The minimum isometric training intensity for reductions in resting blood pressure to occur, after a short-term program

Kyle F. Gill[1], Susan T. Arthur[1], Ian L. Swaine[2], Gavin R. Devereux[3], Yvette M. Huet[1], Erik A. Wikstrom[4], Mitchell L. Cordova[5], Reuben Howden[1].

[1] Laboratory of Systems Physiology, Department of Kinesiology, University of North Carolina at Charlotte, Charlotte NC, USA

[2] Department of Sport Science, Tourism and Leisure, Canterbury Christ Church University, Canterbury, UK

[3] School of Science, Technology and Health, University Campus Suffolk, Ipswich, UK

[4] Biodynamics Laboratory, Department of Kinesiology, University of North Carolina at Charlotte, Charlotte NC, USA

[5] College of Health Professions and Social Work, Florida Gulf Coast University, Fort Myers, FL USA

Correspondence to:
Reuben Howden
Laboratory of Systems Physiology,
Dept. of Kinesiology,
University of North Carolina at Charlotte,
Charlotte,
NC. 28223
rhowden@uncc.edu

Word count 2,781

ABSTRACT

Recently, a minimum threshold of training intensity for reducing resting blood pressure (RBP) after short-term isometric exercise training (IET; < 4wks) had been suggested. However, variations in IET protocols employed are evident, including different methods for setting training intensity. Therefore, the minimum IET intensity required for RBP adaptations to occur, after short-term IET programs, is not known. **Purpose:** The purpose of this study was to compare the effects of short-term moderate- and low-intensity IET programs on RBP in normotensive subjects. **Methods and Results:** 3wks of IET at 30%EMG_{peak} resulted in significant reductions in RBP (e.g. -3.9 ± 0.99 mmHg, P<0.001, mean arterial RBP) whereas IET at 20%EMG_{peak} did not (-2.3 ± 2.9 mmHg; P>0.05, mean arterial RBP). However, within the 20%EMG_{peak} training group, systolic RBP in female subjects was significantly lower than their male counterparts following IET (105.8 ± 3.0 vs. 123.6 ± 3.0 mmHg for women and men respectively). **Conclusions:** Results confirmed previous predictions that an IET intensity of 20-30%EMG_{peak} is required to elicit a significant RBP reduction in a short-term training period (3-4wks). In addition, sex differences may exist in the magnitude of reductions. This may be important in understanding the mechanisms responsible for this established phenomenon.

Keywords: Isometric exercise training; resting blood pressure; isometric exercise intensity

INTRODUCTION

Reduced resting blood pressure (RBP) following 4-10 weeks of isometric exercise training (IET) has been described repeatedly, using unilateral and bilateral handgrip (Millar et al., 2008; Millar et al., 2007; Millar et al., 2012; Mortimer & McKune, 2011; Taylor et al., 2003; Wiley et al., 1992) and bilateral quadriceps or biceps (Devereux et al., 2011; Devereux et al., 2010; Howden et al., 2002; Wiles et al., 2008; Wiles et al., 2010) training protocols. Lowering RBP by means of these simple, short-term exercise training programs could have important clinical implications for controlling RBP. For example, reduced RBP in response to IET has been demonstrated in hypertensive patients (Taylor, et al., 2003), medicated hypertensive patients (McGowan et al., 2007; Millar, et al., 2007; Millar, et al., 2012) and normotensive subjects (Millar, et al., 2008; Mortimer & McKune, 2011; Wiley, et al., 1992), demonstrating a potential protective effect against development of hypertension.

