The Acute Effect of Continuous and Intermittent Exercise on the Exercise Efficiency and Physiological Responses of Ischemic Heart Disease Patients

James Faulkner, Michael Mann, Rebecca Grigg, Danielle Lambrick

School of Sport & Exercise
Massey University, Wellington, New Zealand
1 Introduction

Continuous (Dimopoulos et al., 2006; Hambrecht et al., 2004; Roditis et al., 2007) and high-intensity intermittent exercise (Helgerud et al., 2010; Rognmo et al., 2004; Wisløff et al., 2007) have been advocated to be an appropriate training stimulus for patients with elevated cardiovascular risk, coronary artery disease (CAD) and heart failure. Continuous exercise training has been shown to improve peak stroke volume and left ventricular function in CAD patients (Hagberg 1991; Hambrecht et al., 2000), and improve oxygen uptake kinetics (Roditis et al., 2007) and heart rate recovery in chronic heart failure patients (Dimopoulos et al., 2006). High-intensity interval training, which is a well tolerated method of exercise for these population groups (Guiraud et al., 2010; Meyer et al., 2012), is generally associated with improvements in peak oxygen consumption, cardiovascular and muscular function, and quality of life in cardiac and non-cardiac subjects alike (Helgerud et al., 2010, 2007; Guiraud et al., 2010; Karlsen et al., 2008; Rognmo et al., 2004; Warburton et al., 2005; Wisløff et al., 2007). For example, two to four minutes of high-intensity walking, interspersed with an active recovery period, has been shown to be an effective training protocol for CAD patients (Rognmo et al., 2004; Warburton et al., 2005; Wisløff et al., 2007). More recently, repeated short-bouts of high-intensity cycling (15 to 30 s) has been advocated to be an alternative and appropriate training stimulus for CAD and heart failure patients (Guiraud et al., 2010; Meyer et al., 2012; Normandin et al., 2013).

Four key parameters have been identified for the assessment of an individual’s aerobic fitness: maximal or peak oxygen uptake ($\text{VO}_2\text{max} / \text{VO}_2\text{peak}$), the gas exchange threshold (GET), exercise economy/efficiency and $\text{VO}_2$ kinetics. Exercise efficiency is used to examine the ratio between useful work produced and the energy expended during the work. Improvements in exercise efficiency are often represented by a decrease in the $\text{VO}_2$ required to sustain a given mechanical work output (Faria et al., 2005; Lucia et al., 2002). In healthy populations, it has been reported to be in the range of 8–25% (Gaesser & Brooks, 1975; Moseley & Jeukendrup, 2001), implying that ~75-92% of all the energy obtained from ATP hydrolysis is used to maintain homeostasis or is wasted as heat (Moseley & Jeukendrup, 2001). Although exercise efficiency has been suggested to be pertinent in reducing obesity (Schrauwen et al., 1999), promoting weight loss (Lammert & Hansen, 1982; Poole & Henson, 1988) and improving exercise performance (Horowitz et al., 1994), for the cardiac disease population, exercise inefficiency may be a more important factor. It is plausible that the more inefficient one is, the greater the energy expenditure (as demonstrated by a higher $\text{VO}_2$) for a given exercise intensity and therefore the greater the impact there may be on improving cardiovascular risk factors (i.e., blood pressure, blood lipids, bodyweight) and overall health (Aggarwal et al., 2012). This in turn may reduce morbidity and mortality rates (Rognmo et al., 2004). However, the exercise efficiency of ischemic heart disease patients is yet to be investigated. To our knowledge, only one study has examined the effect of moderate-intensity continuous exercise and high-intensity interval exercise on exercise efficiency (Normandin et al., 2013), but this was in the more severe case of heart failure patients. In their study, Normandin et al., demonstrated that patients were more efficient during high-intensity interval exercise (by ~3%) compared to moderate-intensity cycle exercise. It is important to assess the influence of continuous and intermittent exercise protocols on both the exercise (in) efficiency and physiological responses of ischemic heart disease patients as this may allow us to identify which exercise protocols and training stimuli should be implemented within the rehabilitation setting to improve an individual’s recovery and quality of life.
The purpose of this study was therefore to determine whether ischemic heart disease patients were more (in)efficient during continuous exercise at either a moderate or high-intensity, or during high-intensity intermittent exercise. In accordance with Normandin et al. (2013), it was hypothesised that participants would demonstrate superior (i.e., better) efficiency during high-intensity intermittent exercise.

