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REVIEW

Exercise intensity and hypertension: what's new?

YN Boutcher and SH Boutcher

One bout of aerobic exercise and regular participation in aerobic exercise has been shown to result in a lowering of office and ambulatory blood pressure of hypertensive individuals. Higher-intensity aerobic exercise, up to 70% of maximal oxygen consumption, does not produce a greater hypotensive effect, compared with moderate-intensity aerobic exercise. Intermittent aerobic and anaerobic exercise, however, performed at an intensity >70% of maximal oxygen uptake has been shown to significantly reduce office and ambulatory blood pressure of hypertensive individuals. Thus, faster, more intense forms of exercise can also bring about blood pressure reduction in the hypertensive population. Compared with continuous moderate-intensity aerobic exercise, high-intensity intermittent exercise typically results in a greater aerobic fitness increase in less time and produces greater changes in arterial stiffness, endothelial function, insulin resistance and mitochondrial biogenesis. One of the characteristics of high-intensity intermittent training is that it typically involves markedly lower training volume compared with traditional aerobic and resistance exercise programmes making it a time-efficient strategy to accrue adaptations and blood pressure benefits. This review briefly summarizes the results of studies that have examined the effects of single and repeated bouts of aerobic and resistance exercise on office and ambulatory blood pressure of hypertensive individuals. Then a more detailed summary of studies examining the effect of high-intensity intermittent exercise and training on hypertension is provided.

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INTRODUCTION

Hypertension is one of the major risk factors for cardiovascular morbidity. Hypertension worldwide prevalence has been estimated to be over one billion and treatment costs are substantial.[1] Regular participation in aerobic exercise (continuous walking, jogging and cycling) has been shown to reduce office blood pressure[2] (BP) and ambulatory BP (ABP)[3] of hypertensive individuals and promotes general health and improvement in cardiovascular risk factors.[4] Office BP is typically measured once or twice using an auscultatory cuff in a sitting, resting position, whereas ABP involves continuous assessment over hours. One bout of resistance exercise (weights) also lowers the office diastolic BP of hypertensive individuals.[2] The number of studies that have examined the effect of resistance exercise on the BP of hypertensive adults, however, is minimal. Research examining the effect of high-intensity exercise on hypertension is increasing and promisingly, results indicate that this form of exercise is impactful on hypertension.[5] One bout of high-intensity intermittent exercise (HIIE) typically involves mini-bouts of high-intensity exercise lasting from 6 s to 4 min interspersed by rest or light-intensity exercise recovery periods. High-intensity intermittent training (HIIT) involves repeated bouts of HIIE over months. HIIT has lower training volume, compared with traditional aerobic and resistance exercise programmes, making it a time-efficient strategy to achieve BP benefits. The purpose of this review is to briefly summarize the results of research examining the effect of single and repeated bouts of aerobic and resistance exercise on the office BP and ABP of hypertensive individuals. The issue of optimal exercise intensity will be addressed after which a more detailed examination of studies examining the effect of HIIE and HIIT on the BP of hypertensive individuals will be provided. Regarding search methods two researchers surveyed Medline and Pubmed databases for meta-analyses and reviews involving aerobic and resistance exercise and their effects on BP in hypertensive individuals. To search references on high-intensity exercise the terms HIIE, HIIT and interval sprinting exercise were used separately and associated with hypotension, hypertension, post exercise, BP and ABP. Inclusion criteria for the high-intensity articles were the following: (1) a sample consisting of hypertensive adults; (2) papers reporting BP responses after HIIE for a minimum of 20 min; (3) papers reporting BP responses after a minimum of 8 weeks of HIIT; and (4) papers published in English.

THE EFFECT OF AEROBIC AND RESISTANCE EXERCISE ON BP OF HYPERTENSIVE INDIVIDUALS

Aerobic exercise is usually performed by continually running, cycling or swimming for 30–45 min at a moderate intensity. Frequency of exercise (number of sessions per week) and duration (how long each session lasts) are important characteristics of an exercise programme, but an equally important factor is exercise intensity (how hard an individual works during exercise). For example, high- compared with moderate-intensity running, cycling and swimming has consistently been found to result in greater physiological adaptations. Typically, aerobic exercise has been performed on a stationary cycle ergometer or treadmill at a moderate intensity between 45 and 64% of maximal oxygen uptake ($\dot{V}O_{2max}$). $\dot{V}O_{2max}$ is typically assessed by exercising an individual to exhaustion on a stationary cycle ergometer or treadmill. $\dot{V}O_{2max}$ reflects an individual's aerobic fitness level and is influenced by the ability to utilize oxygen to fuel aerobic exercise. Older individuals and those suffering from disease can

