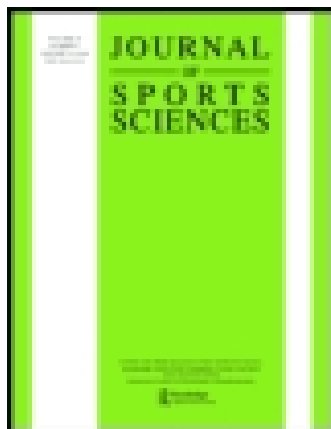


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## Intensity-dependent reductions in resting blood pressure following short-term isometric exercise training

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### Abstract

To reduce resting blood pressure, a minimum isometric exercise training (IET) intensity has been suggested, but this is not known for short-term IET programmes. We therefore compared the effects of moderate- and low-intensity IET programmes on resting blood pressure. Forty normotensive participants ( $22.3 \pm 3.4$  years;  $69.5 \pm 15.5$  kg;  $170.2 \pm 8.7$  cm) were randomly assigned to groups of differing training intensities [20%EMG<sub>peak</sub> (~23%MVC, maximum voluntary contraction, or 30%EMG<sub>peak</sub> (~34%MVC)] or control group; 3 weeks of IET at 30%EMG<sub>peak</sub> resulted in significant reductions in resting mean arterial pressure (e.g.  $-3.9 \pm 1.0$  mmHg,  $P < 0.001$ ), whereas 20%EMG<sub>peak</sub> did not ( $-2.3 \pm 2.9$  mmHg;  $P > 0.05$ ). Moreover, after pooling all female versus male participants, IET induced a 6.9-mmHg reduction in systolic blood pressure in female participants, but only a 1.5-mmHg reduction in systolic blood pressure in male participants, although the difference was not significant. An IET intensity between 20%EMG<sub>peak</sub> and 30%EMG<sub>peak</sub> is sufficient to elicit significant resting blood pressure reductions in a short-term training period (3 weeks). In addition, sexual dimorphism may exist in the magnitude of reductions, but further work is required to confirm this possibility, which could be important in understanding the mechanisms responsible.

**Keywords:** *isometric exercise training, resting blood pressure, isometric exercise intensity*

### Introduction

Exercise training programmes designed to lower resting blood pressure could have important clinical implications for the management of hypertension. Successful short-term training programmes may also be important in patient adherence to this intervention if the patient sees rapid results. Reduced resting blood pressure in response to isometric exercise training (IET) has been demonstrated in hypertensive patients (Taylor, McCartney, Kamath, & Wiley, 2003), medicated hypertensive patients (McGowan, Visocchi, et al., 2007; Millar, Bray, McGowan, MacDonald, & McCartney, 2007; Millar, Levy, McGowan, McCartney, & Macdonald, 2013) and normotensive participants (Millar, Bray, MacDonald, & McCartney, 2008; Wiley, Dunn, Cox, Hueppchen,

& Scott, 1992), demonstrating a possible protective effect against development of hypertension.

Components of IET protocols (e.g. frequency of training sessions, intensity, type and duration) may be important in determining the degree of resting blood pressure adaptations, which have not been studied in detail. Part of the problem has been a lack of uniformity regarding methods used to determine IET intensity. Previous studies have used a wide range of IET intensities based on a participant's maximum voluntary contraction (MVC) force (20–50%) to set IET intensity (Baross, Wiles, & Swaine, 2012; Devereux, Coleman, Wiles, & Swaine, 2012; Howden, Lightfoot, Brown, & Swaine, 2002; Millar et al., 2007, 2008; Taylor et al., 2003; Wiley et al., 1992). However, training protocols, rest periods between each contraction and muscle groups trained were

not consistent among these studies. Therefore, it is difficult to separate the relative effects of isometric exercise intensity from other protocol components.