Interestingly, in the literature, no relationship between the magnitude of RBP reduction and muscle mass trained is evident. Therefore, other factors like training protocols (e.g. frequency of training session, intensity, type and duration of IET) may be important in determining the degree of RBP adaptations, which has not been studied in detail. In particular, little is known about the influence of differing IET intensities on reductions in RBP using identical protocols. Part of the problem has been a lack of uniformity regarding methods used to determine IET intensity. Several studies used a predetermined percentage (20-50%) of a subject's maximum voluntary isometric contraction (MVC) force to set IET intensity (Howden, et al., 2002; Millar, et al., 2008; Millar, et al., 2007; Taylor, et al., 2003; Wiley, et al., 1992). However, training protocols, rest periods between each contraction or muscle groups trained were not consistent among these studies. Therefore, it is difficult to separate the relative effects of isometric exercise intensity from training volume or other protocol components. For example, Wiley et al. reported one study comprising 4 x 2-min contractions at 30% MVC interspersed by 3-mins of rest and in the same report, another study comprising 4 x 45-secs contractions at 50% MVC with only 1-min of rest between contractions (Wiley, et al., 1992).

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, et al., 2008). This method was used to investigate the effects of IET intensity on RBP reductions in 18-34 year old male subjects (Wiles, et al., 2010). While the IET intensities used were relatively low (14 and 20% EMGpeak or ~10 and 14% MVC), modest, but significant reductions in both resting SBP (~5mmHg) and DBP (2-3mmHg) were observed, although 8 weeks of IET was required. Moreover, similar intensities (10 and 20% MVC) were used during 8 weeks of IET in a group of middle-aged men (mean age ~54yrs), resulting in a significant SBP reduction (~10mmHg) in the higher intensity group only (Baross et al., 2012).

This demonstrates a lack of consistency in the reported effectiveness of selecting relatively low IET intensities. This may be associated with the different subject age groups used by Baross et al. (2012) and Wiles et. al. (2010). If a higher IET intensity was used, reductions in RBP may have been observed in fewer weeks of training, which would strengthen the argument for IET intensity being important in producing reliable reductions in RBP. Devereux et al. predicted an exercise intensity of 105.4% of an individual's 2-min torque peak (~30% EMG_{peak}) would elicit a 5 mmHg reduction in systolic blood pressure (SBP) after 4 weeks of IET (Devereux, et al., 2011). Interestingly, a significant reduction in SBP 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 RBP that is not fully understood and therefore warrants further investigation to understand more about designing effective and reliable IET programs to induce RBP reductions. Providing IET intensity is sufficient, 3 weeks of bilateral quadriceps IET should induce a significant reduction in RBP, which would further demonstrate a relationship between IET intensity and time to reduced RBP.

The purpose of this investigation was to assess the effects on RBP of moderate- and low-intensity short-term IET, to determine whether there is a minimum training intensity, as suggested previously. Optimization of IET protocols that are designed to reduce RBP is critical for developing effective, non-pharmacological interventions for RBP control. The usefulness of such IET protocols may not be limited to pre-hypertensive and hypertensive individuals, but may also be effective in preventing the development of hypertension in normotensives, illustrating a potential wide-ranging benefit from simple IET programs. We hypothesized that reductions in RBP would be intensity-dependent and that a training intensity of 20% EMG_{peak} would not be sufficient to induce a reduced RBP, whereas 30% EMG_{peak} intensity would.

MATERIALS AND METHODS

Subjects

All subjects gave written informed consent prior to participation and the University of North Carolina at Charlotte Institutional Review Board approved this study. All subjects were non-smokers, 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. Subjects avoided strenuous exercise for 24 hours, and were at least 4 hours postprandial prior to each training session. All subjects completed a procedure and equipment familiarization session prior to acceptance into the study.

Eleven male and twenty-nine female normotensive subjects (mean age 22.3 ± 3.4 years; body mass of 69.5 ± 15.5 kg; height 170.2 ± 8.7 cm) volunteered to participate. Each of these subjects were randomly assigned to training group 1 (T1), training group 2 (T2) or control group and baseline characteristics were assessed (Table 1) prior to investigating the influence of IET intensity on RBP adaptations.

EMG recording

Surface EMG recordings were made from both vastus lateralis muscles using a BIOPAC MP150 (MP150WSW) data acquisition system and analyzed with Acqknowledge v. 3.8.1 (BIOPAC Systems, Inc., Camino Goleta, CA 93117). EMG signals were sampled at a frequency of 1kHz and smoothed using a RMS algorithm with a 5ms 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-degree 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 standardize the level of stabilization and to isolate the quadriceps (Mendler, 1967).

