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Low and high frequency isometric handgrip exercise training similarly reduce resting blood pressure in young normotensive adults: A randomised controlled trial

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ABSTRACT

We investigated the effects of low and high frequency isometric handgrip exercise training (IHGT) on resting blood pressure, and the affective/perceptual responses during training. Sixty young normotensive adults were randomised to either a no-intervention control group (CON: $n = 20$; 12 female) or a group performing either two (LOW: $n = 20$; 18 female) or four (HIGH: $n = 20$; 13 female) sessions/week of IHGT for 4 weeks. IHGT involved 4 × 2-min holds at 30% maximal voluntary contraction using the dominant hand. Resting blood pressure was measured before and after training. Affective valence was measured during the first session of each training week. Systolic blood pressure was reduced following both LOW (adjusted mean change [95% CI]: −4.5 [−6.8, −2.2] mmHg) and HIGH (−5.3 [−7.6, −3.0] mmHg) frequency IHGT groups compared to CON (+0.5 [−1.8, 2.8] mmHg; $p < 0.01$), with no difference between LOW and HIGH. There were no changes in diastolic blood pressure. During the first session, affective valence decreased by 2.5 ± 2.6 units and became negative (lowest affect: −0.75 ± 1.84 units). However, affective responses improved as training progressed. Low and high frequency IHGT similarly reduce resting blood pressure in young normotensive adults. Negative affective responses in the early phase of training improve as the intervention progresses.

KEYWORDS

Blood pressure; isometric exercise; exercise training; perceptual responses; training frequency

Introduction

Hypertension is the leading modifiable risk factor for cardiovascular disease, stroke, and premature mortality (GBD 2017 Risk Factor Collaborators, 2018). It is estimated that 1.4 *billion* people are living with hypertension worldwide and the prevalence is increasing (Zhou et al., 2021). Whilst clinical intervention has generally been recommended when resting blood pressure exceeded a threshold of > 140/90 mmHg (Whelton et al., 2018), this threshold has recently been lowered to > 130/80 mmHg (Mancia et al., 2023), and it is notable that epidemiological studies report strong and linear increases in the risk of cardiovascular disease and all-cause mortality with a resting blood pressure above 115/75 mmHg (Lawes et al., 2003; Lewington et al., 2002; Rapsomaniki et al., 2014). As such, alongside the effective treatment of already existing hypertension, the development and implementation of simple and effective lifestyle strategies to reduce and/or prevent increases in blood pressure in currently normotensive populations, is an important area of research.

Regular exercise is one of the most effective lifestyle strategies to reduce blood pressure (Sharman et al., 2019). Recent large meta-analyses have demonstrated reductions in both systolic and diastolic blood pressure in normotensive populations following traditionally recommended exercise types, including aerobic exercise training, resistance training, and high-intensity interval training (Edwards et al., 2023). However, the effect sizes following these types of exercise in normotensive individuals are generally quite modest; for example, in the most recent meta-analysis, Edwards and colleagues reported a pooled mean reduction in systolic blood pressure of 3.6, 2.9 and 3.9 mmHg following aerobic training, resistance training, and high-intensity interval training, respectively (Edwards et al., 2023). At the same time, many individuals do not adhere to currently recommended levels of aerobic and resistance exercise (Guthold et al., 2018), with the required time commitment, a lack of motivation, and the associated levels of effort, exertion and discomfort, known to be key barriers to participation (Korkiakangas et al., 2009). Thus, there is a need to investigate alternative exercise interventions which overcome these barriers but remain effective at improving blood pressure (Herrod et al., 2018, 2021).

Isometric handgrip exercise training (IHGT) has been shown to result in large decreases in resting blood pressure in younger and older age groups, in both men and women, and in individuals with normal as well as elevated baseline blood pressure (Edwards et al., 2023; Millar et al., 2014). Furthermore, there is evidence that the magnitude of reduction in both systolic and diastolic blood pressure following IHGT is greater when compared to traditional exercise modes (Edwards et al., 2023). Specifically, the recent meta-analysis by Edwards et al. (2023) reported a pooled mean reduction of 6.7 mmHg in systolic blood pressure following IHGT in normotensive adults, approximately double the reduction observed with other exercise modes.

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There are several potential benefits of IHGT which may help promote longer term adherence, including the time-efficiency (sessions take between 10–15 minutes per session), the ease of which it can be done at home (e.g. whilst watching TV) or at the office, and the low training load/intensity/impact which may help to promote a positive affective response to exercise and overall intervention acceptability (Brand & Ekkekakis, 2018; Ekkekakis et al., 2008). However, it is important to note that, to the best of our knowledge, no studies have characterised the combined affective and perceptual responses during acute sessions of IHGT.

To date, IHGT interventions have almost universally employed four, two-minute isometric contractions at 30% of a maximal voluntary contraction, performed three times per week, for between four weeks and up to one year (Edwards et al., 2023, 2024; Millar et al., 2014). Interestingly, few studies have directly compared the effects of changing different IHGT protocol parameters on reductions in blood pressure in either normotensive or hypertensive populations, and the minimal effective dose of IHGT for improving blood pressure is unknown. Arguably the most important modifiable parameter contributing to the overall dose (and time commitment) of a structured exercise programme is training frequency. However, in general, the dose-response effect of exercise training frequency on health-related parameters does not receive much research attention, with limited examples of studies directly comparing different training frequencies in a randomised controlled trial, and a remarkably large majority of studies opting for a frequency of three sessions/week. For example, in the recent meta-analysis of exercise and blood pressure by Edwards et al (2023), a training frequency of three sessions/week was used by 77% of included studies using continuous cycling/running, 63% of studies on resistance training, and 80% of studies on high-intensity interval training. Strikingly, 18 out of 19 available trials (95%) on IHGT also employed a training frequency of three sessions/week (Edwards et al., 2023).