Department of Exercise Physiology, School of Medical Sciences, Faculty of Medicine, University of New South Wales, Sydney, New South Wales, Australia. Correspondence: Dr SH Boutcher, School of Medical Sciences, Faculty of Medicine, University of New South Wales, High Street, Randwick, Sydney, New South Wales 2052, Australia.
E-mail: s.boutcher@unsw.edu.au
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exercise to exhaustion but can fail to meet the criterion for attaining $\dot{V}O_{2max}$, which typically includes a final exercise heart rate within ±10 beats per minute of age-predicted maximal heart rate, a plateau in oxygen consumption and a respiratory exchange ratio of >1.15. In this situation individuals are deemed to have achieved a $\dot{V}O_{2peak}$. Exercise intensity is typically expressed by what percentage of $\dot{V}O_{2max}$ an individual utilizes during exercise. For example, moderate-intensity aerobic exercise is usually performed at a relative intensity of around 45–64% of $\dot{V}O_{2max}$ or 55–74% of maximal heart rate, whereas hard/vigorous aerobic exercise is usually performed at 70–85% of $\dot{V}O_{2max}$ and 95% and above of maximal heart rate. HIIE and HIIT, to be discussed later, are typically performed at an intensity between 70 and 100+% of $\dot{V}O_{2max}$ although there are intensity issues regarding HIIE that involve sprinting (see next paragraph). Some studies have used maximal heart rate or age-related estimates of maximal heart rate to estimate exercise intensity. Thus, exercising at 70% of maximal heart rate would equate to around 60% of $\dot{V}O_{2max}$. Other studies have used heart rate reserve to calculate exercise intensity, which is the difference between resting heart rate and maximum heart rate.

There is a problem, however, when percent of $\dot{V}O_{2max}$ or per cent of maximal power output are used to categorize the exercise intensity of HIIE regimens that contain sprinting (for example, a pedal rate in excess of 100 revolutions per minute). Thus, in some studies the intermittent exercise phase is performed as a sprint (anaerobic exercise) so energy generation depends mainly on non-aerobic energy pathways. Consequently, assessing $\dot{V}O_2$ during the sprint phase would not be a valid indicator of exercise intensity. Although the recovery phase is typically aerobic in nature assessing $\dot{V}O_2$ would not accurately reflect exercise intensity during sprinting. So there is a problem with using per cent of $\dot{V}O_{2max}$ to express intensity during exercise regimens that involve sprinting. Using a percentage of maximal power output (usually in watts) reflects exercise intensity but does not necessarily reflect the 'sprinting' component. For example, a person working at 90% of a maximal power output of 200 W could by cycling at a high resistance (for example, 2 kg) on a cycle ergometer but with a non-sprinting pedal cadence (for example, 90 revolutions per minute). So their power output would be 90% of their maximal power output (180 W) but they would not be sprinting. Similarly, using a percentage of maximal heart rate could have the same problem. Also it is possible to have a sprinting pedal cadence on a stationary cycle ergometer with a low resistance resulting in an exercise intensity that is at a low percentage of maximal power output. Using the example above a person working at 60% of their maximal power output (120 W) could by cycling with a low resistance (for example, 1 kg) on a cycle ergometer but with a sprinting pedal cadence (for example, 120 revolutions per minute). So their power output would only be 60% of their maximal power output (120 W) but they would be sprinting. So currently, some interval sprinting exercise programmes would not be classified as 'high-intensity' exercise. It is not clear what is more important; exercising quickly (for example, sprinting) or exercising at a high intensity (for example, >85% of maximal power output). Randomized trials have shown that high-sprint/low-resistance stationary cycle ergometer exercise results in significant increases in aerobic fitness and muscle mass, and significant decreases in body fat, visceral fat and insulin resistance,[6] however, the effect of high sprint/low-resistance exercise on BP of hypertensive individuals does not appear to have been examined.

The effect of one bout of aerobic exercise on office BP

The effects of one bout of aerobic exercise on the BP of hypertensive individuals has typically been investigated by exercising individuals who have been mostly stage 1 hypertensive (systolic BP 140–159 mm Hg; diastolic BP 90–99 mm Hg). Participants exercise once on a treadmill or stationary cycle ergometer at an intensity between 40 and 70% of $\dot{V}O_{2max}$ for between 20 and 40 min. Office BP has usually been assessed before exercise and between 1 and 2 h after one bout of exercise. Collectively, results have shown that one bout of aerobic exercise consistently lowers office systolic and diastolic BP of hypertensive adults up to 2 h during the post-exercise period[7] (Table 1).

The effect of one bout of aerobic exercise on ABP

The effect of a single bout of aerobic exercise on post-exercise ABP has also been examined. Hypertensive participants typically exercise on a treadmill or stationary cycle ergometer at an intensity between 40 and 70% of $\dot{V}O_{2max}$ for between 20 and 40 min after which ABP is monitored for up to 24 h. Most studies have found a significant post-exercise ABP decrease in hypertensive individuals.[7] This effect, however, is variable in magnitude (−2 to 12 mm Hg decrease in systolic and diastolic BP) and duration (4 to 16 h) suggesting that individual and exercise characteristics might contribute to the variability of the aerobic post-exercise hypotension response.[8] Collectively, one bout of aerobic exercise has been found to significantly reduce both the office BP and ABP of hypertensive individuals. Higher-intensity aerobic exercise, compared with moderate-intensity aerobic exercise, has not been found to produce a greater post-exercise hypotensive effect.[2]

The effect of regular aerobic exercise on office BP and ABP

It has also been found that hypertensive adults, typically stage 1 hypertensive, who are exposed to aerobic exercise performed regularly every week for months, experience a lowering of BP. For office BP, a meta-analysis[2] found that regular aerobic training was associated with a reduction of 8.3 and 5.2 mm Hg for the systolic and diastolic BP, respectively, of hypertensive individuals (Table 1). For ABP, results of another meta-analysis[3] found that aerobic training was associated with a reduction of 3.8 and 3.0 mm Hg for daytime systolic and diastolic ABP, respectively, of hypertensive individuals (Table 1). Consistently, involvement in regular bouts of aerobic exercise, performed over months, has been found to significantly reduce both the office BP and ABP of hypertensive individuals. Higher-intensity regular aerobic exercise, compared with moderate-intensity aerobic exercise, has not been found to produce a greater reduction in office BP or ABP.[2] With regard to exercise-induced hypotension effects during the following 24 h the meta-analysis by Cornelissen *et al.*[3] concluded that regular aerobic exercise significantly decreases daytime but not night-time ambulatory BP of normotensive adults.