Maximal voluntary contraction and peak EMG

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

Arterial blood pressure

RBP and heart rate (HR) measurements were obtained using an automatic sphygmomanometer (Colin STBP-780, Colin Inc., San Antonio, TX, USA). All measurements started after 15 minutes of quiet rest in a temperature controlled laboratory and were repeated once per minute for five minutes. RBP was measured during weekly visits to the laboratory by control subjects or immediately prior to the first training session of each week. The three lowest measurements were averaged to represent RBP.

Training sessions

Subjects performed 4 x 2-min bouts of isometric exercise separated by 3-minute rest periods 3 days.wk^{-1} and training sessions were separated by at least 24 hours (typically 48-72 hours). Subjects and 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 manoeuver. T1 performed IET at 20 %EMG_{peak} and T2 at 30 %EMG_{peak} for 3 weeks.

Data Analyses

Differences in baseline group (T1, T2 and C) characteristics and the influence of IET intensity on changes in SBP, DBP, MAP and HR were assessed by a one-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 subjects for this study, it was not our intention to investigate sex differences in responsiveness to IET-induced BP adaptations. However, it has been suggested that female subject may be more sensitive the IET than male subjects (Millar, et al., 2008). Our C and T2 groups both comprised ~80% female subjects and therefore a useful assessment of sex differences would be difficult. However, our T1 group comprised 50% female and 50% male subjects. We therefore, compared pre-IET and post-IET RBP and HR in T1 female and male subjects using a one-way ANOVA. Again, the 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.

RESULTS

No differences in baseline group mean characteristics, including RBP and HR, were found ($P > 0.05$; Table 1). However, 3 weeks of IET resulted in significant reductions in SBP in T2 (30% EMG_{peak}), compared to pre-IET (-3.6 ± 1.03 mmHg, $P = 0.005$; Figure 1). SBP in T2 was also significantly lower compared to post-IET SBP in T1 (20% EMG_{peak}; $P = 0.004$) and control ($P = 0.039$) groups, but T1 post-IET SBP was not significantly different from the control group after IET. No significant changes in SBP were observed in the control group throughout the training period.

A significant reduction in DBP was also found in T2 (-4.0 ± 0.99 mmHg, $P < 0.001$; Figure 2) and DBP in T2 was significantly lower compared to T1 ($P < 0.001$) and control groups ($P = 0.001$) after IET. DBP in T1 and control groups did not change throughout the training period. MAP reduced significantly in T2 (-3.9 ± 0.99 mmHg, $P < 0.001$; Figure 3), which was different from T1 ($P < 0.001$) and control ($P = 0.002$) groups. MAP did not change after IET period in T1 or control groups. Despite mean RBP of T2 being lower by a physiologically significant degree ($P > 0.05$) than T1 and control groups, a significant reduction in RBP was still observed after 3 weeks of IET. No changes in HR were found in any group after IET ($P > 0.05$; Figure 4).

Since the number of male and female subjects in T1 was well balanced, we separated male and female RBP and HR data within this group. Mean male pre-IET SBP was ~10mmHg higher compared to female pre-IET SBP, although the difference was not significant ($P > 0.05$; Figure 5). However, post-IET SBP in the female subjects was significantly lower than post-IET SBP in the male subjects (~18mmHg; $P = 0.016$).

DISCUSSION

When assessing the effect of IET intensity on RBP adaptations, our higher intensity IET program (30% EMG_{peak}) induced a significant reduction in systolic, diastolic and mean arterial blood pressure, but no significant RBP changes were seen when IET was performed at 20% EMG_{peak} (T1) or during the same period in controls. This suggests a threshold for IET is between 20-30% EMG_{peak} using the same protocol for both intensities. These results agree with the prediction of Devereux *et. al.* that a threshold for IET intensity exists to induce a significant reduction in RBP in short IET programs (3-4 weeks) (Devereux, et al., 2011). Further, unlike aerobic training intensity differences (Cornelissen et al., 2010), IET intensity was an important factor in the observed RBP adaptations.