2 Methods

2.1 Participants

Fourteen men with ischemic heart disease volunteered to participate in this study. Demographic and baseline characteristics are presented in Table 1. All participants had recently completed a 12-week, phase II CR programme (3 × 75 minute exercise sessions per week), undertaken a CAD risk factor assessment, health-history questionnaire and a peak and/or symptom limited exercise ECG stress test using the modified-Bruce Protocol (ACSM's guidelines for exercise testing and prescription, 2013). Each exercise session within the 12-week exercise programme consisted of 30 minutes of aerobic exercise and 45 minutes of resistance training and postural, co-ordination and flexibility exercises. During the aerobic exercise, a continuous exercise programme was implemented for the first 6-weeks. Thereafter, participants’ exercise sessions alternated between 30 minutes of continuous exercise and 30 minutes of high-intensity intermittent interval training.

Participants provided written consent prior to participation. Inclusion criteria included stable CAD and completion of a 12-week CR programme. Exclusion criteria included unstable angina pectoris, myocardial infarction or PCI one month prior to the research trial, complex ventricular arrhythmias, atrial fibrillation and orthopaedic limitations to exercise. None of the patients had an artificial cardiac pacemaker. Patients remained on their standard medication throughout the study (Table 1).

Emergency procedures and an automated defibrillator were in place during each exercise test to ensure that appropriate care was available if any adverse events were encountered during testing. Testing took place during the southern hemisphere summer and commenced following ethical approval from New Zealand’s central regional health and disability ethics committee.

2.2 Procedures

All exercise tests were performed on a cycle ergometer (Velotron, RacerMate Inc, Seattle, USA) in a controlled thermo-neutral laboratory environment (temperature, 23.2 ± 1.5 °C; Humidity 43.2 ± 6.3 %; air pressure 1005 ± 10 N·m2). As a consequence of the moderate to high exercise intensities elicited during each exercise test, for safety reasons, a 12-lead ECG was worn throughout each test. Following completion if a graded-exercise test to 85 % HRmax (Gellish et al., 2007), participants completed three experimental tests in a randomised order. This included a moderate-intensity continuous exercise test (MICE), a high-intensity continuous exercise test (HICE), and an intermittent exercise test incorporating both moderate (IE-M) and high (IE-H) intensities. Participants were familiar with these exercise protocols as a result of participating in their local phase II CR programme. Participants had a 48-72 hour recovery period between tests. Physiological data (heart rate [HR], VO2, minute ventilation [ V̇e ]) was continuously recorded before, during and post-exercise. On-line respiratory gas analysis occurred every 10-s via a breath-by-breath automatic gas exchange system (Sensormedic, AEI Technologies, Pittsburgh,
Expired air was collected continuously using a facemask (Hans Rudolph Inc, Shawnee, USA). HR was monitored using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland) and 12-lead ECG (Schiller, Baar, Switzerland). The ECG was used as a monitoring tool throughout each exercise test. All physical and physiological outputs were concealed from the participants.

<table>
<thead>
<tr>
<th>Clinical Variables</th>
<th>Mean ± SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>53.9 ± 10.3</td>
</tr>
<tr>
<td>Men (n)</td>
<td>14 (100 %)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.74 ± 0.04</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>85.5 ± 12.6</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>28.0 ± 3.8</td>
</tr>
<tr>
<td>Medical History</td>
<td></td>
</tr>
<tr>
<td>Previous MI</td>
<td>4 (29 %)</td>
</tr>
<tr>
<td>Previous CABG</td>
<td>8 (57 %)</td>
</tr>
<tr>
<td>Previous PCI</td>
<td>6 (43 %)</td>
</tr>
<tr>
<td>CVD risk factors</td>
<td></td>
</tr>
<tr>
<td>Diabetes Mellitus</td>
<td>4 (29 %)</td>
</tr>
<tr>
<td>Hypertension (&gt; 140/90mmHg)</td>
<td>6 (43 %)</td>
</tr>
<tr>
<td>Previous smoker</td>
<td>7 (50 %)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>0 (0 %)</td>
</tr>
<tr>
<td>Obesity (BMI &gt; 30 kg·m⁻²)</td>
<td>4 (29 %)</td>
</tr>
<tr>
<td>Medications</td>
<td></td>
</tr>
<tr>
<td>B blockers (metropolol)</td>
<td>14 (100 %)</td>
</tr>
<tr>
<td>Anti-coagulants (aspirin, clopidogrel)</td>
<td>14 (100 %)</td>
</tr>
<tr>
<td>Statins (simvastatin, atorvastatin)</td>
<td>13 (93 %)</td>
</tr>
<tr>
<td>ACE inhibitors</td>
<td>5 (36 %)</td>
</tr>
<tr>
<td>Diuretic (furosemide)</td>
<td>2 (14 %)</td>
</tr>
</tbody>
</table>

