Physiological responses to high intensity, constant-load arm exercise in COPD

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\textbf{KEYWORDS}
Chronic obstructive pulmonary disease; Exercise; Dyspnoea; Exercise test

\textbf{Summary}
The aim of the study was to compare the metabolic, ventilatory and dyspnoea responses of a single bout of high intensity, constant-load arm exercise to peak arm exercise in people with chronic obstructive pulmonary disease (COPD). Thirty people with COPD (mean age $\pm$ SD $= 65 \pm 8$ years; FEV$_1$% predicted $= 56 \pm 12$\%) were included. All subjects performed an incremental arm exercise test to peak work capacity on an arm ergometer and, on a separate day, a constant-load arm exercise test at 80\% of the peak work rate achieved on the incremental test. Throughout both exercise tests, oxygen consumption ($\dot{V}_O_2$), minute ventilation ($\dot{V}_E$), dyspnoea and rate of perceived exertion (RPE) were measured each minute. Peak work rate on the incremental test was $33.0 \pm 10.1$ W with a mean duration of $6.6 \pm 2.0$ min. The mean duration of the constant-load test of $7.1 \pm 2.9$ min was not significantly different to the incremental test ($p = 0.3$). At end exercise, $\dot{V}_E$, dyspnoea and RPE for the constant-load test was significantly higher compared to the incremental test ($\dot{V}_E$: $41.3 \pm 14.4$ L/min and $38.3 \pm 11.8$ L/min; dyspnoea: $5.6 \pm 2.7$ and $4.6 \pm 2.1$; RPE: $7.1 \pm 2.3$ and $6.0 \pm 2.0$; all $p<0.05$). Constant-load arm exercise at 80\% peak work rate elicits higher ventilatory, dyspnoea and RPE responses at end exercise compared to incremental arm exercise in people with COPD. This finding suggests that an intensity of 80\% peak work rate may be too high as an initial training intensity for supported arm exercise in people with COPD.

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\textbf{Introduction}

People with chronic obstructive pulmonary disease (COPD) have a reduced arm exercise capacity\textsuperscript{1} and, as a result, are encouraged to perform arm training in pulmonary rehabilitation. While a number of studies have indicated the effectiveness of arm training to improve supported and

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unsupported arm exercise capacity,2–5 the intensity of arm training has either varied significantly or been inadequately described. In contrast, intensity of leg training is well described with studies indicating that a moderate to high intensity of leg cycle training produces the greatest physiological benefit.6,7 One recent study of supported arm training in subjects with COPD utilised a high intensity arm training protocol (80% peak work rate) but no information was provided on how the subjects responded during a session of this training.8 Furthermore, we are not aware of any other study which has compared the physiological responses of a single bout of high intensity, constant-load, supported, arm exercise with incremental, supported arm exercise to peak work capacity in people with COPD. An understanding of this relationship will be important to determine whether prescription of high intensity supported arm training is feasible at the start of a pulmonary rehabilitation program.

The aim of this study was to compare the metabolic, ventilatory and dyspnoea responses of a single bout of high intensity, constant-load, supported arm exercise with those of incremental, supported arm exercise to peak work capacity in subjects with COPD. The hypothesis was that the metabolic, ventilatory and dyspnoea responses at end exercise would be lower in the high intensity, constant-load exercise than the responses at end exercise in incremental arm exercise.

**Methods**

**Subjects**

Thirty subjects, diagnosed with COPD, were recruited from the Department of Respiratory Medicine, Royal Prince Alfred Hospital, Australia. All subjects were stable on entry to the study, had no shoulder problems and had never participated in a pulmonary rehabilitation program. Informed, written consent was obtained from all subjects, and the study was approved by the Sydney South West Area Health Service (Eastern Zone).

**Measurements**

**Respiratory function tests**

Measurements of spirometry (Sensormedics Vmax 20; Sensormedics Corporation, CA) and lung volumes (Sensormedics V6200 Autobox Body Plethysmograph; Sensormedics Corporation, CA) were performed and compared to predicted normal values for spirometry9 and lung volumes.10 Bronchodilators, where prescribed, were given prior to lung function measurements.

