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Review

The effect of high Intensity interval training versus moderate intensity continuous training on arterial stiffness and 24 h blood pressure responses: A systematic review and meta-analysis

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ABSTRACT

Objectives: Greater arterial stiffness and poor 24 h blood pressure (BP) are recognized as indicators of poor cardiovascular health. Evidence has shown that high intensity interval training (HIIT) may be a superior alternative to moderate intensity continuous training (MICT) for improving cardiovascular disease risk factors such as cardiorespiratory fitness and vascular function. However, there are limited data comparing the effect of HIIT to MICT on central arterial stiffness and/or 24 h BP response. The purpose of this study was to compare HIIT versus MICT on central arterial stiffness and 24 h BP outcomes by systematic review and meta-analysis.
Design: A systematic review and meta-analysis was conducted.
Methods: Eligible studies were exercise training interventions ($\geq$4 weeks) that included both HIIT and MICT and reported central arterial stiffness, as measured by pulse wave velocity and augmentation index and/or 24 h BP outcome measures.
Results: HIIT was found to be superior to MICT for reducing night-time diastolic BP (ES: −0.456, 95% CI: −0.826 to −0.086 mmHg; P = 0.016). A near-significant greater reduction in daytime systolic (ES: −0.349, 95% CI: −0.740 to 0.041 mmHg; p = 0.079) and diastolic BP was observed with HIIT compared to MICT (ES: −0.349, 95% CI: −0.717 to 0.020 mmHg; p = 0.063). No significant difference was found for other BP responses or arterial stiffness outcomes.
Conclusions: HIIT leads to a superior reduction in night-time diastolic BP compared to MICT. Furthermore, a near-significant greater reduction in daytime BP was found with HIIT compared to MICT. No significant difference was observed for changes to central arterial stiffness between HIIT and MICT.

1. Introduction

It has been well established that hypertension and greater central (aortic) arterial stiffness are precursors of developing cardiovascular disease (CVD) and indicators of deteriorating cardiovascular health in healthy individuals and those at high risk of CVD, such as people with diabetes and end stage renal disease.[1–3] Additionally, greater arterial stiffness and poor 24 h blood pressure outcomes are strongly associated with an increased risk of cardiovascular events and mortality.[2,3] Prospective studies have demonstrated that higher central arterial stiffness has been significantly associated with greater systolic blood pressure and pulse pressure in healthy, normotensive men and women.[4] This evidence suggests that greater central arterial stiffness may be a part of the underlying pathology that leads to the development of hypertension. In addition, strong associations and higher incidence of greater central arterial stiffness and increased blood pressure has been found in people with a high-risk of CVD including individuals with type 2 diabetes,[5] hypertension[6] and diagnosed cardiovascular conditions such coronary artery disease.[7] Therefore, preventative strategies for hypertension should consider therapeutic approaches to reduce central arterial stiffness for those at risk of developing CVD and with diagnosed cardiovascular conditions.

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Central arterial stiffness can be measured non-invasively through a range of techniques including applanation tonometry (pressure sensors), brachial-cuff plethysmography, mechanotransducers, Doppler ultrasound and echotracking devices.[8] These techniques allow for the indirect calculation of quantifiable measures of regional and systemic arterial stiffness.[9] Heighten central (aortic) arterial stiffness is indicated by elevated pulse wave velocity (PWV) and augmentation index (AIx) outcomes.[9]

It is now well accepted that 24 h blood pressure monitoring is a superior method for the assessment of blood pressure, compared to resting clinic measures. This technique has been found to be more reliable for detecting treatment effects and diagnosing hypertension when compared to clinic measurements, as it accounts for the day-to-day fluctuations in blood pressure.[10] Additional parameters that can be collected through 24 h blood pressure monitoring, including mean 24 h, daytime and night-time blood pressure have been found to be strongly linked to carotid atherosclerosis and left ventricular hypertrophy.[11,12] Furthermore, prospective studies have shown that 24 h blood pressure outcomes have been superior in predicting cardiovascular disease risk compared to clinical measures.[13] As the global burden of cardiovascular disease (CVD) remains high, the management of CVD risk factors like arterial stiffness and hypertension are pertinent in preventing the development of CVD.[14]