It is important to determine whether a lower frequency of IHGT remains beneficial, because this would substantially reduce the required time commitment and may help promote adoption and longer-term adherence to this type of exercise in real-world settings. Several recent studies have reported improvements in health parameters such as cardiorespiratory fitness and glycaemic control following exercise interventions with a frequency of two sessions/week (Adamson et al., 2020; Thomas et al., 2020), supporting the hypothesis that a lower frequency of exercise in general, and of IHGT, may still result in beneficial health related adaptations. At the same time, it is also important to determine whether there is a dose response effect of IHGT frequency, with higher frequency resulting in superior reductions in blood pressure, as this would allow suitably motivated individuals to maximise blood pressure reductions. On this basis, the primary aim of this study was to compare the effects of low (two sessions/week) and high (four sessions/week) frequency IHGT on resting blood pressure in normotensive individuals. The secondary aim was to investigate the acute affective and perceptual responses to a single bout of IHGT and how these responses might change over a short-term training intervention.

Methods

Participants and experimental design

This was a randomised controlled trial with three arms and allocation ratio of 1:1:1: 1) a 4-week IHGT intervention with a frequency of 2 sessions per week (i.e. low frequency; LOW); 2) a 4-week IHGT intervention with a frequency of 4 sessions per week (i.e. high frequency; HIGH); and 3) a 4-week no intervention control (CON). The primary outcome in this study was the change in clinic measured systolic blood pressure. In a meta-analysis of 147 RCTs, a 10 mmHg decrease in SBP reduced coronary heart disease events by 22% (Law et al., 2009). We powered this study to be able to detect a smallest worthwhile effect of 3.0 mmHg, equivalent to a coronary heart disease risk reduction of ~ 7%. Based on a standard deviation of repeated measures of systolic blood pressure of ~2.9 mmHg, we calculated that a sample size of 45 participants (15 per group) would provide 80% power to detect the smallest worthwhile change with an alpha of 0.05.

This study took place across two University sites: Swansea University in Wales and National Taiwan Normal University in Taiwan, with separate ethical approval granted at each site (Swansea University College of Engineering Research Ethics Committee: approval number RM_01–11-21b; National Taiwan Normal University Centre for Research Ethics: approval number 202304HM001). The full study protocol was published on The Open Science Framework (https://doi.org/10.17605/OSF.IO/9K4Y6) and retrospectively registered (prior to data analysis) at ClinicalTrials.org (reference: NCT06329804). The flow of participants through the study is shown in Figure 1. A total of 60 participants completed the study between November 2021 and March 2024 ($n = 30$ in Wales and $n = 30$ in Taiwan, with $n = 10$ per group at each site). Participants were eligible if they were aged between 18 and 40 years of age, had a resting blood pressure < 140/90 mmHg during screening, and were free from any acute or chronic diseases (including diagnosed hypertension) or contraindications to exercise based on a self-report health history questionnaire. In addition, participants self-reported as not currently participating in regular structured exercise or meeting the current guidelines for moderate intensity physical activity (5 days of at least 30 minutes of moderate intensity physical activity) (Bull et al., 2020). The participant characteristics are shown in Table 1. The requirements and risks of the study were explained to participants both verbally and in writing and all participants provided their written informed consent to participate. The study conformed to the requirements of the Helsinki Declaration.

Baseline testing

Participants were asked to refrain from any strenuous or prolonged physical activity for at least two days prior and from consuming any alcohol for at least one day prior to testing. Caffeine intake was permitted in the day prior to testing but participants completed a 1-day food record (including caffeine containing products) prior to the baseline testing, and they were asked to replicate this food diary (timing and composition) as closely as they could prior to post-intervention testing.

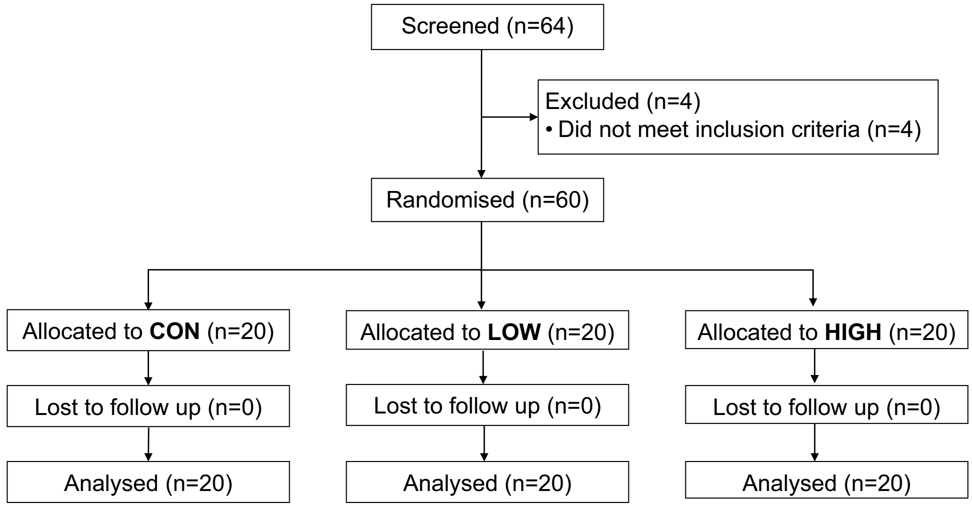

Figure 1. Flow of participants through the study.

Table 1. Participant characteristics.