More recently, a method of determining training intensity by measuring muscle activation (electromyography, EMG) was developed, which produces a steady-state cardiovascular response during isometric exercise, improving intensity quantification (Wiles, Allum, Coleman, & Swaine, 2008). This method was used to investigate the effects of double-leg IET intensity on resting blood pressure reductions in 18- to 34-year-old male participants (Wiles, Coleman, & Swaine, 2010). While the IET intensities used were relatively low (14%EMG<sub>peak</sub> and 20%EMG<sub>peak</sub> or ~10%MVC and 14%MVC), modest but significant reductions in resting systolic blood pressure (~5 mmHg) and diastolic blood pressure (2–3 mmHg) were observed at both intensities after 8 weeks of IET. Moreover, similar intensities (10%MVC and 20%MVC) were used during 8 weeks of IET in a group of middle-aged men (mean age ~54 years), resulting in a larger significant IET reduction (~10 mmHg) in the higher intensity group only (Baross et al., 2012). The difference in the degree of blood pressure reduction between these studies may be associated with the different participant age groups.

If higher IET intensities are used, reductions in resting blood pressure may be observed in fewer weeks of training, which would strengthen the argument for IET intensity being important in producing reliable reductions in resting blood pressure. Devereux, Wiles, and Swaine (2011) predicted an exercise intensity of 105.4% of an individual's 2-min torque peak (~30%EMG<sub>peak</sub>) would elicit a 5-mmHg reduction in systolic blood pressure after 4 weeks of double-leg IET. Interestingly, a significant reduction in systolic blood pressure has been reported after only 3 weeks of bilateral quadriceps IET at 20%MVC (Howden et al., 2002). Taken together, this suggests a relationship between IET intensity and time to a reduction in resting blood pressure that is not fully understood. Demonstrating a relationship between IET intensity and time to reduced resting blood pressure would provide important information to improve our capacity to design effective training programmes.

The purpose of this investigation was to assess the effects of short-term low- and moderate-intensity double-leg IET on resting blood pressure. Optimisation of IET protocols that are designed to reduce resting blood pressure is critical for developing effective, non-pharmacological interventions for resting blood pressure control. We hypothesised that a reduction in resting blood pressure would be intensity dependent using a short-term (3 weeks) IET programme. The objective of this study was to demonstrate a relationship between training intensity and the length of a training programme.

## Materials and methods

### Participants

All participants gave written informed consent prior to participation, and the University of North Carolina at Charlotte Institutional Review Board approved this study. All participants were nonsmokers, they were not taking prescription medications that are known to influence cardiovascular function, and they were required to maintain their normal physical activity and dietary habits for the duration of the study. Moreover, all but one of the female participants reported using an oral contraceptive during the training period and phase of menstrual cycle was not controlled for. Participants avoided strenuous exercise for 24 h and were at least 4 h postprandial prior to each training session. All participants completed a procedure and equipment familiarisation session prior to acceptance into the study.

In all, 11 male and 29 female normotensive participants (mean age  $22.3 \pm 3.4$  years; body mass of  $69.5 \pm 15.5$  kg; height  $170.2 \pm 8.7$  cm) volunteered to participate. Each of these participants were randomly assigned to 20%EMG<sub>peak</sub> group (T1), 30%EMG<sub>peak</sub> group (T2) or control group, and baseline characteristics were assessed (Table I) prior to investigating the influence of IET intensity on resting blood pressure adaptations. The size of the control group was larger than the training groups because a separate control group was used for each training group, who did not train concurrently.

### EMG recording

Surface EMG recordings were made from both vastus lateralis muscles using a BIOPAC MP150 (MP150WSW) data acquisition system and analysed with AcqKnowledge v. 3.8.1 (BIOPAC Systems, Inc., Camino Goleta, CA 93,117). EMG signals

Table I. Resting baseline participant characteristics and post-isometric exercise training (IET) resting heart rate (HR; mean  $\pm$  s<sub>x</sub>). No between group differences were found ( $P > 0.05$ ).