Exercise is an integral component of the primary and secondary management of hypertension and CVD. Current guidelines recommend that adults with an increased risk of CVD should undertake regular aerobic-type exercise at moderate and/or vigorous intensity.[15] There is strong evidence demonstrating that aerobic exercise can benefit an array of CVD risk factors such as low cardiorespiratory fitness,[16] insulin resistance[17] and excess visceral[18] and ectopic adiposity.[19] High intensity interval training (HIIT) has attracted increased attention as a possible time-effective alternative to traditional aerobic exercise. HIIT consists of repeated high-intensity bursts of exercise, interspersed with low intensity recovery activity, and is thought to stimulate larger cardiometabolic changes during and after exercise.[20,21] In contrast, moderate intensity continuous training (MICT) is considered "traditional" aerobic exercise and is performed as a continuous bout of moderate intensity aerobic activity at a steady state for a set duration (typically between 20–60 min).[22] Recent reviews and meta-analyses have indicated that HIIT can be effective and superior strategy to improve CVD risk factors such as poor cardiorespiratory fitness, vascular dysfunction, glycaemic control and insulin resistance.[20,23] However, the efficacy of HIIT on arterial stiffness and 24 h blood pressure outcomes is less clear. Two meta-analyses found significant reductions in arterial stiffness (PWV and AIx) following aerobic exercise across a variety of adult population groups.[24,25] The majority of studies incorporated in these reviews used moderate intensity continuous training (MICT) based protocols, however there was a significant inverse relationship for both PWV and AIx with exercise intensity, suggesting that higher exercise intensities may provide a greater benefit to arterial stiffness.[24,25] Whilst these results suggest that HIIT can be used to improve central arterial stiffness, a direct comparison between the relative efficacy of moderate and high intensity exercise was not performed. Similarly, a meta-analysis conducted by Cornelissen and colleagues has demonstrated that aerobic exercise improves daytime but not nighttime systolic and diastolic blood pressure in healthy, pre-hypertensive and hypertensive adults,[26] with a significant association between larger reductions in daytime blood pressure and increases in cardiorespiratory fitness. In contrast, a more recent meta-analysis by Sosner et al., which involved a larger number of studies, found that regular aerobic exercise significantly reduced 24 h, daytime and night-time systolic and diastolic blood pressure.[27] It should be noted that both of these analyses had pooled data from trials that predominately implemented MICT interventions on these outcomes.[26,27] As HIIT has been demonstrated to be a superior intervention to MICT for improving some cardiovascular outcomes, including cardiorespiratory fitness, it may provide greater benefits for these outcomes than MICT.

To our knowledge, there is limited data comparing the effect of HIIT to MICT on arterial stiffness and/or 24 h blood pressure outcomes, and no systematic examination and meta-analysis of the pooled evidence has been undertaken. Therefore, the purpose of this systematic review was to compare the effect of HIIT versus MICT on arterial stiffness and 24 h blood pressure outcomes using the collective data from all available research trials.

2. Methods

Electronic database searches were performed in AMED, MEDLINE, SPORTDiscus, CINAHL, EMBASE and Web of Science Core Collections from earliest record to September 2018. The search strategy combined terms covering the areas of high-intensity interval training (HIIT), moderate-intensity continuous training (MICT), 24 h blood pressure monitoring and arterial stiffness. HIIT and MICT terms were combined using "and" in-conjunction with 24 h blood pressure monitoring terms and/or arterial stiffness terms. Studies were not excluded based on experimental design and reference lists of all retrieved papers were manually searched for potentially eligible papers. No studies were excluded based on language.

Studies were included if they implemented: i) a chronic exercise training intervention ($\geq$4 weeks) and included both HIIT and MICT intervention groups; ii) adult participants (18 years or older) of any health status; iii) report measurements that assessed central measures of arterial stiffness and/or 24 h blood pressure monitoring. All exercise interventions had to be performed using an aerobic-type exercise modality (walking, running, cycling etc), which involved repetitive, rhythmic movements. Pre and post-intervention data or the change score of these outcome measures had to be reported to be included in this review.

High intensity interval training was considered as repeated short bouts of high intensity aerobic exercise, interspersed with either passive or low-moderate intensity active recovery periods. Studies that reported high-intensity bouts at a vigorous or near maximal intensity (64–100% VO_{2max}/HR_{max} or >60% HRR/VO_2 reserve, >6 METs, >14 Borg rating of perceived exertion (RPE)) in accordance to the ACSM guidelines[28] were included or sprint training where efforts were performed above >100% VO_{2max} or as an "all-out" effort, were included in this review.

Moderate intensity continuous training (MICT) was considered as a training protocol where exercise is performed in a continuous manner to achieve a steady state for a set duration (typically 20–60 mins). Studies that reported continuous exercise at a moderate intensity (46-< 64% VO_{2max}/HR_{max} or 40%–60% HRR/VO_2 reserve, or 3–6 metabolic equivalents or 12–13 RPE) as per ASCM guidelines[28] were defined as MICT and included in this review.