	CON (*n*=20)	LOW (*n*=20)	HIGH (*n*=20)
Male/Female (n)	8/12	2/18	7/13
Age (y)	24±5	23±4	23±5
Height (m)	1.68±0.09	1.63±0.07	1.69±0.09
Weight (kg)	68.1±13.7	62.8±14.4	67.9±17.7
BMI (kg/m^2)	24.2±4.5	23.6±4.2	23.6±4.0
Systolic Blood Pressure (mmHg)	112±12	108±8	110±3
Diastolic Blood Pressure (mmHg)	69±6	69±8	69±7
Mean Arterial Pressure (mmHg)	84±7	82±7	83±8

Data is presented as mean and SD unless otherwise stated. Data is presented by group (CON: no exercise control group; LOW: low frequency IHGT (two sessions/week); HIGH: high frequency IHGT (four sessions/week).

Participants attended the laboratory in the morning between 8 and 10 am after fasting (water only) from 10 pm the previous evening. They were asked to minimise any physical activity on trial mornings and to take the car or public transport to the University. Furthermore, to ensure they were well-hydrated during testing, they were asked to consume ~ 500 ml of water immediately upon waking.

Resting blood pressure was measured following a 10-minute rest period in a supine position in a quiet and dimly lit room. Blood pressure was measured in the (unclothed) left arm using an automated monitor (Omron MIT elite plus) whilst the participant continued to rest in the supine position. Three measurements were initially taken with a one-minute rest interval in between (Pickering et al., 2005). If there was less than 5 mmHg difference either in systolic or diastolic blood pressure between the final two readings, then the mean of these two readings was taken forward for analysis (Pickering et al., 2005). If there was a difference greater than or equal to 5 mmHg between the two readings, then two additional readings were taken and the mean of the four readings was taken forward for analysis (Pickering et al., 2005).

Following the blood pressure assessment, participants were randomised to their experimental group using the sealed envelope method. Randomisation was performed separately at each study site (YCC in Taiwan, RSM in Swansea). Participants who were randomised to one of the IHGT groups then performed a one repetition maximum for an isometric handgrip contraction using an electric hand dynamometer (Camry EH101, Zhongshan Camry Electronic Co. Ltd, Guangdong). The best of three measurements of the dominant hand was used to determine subsequent IHGT intensity.

IHGT intervention

Participants allocated to the IHGT groups completed a 4-week IHGT intervention involving either two or four sessions per week with all training sessions performed at home and supervised remotely via remote video conferencing. Each IHGT session consisted of 4 × 2-minute contractions at 30% maximal voluntary contraction, with 2-minutes of rest in between, performed with the dominant hand. Training was performed using an electronic hand dynamometer (Camry EH101, Zhongshan Camry Electronic Co. Ltd, Guangdong). Training sessions were scheduled on weekdays where possible, and all sessions were supervised by one member of the research team via remote video conferencing to ensure training compliance and fidelity. Participants in the control group were asked to main their normal lifestyle behaviours for 4-weeks and had no contact with the research team over this period (other than to organise post-intervention testing).

During the first training session of each training week, contraction tension was recorded every 15 seconds during each two-minute contraction. Furthermore, during the same sessions, ratings of perceived exertion (RPE) and affective valence were measured every 30 seconds during each two-minute contraction. RPE was measured using the Borg 6–20 scale (Borg, 1982) with participants asked to provide a rating of '*how hard, heavy, or strenuous are you finding the exercise at this exact moment in time?*'. Affective valence was measured using The Feeling Scale (Hardy & Rejesky, 1989), with participants given the following instructions: '*While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across* *time. That is, one might feel good and bad a number of times during exercise. When asked please tell me how you feel at that current moment using the scale you are shown*'.

Post-training testing

Resting blood pressure was measured three days following the final training session using identical procedures to the pre-training assessment.

Statistical analysis

Statistical analysis was performed in IBM SPSS (version 29.0.1.0) and figures were made using GraphPad Prism for Mac Os X (version 10.2.2). Only participants with a full set of data for the relevant outcome were included in statistical analysis. Alpha was set at 0.05 for all analyses.

To determine the effect of training frequency on changes in systolic, diastolic, and mean arterial pressure, we analysed the change score (post-pre) using a repeated measures analysis of covariance (ANCOVA) with the baseline score entered as a covariate. This is the recommended statistical approach in RCTs when there are potential differences in baseline scores between groups and where it is expected that baseline score may influence the change score (Vickers & Altman, 2001). Fishers Least Significant Difference *post hoc* tests were applied to assess between group differences where appropriate, as a significant main effect of the ANCOVA protects against any inflation of type 1 error rate when only three *post hoc* comparisons are being made (Howell, 1997). Cohen's d effect sizes, using the baseline standard deviation of all groups combined as the standardiser, are presented for blood pressure responses where appropriate. A full set of blood pressure data were available for all 60 participants.

The affective responses and ratings of perceived exertion (RPE) during the acute sessions of IHGT were analysed using several different approaches. Firstly, to assess changes in RPE and affective valence during the first session of IHGT, as well as the overall effect of training on the acute perceptual response to IHGT (i.e. acute response in week 1 vs week 4), we initially performed a three-way ANOVA with within (exercise time, training) and between (training frequency) subject factors. However, as there was no significant effect of training frequency for either RPE or affective valence, we subsequently collapsed the two training groups and performed a two-way repeated measures (exercise time x training) ANOVA. Secondly, we calculated simple summary statistics including the lowest reported affective valence and peak RPE for the first IHGT session of each training week and these were used to assess whether affective responses differed over time (i.e. week 1, week 2, week 3, etc) between the LOW and HIGH frequency intervention groups. These summary statistics were compared using a two-way mixed model ANOVA with within (training week) and between (training frequency) subject factors. When interpreting the outcomes of the ANOVA, a Greenhouse-Geisser correction was applied where $\varepsilon < 0.75$, and the Huynh – Feldt correction where there was less severe asphericity (Maxwell & Delaney, 2004). A full set of data for RPE and affective valence were available for week 1 and week 4 ($n = 40$). RPE and affective valence data were missing for $n = 3$ participants from week 2 or 3 (one from HIGH and two from LOW) and so the analysis of changes in peak RPE and lowest affect over the training weeks is presented for $n = 37$.

