A test to assess the mechanical power sustainable during everyday activities in older people

Edda Maria Capodaglio\textsuperscript{1}, Franco Saibene\textsuperscript{1,2}

\textsuperscript{1}Centro Studi Attivit\`a Motorie, Fondazione Salvatore Maugeri, IRCCS, Pavia, Italy
\textsuperscript{2}Laboratory of Physiology, Istituto Tecnologie Biomediche Avanzate, Consiglio Nazionale delle Ricerche, Segrate, Milano, Italy

Address correspondence to: E. M. Capodaglio, Centro Studi Attivit\`a Motorie, Fondazione S. Maugeri, IRCCS, Via Ferrata 4, I-27100 Pavia, Italy. Fax: (+39) 0382 592081. Email: ecapodaglio@fsm.it

Abstract

Objective: to define with a simple test the power sustainable by older people during everyday occupations.

Methods: nine healthy subjects (65–71 years) performed two series of 5–6 trials on bicycle and arm ergometers at constant power. Throughout the exercise they reported their evaluation of the effort, referred either to perceived whole body exertion or to the working muscles, using Borg's category-ratio, CR10, scale. The exercise was interrupted when CR7 was attained. From a linear regression of the individual data of the work done from the start of each trial to the transition from CR4 to CR5, corresponding to 'somewhat heavy' and 'heavy', and the corresponding duration it was possible to calculate the slope of the work/time relationship. This was considered as the value of power sustainable for leg or arm muscles.

Results: on average the sustainable power for the work done on the bicycle ergometer represented 55\% of the maximal mechanical power. During the control trial on the bicycle ergometer at a power corresponding to their sustainable power the subjects were able to exercise for 30 min without symptoms of fatigue or discomfort, with an average CR of 3. The average heart rate was 114 bpm and the blood lactate concentration at the end of the exercise was always lower than 4 mmol/l. Sustainable power calculated for the arm muscles was about one quarter that of the leg muscles, but all subjects reported the evaluation of the effort as more difficult.

Conclusion: the determination of power sustainable for the leg muscles with this simple test appears reliable and accurate.

Keywords: sustainable power, leg work, arm work, older people

Introduction

It is a common observation that the maximal power that can be sustained until exhaustion at a constant intensity decreases progressively with the duration of the exercise. Scherrer \textit{et al.} \textsuperscript{1} and Monod and Scherrer \textsuperscript{2} observed that the relationship between mechanical power, \(P\), and duration, \(t\), is well described by the hyperbolic equation \(P = b + a/t\), where the asymptote \('b'\), represents the power that can be sustained over a 'long' period. With a known efficiency of exercise, it can be said that \('a'\) represents the energy derived by the anaerobic metabolism, and \('b'\) a 'critical' power, associated with the maximal aerobic power \textsuperscript{3}. Even if the energy stores of the body are enormous maximal aerobic power cannot be sustained indefinitely because a number of factors (muscular, nervous, hormonal, psychological) cause peripheral and/or central fatigue. Below this critical power there are various levels of metabolic power that can be maintained for much longer duration. The lowest level is represented by the resting metabolic rate; a slightly higher level, one time the resting metabolic rate, is the sustained metabolic rate \textsuperscript{4} corresponding to the average metabolic power that can be maintained over days, even weeks, keeping constant the body mass, i.e. equalling over that period energy intake and energy expenditure. On a shorter time basis one can also define a higher metabolic power corresponding to the level of physical activity characteristics of domestic or professional occupations.

In the present study we tried a test to assess the mechanical power (\(P_{\text{sust}}\)) that can be sustained without discomfort or fatigue by aged people during a normal
everyday activity lasting 20–40 min. To this end we utilised the rating of the subjective perceived exertion according to the CR10 scale of Borg [5], which is commonly used for measuring many somatic symptoms. Also the classical critical power test [3] relies on a subjective evaluation of the effort and toward the end of the test a verbal encouragement is given to the subject, even if often a drop in cycling cadence is utilised as a criterion for defining the end-point. In this scale 0 corresponds to ‘no exertion’, 5 to ‘strong’ and 10 to ‘maximal’ exertion. In this study a CR of 5 was used as a criterion to define Psust.