**Exercise tests**

All subjects performed a symptom-limited, incremental, supported arm exercise test to peak work capacity and, on a separate day, performed a symptom-limited, constant-load, supported arm exercise test which represented a single-bout of endurance arm exercise training. The arm exercise tests utilised an electrically braked bicycle ergometer (Seimens-Elma; Solina, Sweden), modified for arm work (i.e. the gear system was mounted on an adjustable table and pedals were replaced with handles). For both tests, subjects were seated and the crutch height was adjusted so that the fulcrum of the pedals was at the level of the gleno-humeral joint. During the incremental test, workloads were increased by 5 W every minute until the subjects indicated that they could not continue. The work rate for the constant-load test was set at 80% of the peak work rate attained during the incremental test. During both exercise tests, the subjects exercised at 50–60 rpm and breathed through a calibrated mass flow sensor with expired gas sampled on a breath-by-breath basis (Vmax 29 Cardiopulmonary Exercise Testing Instrument; Sensormedics Corporation, California, USA) so that oxygen consumption (\(V_{O2}\)), carbon dioxide production (\(V_{CO2}\)), minute ventilation (\(V_E\)), tidal volume (\(V_T\)) and breathing frequency (\(F_R\)) could be determined. Maximal voluntary ventilation (MVV) was determined by multiplying the FEV\(_1\) by \(35\) so that \(V_E/MVV\) could be determined. End-expiratory lung volume (EELV) was also measured during both tests by instructing the subject to perform inspiratory capacity manoeuvres at rest and in the final 3 s of each minute of exercise. At least three breaths prior to the manoeuvres were monitored to ensure stability of each subject’s end expiratory lung volume. This methodology has been described previously during leg exercise and supported arm exercise,12 and has been shown to be reliable and reproducible in COPD subjects.13,14 Heart rate (HR) and pulse oxygen saturation (Sp\(O_2\)% were obtained with a forehead probe attached to a pulse oximeter (N200: Nellcor, Hayward CA). Subjects scored their dyspnoea and rate of perceived exertion (RPE) on a modified Borg scale reading 0 ("nothing at all") to 10 ("maximal").15,16 Subjects were also asked to comment on whether exercise was terminated due to dyspnoea, arm fatigue or a combination of both.

**Statistical analysis**

The StatView statistical package was used for analysis (Version 4.57 1992–1996, Abacus Concepts Inc., California). Statistical guidelines were provided by Altman.17 All data are presented as mean±SD. The mean difference with the 95% confidence interval (CI) is included where appropriate. The measurements taken during both exercise tests were compared using a paired t-test. Significance was set at \(p<0.05\).

**Results**

Mean anthropometric data and lung function results for the 30 COPD subjects are presented in Table 1.

**Responses at the end of exercise**

The metabolic and ventilatory responses in the COPD subjects can be found in Table 2. There was no significant difference in the duration of the incremental test and the constant-load test. The work rate performed during the constant-load test averaged 6 W less than that performed during the incremental test. Despite this, there was a significantly higher \(V_E\), \(V_E/MVV\), \(V_T\) dyspnoea and RPE for the constant-load test compared to the incremental test at end
exercise. The predominant symptom reported by subjects as the reason for stopping exercise during both the incremental test and constant-load test is given in Figure 1. Of the 15 subjects who reported arm fatigue as the reason for terminating incremental arm exercise, nine of these subjects also reported arm fatigue as the reason for terminating the constant-load test while the remaining six subjects complained of both arm fatigue and dyspnoea at the end of the constant-load test.

Responses throughout exercise

The metabolic and ventilatory responses during the incremental test and constant-load test in a representative subject with COPD are shown in Figures 2 and 3, respectively. This subject’s responses corresponded to the pattern of exercise response seen by the group. There was a linear increase in both $\text{VO}_2$ and $\text{VE}$ with increasing work rate while the relationship of both $\text{VO}_2$ and $\text{VE}$ to time during constant work rate exercise tended to be curvilinear. $\text{VO}_2$ started to plateau towards the end of the constant-load test. There was a curvilinear relationship of dyspnoea and RPE to work rate and dyspnoea and RPE to time. This pattern indicated that larger increases in dyspnoea and RPE occurred towards the end of exercise for a given change in work rate or time.

Table 1 Baseline anthropometric and lung function data.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline (mean±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>65 ± 8</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.3 ± 5.4</td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>1.5 ± 0.4</td>
</tr>
<tr>
<td>% pred</td>
<td>56 ± 12</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>3.0 ± 0.7</td>
</tr>
<tr>
<td>% pred</td>
<td>78 ± 13</td>
</tr>
<tr>
<td>TLC (L)</td>
<td>6.7 ± 1.3</td>
</tr>
<tr>
<td>% pred</td>
<td>117 ± 17</td>
</tr>
<tr>
<td>FRC (L)</td>
<td>4.4 ± 1.2</td>
</tr>
<tr>
<td>% pred</td>
<td>134 ± 29</td>
</tr>
<tr>
<td>RV (L)</td>
<td>3.7 ± 1.1</td>
</tr>
<tr>
<td>% pred</td>
<td>170 ± 48</td>
</tr>
</tbody>
</table>