The effect of one bout of resistance exercise on office BP and ABP

Resistance exercise, often termed dynamic resistance exercise, is usually performed by lifting weights or by performing exercise on resistance machines. The weight-training protocols used have typically involved around eight different exercises, with 8–12 repetitions, repeated three times, each exercise. The individual exercises have typically involved upper arm, abdominal and leg muscles. In studies using one bout of resistance exercise the session has typically lasted between 30 and 60 min, and in regular resistance exercise trials this type of session is repeated 2–3 times per week for months. Dynamic resistance exercise involves moving joints and muscle against an opposing force, whereas isometric resistance exercise is performed by contracting muscles without joint or muscle movement. Only two studies have examined the effect of one bout of dynamic resistance exercise on the office BP of hypertensive individuals and a small exercise-hypotension effect has been documented[7] (Table 1). Three studies have examined the effect of one bout of dynamic

Table 1. Summary of meta-analyses and reviews examining the effect of one bout and regular aerobic and resistance exercise on office BP and ABP of hypertensive adults

	Study design	*Findings*
One bout of aerobic exercise		
Office BP		
Gomes *et al.*[7]	Review: 8 studies, 107 participants	⇩SBP and ⇩DBP up to 2 h post exercise
ABP		
Gomes *et al.*[7]	Review: 18 studies, 489 participants	⇩SBP and ⇩DBP from 1 to 24 h post exercise
Regular aerobic exercise		
Office BP		
Cornelissen and Smart[2]	Meta-analysis: 26 trials, 585 participants	⇩SBP of 8.3 mm Hg and ⇩5.2 mm Hg DBP
ABP		
Cornelissen *et al.*[3]	Meta-analysis: 6 trials, 147 participants	⇩Daytime SBP of 3.8 mm Hg and 3.0 mm Hg DBP
One bout of dynamic resistance exercise		
Office BP		
Gomes *et al.*[7]	Review: 2 studies, 27 participants	⇩ SBP and DBP up to 1 h post exercise
ABP		
Gomes *et al.*[7]	Review: 3 studies, 45 participants	⇩Daytime SBP and ⇩DBP from 1 to 10 h post exercise
Regular dynamic resistance exercise		
Office BP		
Cornelissen and Smart[2]	Meta-analysis: 4 trials, 58 participants	⇧SBP of .47 mm Hg and ⇩1 mm Hg DBP
ABP		
Cardoso *et al.*[8]	Review: 2 trials, 65 participants	⇔Daytime systolic and diastolic ABP
Regular isometric resistance exercise		
Office BP		
Carlson *et al.*[9]	Meta-analysis: 3 trials, 32 participants	⇩SBP of 4.31 mm Hg and ⇩5.48 mm Hg DBP

Abbreviations: ABP, ambulatory blood pressure; BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure. Note: ⇧ increased; ⇩ decreased; ⇔ no change.

resistance exercise on the ABP of hypertensive adults. For example, Hardy and Tucker[9] administered a resistance programme to hypertensive adults and found a small hypotensive effect on systolic BP lasting 1 h after dynamic resistance exercise. Similar results for both systolic and diastolic ABP were found by Moraes *et al.*[10] In contrast, Melo *et al.*[11] administered one bout of dynamic resistance exercise to hypertensive males and found a large hypotensive effect lasting up to 10 h. Thus, three studies have found that one bout of dynamic resistance exercise reduces daytime ABP of hypertensive adults. Studies examining the effect of one bout of isometric resistance exercise on the office BP or ABP of hypertensive individuals do not appear to have been carried out.

The effects of regular dynamic resistance exercise on office BP and ABP

Meta-analysis has indicated that regular dynamic resistance exercise does not influence office systolic BP of hypertensive individuals but results in a small reduction in diastolic BP[2] (Table 1). Similarly, regular dynamic resistance exercise does not lower the ABP of hypertensive individuals[7] (Table 1). Also, similar to aerobic exercise, resistance exercise intensity does not appear to impact on BP response. The number of studies that have examined the effect of regular dynamic resistance exercise on the office BP and ABP of hypertensive adults, however, is minimal, and more studies need to be conducted in this area.

The effects of regular isometric resistance exercise on office BP

With regard to regular isometric resistance exercise Carlson *et al.*[12] conducted a meta-analysis with nine trials and concluded that isometric resistance exercise, carried out for more than 1 h per week for at least 4 weeks, reduced office systolic BP by 6.77 mm Hg and diastolic BP by 3.96 mm Hg (Table 1). However, only three of the studies included in the meta-analysis examined hypertensive patients, whereas the other studies involved normotensive individuals. The hypertensive patients recorded a smaller reduction in exercise-induced systolic BP with a 4.31 mm Hg decrease and a slightly greater decrease in diastolic BP of 5.48 mm Hg (Table 1). Similar to regular dynamic resistance exercise more studies need to be conducted in this area using ABP to monitor BP change.

