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The effect of underwater massage during hot water immersion on acute cardiovascular and mood responses

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A R T I C L E I N F O

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Passive heating
Hot water immersion
Massage
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A B S T R A C T

Purpose: There is emerging evidence that demonstrates the health benefits of hot water immersion including improvements to cardiovascular health and reductions in stress and anxiety. Many commercially available hot tubs offer underwater massage systems which purport to enhance many benefits of hot water immersion, however, these claims have yet to be studied.
Methods: Twenty participants (4 females) completed three, 30-min sessions of hot-water immersion (beginning at 39 °C) in a crossover randomized design: with air massage (Air Jet), water massage (Hydro Jet) or no massage (Control). Cardiovascular responses comprising; heart rate, blood pressure and superficial femoral artery blood flow and shear rate were measured. State trait anxiety, basic affect, and salivary cortisol were recorded before and after each trial. Data were analysed using a mixed effects model.
Results: Post immersion, heart rate increased (Δ31bpm, $P < 0.001$, $d = 1.38$), mean arterial blood pressure decreased (Δ16 mmHg, $P < 0.001$, $d = -0.66$), with no difference between conditions. Blood flow and mean shear rate increased following immersion ($P < 0.001$, Δ362 ml/min, $d = 1.20$ and Δ108 s^{-1}, $d = 1.00$), but these increases were blunted in the Air Jet condition ($P < 0.001$,Δ171 ml/min, $d = 0.43$ and Δ52 s^{-1}, $d = 0.52$). Anxiety and salivary cortisol were reduced ($P = 0.003$, $d = -0.20$, $P = 0.014$, $d = -0.11$), but did not vary between conditions. Enjoyment did not vary between conditions.
Conclusion: These data demonstrate positive acute responses to hot water immersion on markers of cardiovascular function, anxiety, and stress. There was no additional benefit of water-based massage, while air-based massage blunted some positive vascular responses due to lower heat conservation of the water.

1. Introduction

In recent years there has been research interest investigating the potential health benefits of passive heating by use of hot tubs or saunas (Brunt and Minson, 2021; Cullen et al., 2020). Regular hot tub use has been documented to induce significant improvements in macro and micro-vascular function (Brunt et al., 2016a, 2016b), reduce chronic inflammation (Hoekstra et al. 2020), and reduce stress (Antonelli and Donelli, 2018). Despite these impressive results, research into the benefits of hot water immersion is still very much in its infancy compared to traditional health interventions such as exercise (Amercian College of Sports Medicine., Ehrman, Liguori, Magal & Riebe 2018), and it is still poorly understood which factors of protocol design (e.g., temperature, duration, depth of immersion) cause specific health benefits. It is thought that chronic adaptations to hot water immersion arise due to transient acute stresses to the cardiovascular, thermoregulatory and metabolic systems (Cullen et al., 2020; Carter et al., 2014; Hoekstra et al., 2018). Therefore, understanding acute physiological and psychological responses to various aspects of protocol design is important for improving our understanding and more effectively advising on appropriate intervention design.

Traditional hot water therapies such as balneotherapy are widely seen as enjoyable and have established benefits in reducing stress (Antonelli and Donelli, 2018). Several of the recent studies investigating hot water immersion, have used protocols ≥60 min in duration with water temperatures ~40 °C to achieve high core body temperatures

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(Brunt, Howard, et al., 2016; Hoekstra et al., 2018). However, this can be uncomfortable or even intolerable for some individuals and result in adverse responses if prolonged (>30 min) and performed without additional precautions (Steward et al., 2023). Other studies have recognised this phenomenon, and have sought to manipulate the water immersion protocols, by use of fan cooling (for example), to improve psychological affective responses without negatively impacting the potentially beneficial acute anti-inflammatory responses (Mansfield et al., 2021). As such, it is important to consider comfort, tolerability, and enjoyment during protocol design, while also evaluating beneficial physiological effects.

