The effect of high intensity interval training (HIIT) upon resting and ambulatory blood pressure in physically inactive adults.

Jamie J. Edwards[1*], Katrina A. Taylor[1*], Christian Cottam[1], Navazh Jalaludeen[2], Damian A. Coleman[1], Jonathan D. Wiles [1] & Jamie M. O'Driscoll[1]

Author Affiliations:

[1] School of Human and Life Sciences, Canterbury Christ Church University, Kent, UK.

[2] Cambridge Clinical Trials Unit, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK.

* Both authors contributed equally to this manuscript.

Corresponding Author: Correspondence to Dr Jamie O'Driscoll, School of Human and Life Sciences, Canterbury Christ Church University, Kent, CT1 1QU. Email: jamie.odriscoll@canterbury.ac.uk; Telephone: 01227 782711

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Abbreviations

ABPM - ambulatory blood pressure monitoring
BP - blood pressure
BPV - blood pressure variability
dBP - diastolic blood pressure
HR - heart rate
HIIT - high-intensity interval training
mBP - mean blood pressure
MICT - moderate intensity continuous training
PP - pulse pressure
RPP - rate pressure product
sBP - systolic blood pressure

Abstract

Objective: Hypertension remains the leading cause of cardiovascular disease and premature mortality globally. While high-intensity interval training (HIIT) is an effective non-pharmacological intervention for the reduction of clinic blood pressure (BP), very little research exists regarding its effects on ambulatory BP. The aim of this study was to measure alterations in ambulatory and clinic BP following HIIT in physically inactive adults.

Methods: Forty-one participants (22.8 ± 2.7 years) were randomly assigned to a 4-week HIIT intervention or control group. The HIIT protocol was performed on a cycle ergometer set against a resistance of 7.5% bodyweight and consisted of 3 X 30-s maximal sprints separated with 2-mins active recovery. Clinic and ambulatory BP was recorded pre and post the control period and HIIT intervention.

Results: Following the HIIT intervention, 24-hour ambulatory BP significantly decreased by 5.1 mmHg in systolic BP (sBP) and 2.3 mmHg in diastolic BP (dBP) (p=0.011and p=0.012, respectively), compared to the control group. Additionally, clinic sBP significantly decreased by 6.6 mmHg compared to the control group (p=0.021), with no significant changes in dBP and mean BP (mBP). Finally, 24-hour ambulatory diastolic, daytime sBP, mBP and dBP, and night-time sBP and mBP variability significantly decreased post-HIIT compared with the control group.

Conclusion: HIIT remains an effective anti-hypertensive intervention. Our findings support enduing BP reduction and improved BP variability, which are important independent risk factors for cardiovascular disease.

Introduction

Hypertension, characterised as the chronic elevation in resting arterial blood pressure (BP), is the leading attributable risk factor for cardiovascular disease and all-cause mortality [1,2]. Globally, hypertension is estimated to affect 1.13 billion people and due to its asymptomatic nature, this figure may be underestimated [3,4]. Given that the use of hypertensive medication has considerable economic burden and appears to only be efficacious in approximately 50% of patients, it is fundamental that effective non-pharmacological approaches are utilised to tackle the current hypertension crisis [5,6].

The current global physical activity guidelines recommend a minimum of 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity exercise per week, with the inclusion of strength training twice per week [7]. While the benefits of such exercise on blood pressure are well-established, adherence to these guidelines are alarmingly low with current physical inactivity levels remaining at an estimated 27.5% globally [8]. Thus, establishing exercise which better promotes adherence while achieving significant reductions in blood pressure is crucial to global health.