In summary, office BP and ABP of hypertensive individuals, who have been mostly stage 1 hypertensive, have typically been reduced after one bout of aerobic exercise and after participation in regular aerobic exercise performed at an intensity of between 40 and 70% of $\dot{V}O_{2max}$ (Table 1). Aerobic exercise intensity does not appear to have an effect on the BP response of hypertensive adults. One bout of dynamic resistance exercise (weights) has been found to have a small but significant reduction of office BP and ABP of hypertensive individuals (Table 1). Regular participation in dynamic resistance exercise has been found to have a minimal effect on the office BP and ABP of hypertensive individuals (Table 1). The effect of one bout of isometric resistance exercise on office BP and ABP does not appear to have been examined. Participation in regular isometric resistance exercise has a large lowering effect on the office BP of hypertensive individuals. The number of studies that have examined the effect of dynamic and isometric resistance exercise on the BP of hypertensive adults, however, is minimal. One bout of aerobic exercise and participation in regular aerobic exercise, varying at an intensity between 40 and 70% of $\dot{V}O_{2max}$, have been found to have a similar influence on the office BP and ABP of hypertensive individuals. Resistance exercise intensity also does not appear to affect BP in the small number of studies published so far. However, as discussed below, exercising at an intensity $>70\%$

of $\dot{V}O_{2max}$, has produced a hypotensive effect in hypertensive individuals.

The optimal aerobic exercise intensity required to reduce BP of hypertensive individuals

Concerning the optimal aerobic exercise intensity for BP reduction, results of research conducted in the 1990s involving one bout of exercise and hypertensive populations has indicated that higher, compared with lower aerobic exercise intensity, had no greater post-exercise BP reduction.[13] However, prior research has typically used only moderate-intensity aerobic exercise. For example, Pescatello *et al.*[13] had six hypertensive men perform 30 min of stationary cycling exercise at either 40 or 70% of $\dot{V}O_{2max}$ on separate days. No intensity effect was found as both intensities produced an average systolic and diastolic BP reduction of 5 and 8 mm Hg, respectively, over a 24 h period. Quinn,[14] however, monitored ABP of hypertensive individuals after a bout of treadmill running at two differing intensities (50% versus 75% $\dot{V}O_{2max}$). In contrast to prior findings, results showed that the BP reduction following one bout of aerobic exercise was intensity dependent. It was found that higher-intensity exercise produced greater BP benefits whereby the hypertensive men and women averaged a 4 and 9 mm Hg decrease in systolic BP and a 5 and 7 mm Hg decrease in diastolic BP for the 50% and 75% exercise intensities, respectively.[14] The hypertensive men (Figure 1) and women maintained a significant reduction in systolic and diastolic BP for 13 h following the 75% exercise compared with 4 h after the 50% intensity. Thus, both 50 and 75% exercise intensities resulted in a significant reduction in BP of hypertensive men and women, however, the 75% intensity produced a larger and longer-lasting BP reduction (Figure 1). Thus, exercising at a slightly higher exercise intensity (75% of $\dot{V}O_{2max}$) produced greater BP reduction compared with previous studies using intensities between 40 and 70% of $\dot{V}O_{2max}$. Consequently, exercising at an exercise intensity of 75% of $\dot{V}O_{2max}$ and above also appears to produce an exercise hypotensive effect in hypertensive individuals. Other studies have confirmed this high-intensity effect. For example, Eicher *et al.*[15] exposed 45 males, possessing elevated ambulatory BP, to low- (40% $\dot{V}O_{2peak}$), moderate- (60% $\dot{V}O_{2peak}$) and high-intensity (100% $\dot{V}O_{2peak}$) stationary cycle exercise for 45 min. Systolic and diastolic ABP was significantly decreased after the high-intensity exercise, carried out to voluntary exhaustion, compared with the low- and moderate-intensity exercise bouts. Similar results were found by de Morais *et al.*[16] who examined the effects of high- (69% $\dot{V}O_{2peak}$) and maximal (100% $\dot{V}O_{2peak}$)-intensity cycle ergometer exercise on 24 h ABP response in 10 type 2 diabetic adults with prehypertension. Compared with a control group only the maximal-intensity exercise bout brought about ABP reduction that lasted for 8 h after exercise and during sleep. Lima *et al.*[17] had 11 type 2 diabetic patients perform one bout of cycle ergometer exercise for 20 min at either 63 or 74% $\dot{V}O_{2peak}$. Both exercise intensities resulted in reduced systolic BP, however, diastolic BP and mean arterial pressure were only reduced after higher-intensity exercise. Although more research needs to be done on the intensity issue these results indicate that compared with low-intensity exercise, exercising at an intensity at or above 74% $\dot{V}O_{2max}$ results in significant hypotension effects in hypertensive and pre-hypertensive individuals.