In the attempt to evaluate lower and upper limb muscle performance the subjects performed two types of exercise, one with the bicycle ergometer and the other with the crank ergometer.

### Methods

#### Subjects

Nine healthy males, aged between 65 and 71 years, participated in the experiments. In a previous study in this laboratory [6] they had already undertaken a comprehensive medical evaluation and their maximal mechanical and aerobic power had been measured (Table 1). The subjects were informed of the scope and the procedure of the study, approved by the local ethical committee, and all gave written consent.

#### Experimental protocol

The experimental protocol consisted of two series of trials: one with a bicycle ergometer (Mijnhart, KEM2, The Netherlands) and the other with a crank ergometer (Monark, 881, Sweden), at various constant powers, range 60–125 W for the former, 20–70 W for the latter. The subjects were instructed in the use of the ten-point category-ratio scale, CR10 of Borg [5]. They exercised at the selected constant load until the perception of the effort reached the submaximal level defined as ‘very strong’, CR7. Even though a value of CR5 was utilised to define Psust, the subjects were allowed to continue the exercise in order to assure that they reported a true evaluation of the effort. In all trials on the bicycle ergometer the mechanical power never exceeded 80% of the individual maximal power determined in the previous research [6], as it was not expected to collect useful data beyond that intensity. At the end of each exercise they were fatigued but not exhausted. In principle the trials should have lasted more than 1 minute and less than 10 min [7, 8]: the first trial was generally fixed at 70 W on the bicycle ergometer and 30 W on the crank ergometer and according to its duration the intensity of the subsequent trials, 4–5, was then chosen. The subject was asked to report his perceived effort, corresponding to a number on the scale displayed in front of him, every 30 s, or whenever he felt that his effort was increased. Two ratings were applied: one for the overall sensation of fatigue and discomfort (CRo), the other for the perception at the level of the working muscles (CRm). The cadence was fixed at 60 rpm and was monitored visually and acoustically with a metronome. If a subject was not able to keep the cadence the trial was interrupted and discarded. The next trial started 5 min after the heart rate had resumed the resting value and the subject felt to be ready to continue. The tests for upper or lower limb endurance were done on different days. Some weeks later the subjects were recalled to the laboratory to perform a trial on the bicycle ergometer at the Psust calculated previously, to verify if they were able to perform at the power calculated as Psust (see below) for at least half an hour without discomfort and fatigue and to measure the corresponding energy expenditure. On the same occasion heart rate and blood lactate concentration were also measured.

#### Measurements

For all the duration of the trial the heart rate was recorded by means of a Polar heart rate monitor (Polar Electro Oy, Finland). Before and after 3 min from the end of the trials on the crank ergometer blood samples (20 µl) were collected from the earlobe for the determination of blood lactate concentration (Biosen 5030, Eppendorf, Germany). Energy expenditure was measured by means of a computerised O₂-CO₂ analyser-flowmeter combination (Oxycon Delta, Jaeger, Germany).

#### Calculations

For each trial the time elapsed from the start to the passage from CR4 to CR5 (from ‘somewhat strong’ to ‘strong’) was multiplied by the power set for that trial to calculate the total work (Wtot) done. From these data it was then possible to describe for each subject with a linear regression the relationship work/duration by the equation: \( W_{\text{tot}} = W_{\text{anaer}} + Psust \cdot t \), where the slope \( Psust \) represents the value of the mechanical power that can be maintained without discomfort, and the intercept that of the mechanical work whose energy was provided by the anaerobic sources [9].