High-intensity interval training (HIIT) is a highly practical, time-efficient exercise modality which typically involves short bouts of high intensity work separated with appropriate recovery periods. HIIT has been demonstrated in several research papers to produce significant reductions in resting arterial blood pressure, with evidence of reductions which are comparable to traditional moderate-intensity continuous exercise (MICT) [9,10]. Specifically, a meta-analysis from Costa et al (2018) reported statistically significant reductions in systolic (sBP) and diastolic (dBP) BP by 6.3 and 3.8 mmHg respectively, with no significant difference to the reductions observed in the MICT group (-5.8 sBP and -3.5 dBP). While this provides strong evidence for the efficacy of HIIT, there are clear gaps in the current literature. Particularly, this meta-analysis identified an insufficient number of HIIT studies (two) utilising an ambulatory BP monitoring (ABPM) technique and were therefore compelled to exclude such methodology from the analysis [10]. This is detrimental as ABPM is recognised as a more reliable measure of BP through its increased precision, elimination of observer bias and its eradication of potential ‘white-coat hypertension’ [11]. Additionally, ABPM provides information regarding blood pressure variability (BPV) and non-dipping, which are important independent predictors for cardiovascular risk [12,13]. Therefore, the

aim of the present study is to investigate the ambulatory BP responses to a short-term HIIT intervention in a cohort of physically inactive adults. We hypothesise that a 4-week randomised HIIT intervention will statistically significantly reduce clinic and ambulatory BP compared to a control group.

Methodology

Participant population and ethical approval

Forty-four participants were voluntarily recruited; however, three participants dropped out prior to baseline testing, leaving a final study population of forty-one (20 males and 21 females). Based on the inclusion criteria, all participants were healthy (22.8 ± 2.7 years), but physically inactive (self-reported in accordance with the current guidelines) [7]. Participants were within the normal resting blood pressure range [14] and reported no previous history of cardiovascular disease.

Through stratifying the randomization on gender, participants were assigned into the 4-week HIIT intervention or control group [15]. This research study ensured conformity to the Declaration of Helsinki principles, and was approved by the Canterbury Christ Church Universities Ethics Committee. All participants completed and signed informed consent prior to testing.

Blood pressure measurements

All participants were required to fast for at least 4 hours and refrain from alcohol and caffeine consumption 24-hours before testing. Additionally, participants were requested to maintain normal dietary and circadian routines throughout the study and each phase of testing.

Participants attended a temperature-controlled laboratory for baseline BP screening using an automated oscillometric BP monitor (Dinamap Pro 200 Critikon; GE Medical Systems, Freiburg, Germany). Resting sBP, dBP and mean BP (mBP) from the brachial artery were recorded as an average of 3 measures separated by 5-min following 15-min of seated rest; and in accordance with the current guidelines [16].

Ambulatory BP measurements were acquired pre and post the HIIT intervention or control period over 24-hours using a commercially available and validated oscillometric sphygmomanometer measured at the brachial artery (Welch Allyn 6100 ambulatory BP monitor; Welch Allyn Inc., Skaneateles Falls, New York, USA). An appropriately sized cuff was set to inflate at pre-programmed intervals of 20/30 minutes during the daytime (08.00 to

22.00) and 30/60 minutes during the night-time (24.00 to 06.00) over a 24-hr period. Acceptable recordings were determined by 14 successful measurements during daytime hours and 6 measurements at night-time [17]. All Participants confirmed that they had slept during the specified night-time period. During the 24-hour measurement, participants were asked to perform usual daily activities, but were prohibited from exercise. All BP readings were stored on the device during the measurement period and were then transferred to a computer for evaluation (Welch Allyn Cardio Perfect Workstation Software for Windows; Welch Allyn Inc.). Variability of ambulatory sBP, dBP and mBP was calculated using standard deviation of measures taken over the 24-hour period.

High intensity interval training intervention

The HIIT intervention was performed over 4-weeks, with participants attending the laboratory for training 3 times per week. The exercise protocol was performed on a Wattbike cycle ergometer (Wattbike Ltd, Nottingham, UK), and was based on a Wingate test protocol. Participants performed a 5-minute steady state warm-up, followed by 3 x 30-s maximum effort sprint intervals, each separated by 2 minutes of active recovery. Resistance during the sprint intervals was calculated at 7.5% of the individuals body mass. Following the 4-week intervention period, post HIIT laboratory assessments were performed 48 hours after the final HIIT session in order to avoid any residual effects of post exercise hypotension. During the control period, participants were requested to maintain their usual routine and daily activities and adherence to this was confirmed prior to laboratory assessment.