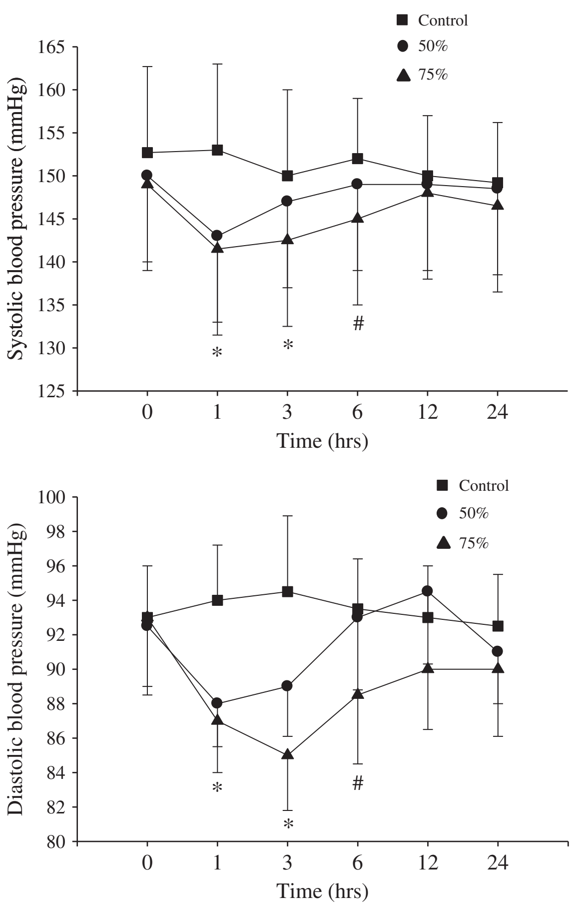

Figure 1. Twenty-four hour systolic and diastolic ABP response of hypertensive men following the exercise sessions as opposed to the control session. Values are means±s.d. *Both the 50 and 75% $\dot{V}O_{2max}$ exercise intensities are significantly lower than the control value at the same time point, $P < 0.05$. #The 75% $\dot{V}O_{2max}$ intensity is significantly lower than the control at the same time point, $P < 0.05$ (adapted from Quinn[14]).

The effect of one bout of HIIE and regular training on office BP and ABP

HIIE (one bout of high-intensity exercise) is typically performed at an exercise intensity of 75% of $\dot{V}O_{2max}$ and above. HIIE protocols have varied considerably but typically involve repeated brief sprinting (anaerobic exercise) or high-intensity aerobic exercise immediately followed by low-intensity exercise or rest. The length of both the exercise and recovery period has varied from 6 s to 4 min.[6] Typically, HIIE is performed on a stationary cycle ergometer or a treadmill at an intensity between 75 and 100% of $\dot{V}O_{2max}$. A small number of studies have studied hypertensive adults although a number of studies have examined adolescents, young men and women, older individuals and a number of patient groups. The most utilized protocol in past research has been the Wingate test, which consists of 30 s of all-out sprint with a hard resistance. Insight into skeletal muscle adaptations to HIIT (high-intensity exercise training) has mainly been achieved using this type of exercise, however, as this protocol is extremely hard participants have to be highly motivated to tolerate the resulting discomfiture. Other less-demanding HIIT protocols have also been utilized. For example, an 8 s cycle sprint followed by 12 s of low-intensity cycling for a period of 20 min has shown to bring about a number of body composition and metabolic changes.[18–20] The effect of high-sprint/low-resistance versions of HIIT on the BP of hypertensive individuals does not appear to have been carried out. The majority of HIIT protocols examining BP have typically involved a longer exercise bout (2–4 min) at 70–80% of $\dot{V}O_{2max}$ interspersed with rest period periods from 2 to 3 min.[6] The results of studies examining the effect of HIIE and HIIT on resting office BP and ABP of hypertensive individuals are summarized in Table 2.

Table 2. Results of studies examining the effect of one bout of HIIE and participation in regular HIIT on office BP and ABP of hypertensive individuals

Study	*Systolic BP (mm Hg)*	*Diastolic BP (mm Hg)*	*Other measures*	*Treated/ untreated*	*Design*	*Sample size*[a]	*Type of HIIE/ HIIT*	*Length of exercise bout/intervention*	*Exercise intensity (% $\dot{V}O_{2max/peak}$)*	*$\dot{V}O_{2max/peak}$ increase*
HIIE										
Office BP										
Tomszak *et al.*[21]	NR	NR	⇩MAP (8 mm Hg)	T	NC	9/0/0	4 × 4 min/ 3 min R, T	28 min	85%	—
da Cunha *et al.*[22]	⇩16	⇩8	NA	T	NC	11/0/0	15 × 1 min/ 2 min R, T	45 min	75%	—
ABP										
Ciolac *et al.*[23]	⇩2.8	⇔	NA	T	NC	26/26/0	1 min/2 min R, T	45 min	70%	—
HIIT										
Office BP										
Gunjal *et al.*[24]	⇩12	⇩8	⇩VR	U	NC	30/0/0	3 × 3–4 min/ 4 min R, T	12 weeks	75–80%	NA
Mohr *et al.*[25]	⇩6	⇔	NA	U	C	21/21/ 20	6–10 × 30 s/ 2 min R, S	15 weeks	All-out sprint	NA
Nemoto *et al.*[26]	⇩10	⇩5	NA	U	C	12/10/ 10	5 × 3 min/ 3 min R, T, W	20 weeks	70%	⇧9%
Parpa *et al.*[27]	⇩7	⇩4	⇧HRV	T	NC	14/0/0	6 × 2 min/ 2 min R, T	12 weeks	70–80%	NA
Tjonna *et al.*[28]	⇩9	⇩6	⇧EF, ⇩IR, ⇧MB	U	NC	42/51/0	4 × 4 min/ 3 min R, T	16 weeks	80%	⇧35%
Munk *et al.*[29]	⇔	⇩4	⇧EF, ⇩IN	T	C	20/20	4 × 4 min/ 3 min R, T/C	24 weeks	70–80%	⇧17%
Rognmo *et al.*[30]	⇔	⇔	⇩AS, ⇧EF, ⇩IR	U	NC	8/9/0	4 × 4 min/ 3 min R, T	10 weeks	80–90%	⇧18%
Warburton *et al.*[31]	⇔	⇔	NA	T	NC	7/7/0	7–8 × 2 min/ 2 min R, T, C	16 weeks	80–85%	⇧10%
Wisloff *et al.*[32]	⇔	⇔	⇧EF, ⇧MB	T	C	9/9/9	4 × 4 min/ 3 min R, T	12 weeks	85%	⇧46%
ABP										
Guimaraes *et al.*[33]	⇩2	⇩2	⇩AS	T	C	26/26/ 13	13 × 1 min/ 2 min R, T	16 weeks	80–90%	NA
Molmen-Hansen *et al.*[34]	⇩12	⇩8	⇧EF, ⇩VR	U	C	31/28/ 29	4 × 4 min/ 3 min R, T	12 weeks	85–90%	⇧15%