Characteristic	Training group 1	Training group 2	Control group
Age (years)	25.00 $\pm$ 2.28	21.33 $\pm$ 0.33	22.28 $\pm$ 0.46
Sex			
Male	4	2	4
Female	4	7	14
Height (cm)	169.5 $\pm$ 2.70	167.4 $\pm$ 1.7	171.20 $\pm$ 2.28
Mass (Kg)	73.5 $\pm$ 6.6	67.9 $\pm$ 4.9	67.40 $\pm$ 3.65
SBP (mmHg)	116.4 $\pm$ 4.3	110.4 $\pm$ 3.3	112.6 $\pm$ 2.5
DBP (mmHg)	68.7 $\pm$ 3.7	62.1 $\pm$ 1.3	65.1 $\pm$ 2.1
MAP (mmHg)	84.3 $\pm$ 3.6	78.2 $\pm$ 1.7	80.9 $\pm$ 1.9
HR (bpm)	60.0 $\pm$ 3.4	63.4 $\pm$ 4.7	67.1 $\pm$ 5.1
Post-IET resting HR (bpm)	63.6 $\pm$ 4.2	61.4 $\pm$ 4.5	63.7 $\pm$ 3.4

were sampled at a frequency of 1 kHz and smoothed using a RMS algorithm with a 5-ms moving average.

#### *Isometric exercise*

All tests and training were conducted using a Biodex System 3 Pro isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY). The Biodex leg extension attachment was modified to allow bilateral-leg contractions at a 90° knee joint angle once participants were appropriately restrained. Participants were instructed to avoid using their upper body in generating force during isometric contractions in order to standardise the level of stabilisation and to isolate the quadriceps (Mendler, 1967).

#### *Maximal voluntary contraction and EMG<sub>peak</sub>*

Participants performed at least three (no more than five) maximal voluntary bilateral-leg contractions for 2 s, each 120 s apart, which were not different by more than 20%. MVCs were performed at a knee angle of 90° (180° corresponds to full knee extension) on the isokinetic dynamometer (Alkner, Tesch, & Berg, 2000). MVCs were performed prior to each IET session. Isometric exercise intensity for each session was determined by averaging the three highest MVC EMG signals and asking participants to maintain a percentage of that signal average (% EMG<sub>peak</sub>).

#### *Arterial blood pressure*

At the same time of day for each participant, resting blood pressure and heart rate (HR) measurements were obtained at the brachial artery with an automatic sphygmomanometer by R-wave gated auscultation using a microphone in the blood pressure cuff (Colin STBP-780, Colin Inc., San Antonio, TX, USA). All measurements were started after 15 min of quiet seated rest in a temperature-controlled laboratory and were repeated once per min for 5 min. Resting blood pressure was measured immediately prior to and after the training period in both control and training participants. The three lowest measurements were averaged to represent resting blood pressure.

#### *Training sessions*

Participants performed 4 × 2 min bouts of double-leg isometric exercise separated by 3-min rest periods, 3 days · week<sup>-1</sup>, and training sessions were divided by at least 24 h (typically 48 h). Participants and the investigator monitored a real-time EMG signal display to ensure the appropriate

EMG activity level was maintained throughout IET. Participants were instructed to breathe normally at all times during isometric exercise to avoid a Valsalva manoeuvre. One participant group performed IET at 20%EMG<sub>peak</sub> (~23%MVCs) and another group at 30%EMG<sub>peak</sub> (~34%MVCs) for 3 weeks. Participants in the control group did not perform any IET during the training period.

#### *Data analyses*

Differences in baseline group (20%EMG<sub>peak</sub>, 30%EMG<sub>peak</sub> and control groups) characteristics and the influence of IET intensity on changes in systolic blood pressure, diastolic blood pressure, mean arterial pressure and HR were assessed by a two-way ANOVA. An alpha level of 0.05 was set as the threshold for statistical significance, and the Holm–Sidak post hoc test was used for pairwise comparisons.

When recruiting participants for this study, it was not our intention to investigate sex differences in responsiveness to double-leg IET-induced blood pressure adaptations. However, it has been suggested that female participants may be more sensitive to IET than male participants (Millar et al., 2008). Therefore, as an exploratory objective, we pooled 20%EMG<sub>peak</sub> group and 30%EMG<sub>peak</sub> group female participants, and 20%EMG<sub>peak</sub> group and 30%EMG<sub>peak</sub> group male participants, from which delta systolic blood pressure, diastolic blood pressure, mean arterial pressure and HR were calculated. Sex differences for each parameter were assessed by *t*-test, and the alpha level of 0.05 was set as the threshold for statistical significance.