Many commercially available hot tubs offer underwater massage systems, which manufacturers purport to increase relaxation, enjoyment and enhance the overall benefits of hot water immersion. However, there are no available studies assessing the combined effect of hot water immersion and massage. Given that massage by manual therapy is widely considered to be enjoyable (Field, 1998) and has been suggested to benefit the skeletal muscles by increasing local blood flow and facilitating enhanced nutrient and oxygen delivery (Goats, 1994), these claims are plausible, but require investigation. As such, the primary aim of this study was to assess the acute physiological and psychological responses to hot water immersion with and without underwater massage using a commercially available hot tub. It was hypothesised that underwater massage would enhance blood flow, improve mood and reduce anxiety to a greater extent than water immersion without massage.

2. Materials and methods

2.1. Participants

Participants provided written informed consent and completed a health screening questionnaire prior to enrolment in the study. The study was approved by the local University ethics committee (approval code P140702) and all procedures conformed with the Declaration of Helsinki, with the exception of prior registration in a public database. Twenty healthy participants (16 males and 4 females), mean age of 37 ± 8.4 years took part in the study. Female participants were all premenopausal and were not instructed to attend test sessions during a particular phase of their menstrual cycle. Participants had no underlying medical conditions and were not on any medications during the study. Participants who were pregnant, clinically hypotensive (<90/60 mmHg) or with a history of orthostatic intolerance were also excluded as these are known risk factors for orthostatic hypotension following hot water immersion (Steward et al., 2023). Regular smokers or having stopped smoking in the last 3 months were also excluded as this can impact vascular responses.

2.2. Experimental design

Participants completed 3 test sessions in a randomised order with a series of physiological and psychological measurements (described below) taken before, during and after each hot tub session. The test sessions comprised of 30 min seated in a hot tub with additional water jet massage (Hydro Jet), air jet massage (Air Jet) or no massage (Control). All hot tub sessions took place in the same model of hot tub (LAY-Z-SPA, Majorca). Prior to the start of each session, water temperature was set to 39°C, which can be broadly classified as 'hot' (Ntoumani et al., 2023). The depth of the immersion was kept the same for each participant (up to the armpit) and their arms were submerged throughout. Ambient temperature and relative humidity in the laboratory were 19.7 ± 1.0°C and 47 ± 11%. Upon arrival at the laboratory and prior to any measurements, participants drank 500 ml of water to help prevent dehydration (Francisco et al., 2021). Each visit was separated by at least 48hrs to avoid any carryover effects and took place at the same time of day to (±1hr) control for any potential effects of circadian rhythm.

2.3. Experimental measures

2.3.1. Water temperature

A thermocouple (Grant Instruments, UK) was kept submerged in the water and used to measure the water temperature throughout each hot tub session with recordings made at 10-min intervals.

2.3.2. Cardiovascular responses

Following a 10-min period of quiet seated rest (Baseline), blood pressure measurements were recorded in accordance with the European Society of Cardiology (Williams et al., 2018) using an automated blood pressure cuff (M3 Omron, Kyoto, Japan). Repeated measurements were subsequently taken at the end of the 30-min hot tub trial (Post). Blood pressure measurements were taken in triplicate with the average of these measurements reported in the manuscript. Systolic and diastolic blood pressure were used to calculate mean arterial pressure and pulse pressure. Measurements of heart rate (Polar FT1, Polar, Kempele, Finland) were taken at rest and at 10-min intervals throughout immersion.

After baseline blood pressure, participants laid supine to allow ultrasound recordings of the superficial femoral arteries. Ultrasound scans of the superficial femoral artery were completed in a supine position at Baseline and Post hot tub sessions. Superficial femoral artery diameter and velocities were recorded continuously for 30 s using a 15-MHz multifrequency linear array probe attached to a high-resolution duplex ultrasound machine (Terason uSmart 3300, Teratech, Burlington, MA, USA). Ultrasound parameters were set to optimise the longitudinal B-mode image of the lumen-arterial wall interface with concurrent Doppler velocities collected using the lowest possible insonation angle (always <60°). The depth, focus position and gain settings were standardised for each individual participant and then replicated for each subsequent visit. Analysis of artery diameter and velocity was performed using custom-designed edge-detection and wall-tracking software, which is independent of investigator bias and has been previously described elsewhere (Woodman et al., 2001). From synchronized diameter and velocity data, mean blood flow (the product of lumen cross-sectional area and Doppler velocity) was calculated at 30 Hz and shear rate, an estimate of shear stress without viscosity, was calculated as 4 × mean blood velocity/vessel diameter.