<table>
<thead>
<tr>
<th>Subject name</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Pmax (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>70</td>
<td>77</td>
<td>140</td>
</tr>
<tr>
<td>SB</td>
<td>67</td>
<td>72</td>
<td>140</td>
</tr>
<tr>
<td>SL</td>
<td>69</td>
<td>72</td>
<td>140</td>
</tr>
<tr>
<td>LN</td>
<td>65</td>
<td>74</td>
<td>145</td>
</tr>
<tr>
<td>FR</td>
<td>68</td>
<td>82</td>
<td>150</td>
</tr>
<tr>
<td>GS</td>
<td>70</td>
<td>96</td>
<td>180</td>
</tr>
<tr>
<td>FS</td>
<td>71</td>
<td>74</td>
<td>130</td>
</tr>
<tr>
<td>DS</td>
<td>69</td>
<td>100</td>
<td>220</td>
</tr>
<tr>
<td>GS</td>
<td>66</td>
<td>84</td>
<td>180</td>
</tr>
</tbody>
</table>
Sustainable mechanical power

Statistics
Statistical analysis was performed to test the differences between mean values (t-test for dependent group; Statistics for Windows release 5.0 B, Starsoft Inc., USA, 1996).

Results

Bicycle ergometer

All nine subjects performed at least 5 trials. The trials whose scores in the first seconds from the start were higher than 4, and whose scores after 20 min of exercise were lower than 4, were discarded, so that only 38 trials were considered. Individual Psust ranged from 68–114 W. When expressed as a percentage of Pmax the range diminished considerably because Pmax, which was in part related to the different body mass and in part to the different fitness of the subjects, presented the same variability. The average Psust corresponded to 55% of the average Pmax. The individual values of Psust, in W, together with those of Wanaer, in kJ are presented in Table 2. In the same table for each subject are also indicated the r² of the linear regression, the ratio Psust/Pmax, the average heart rate measured at the end of the trials and its coefficient of variation.

The data for CRm are also presented in Table 2: Psust was almost equal to that calculated for CRo in seven subjects, higher in one and lower in the other, while Wanaer was almost equal in five subjects, higher in three and lower in one. On average the differences either of Psust and Wanaer were not significant.

The results of the control trial are presented in Table 3. One subject did not report to the laboratory; another subject stopped after 18 min due to intense knee pain. The other seven subjects completed the 30-min trial; the average CRo of these subjects was 3, range 2–4, while Wanaer was almost equal in five subjects, higher in one and lower in the other. The results obtained in both tests were found at the end of all trials was significantly different from the resting value, ranging from 1.98–3.46 mmol/l.

Crank ergometer

Table 2 shows also the values of Psust and of Wanaer, in kJ, as calculated by linear regression of the work performed with the bicycle ergometer (left side) or the crank ergometer (right side) during a constant power in different trials, and the corresponding duration. In the table are also indicated the r² of the linear regression, the ratio Psust/Pmax, the average heart rate measured at the end of the trials and its coefficient of variation. (CRo and CRm: defined in the text.; sust/max: Psust as per cent of Pmax; HR=heart rate; [La]=blood lactate concentration)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Psust W</th>
<th>Wanaer kJ</th>
<th>r²</th>
<th>Sust/ max %</th>
<th>HR Min⁻¹</th>
<th>CV %</th>
<th>CRo W</th>
<th>Wanaer kJ</th>
<th>r²</th>
<th>CRm W</th>
<th>Wanaer kJ</th>
<th>r²</th>
<th>[La] mM</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>76</td>
<td>1.2</td>
<td>0.99</td>
<td>54</td>
<td>120</td>
<td>1.8</td>
<td>76</td>
<td>1.6</td>
<td>0.99</td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SB</td>
<td>68</td>
<td>0.95</td>
<td>0.53</td>
<td>127</td>
<td>37</td>
<td>65</td>
<td>73</td>
<td>1.34</td>
<td>0.71</td>
<td>13</td>
<td>3.8</td>
<td></td>
<td>0.78</td>
</tr>
<tr>
<td>SL</td>
<td>74</td>
<td>0.95</td>
<td>0.53</td>
<td>123</td>
<td>36</td>
<td>74</td>
<td>3.5</td>
<td>0.96</td>
<td>0.70</td>
<td>8.1</td>
<td>0.95</td>
<td></td>
<td>0.92</td>
</tr>
<tr>
<td>LN</td>
<td>80</td>
<td>0.95</td>
<td>0.53</td>
<td>129</td>
<td>36</td>
<td>81</td>
<td>4.4</td>
<td>0.96</td>
<td>0.95</td>
<td>5.5</td>
<td>0.95</td>
<td></td>
<td>0.95</td>
</tr>
<tr>
<td>FR</td>
<td>88</td>
<td>0.95</td>
<td>0.53</td>
<td>120</td>
<td>3.6</td>
<td>100</td>
<td>7.8</td>
<td>1.97</td>
<td>0.95</td>
<td>25</td>
<td>0.95</td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>GS</td>
<td>109</td>
<td>0.95</td>
<td>0.53</td>
<td>118</td>
<td>4.6</td>
<td>92</td>
<td>8.1</td>
<td>0.94</td>
<td>0.95</td>
<td>1.7</td>
<td>0.95</td>
<td></td>
<td>0.99</td>
</tr>
<tr>
<td>FS</td>
<td>82</td>
<td>0.95</td>
<td>0.53</td>
<td>121</td>
<td>2.1</td>
<td>88</td>
<td>6.5</td>
<td>0.93</td>
<td>0.95</td>
<td>4.5</td>
<td>0.98</td>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td>DS</td>
<td>114</td>
<td>0.95</td>
<td>0.53</td>
<td>117</td>
<td>4.7</td>
<td>107</td>
<td>1.9</td>
<td>0.94</td>
<td>0.95</td>
<td>3.0</td>
<td>0.98</td>
<td></td>
<td>0.87</td>
</tr>
<tr>
<td>GS</td>
<td>90</td>
<td>0.95</td>
<td>0.53</td>
<td>115</td>
<td>6.2</td>
<td>85</td>
<td>6.8</td>
<td>0.99</td>
<td>0.95</td>
<td>–</td>
<td>–</td>
<td></td>
<td>–</td>
</tr>
</tbody>
</table>