Table 2 End-exercise responses to incremental and constant-load arm exercise (including the mean difference between the parameters measured).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Incremental (mean±SD)</th>
<th>Constant-load (mean±SD)</th>
<th>Mean diff (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work rate (W)</td>
<td>33.0 ± 10.1</td>
<td>26.8 ± 9.1</td>
<td>−6 (−5 to −7)*</td>
</tr>
<tr>
<td>(% of incremental)</td>
<td>(80.9 ± 5.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (min)</td>
<td>6.6 ± 2.0</td>
<td>7.1 ± 2.9</td>
<td>0.5 (−0.5 to 1.5)</td>
</tr>
<tr>
<td>$\text{VO}_2$ (L/min)</td>
<td>0.82 ± 0.2</td>
<td>0.83 ± 0.2</td>
<td>0.01 (−0.3 to 0.5)</td>
</tr>
<tr>
<td>$\text{VO}_2$ (ml/kg/min)</td>
<td>11.0 ± 3.0</td>
<td>11.1 ± 3.0</td>
<td>0.1 (−0.3 to 0.6)</td>
</tr>
<tr>
<td>$\text{VCO}_2$ (L/min)</td>
<td>0.91 ± 0.3</td>
<td>0.94 ± 0.3</td>
<td>0.03 (−0.02 to 0.1)</td>
</tr>
<tr>
<td>$\text{VE}$ (L/min)</td>
<td>38.3 ± 11.8</td>
<td>41.3 ± 14.4</td>
<td>3 (0.9 to 5)*</td>
</tr>
<tr>
<td>$\text{VE}$/MVV</td>
<td>73 ± 17</td>
<td>80 ± 19</td>
<td>7 (3 to 11)*</td>
</tr>
<tr>
<td>$V₁$ (L)</td>
<td>1.12 ± 0.3</td>
<td>1.18 ± 0.3</td>
<td>0.1 (0.001 to 0.1)*</td>
</tr>
<tr>
<td>$F_b$ (brths/min)</td>
<td>35 ± 8</td>
<td>35 ± 8</td>
<td>0.4 (−0.8 to 1.6)</td>
</tr>
<tr>
<td>$\text{SpO}_2$ (%)</td>
<td>98 ± 3</td>
<td>96 ± 3</td>
<td>−1.2 (−2.3 to 0.01)</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>109 ± 18</td>
<td>109 ± 23</td>
<td>0.7 (−6 to 8)</td>
</tr>
<tr>
<td>Dyspnoea</td>
<td>4.6 ± 2.1</td>
<td>5.6 ± 2.7</td>
<td>1 (0.1 to 2)*</td>
</tr>
<tr>
<td>RPE</td>
<td>6.0 ± 2.0</td>
<td>7.1 ± 2.3</td>
<td>1 (0.5 to 2)*</td>
</tr>
<tr>
<td>Change in EEL V (L)</td>
<td>0.5 ± 0.3</td>
<td>0.5 ± 0.3</td>
<td>−0.04 (−0.1 to 0.04)</td>
</tr>
</tbody>
</table>

Definition of abbreviations: $\text{VO}_2$: oxygen consumption, $\text{VCO}_2$: carbon dioxide production, $\text{VE}$: minute ventilation, $\text{VE}$/MVV: ratio of minute ventilation to maximal voluntary ventilation, $V₁$: tidal volume, $F_b$: breathing frequency, $\text{SpO}_2$: pulse oxygen saturation, HR: heart rate, RPE: rate of perceived exertion, EEL V: end-expiratory lung volume, min: minute, L/min: litres per minute, ml/kg/min: millilitres per kilogram per minute, L: litres, brths/min: breaths per minute, %: percentage, bpm: beats per minute.

*Significant difference between tests ($p < 0.05$).
Discussion

This study is the first to compare the physiological responses of a single bout of constant-load, supported arm exercise at an intensity of 80% peak work rate compared to incremental, supported arm exercise to peak work rate in people with COPD. The main findings were that the ventilatory, dyspnoea and arm fatigue responses at end exercise during the constant-load arm exercise were significantly higher than those at the end of the incremental arm exercise. In addition, more people with COPD indicated that arm fatigue or a combination of arm fatigue and dyspnoea limited exercise during both types of tests rather than dyspnoea alone. These results have implications for the initial prescription of arm training intensity for people with COPD.