After eliminating duplications the search results were screened by one investigator (KW) against the eligibility criteria, and those references that could not be eliminated by title or abstract were retrieved and independently reviewed by one reviewer (KW) in an unblinded manner. Disagreements were resolved by discussion or by a second and third researcher (MB, NJ). In cases where journal articles contained insufficient information, attempts were made to contact authors to obtain missing details (KW).

Data relating to participant characteristics (age, sex, body mass index), exercise intervention (mode of exercise, exercise frequency, intensity, duration and intervention duration) and measures of arterial stiffness and 24 h blood pressure monitoring were extracted independently by two researchers (KW, RS), with disagreements resolved by discussion or by two researchers (MB, NJ). Two researchers (KW, AS) assessed the methodological quality of the included studies (in a blinded manner) using a modified Downs and Black[29] checklist recommended by the Cochrane Handbook for Systematic Reviews of Interventions.[30] One extra criterion was added to the checklist, to assess exercise supervision (Supplementary Table 1). Disagreements resolved by discussion or by two researchers (MB, NJ).

The within-trial standardised mean difference, or effect size (ES) and 95% confidence intervals (CIs) were calculated. The ES was determined by calculating the difference in the mean outcome between groups and dividing by the standard deviation of the outcome among the subjects. ES values of 0.2, 0.5 and 0.8 were considered low, moderate and large ES, respectively. Between-study variability was examined using the I^2 measure of inconsistency. Values of <25%, 50% and 75% were considered to indicate low, moderate and high heterogeneity, respectively. Publication bias was assessed using Egger's test and visual inspection of funnel plots.

Pooled estimates of the effects of HIIT and MICT on central (aortic) arterial stiffness (augmentation index, augmentation index at a heart rate of 75, pulse wave velocity) and 24 h blood pressure outcomes (mean 24 h, daytime and nighttime scores), using ES, were obtained using a random-effects model. All analyses were conducted using Comprehensive Meta-analysis, version 2 (Biostat Inc, Englewood, NJ).

3. Results

The original search yielded 601 studies. No additional studies were found from the reference lists of the manuscripts retrieved. After removal of duplicates and elimination of papers based on the eligibility criteria, 16 studies remained (Supplementary Fig. 1).

Participant characteristics for included studies are shown in Supplementary Table 2. The majority of studies were conducted in previously inactive healthy males. When combined, 491 individuals (257 male; 187 female; 27 not reported) participated in the trials. One study exclusively recruited female participants,[31] and four exclusively recruited male participants,[32–35] ten studies recruited both males and females[36–45] and sex was not reported in one study.[46] The reported mean age of participants ranged from 21 to 68 years. Based on body mass index (BMI) classification,[47] six studies had participants who were classified on average as overweight,[34,37–39,42,46] six as normal weight,[31,33,35,40,43,44] and three as obese class I[32,36,41] and BMI was not reported in one study.[45]

Exercise intervention characteristics for studies assessing arterial stiffness and 24 h blood pressure outcomes are displayed in Supplementary Tables 3 and 4, respectively. Of the 16 studies, exercise training interventions lasted 4–16 weeks, with exercise sessions performed one to five times per week.[31–46] Cycling was the most common mode of exercise and was prescribed in nine studies,[32–35,37,40–42,44] followed by treadmill exercise.[31,38,39,43,45] One study implemented boxing as a mode for HIIT.[36] Boxing has been found to have a large aerobic metabolic component and places a high cardiovascular demand on the body, despite the static component of the exercise.[48] The interval nature of boxing implements continuous, repetitive upper-body or lower-body movement during the exercise phase, with passive recoveries between intervals.[48] Therefore, we deemed this as an appropriate to categorize this modality as "HIIT" for inclusion in the meta-analysis. For the MICT studies intensity was prescribed at 45–75% of $VO_{2max/peak}$, $HR_{max/peak}$ or heart rate reserve for the entire stimulus phase of the session. The majority (9 of 16) of the HIIT studies[31,36–39,41,43,45,46] used high intensity bouts lasting 1 to 4 min and interspersed with 1 to 4 min of active recovery. Exercise prescription for the intensity of the high intensity bouts ranged from 75–95% of $HR_{max/peak}$ repeated 4–15 times with active recoveries prescribed between 45–70% of $HR_{max/peak}$ or HRR. One study did not define the intensity of the active recovery during their supervised sessions.[36] Seven studies conducted HIIT interventions as "sprint interval training"[32,33,35,40,42,44] with sprint efforts lasting between 20–60 s prescribed between either 80–200% of W_{max}, $HR_{max,}$ VO_{2max} or as an "all-out" effort. Sprints were repeated 3–6 times and interspersed with 10–270 s active or passive recoveries between each effort. The intensity of the recovery periods were prescribed between 30–50 Watts[32–34,40] and two studies did not report the intensity for recovery.[35,42] Overall, the duration of HIIT sessions ranged from 2.5–40 min excluding warm-up and cool-down. The duration of MICT interventions ranged from 30–60 min, excluding warm-up and cool-down.