Results

Training characteristics

In LOW, overall training adherence was 98%, with one participant missing two training sessions (75% adherence), two participants missing one training session (87.5% adherence), and the other seventeen participants completing all eight training sessions (100% adherence). In HIGH, training adherence was 99%, with one participant missing two training sessions (87.5% adherence), one participant missing one training sessions (94% adherence), and the other eighteen participants completing all sixteen training sessions (100% adherence). Thus, as intended, the dose of IHGT completed was approximately double in the HIGH compared to the LOW frequency training group. All participants were retained in the analysis. Contraction intensity during the first session of each training week was 30.3 ± 3.0% and 31.3 ± 2.9% (week 1), 30.9 ± 2.7% and 31.3 ± 3.2% (week 2), 31.1 ± 2.5% and 31.6 ± 3.4% (week 3), and 31.3 ± 2.5% and 31.6 ± 3.3% (week 4) for the LOW (Figure 2(a)) and HIGH (Figure 2(b)) frequency training groups, respectively. There were no changes in body mass in any of the groups (data not shown).

Effect of IHGT Frequency on resting blood pressure

For systolic blood pressure, there was a significant main effect of group ($p < 0.001$): systolic blood pressure was reduced in both the LOW ($p < 0.01$, d = 0.46) and in the HIGH ($p < 0.001$, d = 0.53) frequency training groups compared to CON (Figure 3(a,b)). There was no significant difference in the change in systolic blood pressure between LOW and HIGH frequency training groups ($p = 0.63$, d = 0.07; Figure 3(a,b)). There was no statistically significant main effect of group for diastolic blood pressure (Figure 3(c,d)). For mean arterial pressure, there was a significant main effect of group ($p < 0.05$): mean arterial blood pressure was reduced in both the LOW ($p < 0.05$, d = 0.40) and in the HIGH ($p < 0.05$, d = 0.38) frequency training groups compared to CON (Figure 3(e,f)). There was no significant difference in the change in mean arterial blood pressure between LOW and HIGH frequency training groups ($p = 0.92$, d = 0.02; Figure 3(e,f)).

Perceptual responses: RPE

There was a main effect of exercise time for RPE ($p < 0.001$), reflecting the overall trends for RPE to increase progressively over the course of each distinct two-minute bout, and for RPE to get progressively higher as the duration of the first training session progressed (Figure 4(a)). RPE peaked at 15.4 ± 2.2 units during the first training session corresponding to a qualitative descriptor of 'hard' (Figure 4(a,b)). The pattern of change in RPE over the IHGT session was not different during the first session of week 4 compared to week 1 ($p = 0.175$ for training x exercise time interaction); however, RPE was lower throughout the IHGT session in week 4 compared to week 1 ($p = 0.003$ for main effect of training) (Figure 4(a)).