ACE: angiotensin-converting enzyme; BMI: body mass index; CABG: coronary artery bypass graft; CVD: cardiovascular disease; MI: Myocardial infarction; PCI: percutaneous coronary intervention.

Table 1: Demographic and baseline characteristics of patients with ischemic heart disease. Values are reported as means ± SD or numbers of patients (%).

2.3 Measures

2.3.1 Graded-exercise Test (GXT)

The GXT was a continuous exercise test, commencing at 60 W and increasing by 1 W every 6-s until the attainment of 85% HRmax. The test was terminated at a sub-maximal intensity as maximal exercise constitutes a physiologic stress that may pose a great risk for people with previous cardiac diagnoses (Heyward, 2006; Ehrman et al., 2009). For the purpose of this study, the termination of the exercise test will be referred to as VO₂ peak. HR, VO₂, VE and blood pressure were monitored throughout the test.
2.3.2 Calculating Moderate & High Exercise Intensities

The V-slope method was used to analyse the slopes of $\dot{V}O_2$ and $\dot{V}CO_2$ volume curves from the initial GXT (Beaver et al., 1986). The power output equivalent to each individual’s gaseous exchange threshold (GET) was used for the moderate exercise domain. Using the $\dot{V}O_2$ values reported at GET (first ventilatory threshold) and $\dot{V}O_2$ peak, the power output equivalent to 40% delta ($\Delta$; difference between GET and $\dot{V}O_2$ peak) was calculated (Carter et al., 2002). This was used to reflect the high intensity exercise and ensured that participants were exercising at an equivalent physiological intensity. The GET and 40% $\Delta$ exercise intensities were verified by three independent researchers, and were used for the subsequent independent experimental exercise tests.

2.3.3 Exercise Efficiency Tests

Each experimental test was completed following 10-minutes of supine rest and a 5-minute warm-up at 60 W. During the continuous exercise tests subjects exercised at either the power output equivalent to GET (for MICE) or the power output equivalent to 40% $\Delta$ (for HICE) for 30 minutes. During the intermittent exercise test (IE), participants exercised at their moderate intensity for 4.5 minutes (IE-M) followed by a 30s sprint at the high exercise intensity (IE-H). This protocol was repeated six times to ensure the completion of 30-minutes of exercise. Participants freely chose their pedal cadence throughout each exercise test.

2.4 Data Analysis

The energy expenditure (EE) from MICE, HICE and IE was quantified using the following equation (Volpe Ayub & Bar-Or, 2003):

$$EE (\text{KJ} \cdot \text{min}^{-1}) = \dot{V}O_2 (\text{L} \cdot \text{min}^{-1}) \times (\text{RER} \times 1.232 + 3.815) \times 4.184$$

Gross efficiency (GE) was used to quantify exercise efficiency (Faria et al., 2005; Gaesser et al., 1975; Moseley & Jeukendrup, 2001). GE is the ratio of work done during the specific activity to the total EE:

$$GE (\%) = \frac{\text{Work rate [W]}}{\text{EE [J}\cdot\text{s}^{-1}] \times 100\%}$$

2.5 Statistical Analyses

A one-way ANOVA was firstly used to compare the mean power output elicited during MICE, HICE and IE. A series of two-factor repeated-measures ANOVAs (Test [MI, HI, IE-M, IE-H] × Time [5, 10, 15, 20, 25 & 30 minutes]) were then used to compare participants’ GE between conditions. A similar analysis was used to assess physiological responses. A one way ANOVA compared EE from the MICE, HICE and IE tests. Where assumptions of sphericity were violated, the critical value of $F$ was adjusted by the Greenhouse-Geisser epsilon value following the Mauchly test to reduce the risk of type 1 error. Alpha was set at 0.05 and adjusted accordingly. Tukey’s honestly significant difference test detected where statistical differences lay. All data were analysed using SPSS, version 18.
3 Results