2.3.3. Subjective measurements

Participants completed the State-Trait Anxiety inventory (Spielberger, 1983) before and immediately after each hot tub session. Perceptual measures of thermal comfort and thermal sensation were measured every 10 min on scales of +5 (very comfortable and very hot respectively) to −5 (very uncomfortable and very cold respectively) modified from (Epstein and Moran, 2006). To assess changes in mood throughout each session, participants provided a score on the feelings scale, a single-item measure of the valence dimension of affect (Williams et al., 2008). The scale ranges from +5 (very good) to −5 (very bad). Enjoyment of each session overall was measured using a modified version of the physical activity enjoyment scale (PACES) after each session (Mullen et al., 2011). The scale asks participants to rate their enjoyment (1–7 scale, with a score of 1 being positive and 7 negative), across the following 8 subcategories; Pleasurable, Fun, Pleasant, Invigorating, Gratifying, Exhilarating, Stimulating, Refreshing. After the final trial, participants were asked to rank the experimental trials from most to least preferred.

2.3.4. Saliva sampling and analysis

Whole mixed unstimulated saliva samples were collected by passively drooling into a sterile Eppendorf. Samples were then centrifuged 3000 *g* for 10 min to separate particulate matter and then stored at −20 °C until batch analysis. Salivary cortisol was measured using a commercially available enzyme-linked immunosorbent assay kit (product code KGE008B, Bio-Techne, Abingdon, United Kingdom). All samples were analysed in duplicate and all procedures were followed according to the manufacturer instructions. To minimise variation between assays, all samples from an individual participant were assessed on the same assay. Protein concentrations were determined in relation to a four-parameter logistic curve (GraphPad Prism Version 10, Boston, Massachusetts, USA). In our hands, the intra-assay coefficient of variation was 7.2 ± 1.3 %.

2.4. Statistical analysis

Unless stated otherwise, data were analysed using a linear mixed model with time and condition as fixed effects and subjects coded as a random effect. To identify the location of any statistically significant effects (reported as P values, where $P < 0.05$ is a significant result), post-hoc pairwise comparisons were conducted using Tukey's test. Enjoyment data were nonparametric and therefore analysed using a Kruskal-Wallis test. Participant preferences for each trial were calculated as counts then analysed used the chi-square test. Empirical data are presented as mean ± standard deviation when describing absolute values, mean difference and 95% confidence intervals (CI) are presented when describing differences identified in post hoc testing. Effect sizes (Cohen's *d*) were calculated in order to assist with assessing the practical significance of the findings. Enjoyment and mood data which are reported as median and interquartile range. All analyses and figures were created with GraphPad Prism version 10.

3. Results

3.1. Temperature responses

Water temperature showed significant interaction between condition and time (F = 87.4, $P < 0.001$). At the start of each session the average water temperature was within 0.1 °C of the temperature set on the device (39 °C) and then subsequently decreased in all conditions ($P < 0.001$) (Fig. 1A), reaching 38.6 ± 0.3 °C, 38.4 ± 0.3 °C and 37.5 ± 0.2 °C in the Control, Hydro Jet and Air Jet respectively. The decrease in temperature was significantly greater in Air Jet compared to the Control (mean difference, 1.08 °C, 95% CI = 0.79–1.38 °C, P < 0.001, $d = 2.27$), and Hydro Jet conditions (mean difference, 0.92 °C, 95% CI = 0.63–1.20 °C, $P < 0.001$, $d = 1.93$).