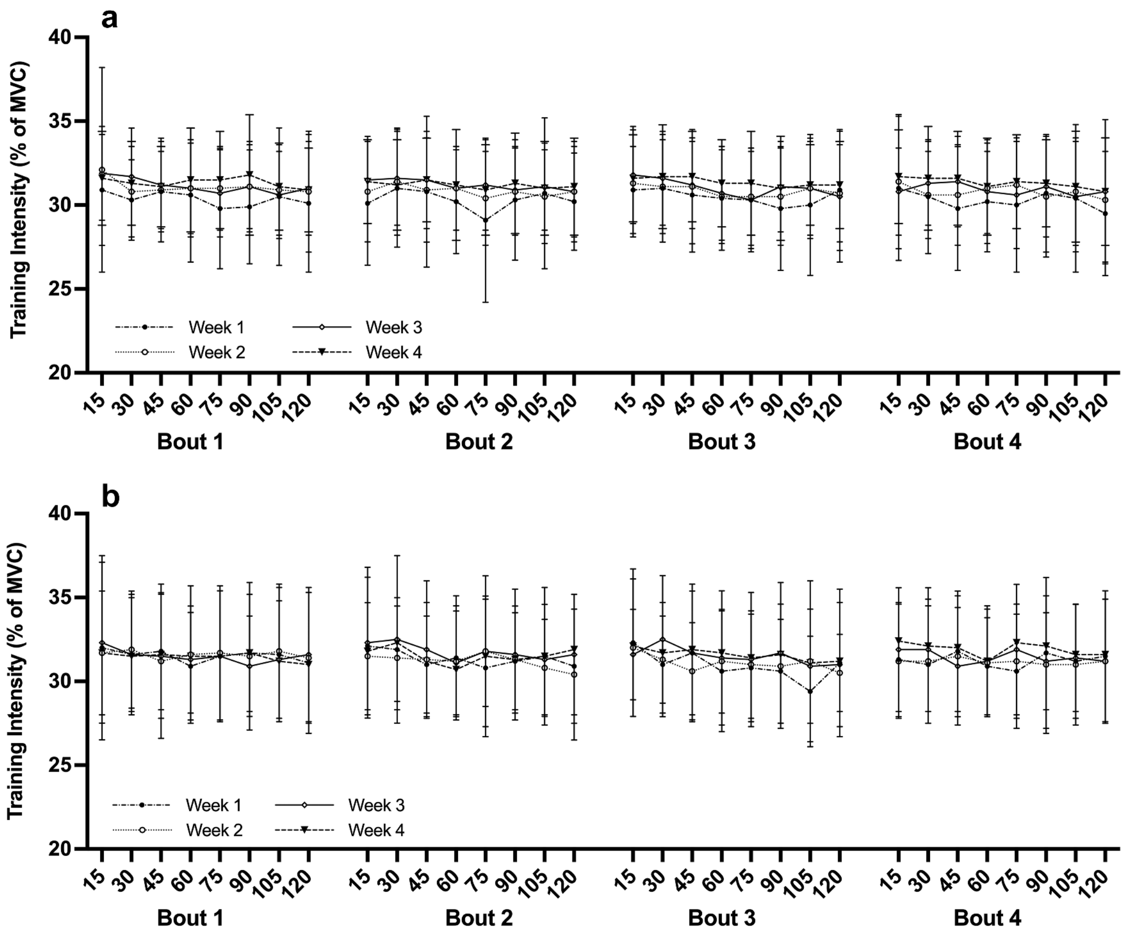

Figure 2. Handgrip contraction intensity during the first session of each week in the LOW (a) and HIGH (b) frequency training groups. Data is presented as mean and standard deviations ($n = 40$; $n = 20$ per group). MVC, maximal voluntary contraction.

The peak RPE became progressively lower as the training intervention progressed ($p < 0.001$ for main effect of training week) and was comparable between the LOW and HIGH frequency groups throughout training ($p = 0.158$ for main effect of group and $p = 0.895$ for training x group interaction, respectively; Figure 4(b)).

Perceptual responses: Affective valence

Over the course of the first training session (week 1), affective valence decreased by 2.4 ± 2.5 units during IHGT ($p < 0.001$ for main effect of exercise time) and became negative on average during the session (lowest reported affective valence: −0.5 ± 1.9 units) (Figure 4(c,d)). The pattern of change in affective valence during an IHGT session was not different between the first session of week 4 compared to week 1 ($p = 0.093$ for training x exercise time interaction; Figure 4(c)); however, affective valence was higher throughout the session in week 4 compared to week 1 ($p = 0.016$ for main effect of training week; Figure 4(c)). The lowest reported affective valence became more positive as the training intervention progressed ($p < 0.01$ for main effect of training) and was comparable between the LOW and HIGH frequency groups throughout training ($p = 0.721$ for main effect of group and $p = 0.44$ for training x group interaction, respectively; Figure 4(d)).

Discussion

To date, studies investigating the effects of IHGT on blood pressure have almost universally employed a training frequency of three sessions/week (Edwards et al., 2023, 2024), yet there are no indications that this would be the lowest training dose of IHGT resulting in a meaningful reduction in blood pressure, or the dose of IHGT associated with the greatest reduction in blood pressure. On the contrary, the present data demonstrate, for the first time, that both systolic and mean arterial blood pressure can be reduced in young normotensive individuals with two sessions of IHGT per week and a total weekly time commitment of ~25 mins. Furthermore, in the short term there appears to be no added blood pressure benefit of doubling the frequency (and dose and time commitment) of IHGT from two sessions/week to four sessions/week.

Only one study has investigated the effect of IHGT frequency on resting blood pressure and they reported similar reductions in systolic blood pressure following a training frequency of three or five sessions per week over 8 weeks (Badrov et al., 2013). However, the sample size in this study was small (between 9 and 12 participants per group) and average blood pressure of their cohort at baseline was low (~95 mmHg systolic and ~57 mmHg diastolic) (Badrov et al., 2013). Together the low statistical power and low potential for change to occur may