3.1 GXT

At the termination of the GXT participants \( \dot{V}O_2 \) peak, HR, PO and RPE were 38.3 ± 5.5 ml · kg\(^{-1}\)·min\(^{-1}\), 147 ± 14 b · min\(^{-1}\) (86 ± 4 %HRmax), 210 ± 23 W, and 17.6 ± 0.8, respectively. For the experimental tests, HICE elicited a significantly higher mean power output (135 ± 10 W) than MICE (93 ± 12 W) or IE (96 ± 12 W) (\(F_{(2,26)} = 1175.75, P < .001\)).

3.2 Exercise Efficiency Tests

A significant difference in GE was observed between tests (\(F_{(1.9,24.6)} = 40.21, P < .001\); Table 2). GE was higher during MICE (11.0 ± 2.1 %) than all other exercise tests (\(P < .001\)), while IE-M (9.6 ± 1.4 %) was greater than HICE (8.8 ± 1.3 %) or IE-H (6.9 ± 1.4 %) (both \(P < .01\)). A time main effect was observed for GE (\(F_{(2.5,32.4)} = 15.71, P < .001\)), with a significant decrease in exercise efficiency observed between the 5th (10.2 ± 1.3 %) and 10th (9.0 ± 1.2 %) minute of the exercise tests (Table 2).

<table>
<thead>
<tr>
<th>Test</th>
<th>(5)</th>
<th>(10)</th>
<th>(15)</th>
<th>Time (min)(,(20))</th>
<th>(25)</th>
<th>(30)</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICE</td>
<td>11.9 ± 2.6</td>
<td>10.7 ± 1.7</td>
<td>11.0 ± 2.6</td>
<td>10.8 ± 2.3</td>
<td>10.9 ± 2.3</td>
<td>10.8 ± 2.1</td>
<td>11.0 ± 2.1**</td>
<td>9.8 – 12.2</td>
</tr>
<tr>
<td>HICE</td>
<td>9.8 ± 1.2</td>
<td>9.0 ± 1.2</td>
<td>8.7 ± 1.8</td>
<td>8.8 ± 1.7</td>
<td>8.2 ± 1.5</td>
<td>8.2 ± 1.5</td>
<td>8.8 ± 1.3</td>
<td>8.0 – 9.6</td>
</tr>
<tr>
<td>IE-M</td>
<td>11.5 ± 1.9</td>
<td>9.5 ± 1.7</td>
<td>9.3 ± 1.5</td>
<td>9.1 ± 1.5</td>
<td>9.3 ± 1.9</td>
<td>9.1 ± 1.7</td>
<td>9.6 ± 1.4**</td>
<td>8.8 – 1.5</td>
</tr>
<tr>
<td>IE-H</td>
<td>7.4 ± 1.7</td>
<td>6.8 ± 1.4</td>
<td>6.9 ± 1.4</td>
<td>6.9 ± 1.5</td>
<td>6.9 ± 1.5</td>
<td>6.3 ± 1.4</td>
<td>6.9 ± 1.4</td>
<td>6.1 – 7.7</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>10.2 ± 1.3</td>
<td>9.0 ± 1.2**</td>
<td>9.0 ± 1.6</td>
<td>8.9 ± 1.4</td>
<td>8.8 ± 1.6</td>
<td>8.6 ± 1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>95% CI</td>
<td>9.4 – 10.9</td>
<td>8.4 – 9.7</td>
<td>8.1 – 9.9</td>
<td>8.1 – 9.7</td>
<td>7.9 – 9.7</td>
<td>7.8 – 9.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test main effect: **Significantly higher than all other tests (\(P < .001\)); *Significantly higher than HICE, IE-H (\(P < .01\))

Time main effect: *Significantly lower than 5-minutes (\(P < .001\))