The assessment of methodological quality via the Downs and Black checklist found all included studies specified their hypotheses, main outcomes, interventions, main findings, variability estimates, representative participants, no presence of data dredging, statistical tests, p values and accuracy of measures (Supplementary Table 1). Due to the nature of exercise trials, participants were not blinded to the intervention groups. The majority of studies provided supervision for the intervention groups[31–33,35,36,39–46] and reported compliance to exercise training.[31,34–36,38,41–46] Five studies did not report adverse events during the intervention[35–38,46] and one study did not perform randomisation for participant intervention allocation.[34] The total score for methodological quality ranged from 17 to 23, out of a possible 27 points, indicating generally moderate study quality for the majority of included trials.

Supplementary Tables 5 and 6 show the outcome measures for arterial stiffness and 24 h blood pressure for all included studies. One study reported arterial compliance[46] and two studies reported arterial distensibility[34,40] and were excluded from the meta-analyses due to insufficient data. In these studies, Kim and colleagues[46] found that MICT was superior to HIIT for improving carotid arterial compliance (HIIT: pre: 0.11 ± 0.04, post: $0.12 \pm 0.04\,mm^2/mmHg$ vs MICT: pre: 0.11 ± 0.04, post: $0.14 \pm 0.07\,mm^2/mmHg$, $p = 0.04$). However, in studies investigating the effect of these interventions on arterial distensibility, there was no significant difference between HIIT versus MICT.[34,37,40,41]

Meta-analyses were conducted for central arterial stiffness and 24 h blood pressure responses with a total of 15 eligible studies involving 439 adult participants across all analyses. One study reported both arterial stiffness and 24 h blood pressure outcomes and was included in both analyses.[31] Thirteen studies reported arterial stiffness outcomes and were eligible for meta-analysis involving 405 individuals. Of the 12 studies, five reported augmentation index (AIx),[37,41,43–45] seven studies investigated augmentation index at a heart rate of 75 (AIx@75)[32,33,36,41–44], and ten studies examined pulse wave velocity (PWV).[31–35,41,43–46] One study implemented both a 4×4 HIIT and a low-volume 1×4 HIIT intervention.[41] To reduce heterogeneity, the 4×4 HIIT intervention was used for analysis. Data were pooled separately to compare the effect of HIIT versus MICT on central arterial stiffness measured via: i) AIx; ii) AIx@75; and ii) PWV (Fig. 1). Based on the reported information from the eligible trials, when examining the efficacy of either HIIT or MICT interventions independently (pre- versus post-training), two studies reported no significant changes in AIx following either HIIT or MICT,[37,41] and three studies did not report if HIIT or MICT led to significant independent changes.[43–45] Of the seven studies examining AIx@75, three studies reported a significant decrease in AIx@75 following HIIT,[32,33,36] two studies found a significant reduction as a result of MICT,[32,33] and two studies did not report the statistical significance of the independent intervention changes.[43,44] Of the ten studies that reported PWV, four studies