#### **Results**

No statistically significant differences in baseline group mean characteristics, including resting blood pressure and HR, were found ( $P > 0.05$ ; Table I); 3 weeks of double-leg IET resulted in significant reductions in systolic blood pressure in the 30%EMG<sub>peak</sub> group, compared to pre-IET ( $-3.6 \pm 1.03$  mmHg,  $P = 0.005$ ; Figure 1A). Post-IET systolic blood pressure in 30%EMG<sub>peak</sub> group was also significantly lower compared to post-IET systolic blood pressure in the 20%EMG<sub>peak</sub> ( $P = 0.004$ ) and control ( $P = 0.039$ ) groups, but 20%EMG<sub>peak</sub> group post-IET systolic blood pressure was not significantly different from the control group after IET (Figure 1A). No significant changes in systolic blood pressure were observed in the control group throughout the training period.

A significant reduction in diastolic blood pressure was also found in the 30%EMG<sub>peak</sub> group ( $-4.0 \pm 0.99$  mmHg,  $P < 0.001$ ; Figure 1B), and diastolic

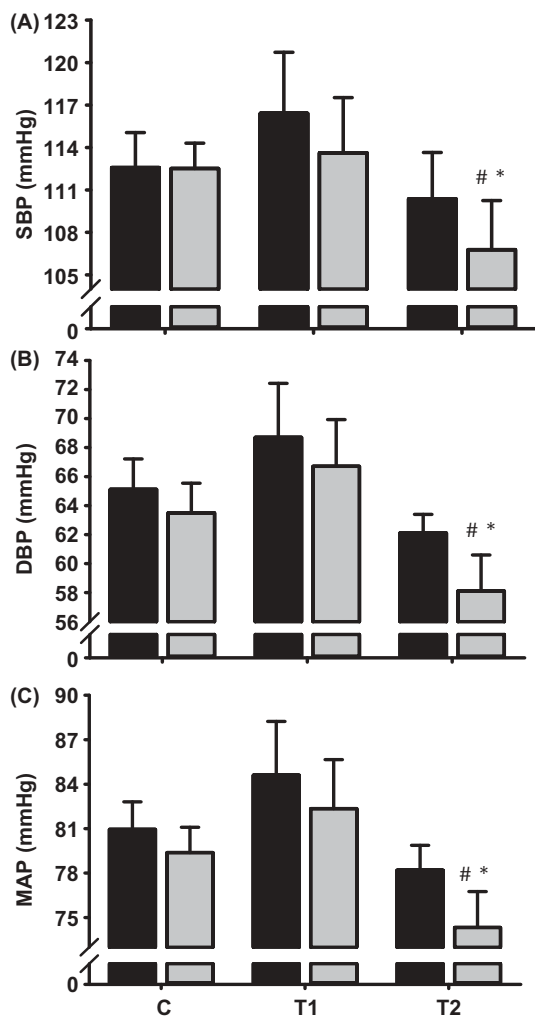


Figure 1. Mean  $\pm$   $s_x$  resting systolic (A), diastolic (B) and mean arterial (C) BP before and after 3 weeks of IET in 20%EMG<sub>peak</sub> (T1), 30%EMG<sub>peak</sub> (T2) and control (C) groups. Black bars = pre-IET and grey bars = post-IET. \* = significant difference compared to pre-training ( $P \leq 0.005$ ). # = significant difference from post-IET C and T1 ( $P < 0.05$ ).

blood pressure in the 30%EMG<sub>peak</sub> group was significantly lower compared to the 20%EMG<sub>peak</sub> group ( $P < 0.001$ ) and control groups ( $P = 0.001$ ) after IET. Diastolic blood pressure in the 20%EMG<sub>peak</sub> group and control groups did not change throughout the training period (Figure 1B). Mean arterial pressure reduced significantly in the 30%EMG<sub>peak</sub> group ( $-3.9 \pm 0.99$  mmHg,  $P < 0.001$ ; Figure 1C), which was different from the 20%EMG<sub>peak</sub> group ( $P < 0.001$ ) and control ( $P = 0.002$ ) groups. Mean arterial pressure did not change after IET in the 20%EMG<sub>peak</sub> group or control groups (Figure 1C). No changes in HR were found in any group after IET ( $P > 0.05$ ; Table 1).