Abbreviations: ABP, ambulatory blood pressure; AS, arterial stiffness; BP, blood pressure; C, control group; C, stationary cycle; EF, endothelial function; HIIE, high-intensity intermittent exercise; HIIT, high-intensity intermittent training; IN, inflammation; IR, insulin resistance; MAP, mean arterial pressure; MB, mitochondrial biogenesis; NA, not assessed; NR, not reported; R, recovery; S, swimming; T, treadmill; T, treated with blood pressure medication; U, untreated; UC, no control group; VR, vascular resistance; W, walking. Note: ⇧ increased; ⇩ decreased; ⇔ no change. [a]Sample size is reported as follows: number of participants in a HIIE or HIIT group; a moderate continuous aerobic exercise group; and a non-exercise control group.

The effects of one bout of HIIE on office BP

Two studies have examined the effect of HIIE on the office BP of hypertensive individuals. Nine hypertensive patients were allocated to a HIIE group,[21] which consisted of a warm-up, followed by a 4 min bout of treadmill exercise at 95% of peak heart rate, followed by 3 min of low-intensity exercise. Participants performed four bouts of high-intensity exercise with four 3 min recovery periods. Following exercise, office mean arterial BP was significantly reduced by 8 mm Hg (Table 2). da Cunha *et al.*[22] also had 11 hypertensive patients perform one bout of HIIE that consisted of 1 min of running at 75% of heart rate reserve followed by 2 min of easier running at 56% of heart rate reserve for 45 min. Following exercise, office systolic and diastolic BP was significantly reduced (Table 2).

The effects of one bout of HIIE on ABP

Ciolac *et al.*[23] have compared the effect of one bout of HIIE and continuous aerobic exercise on the ABP of hypertensive individuals. In this study, 52 hypertensive patients were randomized to either an HIIE or moderate intensity, continuous, aerobic exercise group. HIIE consisted of a warm-up, followed by 1 min of treadmill exercise at 80% of heart rate reserve, followed by 2 min of less-intense exercise at 50% of heart rate reserve for a total time of 45 min. Continuous exercise involved walking or running on a treadmill at 60% of heart rate reserve for 47 min. Following both bouts of exercise, 24 h systolic ABP was reduced by 2.8 mm Hg in the HIIE group and by 2.6 mm Hg in the continuous group (Table 2). A nonsignificant trend for a reduction in diastolic ABP was found for the HIIE group. Thus, HIIE and continuous aerobic exercise resulted in a moderate reduction in 24 h systolic ABP in treated hypertensive individuals.

The effects of HIIT on office BP

Examining office BP, Gunjal *et al.*[24] studied the effects of 12 weeks of HIIT performed on a treadmill on the office BP of 30 hypertensive patients (Table 2). HIIT involved 3–4 min intervals performed at 80–85% of maximal heart rate, interspaced by 4 min active recovery, at 60–70% of maximal heart rate. After 12 weeks, systolic BP decreased by 12 and 8 mm Hg for the HIIT group (Table 2) and vascular resistance was also significantly reduced. No control group was included in the study design. The effects of 15 weeks of either HIIT swimming or moderate continuous swimming on the office BP of 21 moderately hypertensive, premenopausal women has also been examined.[25] HIIT involved

6–10, 30 s all-out swimming sprints, interspaced by 2 min easy swimming recovery, whereas continuous swimming involved an hour of exercise at a moderate intensity. After 15 weeks, systolic BP decreased by 6 and 4 mm Hg for the HIIT and continuous swimming groups (Table 2). No effect on diastolic BP was found. Systolic BP reduction was similar for both groups, however, HIIT involved significantly less time and swimming distance. Nemoto *et al.*[26] had 12 middle-aged and older men and women perform 5 months of high-intensity walking that consisted of five or more sets of 3 min low-intensity at 40% of $\dot{V}O_{2peak}$ followed by a 3 min high-intensity bout of walking above 70% of $\dot{V}O_{2peak}$, repeated four times per week, for 5 months. Another two groups acted as a control and a low-intensity walking group. High-intensity, compared with low-intensity walking, resulted in a significant drop in office systolic BP and a 9% increase in aerobic fitness (Table 2).