Sample size estimation

A reduction of 5 mmHg in sBP from resting and ambulatory measures is considered clinically significant [18]. Based on instrument coefficient of variation (4.6%) (Dinamap BP monitor) [19], a sample size of 20-participants in each group has 80% power to detect this difference with a 2-sided $p<0.05$. We estimated a dropout rate of between 5-10% leading to an overall sample size of 44 participants.

Statistical analysis

All data was analysed using a statistical package for social sciences (SPSS V22.0, release version for windows; SPSs Ins., Chicago, IL, USA). Continuous variables are presented as mean ± standard deviation unless stated otherwise. Analysis of covariance (ANCOVA) was performed which used baseline BP values as covariates to assess whether changes in resting and ambulatory BP (sBP, dBP and mBP) following both intervention and control group was influenced by the initial resting BP values. Data was reported as statistically significant when $p < 0.05$.

Results

Participants randomised to the intervention group (n=21) completed a total of 12 training sessions during the 4-week study period. Adherence to the exercise sessions was 100% for all participants with no withdrawals.

Resting office blood pressure

Following the 4-week HIIT intervention, there was a significant reduction in resting sBP (-6.6 mmHg) compared with the control group (-1.2 mmHg, p=0.021). However, there were no significant differences in resting dBP, mBP or pulse pressure (PP) in either the HIIT or control groups (Table 1).

Ambulatory blood pressure

As shown in Table 2, 24-hour sBP, mBP and dBP significantly decreased following the HIIT intervention (-5.1 mmHg, p=0.011; -3.1 mmHg, p=0.002; and -2.3 mmHg p=0.012 respectively), compared to the control group. Figure 1 illustrates the 24-hour BP responses following the HIIT and control period. The reduction in sBP resulted in a significant reduction in 24-hour rate pressure product (RPP) following HIIT (-473.6 mmHg*b·min^{-1}, p=0.025) compared to the control group.

For daytime ambulatory BP, there was a significant reduction in sBP (-3.7 mmHg, p=0.032) and dBP (-2.8 mmHg, p=0.046) compared to the control group; however, there were no significant changes in daytime mBP. For night-time ambulatory BP, there was a significant reduction in sBP (-6.8 mmHg, p=0.001), and mBP (-2.9 mmHg, p=0.016), but no significant changes in dBP, compared to the control group. Figure 2 demonstrates daytime and night-time BP responses following the HIIT and control period. The reduction in night-time ambulatory sBP resulted in a significant reduction in 24-hour night-time RPP following HIIT (-67.3 mmHg*b·min^{-1}, p=0.035) compared to the control group.

Blood pressure variability

As presented in Table 2, following the HIIT intervention, 24-hour diastolic BP variability (BPV) significantly decreased (-0.9, p=0.032), whereas there were no significant changes in systolic or mean BPV compared to the control group. Additionally, there were significant decreases in systolic (-1.6 mmHg, p=0.023), mean (-1.57 mmHg, p=0.027) and diastolic (-1.7 mmHg, p=0.037) daytime ambulatory BPV, and a significant decrease in systolic and mean night-time ambulatory BPV (-3.3 mmHg, p=0.008 and -1 mmHg, p=0.003, respectively) compared to the control group. However, there was no significant reduction in night-time diastolic BPV compared to the control group. Mean hourly sBP, dBP and mBP pre and post HIIT intervention are displayed in Figure 3.

Heart rate, pulse pressure and body mass

No significant differences were recorded in heart rate (HR) or pulse pressure in 24-hour, daytime, or night-time ambulatory measurements for the HIIT intervention compared to the control group. In addition, there was no significant change in body mass in following HIIT compared to the control group.