Table 2: Mean (± SD) GE (%) between tests and across time

3.3 Physiological Markers

A test main effect was observed for \(\dot{V}O_2\), HR and \(\dot{V}E\) (all \(P < .001\); Figure 1). IE-H produced a higher \(\dot{V}O_2\) value (74 ± 12 %) than all other exercise tests (50 ± 8 % MICE; 65 ± 5 % HICE; 52 ± 8 % IE-M). For HR, despite similarities between HICE and IE-H (80 ± 8 % & 76 ± 9 %, respectively) both tests elicited a higher HR response than MICE and IE-M (61 ± 8 % & 65 ± 7 %, respectively). A significant time main effect was also observed for \(\dot{V}O_2\), HR and \(\dot{V}E\) (\(P < .001\)). \(\dot{V}O_2\) significantly increased at the start (5 to 10 minutes) and end of the tests (20 to 30 minutes; \(P < .05\)), while HR sequentially increased with each 5 minute increment (\(P < .01\)). \(\dot{V}E\) increased between 5 and 10 minutes and between 15 and 30 minutes (\(P < .05\)). With regards to EE, this was significantly greater during HICE (40.1 ± 4.2 KJ·min\(^{-1}\)) than either MICE (28.6 ± 4.4 KJ · min\(^{-1}\)) or IE (32.0 ± 3.5 KJ · min\(^{-1}\)) (\(F_{(2,26)} = 146.19, P < .001\)).
4 Discussion

This study assessed the exercise (in)efficiency of ischemic heart disease patients during continuous and intermittent exercise at moderate and high intensities. Unlike previous research (Normandin et al., 2013), ischemic heart disease patients were more efficient during 30-minutes of continuous exercise (MICE) than high-intensity intermittent exercise (IE-H), causing us to reject our study hypothesis. However, high-intensity continuous exercise (HICE) and IE-H elicited a greater energy expenditure (EE) and higher physiological intensity than MICE.

Figure 1: Mean (± SD) $\dot{V}O_2$, $V_e$ and HR from each test.
Participants’ gross efficiency during MICE was statistically superior (i.e., 2.2% better) than during continuous exercise of a high intensity (HICE). Similarly, MICE was superior to intermittent exercise of both a moderate- (IE-M) and high intensity (1.4% & 4.1%, respectively). Participants were also more efficient during IE-M than either high-intensity condition (HICE or IE-H; Table 2). An inverse relationship between whole-body exercise economy and exercise intensity has been shown with healthy men and women during isometric plantar flexion (Hunter et al., 2001), treadmill walking (Hunter et al., 2005) and cycling exercise (Lucia et al., 2002). As exercise intensity (and thus force production) increases, skeletal muscle become less economical (Lucia et al., 2002; Hunter et al., 2001; 2005). This is likely due to an increased dependence on inefficient Type II muscle fibres and may be related to differences in muscle fibre shortening velocities (Hopker et al., 2009). Oxygen and energy demand may be greater in Type II than Type I muscle fibres for a given amount of contractile work as Type II muscle fibres consume more ATP (i.e., to drive calcium pumps within the sarcoplasmic reticulum) and hence, this may result in a reduced exercise economy (Coyle et al., 1992; Lucia et al., 2002). However, the findings reported in this study differ from those reported by Normandin and colleagues with heart failure patients (Normandin et al., 2013). In their study, high-intensity interval exercise, which incorporated 2 × 8 minutes of 30 s intervals at 100% peak power output and a 30 s passive recovery interval, proved more efficient (GE = 15%) than a 22-minute continuous cycle at 60 % peak power output (GE = 12.4%). When comparing these results with our study, differences between populations groups (ischemic heart disease cf. heart failure) and exercise protocols (duration, intensity, intervals, etc.) may explain the observed differences in the studies’ findings. As fitness levels, physiological responses, pedal cadence, diet, genetics and fibre-type distribution have all been shown to be mediating factors when assessing and interpreting exercise efficiency in healthy populations (Coast et al., 1986; Coyle et al., 1992; Poole & Henson, 1988), further research is necessary to identify the physiological and physical underpinnings for such differences in Exercise efficiency between ischemic heart disease and other cardiac populations.

Ischemic heart disease patients were significantly more efficient in the first five minutes of exercise, regardless of the exercise intensity. A significant decrease in exercise efficiency was typically observed (~1.2%) between the fifth and tenth minute of the exercise tests. In both the continuous (MICE & HICE) and high-intensity intermittent exercise conditions, VO2 drift was observed. Elevated VO2 responses were noted at the start (5-10 min) and completion (20-30 minutes) of the exercise bout. This gradual increase in VO2, which was similarly observed for HR and VE, is the primary mediating factor for the change in exercise efficiency over the course of the exercise tests.