Parpa *et al.*[27] exposed one group of 14 type 2 diabetic individuals to 12 weeks of 30 min of HIIT, for four times per week. High-intensity treadmill running consisted of six, 2 min bouts of exercise performed at 80–90% of maximal heart rate, separated by six 2 min easy bouts of exercise performed at 50–60% maximal heart rate. High-intensity treadmill exercise training resulted in a significant drop in office systolic and diastolic BP and a 9% increase in heart rate variability (Table 2). Tjonna *et al.*[28] also examined office BP (Table 2) by randomizing 32 metabolic syndrome patients to either moderate continuous exercise or aerobic interval training, three times per week, for 16 weeks. High-intensity treadmill running consisted of four, 4 min bouts of exercise performed at 80–90% of maximal heart rate, separated by four 3 min easy bouts of exercise performed at 50–60% maximal heart rate intensity. The two exercise programmes were equally as effective at lowering office systolic and diastolic BP but HIIT, compared with continuous exercise, resulted in a greater increase in aerobic fitness and also significantly enhanced endothelial function, insulin signalling and skeletal muscle mitochondrial biogenesis.

As shown in Table 2 not all HIIT studies have produced a significant BP-lowering effect.[29–32] The majority of these studies used hypertensive individuals on BP medication, which normalized their resting BP,[29,31,32] which may explain their lack of exercise-induced hypotension. Despite not lowering their office BP response to 10–24 weeks of HIIT, however, all HIIT groups increased aerobic fitness, with some groups recording improved endothelial function,[29,32] attenuated inflammation[29] and enhanced mitochondrial biogenesis[32] (Table 2).

The effects of HIIT on ABP

With regard to ABP, Guimaraes *et al.*[33] randomized 65 hypertensive patients to either an HIIT, a moderate-intensity continuous aerobic exercise, or a control group (Table 2). HIIT was performed for 40 min on a treadmill with the intensity alternating between 50% (2 min) and 80% (1 min) of heart rate reserve. This protocol was repeated three times per week for 16 weeks. Continuous exercise training involved running on a treadmill at 60% of heart rate reserve for 40 min, three times per week, for 16 weeks. Following 16 weeks of exercise training ABP was significantly reduced only in participants possessing higher resting BP values independent of exercise training modality. Arterial stiffness, however, was reduced in the HIIT group only. Authors concluded that HIIT and continuous exercise training were both beneficial for BP control in treated hypertensives but only HIIT reduced arterial stiffness. Molmen-Hansen *et al.*[34] also examined the effect of HIIT on the ABP of hypertensive adults by randomizing 88 hypertensive patients to either an HIIT or moderate intensity continuous aerobic exercise training group (Table 2). HIIT consisted of a warm-up followed by 4 min of treadmill exercise at 90–95% of maximal heart rate with 3 min of active pause between exercise bouts for a total time of 38 min. Continuous training involved walking or running on a treadmill at 70% of maximal heart rate for 47 min. Impressively, after 12 weeks of exercise, office systolic ABP was reduced by 12 mm Hg in the HIIT group and by 4.5 mm Hg in the continuous group. Twenty-four hour ABP was reduced by 8 mm Hg in the HIIT group and by 3.5 mm Hg in the continuous exercise group (Figure 2). Reduced vascular resistance and enhanced flow-mediated dilation were found only in the HIIT group. Authors concluded that the BP-reducing effect of exercise in essential hypertension is intensity dependent and that HIIT is an effective method to lower BP, increase aerobic fitness and decrease vascular resistance. The much greater lowering of ABP after HIIT found in the Molmen-Hansen *et al.*[34] compared with the Guimaraes *et al.*[33] study is likely explained by the BP medication status of their hypertensive patients. In the study by Guimaraes *et al.*[33], patients' BP was normalized using BP medication so their average daily systolic and diastolic BP was 125 and 80 mm Hg. In contrast, the patients in the study by Molmen-Hansen *et al.*[34] were free of BP medication resulting in a daily systolic and diastolic BP of 153 and 93 mm Hg. As more significant reductions in BP have been observed following exercise training in patients with high initial resting BP it is likely that medicating hypertensive patients will deflate the exercise-induced BP response. Also the finding that HIIT only reduced evening ABP is the opposite to that found by Cornelissen *et al.*[3] who examined the effect of regular aerobic exercise on 24 ABP and concluded that daytime but not night-time ambulatory BP of normotensive adults was reduced. Some studies, however, similar to the results of Molmen-Hansen *et al.*[34], have found that higher intensity continuous aerobic exercise resulted in significantly greater night-time compared with