Discussion

The present randomised controlled study demonstrated significant reductions in 24-hour ambulatory sBP, mBP, and dBP of -5.1 mmHg, -3.1 mmHg, and -2.3 mmHg, respectively, as well as a significant reduction in clinic sBP of -6.6 mmHg following 4-weeks of HIIT compared to a control group. A decrease of this magnitude is considered clinically significant and similar to the anti-hypertensive effects observed using drug monotherapy [20]. While the results compliment many studies that have reported the beneficial effects of HIIT on resting office BP, ABPM provides valuable information regarding the continued BP effect over the 24-hour period, which is crucial in understanding the chronic effects of any anti-hypertensive intervention. In accordance with previous meta-analysis evidence, the magnitude of 24-hour ambulatory BP reduction following our HIIT intervention is comparable to other ambulatory BP reducing exercise interventions including traditional MICT [21,22]. Importantly, such results are associated with statistically significant reductions in the risk of cardiovascular disease and all-cause mortality [23,24]. This is fundamental as ABPM has been consistently reported to provide superior prognostic information regarding cardiovascular risk compared to office or home BP, thus enhancing the implications of such results [25].

In general, the ambulatory BP responses from this study support the findings from previous research in this limited evidence base; however, the primary differences are centred around the magnitude of reduction. Specifically, Molmen-Hansen *et al* (2012) reported significant reductions ($p<0.001$) in 24-hour ambulatory BP by a substantial 12 mmHg sBP and 8 mmHg dBP following a 12-week HIIT intervention [23]. In addition to the prolonged intervention duration (8 weeks longer), the increased magnitude of BP reduction observed in this study may be linked to the cohort recruited being Stage 2 hypertensive (>140/90 mmHg), as similar anti-hypertensive interventions have reported greater reductions in groups with higher baseline BP values [26,27]. This is potentially due to a lower limit of BP response where a physiological component cannot be decreased below its homeostatic clinical level without producing a mechanistic response to prevent hypotension [28]. Regardless of this, the limited number of other homogenous studies investigating the effects of HIIT on ambulatory BP have reported similar results to ours, thus reinforcing the role of HIIT in the management and prevention of hypertension [28–31].

Although complex, the mechanisms whereby BP is reduced following HIIT must involve either cardiac output or total peripheral vascular resistance as the two determining factors of arterial pressure. Typically, the mechanisms following HIIT have been primarily associated with changes to peripheral vascular resistance due to reports of a significant decrease in BP without accompanying decreases in cardiac output [32]; which is supported in the unchanged heart rate results of the present study. Additionally, O'Driscoll et al (2018) reported no significant changes in cardiac dimensions or left ventricular ejection fraction following HIIT, which further supports this concept. However, significant improvements in systolic and diastolic left-ventricular mechanical adaptations were reported, which supports the value of HIIT on cardiac health [32].

Our results show significant reductions in RPP which is understood as a determinant of myocardial oxygen consumption. With this, a reduction in RPP following the 4-week HIIT intervention suggests a chronic decrease in myocardial workload which provides clinical implications regarding long-term cardiac structural and functional health and thus cardiovascular risk [33]. Conversely, our results show no significant changes in PP, which is an indicator of arterial stiffness through its causal role in isolated systolic hypertension. Therefore, the lack of decrease observed in this study suggests the reductions in ambulatory BP may not be a result of improved arterial compliance and distensibility [34]. When considering the young population measured in this study, these results are only logical as arterial stiffness generally declines linearly with age and therefore the measured cohort are likely to be free from functional and structural vascular decline, thus limiting the capacity for change. Accordingly, our observed reductions in BP may therefore reinforce the potential value of HIIT as a therapeutic early intervention to reduce BP in advance of global systemic physiological (arterial) decline with sustained hypertension. This highlights a need to explore the de-training effects following a HIIT intervention, and to establish the optimal ongoing training commitment required to maintain or induce further BP reductions to allow for the optimal prescription of HIIT.

