and to understand the mechanism by which physical activity interventions might affect the metabolic cost of walking.

Conflict of interest

The authors declare no conflict of interest. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

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