After pooling 20%EMG<sub>peak</sub> group and 30%EMG<sub>peak</sub> group female and male participants into two separate groups, we did not find any significant differences in delta systolic blood pressure ( $-6.9 \pm$

$3.8$  vs.  $-1.5 \pm 4.3$  mmHg,  $P = 0.194$ ), delta diastolic blood pressure ( $-2.7 \pm 3.3$  vs.  $-3.3 \pm 2.9$  mmHg,  $P = 0.182$ ), delta mean arterial pressure ( $-5.6 \pm 3.4$  vs.  $-1.1 \pm 3.4$  mmHg,  $P = 0.832$ ) or delta HR ( $-2.6 \pm 4.4$  vs.  $5.4 \pm 3.3$  bpm,  $P = 0.073$ ).

## Discussion

In this study, 3 weeks of double-leg IET at 30%EMG<sub>peak</sub> induced a significant reduction in systolic, diastolic and mean arterial blood pressure; however, IET at 20%EMG<sub>peak</sub>, using the same protocol, or an absence of IET (control group) did not, suggesting a threshold for double-leg IET of between 20%EMG<sub>peak</sub> and 30%EMG<sub>peak</sub>. Interestingly, the present results are concordant with Devereux et al. (2011), who predicted a threshold for IET intensity to induce a significant reduction in resting blood pressure in short IET programmes (3–4 weeks). Although the following discussion focuses on IET intensity, it is important to recognise that a recent study demonstrated IET volume as an influential factor in resting blood pressure responses to IET (Badrov, Horton, Millar, & McGowan, 2013). Therefore, IET intensity should be considered alongside other protocol components when designing IET programmes.

Several studies have used IET to induce reductions in resting blood pressure in both healthy participants and medication hypertensive patients (Howden et al., 2002; McGowan, Levy, McCartney, & MacDonald, 2007; Millar et al., 2007; Stiller-Moldovan, Kenno, & McGowan, 2012; Taylor et al., 2003; Wiley et al., 1992). Recent meta-analyses of IET studies reported average reductions in resting blood pressure that were substantial [ $-6.77$  to  $-10.9$  mmHg systolic blood pressure and  $-3.9$  to  $-6.7$  mmHg diastolic blood pressure (Carlson, Dieberg, Hess, Millar, & Smart, 2014; Cornelissen, Verheyden, Aubert, & Fagard, 2010; Owen, Wiles, & Swaine, 2010)] and similar to blood pressure reductions expected with pharmacological intervention. However, the mechanisms responsible for IET-induced reductions in resting blood pressure remain elusive, with numerous candidates that were recently been reviewed (Lawrence, Cooley, Huet, Arthur, & Howden, 2014; Millar, McGowan, Cornelissen, Araujo, & Swaine, 2014). In the meantime, understanding more about the most effective protocol for IET-induced reductions in resting blood pressure could have significant clinical implications, especially as an alternative for pharmacological interventions. This is because hypertension has been reported to be increasing in the United States, suggesting the success of lifestyle modification recommendations and antihypertensive medication are not adequate (Hajjar & Kotchen, 2003), which may be associated with low adherence

rates (Brook et al., 2013; Cooney & Pascuzzi, 2009). It is possible that rapid success in reducing resting blood pressure (i.e. short, higher intensity IET programmes) may be an important factor in patient adherence and effective resting blood pressure control, highlighting the need to develop successful IET protocols, which includes understanding more about the components of training programmes (i.e. intensity, frequency and duration). In this study, we provide evidence for IET intensity being an important factor in successful IET-induced reductions in resting blood pressure.