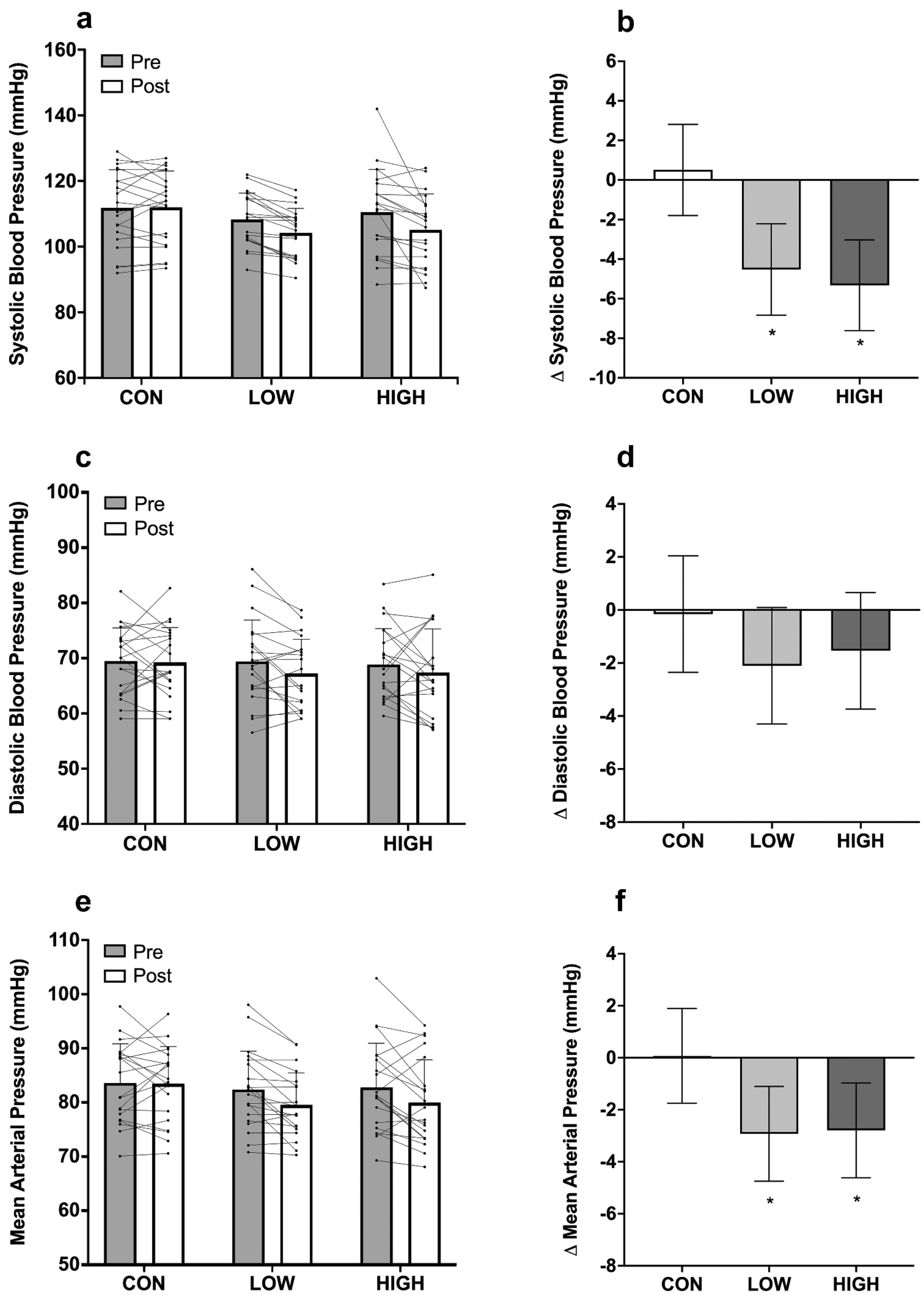

Figure 3. The effect of IHGT frequency on systolic blood pressure (A and B), diastolic blood pressure (C and D) and mean arterial pressure (E and F). Data in A, C, and E are presented as raw means and standard deviations at pre (grey bars) and post (white bars) training time points with individual participant responses overlaid. Data in B, D and F are presented as adjusted mean changes and 95% confidence intervals from the ANCOVA. * denotes a significant difference compared to CON. Data is presented for $n = 60$ ($n = 20$ per group).

have impacted the validity of this study to detect a dose-response effect of increasing IHGT frequency on blood pressure if it exists. The findings of the present study are in agreement with the findings of Badrov et al (2013), and together these two studies provide good evidence that there is no dose response effect of increasing IHGT frequency on changes in systolic blood pressure, at least in young normotensive adults. At the same time, our data provide an important and novel extension of the findings of Badrov et al (2013), as well as the entire IHGT evidence base (Edwards et al., 2023, 2024), by demonstrating that systolic and mean arterial blood pressure can be reduced with a lower frequency of IHGT than was previously thought. Together these studies show that similar resting blood pressure reductions can be achieved across a training frequency range of between 2 and 5 sessions/week over as little as 4 weeks (Badrov et al., 2013). Given that a perceived lack of time is an important barrier to exercise (Korkiakangas et al., 2009), reducing the frequency and time commitment of an exercise programme could be expected to positively impact longer term compliance. Thus, the current data have important implications for the practical design of IHGT as a therapeutic intervention for preventing the development of high blood pressure, the

