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Ambulatory blood pressure adaptations to high intensity interval training: A randomised controlled study.

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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 intervention for the management of BP. Our findings support enduring BP reduction and improved BP variability, which are important independent risk factors for cardiovascular disease.

Introduction

Hypertension, characterised as a 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 significantly underestimated [3,4]. Given that the use of hypertensive medication has considerable economic burden, is often associated with undesirable side-effects and appears to only be efficacious in approximately 50% of patients, it is imperative 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 BP are well-established, adherence to these guidelines is alarmingly low [8]. Thus, establishing novel exercise modes which promote better adherence while achieving significant reductions in BP is crucial to global health.

High-intensity interval training (HIIT) is a highly practical, time-efficient exercise modality which typically involves short bouts of maximal intensity work separated with appropriate recovery periods. HIIT has previously been demonstrated to produce significant reductions in resting arterial BP, with the magnitude of reductions comparable to traditional moderate-intensity continuous exercise (MICT) [9,10]. Specifically, a recent meta-analysis [10] reported statistically significant reductions in systolic (sBP) and diastolic (dBP) BP of 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 BP 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 volunteers were recruited; however, three participants dropped out prior to baseline testing, leaving a final study population of forty-one (20 males and 21 females). All participants were healthy (22.8 ± 2.7 years), but physically inactive (self-reported in accordance with the current guidelines) [7], were within the normal resting BP 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 conformed 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, whilst maintaining 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 in accordance with current guidelines [16].

ABPMs were acquired pre and post the HIIT intervention and 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 20-minute intervals between 06.00 and 22.00 h and every 30-minutes in the remaining time period. Data was analysed for the entire 24-h period, as well as separately for day time (08.00 to 22.00) and night-time (24.00 to 06.00) periods [17]. Acceptable recordings were determined by ≥14 successful measurements during daytime hours and ≥7 measurements at night-time [18]. 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.). The average real variability of ambulatory sBP, mBP and dBP were calculated to determine BP variability as described in previous research [19].

High intensity interval training intervention

The HIIT intervention was performed over 4-weeks, with participants attending the laboratory for training (group sessions) 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. Participants were asked to perform 2 to 3, 5-second high revolution spins during their warm-up period to ensure they were familiarised with the pedalling speed requirement of the Wingate test. 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 [20]. Based on instrument coefficient of variation (3-3.4%) from resting BP measures (Dinamap BP monitor) in our laboratory, 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 values as covariates to assess whether changes in resting and ambulatory BP parameters following both intervention and control group was influenced by the initial resting values. All data was assessed using 2-tailed analysis and 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. Mean hourly sBP, mBP and dBP pre and post HIIT intervention are displayed in Figure 3.

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 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.

Heart rate, pulse pressure and body mass

No significant differences were recorded in heart rate (HR) or pulse pressure (PP) 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 BP reducing effects observed using drug monotherapy [21]. 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 response over the 24-hour period, which is crucial in understanding the chronic BP lowering effect of any 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 [22,23]. Importantly, such results are associated with statistically significant reductions in the risk of cardiovascular disease and all-cause mortality [24,25]. This is fundamental as ABPM has been reported to provide superior prognostic information regarding cardiovascular risk compared to office or home BP, thus enhancing the implications of such results [26].

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, previous evidence [27] 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. In addition to the prolonged intervention duration (8 weeks longer), the increased magnitude of BP reduction observed in their 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 [27,28]. This is potentially due to a lower threshold of BP response, where it cannot be decreased further below its homeostatic clinical level without producing a mechanistic response to prevent hypotension [29]. Separately, the observed differences in the magnitude of BP response can be potentially linked to the differences in HIIT protocol. Our study incorporated a time-efficient Wingate protocol, whereas previous research commonly utilise protocols employing prolonged work periods, as highlighted in intervals of 4-minutes [27]. While the optimal HIIT protocol is yet to be established, these separate findings provide support for HIIT as a flexible training modality, which can be successfully applied through various effective protocols. Regardless of these methodological differences, the limited number of studies investigating the effects of HIIT on ambulatory BP have reported similar results to ours, thus reinforcing the role of HIIT in the management of BP [29–32].

Although complex, the mechanisms whereby BP is reduced following HIIT must involve a change in cardiac output and/or total peripheral vascular resistance as the two determining factors of arterial pressure. Typically, the mechanisms following HIIT have been primarily associated with changes in peripheral vascular resistance due to reports of a significant decrease in BP without accompanying decreases in cardiac output [33]; which tends to be supported by the unchanged heart rate results of the present study. Additionally, previous research [33] reported no significant changes in cardiac dimensions or left ventricular ejection fraction following HIIT, which further supports this concept. Despite no likelihood of any change in cardiac output, significant improvements in systolic and diastolic left-ventricular mechanical adaptations were reported, which affirms the value of HIIT on cardiac health [33].

Our results also show a significant reduction in RPP, which is a non-invasive indices of myocardial oxygen consumption. This reduction in RPP following the 4-week HIIT intervention suggests a reduction in myocardial workload, which may improve myocardial efficiency as well as have important long-term clinical implications regarding cardiac health and thus cardiovascular risk [34]. Conversely, our results show no significant changes in PP, which is a known indicator of arterial stiffness. However, this result is probably not surprising when considering the population recruited in this study were young, and arterial stiffness generally increases linearly with increasing age. As such, the measured cohort are less likely to evidence a decline in vascular function, and thus have a limited capacity for change. Conversely, as opposed to arterial stiffness, previous evidence has shown stroke volume to be a significant independent contributor to clinic and 24-hr PP in young, healthy participants through the expression of a hyperkinetic state, potentially explaining the non-significant change in our study [35–37].

In addition, 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 potentially important as nocturnal BP is a significant risk factor for mortality and cardiovascular morbidity in both normotensive and hypertensive populations [38]. Particularly, sleeping systolic BP should be >10% lower than daytime sBP which is termed ‘dipping’ [39]. Despite the observed reductions in night-time sBP and mBP, there was no significant difference in proportion of dippers following HIIT compared to the control group, thus limiting the implications of such findings.

Blood pressure variability

To our knowledge, this is the first study to measure the chronic 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 [40]. 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 further research is required, these results may have prognostic importance. Specifically, previous evidence has reported significant associations between increased daytime BPV and early development of atherosclerosis [41], target organ damage [42] and cardiovascular and stroke mortality [43], 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 [44]. This is supported in previous evidence [33] which reported a significant increase in total power spectrum of heart rate variability with a significant decrease in the R-R low frequency/high frequency ratio following a 2-week HIIT intervention, indicating enhanced cardiac autonomic modulation with increased parasympathetic activity parallel to decreased sympathetic activity; which are understood to play a role in the regulation of short-term BPV [33,45,46]. 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 [47]. 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 [47,48]. However, further 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, as we recruited a young normotensive population, it is unknown if our findings have application to hypertensive and elderly populations, highlighting the need for future research in these groups. It is also important to consider the safety of HIIT in hypertensive populations at greater cardiovascular disease risk. Furthermore, using a traditional Wingate protocol, we applied the same resistance to both males and females, which may be a suboptimal workload considering gender differences [49–51]. Finally, power output produced during the Wingate sessions was not recorded; therefore, it is unclear if participants undertaking HIIT produced physiological adaptations to generate greater power output following the intervention.

Conclusion

The results of the present study further support the role of HIIT in the management of BP, 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, with preliminary findings showing 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 BP.

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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.