Several studies have used an IET intensity of 30% MVIC to induce reductions in RBP in both healthy and medication hypertensive patients (Araujo et al., 2011; Howden, et al., 2002; McGowan et al., 2007; Millar, et al., 2007; Stiller-Moldovan et al., 2012; Taylor, et al., 2003; Wiley, et al., 1992). Reported reductions in RBP have been substantial (e.g. -10mmHg for SBP) and similar to reductions expected with pharmacological intervention. However, some of these reports used older (60-67yrs), medicated hypertensive patients (McGowan et al., 2007; Millar, et al., 2007; Stiller-Moldovan, et al., 2012; Taylor, et al., 2003). This suggests that blood pressure control mechanisms influenced by common blood pressure medications (e.g. calcium channels blockers, ACE inhibitors and diuretics) may not be important in IET-induced reductions in RBP, although more detail investigative is needed in this respect. Understanding more about the most effective protocol for IET-induced reductions in RBP 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).

The magnitude of RBP reductions has been less (~5mmHg for SBP) using percent EMG_{peak} or HR_{peak} to set IET intensity (Devereux, et al., 2011; Devereux, et al., 2010; Wiles, et al., 2010). This suggests the hitherto IET intensity set by this newer method has not produced a sufficient stimulus to elicit the larger reductions in BP previously seen when IET intensity was set by percent MVIC. The present study used the highest steady state (%EMG_{peak} during MVIC) IET intensity reported to date and found similar reductions in RBP to Wiles et. al. (2010), but in a much shorter time frame (3 vs. 8 weeks), implying IET intensity effects the time to RBP reduction rather than the eventual adaptation. The utility of producing a significant reduction in RBP in as little as 3 weeks of IET has not been established. However, correction of hypertension in a relatively short period may be clinically desirable, whereas lower intensity IET programs may be more useful for long-term prevention of hypertension development, especially in high-hypertension risk groups (e.g. African Americans and post-menopausal women).

Recently, it was suggested than females may be more sensitive to IET-induced reductions in RBP than their male counterparts (Millar, et al., 2008). When data collected from our T1 group were pooled, there was no significant effect of IET at

20%EMG_{peak} on RBP. However, when the male and female subject data were separated, sex differences were found in post-IET SBP, with female subjects developing a significantly lower SBP than male subjects (Figure 5). While the authors acknowledge the number of female and male subjects in this comparison were limited (n = 4 per group), the result remains a point of interest.

Our assessment of IET intensity effects on reductions in RBP (i.e. higher IET intensity equals shorter time to significant RBP reduction) was in agreement with previous reports (Baross, et al., 2012; Wiles, et al., 2010). However, both of these studies used male subjects only. We were not able to make the same sex difference comparison with our T2 group because it comprised 7 females and 2 males and therefore would have been unbalanced. However, considering the significant sex difference in post-IET at 20% EMG_{peak} resting SBP that was not evident pre-IET in T1, it is possible that significant RBP reductions post-IET at 30% EMG_{peak} were partly due to the high percentage of female subjects in the T2 group (Figures 1-3).

The mechanisms for sex differences in responsiveness to IET-induced RBP reductions are not well understood. If sex hormones are important then variation in responsiveness within female IET groups may be evident if estrous stage, and therefore estrogen and progesterone levels, is controlled. Female sex hormones may influence IET-induced RBP 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). Thus it is critically important to have a more comprehensive assessment of sex differences in sensitivity to IET-induced RBP reductions as this may be important in designing sex specific and effective IET programs.

CONCLUSION

In summary, this work has demonstrated that IET-induced reductions in RBP, after double-leg training are dependent on IET intensity and there appears to be a threshold of training intensity between 20 and 30% EMG_{peak}. However, these changes in RBP in response to differing IET intensity may have been associated with different percentages of male and female subjects in the T1 and T2 groups. Further work is required to understand more about sex differences in RBP adaptions in response to IET. This could be important in terms of designing sex specific IET programs or differential expectations in RBP adaptations following IET in men and women.