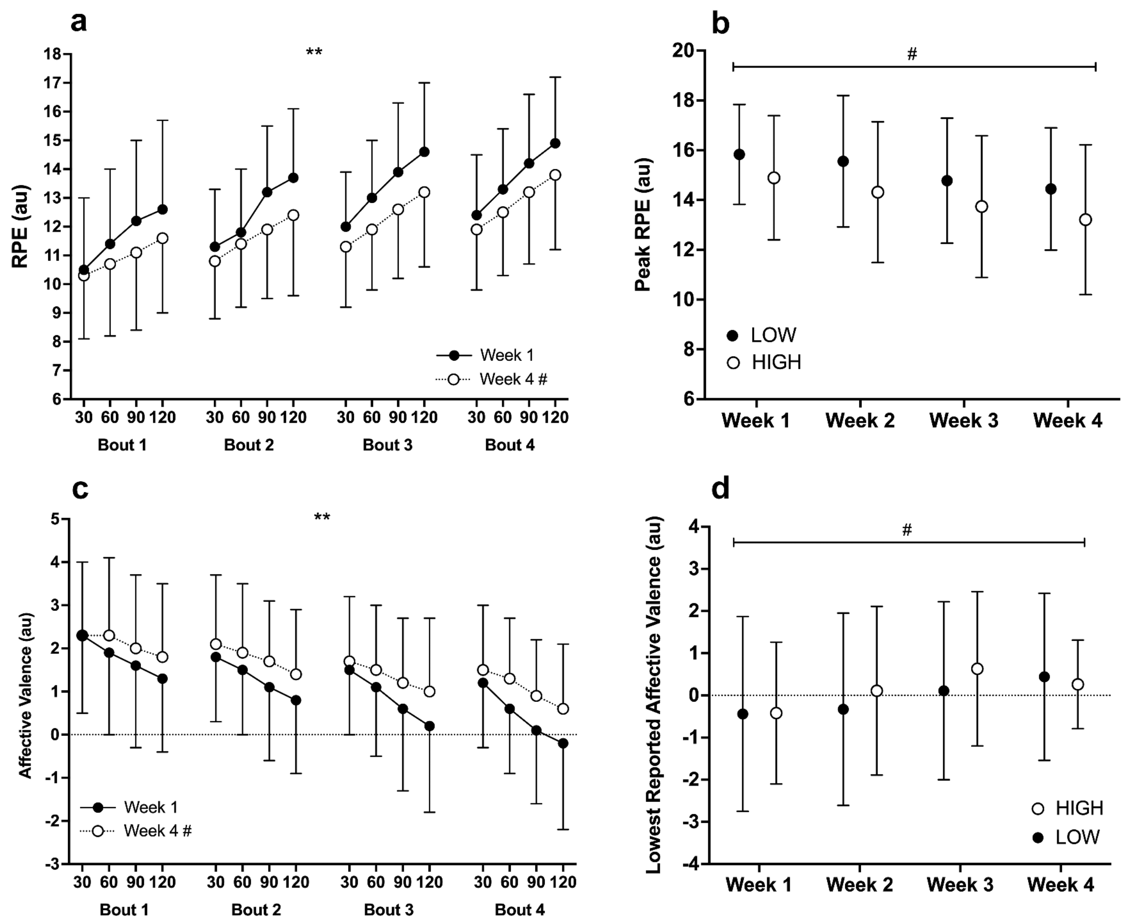

Figure 4. RPE (A and B) and affective valence (C and D) responses during acute IHGT sessions. A (RPE) and C (affective valence) show responses over the course of the first training session of week 1 (black dots) and week 4 (white dots). Data in A and C are shown as the mean and standard deviation ($n = 40$) for the HIGH and LOW training frequency groups combined. B and D show the peak RPE and lowest reported affective valence for both LOW (black dots) and HIGH (white dots) training frequency groups during the first session of each week. Data in B and D are shown as mean and standard deviations ($n = 37$ due to missing data). **denotes a significant main effect of exercise time. # denotes a significant main effect of training week.

leading modifiable risk factor for cardiovascular disease, stroke, and premature mortality (GBD 2017 Risk Factor Collaborators, 2018). Our data also provide a proof of principle for a study investigating the blood pressure and vascular health benefits of lower frequency IHGT in people with diagnosed hypertension.

Training frequency is a primary determinant of the dose of an exercise training programme and, as such, this study takes an important step forward in defining the minimal effective dose of IHGT for reducing blood pressure. However, it remains unknown whether IHGT with an even lower training frequency (e.g. 1 session/week) would still be effective and this will need to be determined in future studies. A recent study by Cohen et al (2023) demonstrated that the large reductions (−10–15-mmHg) in systolic blood pressure observed following an initial 12 week IHGT intervention involving thrice weekly training sessions were then maintained, but not further reduced, during a subsequent period of 12 weeks where participants performed just one session/week. These findings were consistent for both IHGT and for a lower limb isometric training intervention delivered via a wall squat (Cohen et al., 2023). This provides some indirect evidence to suggest that one IHGT session per week may not be a sufficient stimulus to reduce blood pressure, although the prior higher frequency period of IHGT clearly may have masked any effect (Cohen et al., 2023).

Our findings with IHGT are consistent with the wider literature on the effect of training frequency of different exercise types on blood pressure. For example, in people with hypertension, Ishikawa-Takata et al (2003) observed similar blood pressure reductions in groups of individuals who performed aerobic exercise with a frequency of 1–2 times/week, 3–4 times/week, and > 5 times/week, across a range of different weekly exercise durations (30–60 mins/week up to >120 mins/week). Several meta-analyses of aerobic and resistance exercise have also reported similar pooled effect sizes for blood pressure reductions across a range of training frequencies (Cornelissen & Smart, 2013; Edwards et al., 2023). Finally, in an RCT, similar reductions in systolic blood pressure were observed in young overweight men following an 8-week HIIT intervention with a frequency of one, two or three sessions per week (Chin et al., 2020). Thus, training frequency does not appear to be a driver of blood pressure reductions across a range of different exercise training modalities (Chin et al., 2020; Cornelissen & Smart, 2013; Edwards et al., 2023; Ishikawa-Takata et al., 2003).

The specific physiological adaptations that underpin reductions in blood pressure following IHGT are poorly understood. However, the prevailing hypothesis is that reductions in total peripheral resistance related to local vascular adaptations is likely to be more important than changes in cardiac output

(Edwards et al., 2024). Potentially important local vascular adaptations may include improved endothelial function resulting in enhanced conduit or resistance vessel vasodilation, or improvements in vasomotor tone (Edwards et al., 2024). Mechanistically, such adaptations might be driven by the acute (reactive) increases in local blood flow and shear stress following the release of each isometric hold, which subsequently leads to the release of a variety of vasodilatory substances (e.g. nitric oxide) that promote a downstream adaptive response in the hours and days following each IHGT session (Edwards et al., 2024).

Irrespective of the specific mechanisms involved, our data suggest that they are not further potentiated by increasing training frequency. The reason for this is unclear, but one potential consideration is that we did not specifically control or standardise the length of recovery in between repeated IHGT sessions in either group. In LOW, participants typically trained on a Monday and Friday, and in HIGH they typically trained on a Monday, Tuesday, Thursday and Friday. This resulted in two longer periods of recovery (i.e. longer than 24 h) in each of the training groups. As adaptations to any training programme ultimately occur in the recovery period from each acute exercise session, it may be that performing many of the IHGT sessions on consecutive days in the HIGH group, did not provide sufficient recovery time for (additional) adaptations to accrue. Although this is a speculative suggestion, it would be interesting for future studies to standardise the length of recovery in between repeated sessions (e.g. training every 2 days vs every 4 days), to determine whether this results in a different dose-response effect on blood pressure.