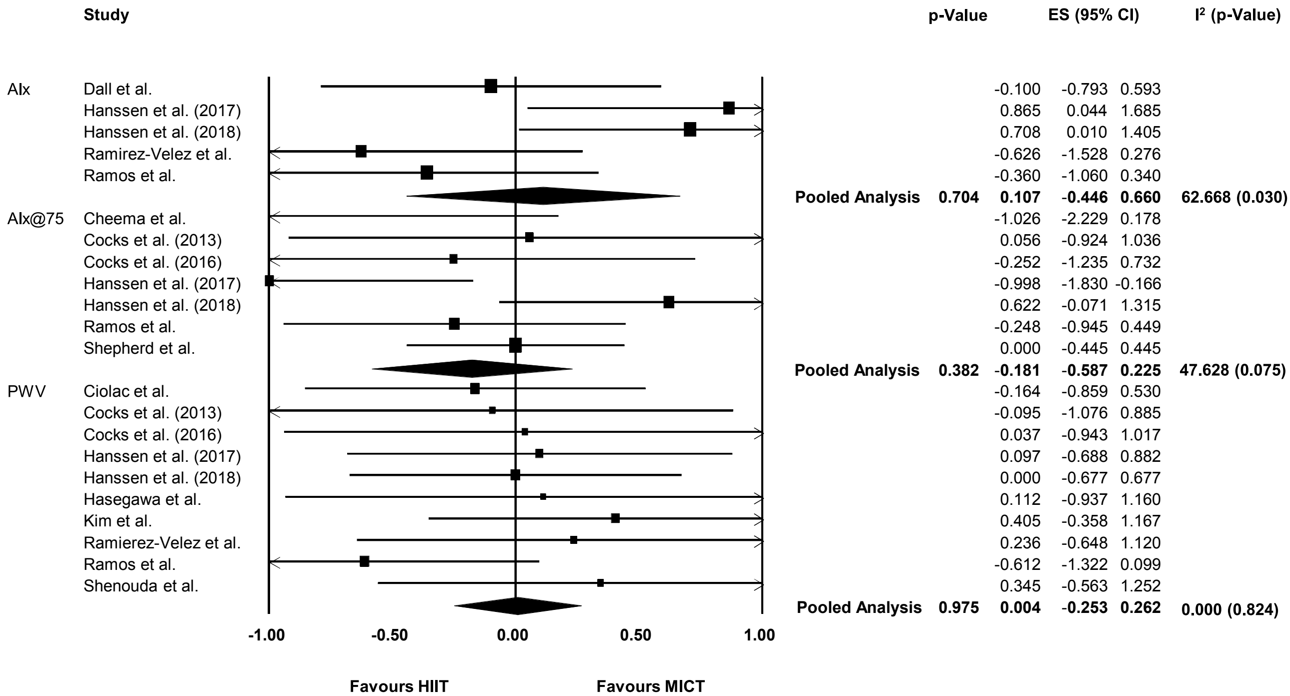

Fig. 1. The comparison of HIIT versus MICT on central arterial stiffness.
AIx = augmentation index; AIx@75 = augmentation index at a heart rate of 75; PWV = pulse wave velocity.

reported a significant improvement in PWV after HIIT,[31–33,35] four studies found a significant decrease after MICT,[32,33,35,46] and three studies did not report the statistical significance of the independent intervention changes.[43–45] It should be noted that one study assessing PWV did not perform randomization for group allocation.[34] This may lead to selection bias and confound the results observed in this study.[34] Upon visual inspection, there was no significant publication bias, and therefore the study was included in the pooled analysis. Three studies[31,38,39] involving 116 adult participants were eligible for meta-analysis to assess the efficacy of HIIT compared to MICT on 24 h blood pressure outcomes involving either: i) 24 h systolic blood pressure (SBP); ii) 24 h diastolic blood pressure (DBP); iii) daytime SBP; iv) daytime DBP; v) night-time SBP; and vi) night-time DBP. When observing the efficacy of either the HIIT or MICT interventions, all three studies observed a significant reduction in 24 h DBP after both types of training. Two studies found both HIIT and MICT were effective strategies for improving 24 h SBP[31,39] and daytime DBP.[38,39] For daytime SBP, only one study observed that both modalities were effective in significantly reducing this outcome.[39] For night-time blood pressure, all studies showed that HIIT produced a significant decrease for both SBP and DBP. There was only one study that found MICT to be an efficacious therapy for improving night-time SBP[31] and two studies found a significant reduction in DBP following MICT.[31,38] All eligible studies had sufficient data for calculation of ES and 95% CIs for the purpose of meta-analysis. There were an insufficient number of studies to perform meta-regressions to assess the effect of exercise characteristic moderators, covariates and the impact of the quality of studies on the mean effect for all outcome measures.[49]

Five studies had examined the effect of HIIT versus MICT on AIx. Three of the studies found a non-significant decrease in AIx in favour of HIIT[37,41,45] and two studies showed a significant reduction in favour of MICT.[43,44] Overall, there was no significant difference between HIIT and MICT and changes to AIx (ES: 0.107, 95% CI: −0.446 to 0.660%, p = 0.704). Of the seven studies investigating the effect on AIx@75, one study found a significant effect[43] and three showed a non-significant[32,36,41] reduction in favour of HIIT over MICT on AIx@75 (Fig. 1a), while two studies found a non-significant effect[33,44] favouring MICT therapy. One study observed similar effects of HIIT and MICT on AIx@75.[42] Overall, the pooled analysis demonstrated no significant difference between HIIT and MICT on AIx@75 (ES: −0.181, 95% CI: −0.587 to 0.225%, p = 0.382). Ten studies had investigated PWV. Three studies showed a non-significant[31,33,41] change in favour of HIIT on PWV, while seven studies showed a non-significant effect in favour of MICT.[32,34,35,43–46] Overall there was no significant difference between HIIT versus MICT on PWV (ES = 0.004, 95% CI: −0.253 to 0.262m/s; p = 0.975).