This study highlighted that the major limitation to arm exercise in this group of subjects with COPD was at the peripheral muscle level rather than due to ventilatory factors. The evidence for this comes from the fact that, at a similar VO$_2$ for incremental and constant-load arm exercise, there was adequate breathing reserve (i.e. $V_E/ MVV < 80\%$) and more subjects terminated both forms of arm exercise because of arm fatigue rather than dyspnoea. As arm exercise is performed by a relatively small muscle mass compared to leg exercise, the peak ventilatory requirements of arm exercise in healthy subjects are low compared to leg exercise. Thus, in COPD subjects with only moderate lung impairment (FEV$_1$ = 56% predicted), the ventilation required for arm exercise will not be high compared to the maximum ventilatory capacity such that arm fatigue could occur prior to ventilatory factors limiting exercise. Muscle fatigue has also been shown to be a factor limiting constant work rate leg exercise in COPD subjects. One study examined quadriceps muscle fatigue using twitch force measures following constant work rate leg exercise and demonstrated the existence of quadriceps muscle fatigue in 50% of the COPD subjects.

Some studies have interpreted constant-load exercise tests based on critical power-duration considerations. While the measurement of critical power was beyond the scope of this paper, these studies are useful in understanding why the COPD subjects in the present study were unable to tolerate a work rate of 80% peak arm work rate. Critical power refers to the highest work rate, which can be sustained without exhaustion. Critical power for leg exercise in COPD subjects occurs at a lower absolute work rate than in healthy subjects but when represented as a percentage of peak work rate, it has been shown to be approximately 82% in COPD subjects and 68% in healthy subjects. These results indicate that COPD subjects can sustain higher relative leg work rates for training than healthy subjects. The fact that subjects in the present study were unable to sustain arm exercise at 80% peak work rate without exhaustion suggests that, for the arms of subjects with COPD, critical power (as a percentage of peak work rate) would be less than 80%. As the arm muscles in COPD subjects

![Figure 2](image-url) The physiological responses during the incremental arm exercise test in one representative subject (Subject 25) with COPD. (A) VO$_2$, (B) $V_E$, (C) dyspnoea and (D) RPE. (Abbreviations: VO$_2$: oxygen consumption, $V_E$: minute ventilation, RPE: rate of perceived exertion).
have been shown to be well preserved, it could be argued that a relatively higher peak work rate for the arms could be achieved such that the critical power for arms now represents a lower fraction of the peak work rate (i.e. a response pattern for the arm muscles in COPD subjects similar to the critical power response seen in the leg muscles of healthy subjects).

The only other studies which have examined both incremental arm exercise and endurance arm exercise at a constant work rate in people with COPD have used a moderate intensity for the constant work rate (i.e. 50% peak work rate). No statistical comparison of the responses was made between the two types of exercise in these studies. Despite this, on further review of the data, the physiological responses were higher at the end of the incremental exercise than at the end of the constant-load exercise. Working at a higher percent of peak work rate (i.e. 80% peak work rate) during constant-load exercise, as in our study, is likely to be above the critical power compared to working at a moderate percent of peak work capacity. This could explain the higher ventilation during constant-load exercise compared to incremental exercise (Figure 3B).

Although more subjects stopped arm exercise because of symptoms of arm fatigue, dyspnoea scores were still high at end exercise for both forms of arm exercise. Our group has previously shown high dyspnoea scores at the end of incremental arm exercise which were not significantly different to those of leg exercise. The mechanism for the increase in dyspnoea scores during exercise has been studied previously with acute dynamic hyperinflation playing a major role. The present study measured the EELV at end exercise during incremental and constant-load arm exercise and showed an increase in mean EELV of 0.5 L for both types of arm exercise. It is likely that this degree of dynamic hyperinflation was a contributing factor to the dyspnoea scores reported in the current study.

The clinical implications of this study are significant. It is clear from the results that an initial high intensity arm training program for the length of time prescribed for aerobic benefits (i.e. approx. 15 min) would not be possible as subjects were only able to exercise for a mean of 7 min. If attempted, subjects are unlikely to comply with training due to the high levels of perceived exertion and dyspnoea which would be experienced. Future research should examine whether high intensity interval training for the arms, in which bouts of high intensity exercise are interspersed with periods of rest or low intensity exercise, could be better tolerated.

This study was limited to evaluating the physiological responses to supported arm exercise. As unsupported arm exercise is recognised as more representative of functional daily arm tasks than supported arm exercise for people with COPD, further studies are required to evaluate the ability of people with COPD to perform high intensity unsupported arm training.

In conclusion, the results of the current study indicate significantly greater ventilatory, dyspnoea and arm fatigue responses at the end of exercise during high intensity, constant-load arm exercise compared to incremental arm exercise in people with COPD. This suggests that supported
arm training at an intensity of 80% peak work rate may be too high as an initial exercise prescription for people with COPD.

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**Conflict of interest**

The authors wish to declare no competing interests with respect to this work.

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**References**