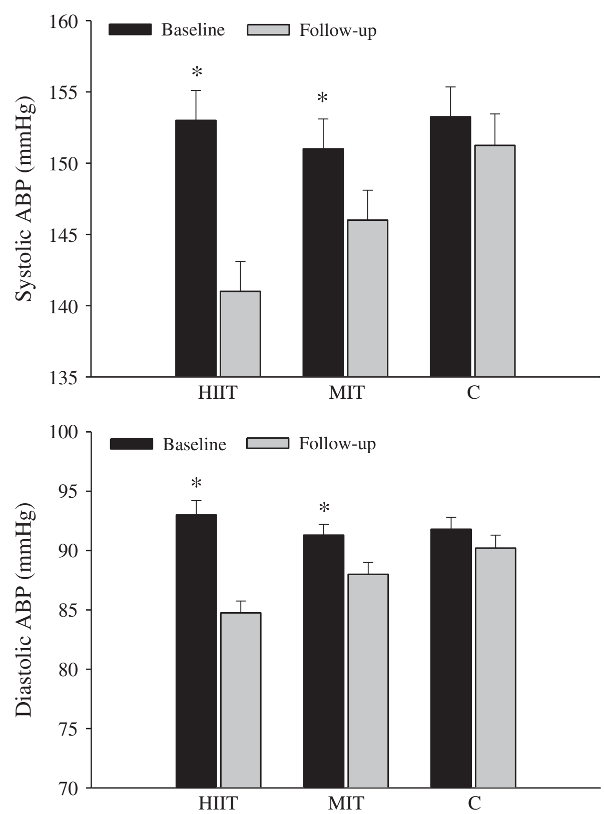

Figure 2. ABP during 24 h displayed as mean value at baseline and follow-up in the three training groups: aerobic interval group (HIIT); moderate-intensity group (MIT); and control group (C). Values are means±s.d. $^*P < 0.05$ between HIIT and MIT in blood pressure reduction (adapted from Molmen-Hansen *et al.*[34]).

daytime ambulatory BP in hypertensive[16] and normotensive individuals.[35] Therefore, more research examining the effect of exercise intensity and daytime and night-time ambulatory BP response of hypertensive and normotensive individuals needs to performed.

SUMMARY

Two uncontrolled studies have shown that HIIE (one bout of exercise) has a moderately large lowering effect on office BP of hypertensive individuals. One other uncontrolled study used ABP but found a small BP-lowering effect. The lack of a control group in all three studies makes results difficult to interpret so future studies, preferably using ABP assessment, containing a control group, need to be carried out. More studies have examined the effect of HIIT (regular bouts of exercise) on office BP and results have generally indicated a moderate lowering effect on office BP. Again the majority of studies did not use a control group making results difficult to interpret. Two stronger designed studies examined ABP of hypertensive individuals after HIIT and showed a small and a large ABP-lowering effect. The effect of HIIT on both office BP and ABP, however, appears to be medication dependent with untreated hypertensive individuals displaying greater decreases compared with their treated counterparts. Thus, when medication is taken into account the office BP reduction after HIIT is similar to that occurring after regular aerobic exercise. More well-controlled studies need to be carried out to confirm this preliminary finding. Compared with continuous moderate intensity aerobic exercise, however, HIIT typically results in greater increases in aerobic fitness in a shorter period of time and has been shown to have a greater impact on arterial stiffness, endothelial function, insulin resistance and mitochondrial biogenesis. Because of the minimal number of studies in this area more research needs to be carried out to confirm and extend these results.

POSSIBLE FACTORS INFLUENCING THE HIGH-INTENSITY EXERCISE HYPOTENSION EFFECT

How HIIE and HIIT brings about hypotensive effects is undetermined. Factors are likely to be multifactorial and for HIIE could be a result of reduced cardiac output, heart rate and vascular resistance.[36] For HIIT, influences could also involve a change in variables such as increased aerobic fitness[37] and decreased insulin resistance[18] and visceral fat.[19] The major direct variable underlying the exercise-induced chronic hypotensive effect appears to be decreased vascular resistance.[38] Decreases in arterial stiffness and sympathetic nerve discharge and increases in arterial baroreceptor sensitivity are also likely contributors to this decreased vascular resistance effect.[39]

ISSUES REGARDING THE HIIE- AND HIIT-INDUCED HYPOTENSION EFFECT

Large multicentre prospective studies using ABP are needed to further confirm the HIIE and HIIT hypotensive effect. Also more research examining the underlying factors influencing the hypotensive effect is required. Whether the hypotensive effect, reported in training studies, is a true result of HIIT or is a transient effect of a previous exercise bout must also be considered. The optimum duration, frequency, intensity and modality of HIIE and HIIT for different hypertensive patient groups (for example, stage 1 and stage 2) need to be established. In particular, the effectiveness of exercising quickly (for example, sprinting with a low resistance) as opposed to exercising at a high intensity (for example, cycling less quickly but with a high resistance) needs to be determined. To determine if participants were sprinting or not it is important for future research to report details regarding their HIIE and HIIT regimens. Thus, when exercising on a treadmill, speed, gradient, heart rate and rating of perceived exertion should be reported. When exercising on a stationary cycle ergometer, pedal rate (revolutions per minute), resistance (kg), watts, heart rate and rating of perceived exertion should be included. Also the possible differing effects of HIIE and HIIT on the BP of medicated and non-medicated hypertensive individuals needs to be clarified. More studies examining female hypertensive individuals are also required. Finally, studies showing that HIIE- and HIIT-induced BP reduction results in reduced cardiovascular events associated with hypertension[4] should be completed. This review was limited to hypertensive individuals and the effects of exercise on clinical BP is likely to be different in normotensive and pre-hypertensive individuals as cardiovascular haemodynamics are altered in the hypertensive state.

CONCLUSIONS

Emerging evidence indicates that exercise performed at an intensity $>70\%$ of $\dot{V}O_{2max}$ may have an important role in the control of hypertension. Both HIIT and regular aerobic exercise have been shown to reduce the BP of hypertensive individuals, however, HIIT has been shown to bring about greater adaptations in physiopathological variables that contribute to the development of hypertension. These effects, together with the reduced time commitment of HIIT, have important implications for the treatment of hypertension.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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