Discussion

The aim of this study was eminently practical, i.e. to find a simple, inexpensive, yet reliable, test to determine the mechanical power that can be sustained by a subject in his everyday activities for the duration of a normal spell of work. The test should be easy to perform both by the subject and the operator, non-invasive and not overly time consuming. However, a laboratory test cannot a longer time. Blood lactate concentration remained below 4 mmol/l in all subjects, average 2.2 ± 1.0.
mimic the real condition of a particular occupation, it is more rhythmic and repetitive that any actual task done at home or in the workplace. Psust is by no means the critical power calculated from a series of an all-out effort, like in the test described by Moritani et al. [3]; the subjects in the present case were required to interrupt the exercise when they felt the effort being strong and heavy, yet not intolerable.

The relationship between psychological and physiologic variables and their reproducibility has been proven by many studies [10–13], however, the problem of the reliability of the subjective evaluation of the effort exists. Even if the subjects were instructed in the use of the 10-point scale and practised with the ergometers before the experiments, they sometimes found it difficult to evaluate their effort; it is known that many factors may influence the evaluation of the effort [14]. However in each series of trials the heart rate measured at the passage from CR4 to CR5 was very similar, for each subject, as can be appreciated by the very low coefficient of variation (range 1.8–6.2%, see Table 2), indicating that the perception of the effort was not reported arbitrarily but was related to a physiologic variable. It is possible that CR5 had a somewhat different evaluation by the subjects, indeed the Borg scale is a subjective scale, but the aim of the experiments was to find a test to assess for each subject the level of effort that can be sustained without fatigue. As expected Psust was lower than the lowest power set on the ergometer during the trials. From Tables 2 and 3 it can be seen that in the control trial the evaluation ranged from CR2 to CR4 (not considering the subject who did not complete the test due to pain in a leg).

The subject of this study reported very similar scores for CRo and Crm; this is in contrast to what was found by Hamilton et al. [13]. They found that at the same mechanical power the local perception exceeded the general perception of effort. However their work bouts lasted only 30 s; it is possible that a much longer duration affects the central sensation more than the peripheral one [15]. The individual energy expenditure measured in the control trial was rather different among subjects implying, beside the measurement error, a different cycling efficiency among the subjects: riding a bicycle was not equally familiar for all subjects.