Conflict of Interest

The authors declare no conflict of interest

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1

2 Table 1. Baseline subject characteristics. No between group differences were found ($P >$
3 0.05)

Characteristic	Training Group 1	Training Group 2	Control Group
Age (yrs)	25.00 ± 2.28	21.33 ± 0.33	22.28 ± 0.46
Sex			
Male	4	2	4
Female	4	7	14
Height (cm)	169.5 ± 2.70	167.4 ± 1.7	171.20 ± 2.28
Mass (Kg)	73.5 ± 6.6	67.9 ± 4.9	67.40 ± 3.65
SBP (mmHg)	116.4 ± 4.3	110.4 ± 3.3	112.6 ± 2.5
DBP (mmHg)	68.7 ± 3.7	62.1 ± 1.3	65.1 ± 2.1
MAP (mmHg)	84.3 ± 3.6	78.2 ± 1.7	80.9 ± 1.9
HR (bpm)	60.0 ± 3.4	63.4 ± 4.7	67.1 ± 5.1

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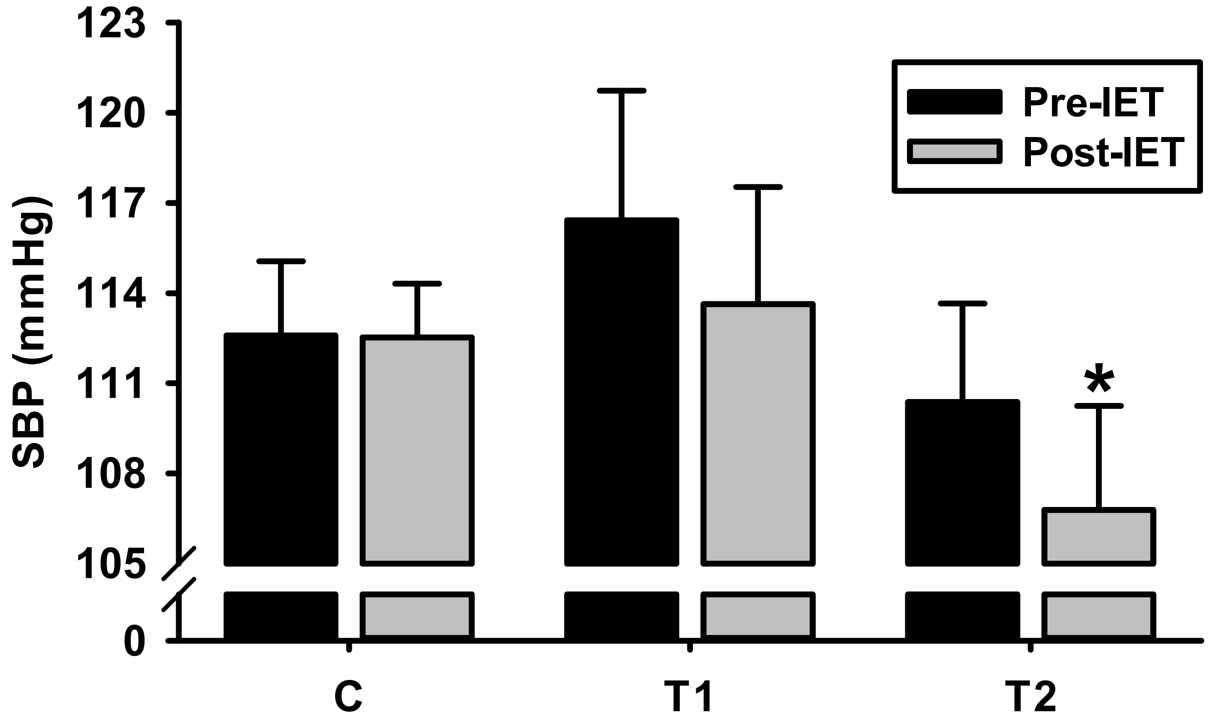

Figure 1. Mean ± SEM resting systolic blood pressure (SBP) before training, during 3 weeks of training, and one week after training in T1, T2 and control groups. * = significant difference compared to pre-training.