For interventions investigating 24 h systolic blood pressure (Fig. 2a), the majority of studies found a significant[39] or non-significant[38] decrease in favour of HIIT therapy, with one study finding a non-significant benefit favouring MICT over HIIT on SBP.[31] No significant difference was found between HIIT and MICT on 24 h SBP (ES: −0.261, 95% CI: −0.662 to 0.469 mmHg; p = 0.200). All studies investigating 24 h DBP found a non-significant effect favouring HIIT over MICT.[31,38,39] However, overall there was no significant pooled difference between HIIT versus MICT on 24 h DBP (ES = −0.072, 95% CI: −0.436 to 0.292 mmHg; p = 0.698). All studies showed a significant[39] or non-significant benefit[31,38] in favour of HIIT over MICT on daytime SBP and DBP (Fig. 2c and d). The overall pooled analysis showed a near-significant difference for changes in daytime SBP (ES: −0.349, 95% CI: −0.740 to 0.041 mmHg; p = 0.079) and DBP (ES: −0.349, 95% CI: −0.717 to 0.020 mmHg; p = 0.063) showing a near-significant greater reduction from HIIT therapy compared to MICT. For both night-time SBP and DBP (Fig. 2e and f), all studies showed a significant[38,39] or non-significant[31,38,39] change favouring HIIT therapy over MICT for both of these outcomes. On the basis of the pooled effect, there was a non-significant difference on night-time SBP (ES: −0.332, 95% CI: −0.725 to 0.061 mmHg, p = 0.098) however, HIIT was found to be superior to MICT for improvements in DBP (ES: −0.456, 95% CI: −0.826 to −0.086 mmHg; p = 0.016).

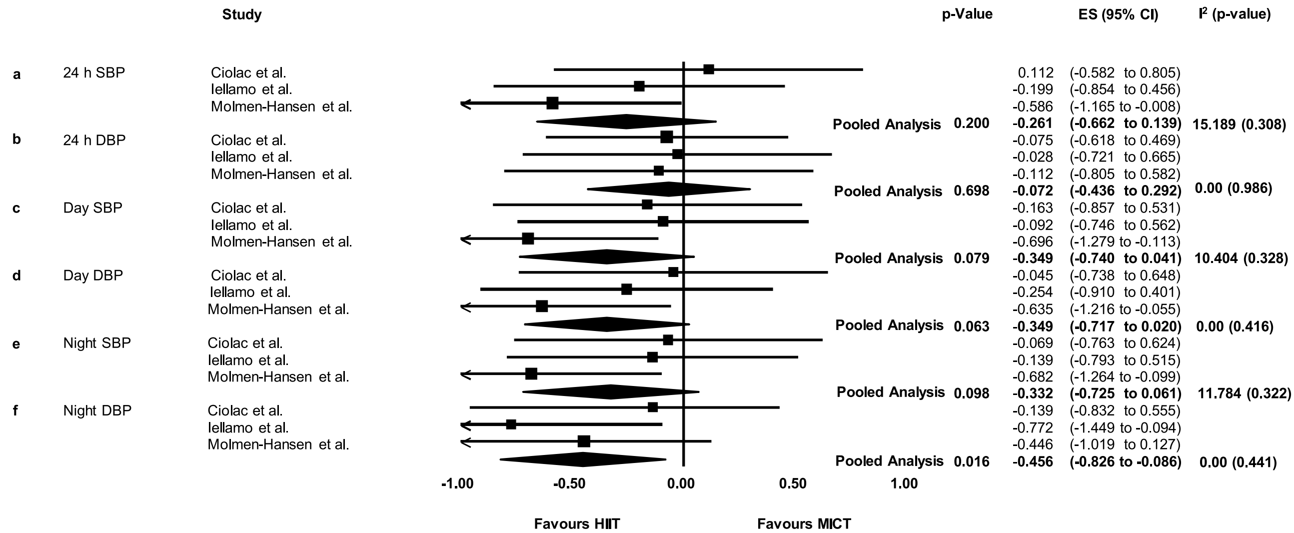

Fig. 2. The comparison of HIIT versus MICT on 24 h blood pressure responses.
SBP = systolic blood pressure; DBP = diastolic blood pressure; Day = daytime; Night = night-time; HIIT = high-intensity interval training; MICT = moderate intensity continuous training.

4. Discussion

This is the first systematic review with meta-analyses to compare the effect of HIIT versus MICT on central arterial stiffness and 24 h blood pressure outcomes in adults. The results from the meta-analyses of 15 pooled studies found no significant difference between HIIT and MICT for changes to arterial stiffness (AIx, AIx@75 and PWV), however, from the limited number of studies (n = 3) which directly compared 24 h blood pressure outcomes, HIIT was superior to MICT for improving night-time DBP and near-significant reductions in daytime SBP and DBP in favour of HIIT.