This study utilised a high-intensity intermittent protocol which is similar to the type of protocols recently assessed and advocated in the literature (Normandin et al., 2013; Rognmo et al., 2005; Warburton et al., 2005; Wisloff et al., 2007; ). Although both high- and moderate intensity exercise may induce a similar cardiac hypertrophy, high-intensity training specifically has been shown to induce important cardiac adaptations such as increased contractility, increased glucose oxidation and improved mitochondrial function (Hafstad et al., 2011). Recent research has advocated the prescription of high-intensity exercise for CAD and heart failure patients (Guiraud et al., 2010; Meyer et al., 2012; Normandin et al., 2013) as it is effective in improving VO2peak, cardiovascular disease risk profile and overall health, which in turn may reduce morbidity and mortality rates (Rognmo et al., 2004). As demonstrated in Figure 1, participants revealed a higher physiological cost during IE-H compared to MICE for VO2 (~32%), VE (41%) and HR (20%). Although participants’ exercise efficiency was superior during MICE, participants only exercised at 61 ± 8% HRmax which was much lower than that
observed during either the HICE or IE-H tests (80 ± 8% & 76 ± 9% HRmax, respectively). Accordingly, higher energy expenditure was observed during the high-intensity exercise bouts. The higher intensity exercise prescribed in this study met recommendations for improving cardio-respiratory fitness (ACSM’s guidelines for exercise testing and prescription, 2013).

When trained individuals are matched for fitness, exercise efficiency may prove to be a decisive factor in distinguishing overall athletic performance (Faria et al., 2005). However, in situations whereby maximal functional capacity and elevated energy expenditure may be a more important factor for undertaking activities of daily living, such as with ischemic heart disease patients, exercise (in)efficiency may be of greater importance. For example, Lammert and Hansen (Lammert & Hansen, 1982) demonstrated that long-term benefits of a weight loss programme may be counteracted over-time by improvements in exercise efficiency. However, researchers and practitioners should be cautious when implementing high-intensity exercise as the risk of a cardiac event is greater during high-intensity exercise compared to moderate intensity exercise (Rognmo et al., 2012; Keteyian, 2012). Future research is needed to compare the long-term effect of prescribing moderate intensity exercise, which may elicit an efficient exercise performance, to an exercise intensity that may generate a higher physiological workload and greater energy expenditure in various cardiac populations.

This study has several limitations, including a small number of patients (although in keeping with previous research in this area (Meyer et al., 1990; Normandin et al., 2013)), the high-level of fitness of the study sample, and the inclusion of only one experimental trial for all continuous and intermittent exercise conditions. As such, further research is needed to examine whether similar findings are evident following repeated trials and/or following a specific training programme with cardiac populations of varying fitness. Inter-individual variation in the calculation of the higher exercise intensity may also have been evident. For safety reasons, the test was terminated at a sub-maximal intensity as maximal exercise constitutes a physiologic stress that may pose a great risk for people with previous cardiac diagnoses (Beaver et al., 1986; Heyward 2006). However, at the point of test termination, inter-individual variability may have been present due to prescribed beta blocker use and chronotropic incompetence (Brubaker & Kitzman, 2011). This may have influenced the calculation of the higher exercise intensity domain. As the workload of the intermittent and continuous exercise bouts were not matched by means of power output or energy expenditure, this is an aspect of the research design which should also be considered in the future. Finally, for a more holistic understanding of ischemic heart disease patients’ and other cardiac populations’ exercise (in)efficiency, it would also be important to implement randomized controlled trials whereby the exercise efficiency pre- and post-rehabilitation (i.e., exercise vs. control [no exercise]) can be examined. By manipulating the exercise programme (intensity, duration, mode, etc.), and by considering a patient’s baseline level of fitness, a greater understanding of the importance of exercise intensity and exercise (in)efficiency may be alluded to with this population. For example, as subjects in the present study completed a greater proportion of continuous exercise during their 12-week CR programme, the greater efficiency observed during MICE may have been due to their greater exposure to this type of exercise training.

In conclusion, ischemic heart disease patients were more inefficient during high-intensity exercise (continuous and intermittent) than during continuous moderate intensity exercise. High-intensity exercise may therefore be of a greater benefit for this population group due to eliciting a higher physiological response and energy expenditure. This may be particularly important when considering the potential for improving cardiovascular risk profiles (i.e., blood pressure, blood lipids, and bodyweight) and overall health of ischemic heart disease patients.
References