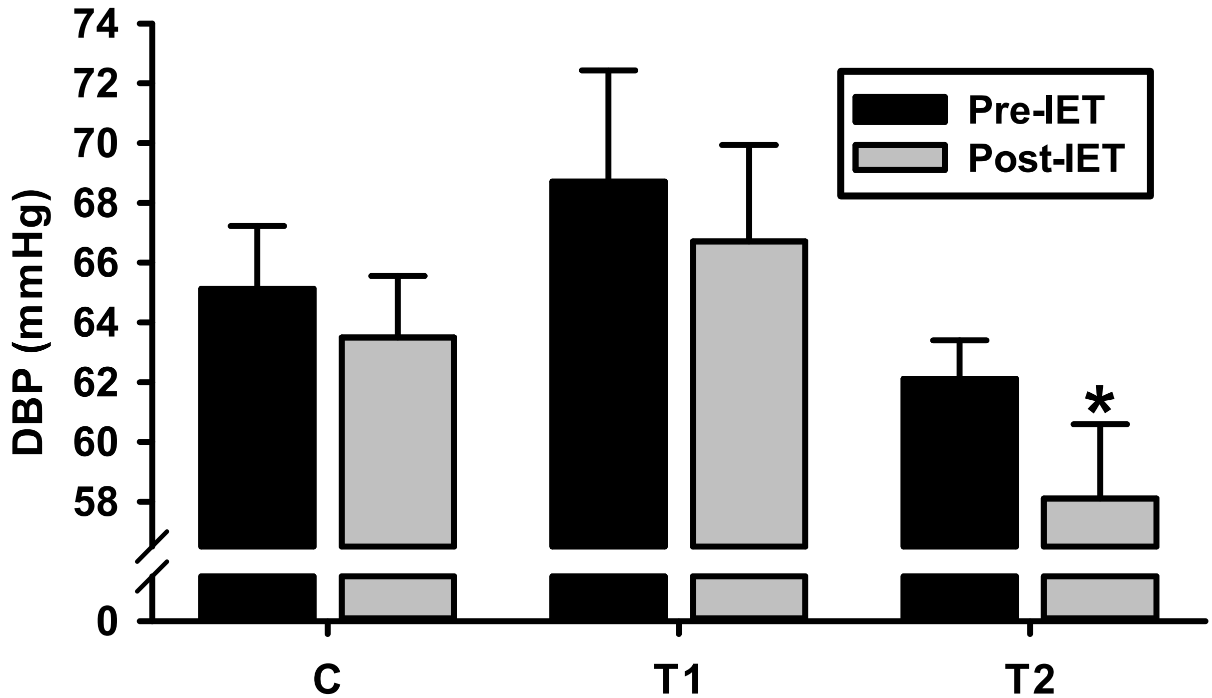

Figure 2. Mean ± SEM resting diastolic blood pressure (DBP) before training, during 3 weeks of training, and one week after training in T1, T2 and control groups. * = significant difference compared to pre-training.