Previous reviews[24,25] investigating the effect of regular aerobic exercise on central arterial stiffness in adults have concluded that aerobic exercise significantly reduces both PWV[24,25] and AIx.[24] Interestingly, both studies found an inverse relationship between exercise intensity and reductions in arterial stiffness, which may suggest that HIIT could be a more effective modality than MICT. Specifically Ashor and colleagues[24] found that higher absolute intensity was related to a greater decrease in AIx and Huang [25] showed moderate to large effect sizes for vigorous or near maximal aerobic exercise intensities, in contrast with a small to moderate effect with moderate intensity for reductions in PWV. However, there was large heterogeneity across each of the intensity categories. It should be noted that these reviews have may have included exercise interventions that implemented high intensity exercise in large volumes. In contrast, our review specifically examined HIIT protocols that implement small bursts of high intensity activity and reduced the overall volume completed at a high intensity.

Our analyses found no difference between either HIIT or MICT for changes to central arterial stiffness as measured by AIx, AIx@75 and PWV. For both outcome measures, nearly half of the pooled studies were conducted as sprint interval training.[32,33,35,40,42,44] To date, there have been limited investigations on low volume approaches of HIIT/sprint interval training (SIT) and central cardiovascular adaptations,[50] however there is evidence to suggest SIT is beneficial for peripheral vascular adaptations.[50] A study conducted in healthy individuals found significant increases in cardiorespiratory fitness, but no changes to cardiac output or stroke volume following SIT.[51] Interestingly, Rakowbowchuk (2008)[40] and colleagues found no changes in central arterial distensibility, but found significant improvements in peripheral arterial distensibility following sprint interval training in healthy individuals. Additionally, SIT resulted in significantly greater brachial vascular function in this study[40]. Studies that have investigated the effect of SIT on central PWV have also described conflicting results. One study conducted in healthy men showed significant improvements in central PWV following SIT.[33] In contrast, there was no change in central PWV, but a tendency for peripheral PWV to reduce after training in an obese cohort.[32] It appears that SIT can provide a benefit for peripheral adaptations, however the potential benefits for central adaptations remain inconclusive. Conversely, other HIIT protocols have led to improvements in central responses such as increased in myocardial contractility, ejection fraction, stroke volume and decreased end systolic volume.[52] This could be due to the longer duration exercising at higher intensities, exposing the central component to a greater haemodynamic response when compared to SIT. This may explain why our results do not support the findings in previous reviews showing no additional benefits to central arterial stiffness with higher intensity.

It has been well established by previous meta-analyses that regular aerobic exercise is an effective strategy for reducing clinical measures of blood pressure in normotensive, pre-hypertensive and hypertensive adults.[53] However, there has been conflicting evidence regarding the efficacy of aerobic exercise on 24 h blood pressure responses. A recent meta-analysis by Sosner and colleagues demonstrated that regular aerobic exercise was effective in significantly reducing all 24 h blood pressure outcomes (mean 24 h, daytime and night-time blood pressure) in normotensive, pre-hypertensive and hypertensive adults. When examining the possible effect of exercise moderators on blood pressure outcomes, there were no significant moderators influencing the reduction in blood pressure (intensity, total number of sessions, duration of program). Similarly, the meta-analysis conducted by Cornelissen et al. found no significant relationship between exercise intensity and changes to ambulatory blood pressure, in normotensive, pre-hypertensive and hypertensive adults.[26] The authors also observed that aerobic exercise had a significant reduction in daytime systolic and diastolic blood pressure there was no significant effect on night-time blood pressure. It should be noted that the studies conducted by Sosner et al. and Cornelissen et al. had a substantially greater number of MICT intervention groups than our current study, which may explain why both studies did not find a significant effect with higher intensities.[26,27] Our meta-analysis also suggests that regular aerobic exercise is effective in reducing daytime and night-time blood pressure; however there was a superior reduction in night-time DBP with greater exercise intensity by utilising HIIT, when compared to MICT. Interestingly, Cornelissen et al. observed that reductions in daytime SBP were associated with greater increases in VO_{2peak}. It has been well established that HIIT has superior benefits on cardiorespiratory fitness when compared to MICT,[20,23] which may partly explain our near-significant change in daytime SBP. A more recent literature review examined different modalities of exercise (aerobic and resistance training) on office and ambulatory blood pressure. Similarly, the study concluded that high intensity aerobic exercise (>70% VO_{2max}) tended to result in larger reductions in ambulatory readings, when compared to moderate intensity exercise.[54]