All subjects found easier the evaluation of the effort done on the bicycle ergometer. Borg et al. [16] observed that the relationship between relative values (relative to the variation range) of rating of perceived exertion (CR scale) and combined physiological variables, like heart rate and blood lactate concentration, is very similar for the exercise performed with the legs or the arms. In our experiments while the bicycle ergometer was a constant power model, the power of the crank ergometer depended on the cadence of the arm’s revolution and some subjects, despite the metronome, were not able to keep it constant at 60 rpm for the entire duration of the trial. The cadence of 60 rpm is close to the stride frequency that occurs when subjects walk at the normal speed [17], on the contrary in work performed with the arms the movement frequency is lower and seldom so repetitive. It has been shown [18] that the cadence influences the local sensation of muscle pain. Even if the perception of pain during muscular work is distinct from the perception of effort [18] it can influence the regular rhythmic execution of the exercise. The range of the values of Psust calculated for the exercise on the crank ergometer is much larger from 10–40 W, and the coefficient of variation is in fact much higher: 48% for the crank ergometer and 18% for the bicycle ergometer. For these reasons Psust calculated for the leg muscles seems more reliable than that measured for the arm muscles.

In Figure 1 the work performed with leg (nine subjects) or arm muscles (seven subjects) is plotted against the respective duration of the two exercises: the slopes of the two functions represent the average Psust of the subjects. Psust of leg muscles is about four times that of arm muscles and consequently for the same exercise duration the work that can be performed by the leg muscles should be three to four times greater. Leg muscles are larger and stronger and are naturally more trained by the normal daily ambulatory activities of individuals. As the cadence imposed in the two exercises was the same and so with some approximation also the contraction velocity of the active muscles, the power output depended on the force exerted by the two muscle groups. The ratio of the torques measured on the same subjects during isokinetic contractions of the knee and the elbow muscles at an angular speed similar to that occurring on the bicycle and crank ergometer at 60 rpm was 3.6 [6], not very different from the ratio Psust leg/Psust arm found in the present study. The intercept of the two functions is not significantly different for the two exercises, but on specific terms (per kg of active muscle mass) one can argue that the involvement of the anaerobic sources was somewhat greater for the exercise with the crank ergometer. However, considering the

![Figure 1](https://academic.oup.com/ageing/article-abstract/32/1/31/26080/162680)
duration of the trials, the contribution of the anaerobic sources in both exercises was extremely small [19].

In similar studies [20, 21] on younger subjects exercising on a bicycle or performing prolonged lifting tasks involving trunk and arm muscles it has been shown that a moderate level of effort, 3–4 of the Borg scale, elicits a heart rate equal to 60–70% of the maximum, a value very similar to that found in the present study.

The present data compare rather well with those [22] of a group of fit active subjects, slightly younger than those of the present experiments, who exercised for 25–30 min at 50% of their VO₂ max reporting a RPE of 12 on the 6–20 scale of Borg, corresponding to 3 of the CR scale [23]. While in a group of active subjects, of about the same age as the subjects of the present experiment, who exercised at four constant loads leading to exhaustion in 2–15 min, the critical power was 115 W, the intercept 8.1 kJ, and the CR at the end of a 24 minute test at the critical power was 5.7 [24]. In another group of subjects aged 60–75 years, performing on a bicycle ergometer high-intensity exercises to fatigue, the critical power was 104 W, corresponding to 88% of the maximum [25]. Therefore the value of 55% of the maximum found in the present experiments seems consistent with the definition of sustainable power.

In conclusion the test on the bicycle ergometer appears a useful and sufficiently accurate way to determine Psust. Assuming an efficiency of cycling of 20% [26] it is possible to calculate the level of energy expenditure that a subject can sustain during his normal daily activities without discomfort and fatigue within safe limits. The results obtained with the crank ergometer are less encouraging due to their higher variability, and also to the inability to take into consideration the trunk muscles, work involved in realistic daily arm use.

Key points
- To assess the mechanical power that can be sustained by older people in their domestic or professional activities.
- To find a simple, inexpensive way to measure the amount of work that can be performed in a given time without discomfort or fatigue.

Conflict of interest
The study was approved by the Committee on the Ethics of Human Experiments of the Fondazione Salvatore Maugeri, IRCCS, Pavia, Italy. The scope and the procedure of the study were illustrated to the subjects who gave their informed written consent.

References


Received 1 March 2002; accepted in revised form 2 September 2002.