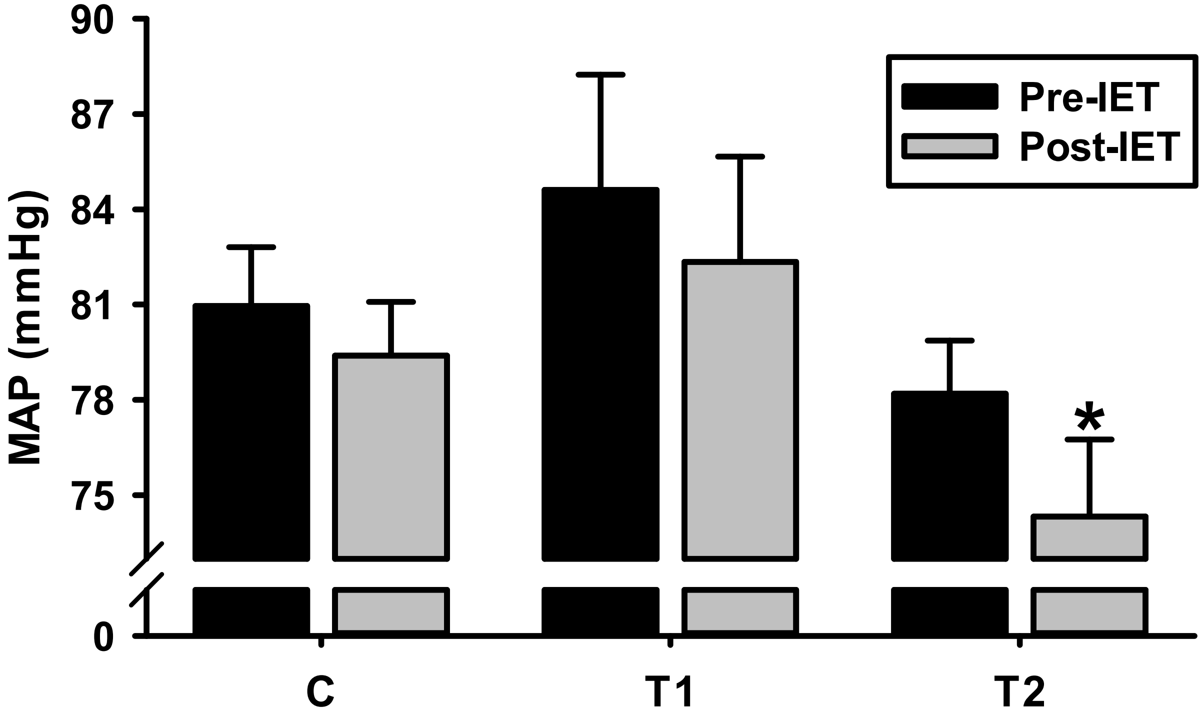

Figure 3. Mean ± SEM resting mean arterial blood pressure before training, during 3 weeks of training, and one week after training in T1, T2 and control groups. * = significant difference compared to pre-training.