An important and novel aspect of the current study is that it provides the first description of the combined affective and perceptual response during acute sessions of IHGT. In this study, we found that RPE peaked at ‘hard’ towards the end of the first training session, whilst affective valence progressively decreases over the course of each distinct two-minute isometric contraction and becomes progressively lower as the number of bouts progress during the session. In addition, affective valence becomes negative (i.e. participants report ‘displeasure’) on average towards the end of the (first) session. This contrasts with a previous study that reported little change in perceptions of physical exhaustion or feelings of tranquillity when measured 10 minutes after completion of IHGT (Yamada et al., 2021). Our data demonstrate that, although IHGT is often described in the literature as being ‘low intensity’ (e.g (Baddeley-White et al., 2019; Cohen et al., 2023)) and involves a low % of maximal force, training sessions clearly were not perceived as low intensity by the young normotensive participants in this study. This is different from research on continuous aerobic exercise modes such as running or cycling, which describes a neutral or positive affective response with low to moderate exercise intensities and a decrease in affective valence following a transition to higher exercise intensities (Ekkekakis et al., 2008, 2010). This is likely explained by the different contraction profile with isometric vs aerobic exercise modes such as cycling or running. Specifically, although the relative contraction intensity is low with IHGT (e.g. 30% of a maximal voluntary contraction), the sustained isometric nature of the contraction increases intramuscular pressure resulting in (partial) occlusion of blood flow to working muscle, relative muscle ischemia, and the subsequent accumulation of metabolites associated with neuromuscular fatigue and pain (Hietanen, 1984; Millar et al., 2014; Sadamoto et al., 1983; Sejersted et al., 1984).

The acute affective response to exercise is thought to be an important predictor of future exercise participation/adherence, with a negative affective response during exercise leading to subsequent exercise avoidance (Brand & Ekkekakis, 2018). In this light, our finding that affective valence becomes negative during the most commonly applied IHGT protocol will have important implications for uptake and compliance when IHGT is delivered in unsupervised real-world settings (e.g. at home or in the office). Indeed, two studies investigating unsupervised IHGT have reported no effect on blood pressure (Danielsen et al., 2023; Farah et al., 2018), and poor adherence and intervention fidelity (i.e. not completing the training as prescribed) related to high perceived exertion and negative affective responses may well partly explain these findings. Although the affective responses to IHGT will also need to be investigated in people with hypertension, our data suggest that future research should determine how changing various IHGT protocol parameters influences both the affective response and the efficacy for reducing blood pressure. The ultimate target should be to develop an IHGT protocol that both reduces blood pressure and is associated with acceptable perceptual responses. Our data clearly show that affective valence progressively declines during each unique two-minute contraction, and then becomes progressively lower with each subsequent bout. As such, reducing either the duration of the bouts (1-min or 1.5-min) or the number of bouts in an IHGT session are two potential options, but whether such protocols would still be efficacious for reducing blood pressure is unknown. Altering recovery duration, bout intensity (e.g. 20% vs 30%), or bilateral (two bouts on both arms) vs unilateral (four bouts in one arm) training sessions, are all potential protocol options that also need to be investigated.

We observed an improved affective response and lower RPE during IHGT in week 4 vs week 1 of the intervention. This is consistent with findings from other types of exercise training including moderate intensity continuous and sprint interval training (Astorino et al., 2012; Saanijoki et al., 2018; Songsorn et al., 2020). Mechanistically, this improved perceptual response is likely to be explained by rapid local metabolic and/or neuromuscular adaptations and attenuated perceptions of fatigue, pain, and discomfort. From a practical perspective, our findings suggest that building up an IHGT intervention progressively over initial weeks, both to limit negative affective responses during early training sessions, and to allow training-induced improvements in the affective/perceptual response to take place, may be a good approach for future studies, particularly those aiming to apply IHGT in unsupervised real-world settings.

There are several important limitations in this study that need to be highlighted. Firstly, we can only make conclusions on the dose response effect of IHGT on blood pressure during a short term 4-week intervention. It is possible that if the intervention period was extended out over several months that differences between the two training frequencies would materialise, although we suspect this is unlikely given the trivial effect size between the two training frequencies that were observed in this study, and the fact that Badrov et al. (2013) still found no effect of different training frequencies after 8-weeks. Nevertheless, longer-term studies of IHGT frequency in both normo- and hypertensive populations are warranted. It is also important to point out that, although we observed no statistical differences between the two training frequencies for changes in blood pressure, our study was not designed or powered to test for statistical *equivalence* of the effects. At the same time, it is important to note that we only measured office blood pressure in this study, but there is evidence that home or 24-h ambulatory blood pressure may have stronger prognostic value (Vollmer et al., 2005). Future studies should investigate the dose response effect of IHGT frequency on home and/or 24-h ambulatory blood pressure, as well as other relevant vascular health outcomes (e.g. endothelial function), in both normotensive and hypertensive populations.

Conclusions

In conclusion, this study shows a reduction in systolic and mean arterial blood pressure following low frequency IHGT with a minimal time commitment of ~25 mins/week, and that increasing the frequency/dose (and therefore time commitment) does not lead to additional reductions in blood pressure. Acute sessions of IHGT are associated with a negative affective response in the early phase of a training intervention but these responses improve as training progresses. These findings suggest that low frequency IHGT may be a simple and highly time-efficient intervention for reducing blood pressure and studies in people with hypertension are warranted.

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Data availability statement

Data is available from the corresponding author on reasonable request.

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