Much like the responses observed with arterial stiffness, the reductions in blood pressure as a result of regular aerobic exercise training appear to be associated with peripheral and regional cardiovascular adaptations. Aerobic training has been found to reduce overactivity of the sympathetic nervous system,[55] increase baroreflex sensitivity,[56] decrease mRNA and protein expression of angiotensin II type 1 receptor (vasoconstriction), improve local vascular function and increase resting arterial diameter. Changes to each of these parameters can lead to reductions in total peripheral resistance, and thus, blood pressure.[57] Whilst there is limited evidence comparing HIIT versus MICT on these physiological adaptations, there is evidence to show that HIIT is a superior alternative for improvements in vascular function.[23] HIIT is thought to induce a greater amount of shear stress on arterial/vascular walls, particularly in exercising muscles, through utilizing small periods of higher intensity activity, which may explain the larger benefits seen in vascular function outcomes. Furthermore, the on-and-off pattern of interval-based exercise is thought to play a role in the superior increases observed in cardiorespiratory fitness. Interval exercise has been found to significantly increase the maximal activity of oxidative enzymes for the same volume work, compared to MICT.[58] Additionally, other practical advantages of HIIT may include shorter mean exercise time and rest intervals for recovery which may make HIIT a more suitable for certain individuals (e.g. severely deconditioned and/or those with cardiopulmonary conditions), and possibly higher levels of enjoyment in some individuals.[20]

In addition, measures of daytime and night-time blood pressure are strongly linked to cardiovascular death and predicting future cardiovascular events (coronary heart disease, stroke).[2] Small reductions in DBP (2 mmHg) can decrease the incidence of coronary heart disease (9%) and stroke (15%).[59] From the pooled studies in our review, the mean change in night-time DBP was −6.1 mmHg for HIIT vs −3.1 mmHg for MICT. Our results found that HIIT had a small, but significantly greater reduction in night-time DBP and appeared to lead to greater reductions in daytime blood pressure. Therefore, HIIT may be a more effective treatment for hypertension compared with traditional aerobic exercise.

There are some limitations to our study that should be considered when interpreting the results. While 13 studies were eligible for meta-analysis, three to ten studies were included in each sub-analyses, and these were limited by small sample sizes. The differences in exercise prescription (intensity, duration, frequency and intervention length) and the overall moderate study quality could contribute to heterogeneity in the available research. Of the included studies, there was a large range in the age and a higher number of male subjects. It is known that both arterial stiffness and blood pressure worsen with age, and his may impact the response to exercise.[4] Furthermore, males have been shown to have greater arterial stiffness compared to females, which could also confound the results.[4] Whilst the majority of studies were conducted in individuals at higher risk of CVD, there was high heterogeneity amongst the population groups in the eligible studies (e.g. overweight, obese, metabolic syndrome and hypertensive individuals). Only a small number of studies were conducted in each of the population groups, and therefore insufficient data to conduct a population specific analysis. For each of the pooled analyses, there was a low I^2 value (low heterogeneity), and there was no significant publication bias across the studies. Despite this inability to conduct population specific analyses at present, these results still provide useful information for the use of HIIT and MICT for exercise prescription for those at risk of CVD. Our results show evidence that HIIT may be a more potent therapy for improvements in blood pressure outcomes and both HIIT and MICT appear to be equally effective strategies for the management of central arterial stiffness. Given the generally positive findings in favour of HIIT, there is a clear need for further research comparing the efficacy of HIIT versus MICT in these outcomes.

The results have implications for clinicians prescribing aerobic exercise to manage hypertension and the possible need to incorporate more vigorous exercise to manage cardiovascular health. This is particularly important to address with the rising acceptance of the use of HIIT to improve clinical outcomes in individuals at high risk of CVD and cardiac conditions. Furthermore, the lack of data in population groups at high risk of CVD and cardiac populations highlights the need for more research investigating HIIT versus MICT to understand the optimal exercise prescription for these individuals when targeting central arterial stiffness and 24 h blood pressure outcomes.

5. Conclusion

This is the first study to collectively pool data and compare the effect of HIIT and MICT on measures of central arterial stiffness and 24 h blood pressure in adults. Our study found that HIIT had a superior benefit on night-time DBP, and a tendency for greater improvements in daytime SBP and DBP when compared to MICT. However, there was no significant difference between the two interventions for arterial stiffness outcomes. Although we demonstrated a general lack of evidence comparing HIIT versus MICT on these outcomes, particularly 24 h blood pressure, the findings suggest that HIIT may be a more suitable alternative to traditional aerobic exercise to manage hypertension and the associated risks.

Declaration of interests

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.09.228.

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