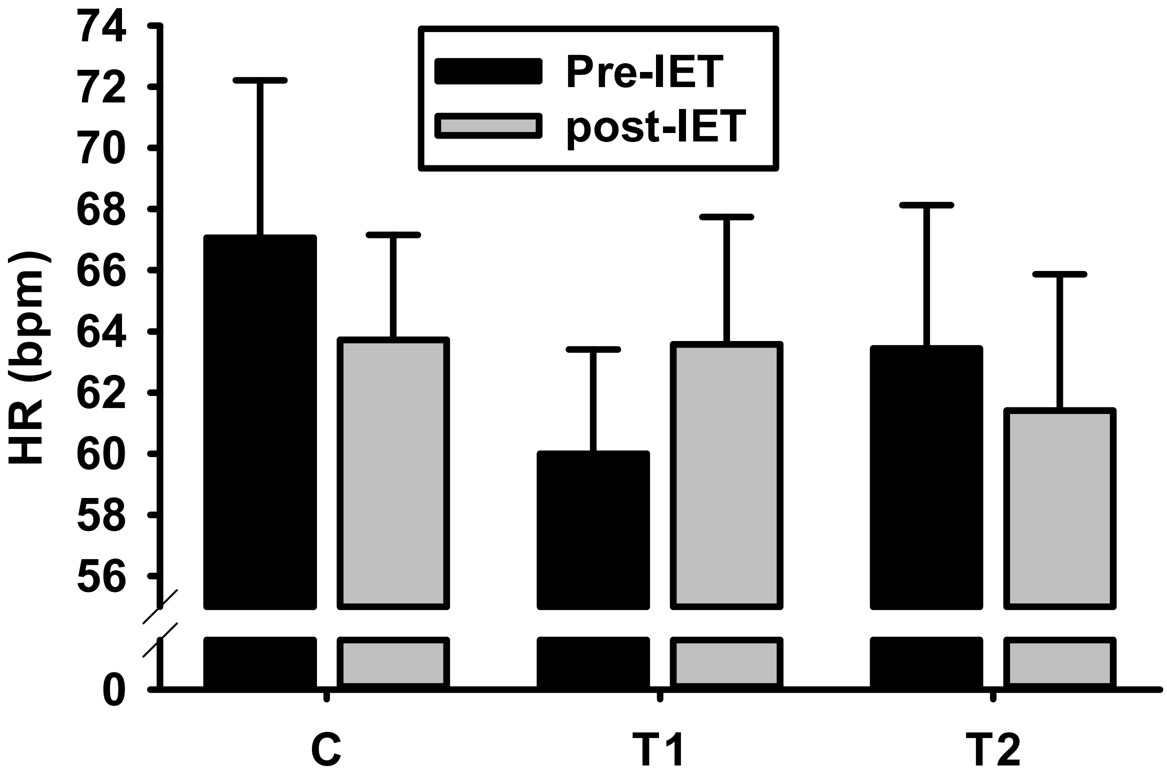

Figure 4. Mean ± SEM resting heart rate (HR) before training, during 3 weeks of training, and one week after training in T1, T2 and control groups. No significant differences were found compared to pre-training or between groups.

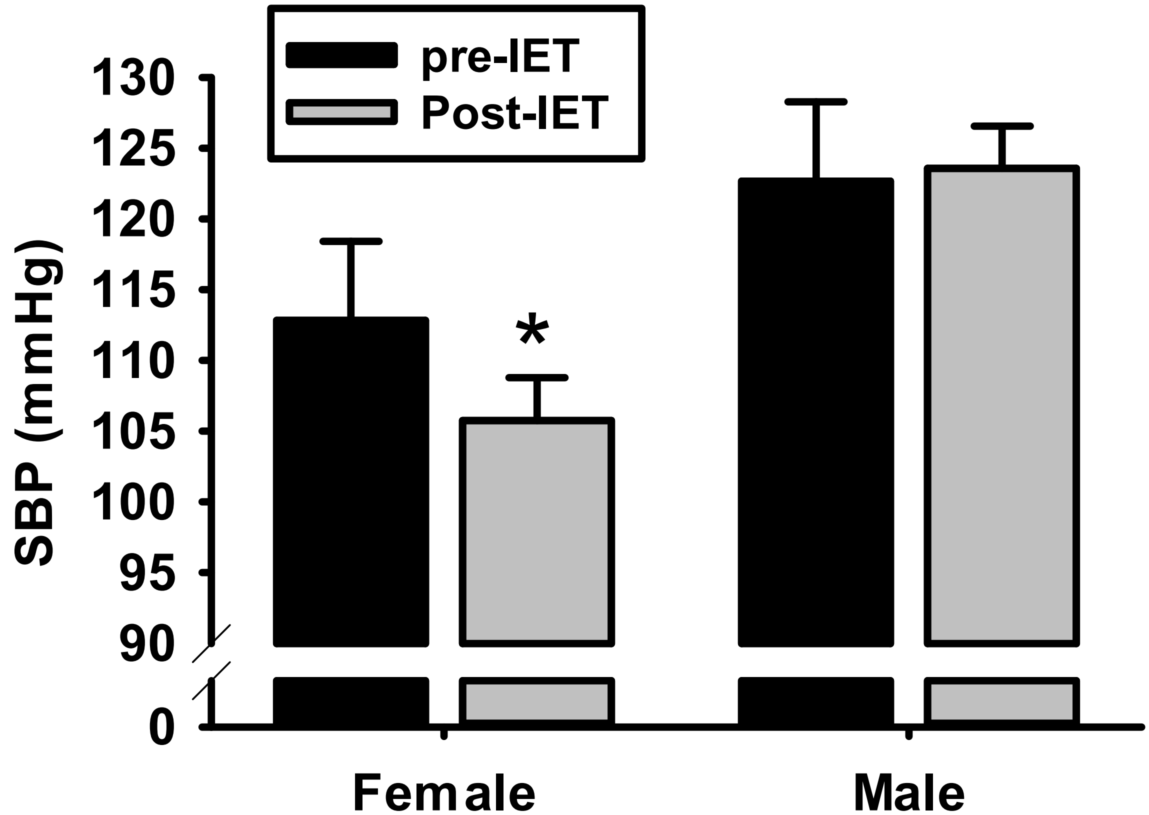

Figure 5. Mean ± SEM female and male resting systolic blood pressure (SBP) before and after 3 weeks of IET in the T1. * = significant difference in post-IET SBP compared to male subjects.