Currently, there are a number of methods reported for setting isometric exercise intensity, including %MVC, %EMG<sub>peak</sub> and %HR<sub>peak</sub>, the latter two set following an MVC, as in the current study, or an incremental isometric exercise test (Devereux, Wiles, & Swaine, 2010; Devereux et al., 2012). Interestingly, the magnitude of resting blood pressure reductions has been less (~5 mmHg for systolic blood pressure) using %EMG<sub>peak</sub> or %HR<sub>peak</sub> to set IET intensity (Devereux et al., 2010, 2011; Wiles et al., 2010), compared to %MVC (e.g. Howden et al., 2002), although the former studies used young male participants, which could have been an influencing factor. However, it is possible that the hitherto IET intensity set by this newer method, as used in the present study, does not produce sufficient stimulus to elicit the larger reductions in blood pressure previously seen when IET intensity was set by %MVC. The present study used the highest steady-state (%EMG<sub>peak</sub>) IET intensity reported to date and found similar reductions in resting blood pressure to Wiles et al. (2010), but in a much shorter time frame (3 vs. 8 weeks). This suggests a relationship between IET intensity and time to a given reduction in resting blood pressure. This relationship could be important from a clinical perspective, as correction of hypertension in a relatively short period may be desirable for an initial restoration of resting blood pressure within the normotensive range.

Moreover, the majority of the participants in the present study were females, which could have influenced the results (Table I). Recently, it was suggested that females may be more sensitive to IET-induced reductions in resting blood pressure than their male counterparts (Millar et al., 2008). When data collected from our both training groups were pooled into female and male groups, IET induced a 6.9-mmHg reduction in resting systolic blood pressure in female participants, but only a 1.5-mmHg reduction in resting systolic blood pressure in male participants (Figure 2). Although differences in female versus male blood pressure reductions were not statistically significant, the sample size was small, and therefore, further investigation into sex dimorphism in responsiveness to IET is warranted.

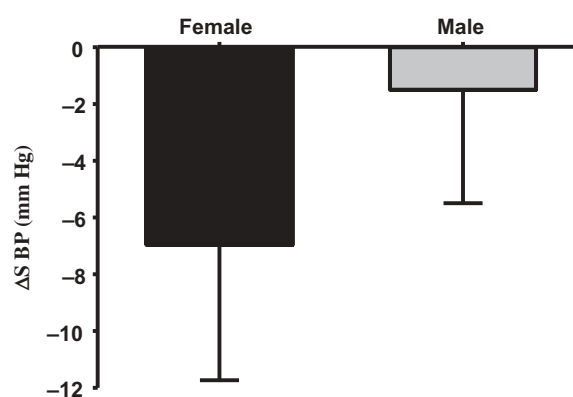


Figure 2. Mean  $\pm$  s<sub>x</sub> female and male  $\Delta$  systolic blood pressure (SBP) after 3 weeks of IET (20%EMG<sub>peak</sub> and 30%EMG<sub>peak</sub> pooled;  $P > 0.05$ ).

If sexual dimorphism exists in responsiveness to short-term double-leg IET-induced resting blood pressure reductions, sex hormones may play an important role. Blood pressure adaptations through alterations in nitric oxide synthase activity, arachidonic acid-derived lipoxygenase metabolites, capillary and venular densities and sympathetic nervous system modulation, and possibly other mechanisms (reviewed in Coimbra et al., 2008; Pfister, 2011; Vongpatanasin, 2009) may be important targets of future research. Thus, it is critically important to have a more comprehensive assessment of sex differences in sensitivity to IET-induced resting blood pressure reductions as this may be important in designing sex-specific and effective IET programmes.

## Conclusion

In summary, this work has demonstrated that IET-induced reductions in resting blood pressure, after short-term double-leg training, are dependent on IET intensity and there appears to be a threshold of training intensity between 20%EMG<sub>peak</sub> and 30%EMG<sub>peak</sub>. However, these changes in resting blood pressure in response to differing IET intensity may have been associated with different percentages of male and female participants in the 20%EMG<sub>peak</sub> and 30%EMG<sub>peak</sub> groups. Further work is required to understand more about sex differences in resting blood pressure adaptations in response to IET. This could be important in terms of designing sex-specific IET programmes or differential expectations in resting blood pressure adaptations following IET in men and women.

## Conflict of interest

The authors declare no conflict of interest.

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