Separately, we found significant reductions in daytime sBP (-3.7 mmHg) and dBP (-2.8 mmHg) as well as night-time sBP (-6.8 mmHg) and mBP (-2.9 mmHg), but not dBP. These substantial reductions in night-time ABP are significant as nocturnal BP is a significant risk factor for mortality and cardiovascular morbidity in both normotensive and hypertensive populations [35]. Particularly, sleeping systolic BP should be >10% lower than daytime sBP

which is termed ‘dipping’ [36]. Following the 4-week intervention, 13 control participants were classified as dippers pre-intervention and 14 participants post intervention. Of the HIIT group, 9 participants were classified as dippers pre-intervention and 11 participants post intervention. There was no significant difference in the proportion of dippers following HIIT compares to the control group.

Blood pressure variability

To our knowledge, this is the first study to measure the effects of HIIT on BPV. Increased variability in BP over a 24-hour period is well established for its role as a prognostic marker for health, independent of mean BP values [37]. Our results show a significant reduction in daytime (sBP, mBP and dBP), night-time (sBP and mBP) and diastolic 24-hour BPV; however, a non-significant reduction in 24-hour systolic and mean BPV. While future research is required, these results may have prognostic importance. Specifically, previous evidence has reported significant associations between daytime BPV and early development of atherosclerosis [38], target organ damage [39] and cardiovascular and stroke mortality [40], thus providing implications for these reductions. As BP is typically at its peak during waking hours, these reductions in daytime variability suggest an improvement in BP regulation in response to daily activities. The mechanisms responsible for reductions in BPV remain inconclusively understood; however, fluctuations of BP over the course of 24-hours generally reflect central and autonomic modulation and arterial elasticity [41]. This is supported in O’Driscoll et al (2018) who reported a significant increase in total power spectrum of heart rate variability following a 2-week HIIT intervention, indicating enhanced cardiac autonomic modulation and thus an increase in the sinoatrial node’s ability to respond to external homeostatic demands [32]. Despite our PP results, the effect of HIIT on vascular health are well established, with meta-analysis evidence reporting greater vascular function adaptations following HIIT compared to MICT [42]. Although complex, these enhanced vascular adaptations have been linked to the promotion of greater shear stress-induced nitric oxide bioavailability as a result of the increased blood flow from such high intensity exercise [42]. Despite this, future research is required to ascertain the effects of exercise training on BPV and the mechanisms underlying such adaptations.

Limitations

It is important to consider the limitations of this study. In particular, this is a single-centre trial and all sessions of HIIT were performed in a laboratory environment as a group. While this is beneficial for adherence and accurate performance of the intervention, this potentially limits the clinical implications of our results. Additionally, while this intervention involved a mixed male and female cohort, we did not account for ethnicity and therefore the relative application of these findings to different ethnic populations who are understood to be at a greater risk of hypertension is unknown.

Conclusion

The results of the present study support the role of HIIT as an effective anti-hypertensive intervention, with clinically significant reductions in ambulatory and resting BP. These results are imperative due to the current inadequate evidence base surrounding the effects of HIIT on ambulatory BP. To our knowledge, this is the first study to investigate the effects of HIIT on BPV, which may have important implications for cardiovascular health. Future research into the long-term effects and adherence to HIIT are crucial for establishing its use as a prolonged nonpharmacological intervention for the management of hypertension.

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Figure legends

Figure 1: Mean systolic (A), mean (B) and diastolic (C) blood pressure change values following control (closed circles) and HIIT (open circles) conditions. Note: Error bars indicate standard error of the mean; * = Significant (p<0.05) difference in the control and HIIT change value.

Figure 2: Mean day time systolic (A), day time mean (B), day time diastolic (C), night time systolic (D), night time mean (F) and night time diastolic (F) blood pressure change values following control (closed circles) and HIIT (open circles) conditions. Note: Error bars indicate standard error of the mean; * = Significant (p<0.05) difference in the control and HIIT change value.

Figure 3: Illustrates the difference in mean hour-by-hour ambulatory BP, pre and post HIIT for (A) ambulatory sBP; (b) ambulatory mBP; (c) ambulatory dBP.