Thermal sensation (Fig. 1B) showed a significant condition by time interaction (F = 5.92, P = 0.003), increasing over time in all conditions, continuing to increase up to 30 min in the Control and Hydro Jet conditions ($P < 0.001$|), but plateauing after 20 min in the Air Jet condition. As such, at 30 min, thermal sensation was significantly lower in the Air Jet compared to the Control (mean difference, 1.1 AU, 95% CI = 0.5–1.7 AU, $P < 0.001$, $d = -0.65$) and Hydro Jet conditions (mean difference, 1.0 AU, 95% CI = 0.36–1.6 AU, $P = 0.002$, $d = -0.58$). In contrast, hot water immersion increased thermal comfort compared to baseline (mean difference, 1.9 AU, 95% CI = 0.9–2.8 AU, $P < 0.001$, $d = 0.30$) (Fig. 1C), but with no condition ($P = 0.17$) or interaction effects ($P = 0.09$). During immersion, thermal comfort gradually declined to a nadir at 30 min (mean difference, 1.15 AU, 95% CI = 0.22–2.08 AU, $P < 0.001$, $d = -0.18$).

3.2. Cardiovascular responses

3.2.1. Heart rate

Heart rate increased in all conditions, showing a significant main effect of time (F = 160.3, $P < 0.001$), peaking at 30 min in all conditions (mean difference, 31 bpm 95% CI = 27–37 bpm, $P < 0.001$, $d = 1.38$) (Fig. 2). There was no significant condition by time interaction (F = 2.5, $P = 0.059$).

3.2.2. Blood pressure

There were main effects of time for all blood pressure metrics ($P < 0.001$). Immediately following the hot tub sessions systolic, diastolic and mean arterial blood pressure (Fig. 3A–C) were significantly reduced (mean difference 9 mmHg, 95% CI = 3.6–14.4, $d = -0.36$, 19 mmHg, 95% CI = 15.8–22.9, $d = -0.84$ and 16 mmHg, 95% CI = 12.2–19.6, $d = -0.66$ respectively, all $P < 0.001$). All blood pressure parameters returned to baseline by 30 min post ($P > 0.05$). There were no condition × time interactions ($P > 0.05$).

3.2.3. Superficial femoral artery diameter, blood flow and shear rate

For blood flow there was a significant interaction between condition x time (F = 4.8, $P = 0.01$) (Fig. 4A). Blood flow was significantly elevated immediately post hot tub in all conditions (P < 0.001, Δ362 ml/min, $d = 1.20$), however, the magnitude of increase was significantly lower in the Air Jet condition compared to the Control ($P < 0.001$, mean difference, 171.8 ml/min, 95% CI = 79.6–263.9 ml/min, $d = 0.43$) and Hydro Jet ($P < 0.005$, mean difference, 124.8 ml/min, 95% CI = 32.7–217 ml/min, $d = 0.18$). Similarly, mean shear rate showed a significant condition × time interaction (F = 4.04, $P = 0.02$) (Fig. 4B), and was elevated immediately post all hot tub conditions ($P < 0.001$), but the magnitude of the increase in shear rate was significantly lower in the Air Jet compared to Control condition ($P < 0.001$, mean difference, 52.24 s^{-1}, 95% CI = 22.57–81.92 s^{-1}, $d = 0.52$). There was no time (F = 1.22, $P = 0.28$), condition (F = 0.11, $P = 0.88$) or interaction effects (F = 1.7, $P = 0.19$) on superficial femoral artery diameter.

3.3. Anxiety and stress responses

State-trait anxiety inventory score showed a main effect of time, reducing post immersion (main effect of time, F = 11.07, $P = 0.0035$, mean difference 3.25 AU, 95% CI = 0.35–6.1, $d = -0.20$) (Fig. 5A). There were no significant effects of condition nor interactions between time and condition ($P > 0.05$). Salivary cortisol showed a similar response to anxiety, there was a main effect of time (F = 7.5, $P = 0.01$), decreasing across all conditions ($P = 0.014$, mean difference 3.02 nmol/L 95% CI = 0.71–5.3 nmol/L, $d = -0.11$) (Fig. 5B). There were no condition or interaction effects ($P = 0.68$ and $P = 0.37$, respectively).

3.4. Mood and enjoyment

Mood, as measured by the feelings scale, was generally positive throughout all conditions (median = 3, IQR 2–4 AU). The were no effects of time (F = 2.1, $P = 0.14$), condition (F = 0.1, $P = 0.86$) or interaction (F = 0.5, $P = 0.65$) on mood. Similarly, there was no difference in the level of enjoyment reported across different subscales for each condition (all $P > 0.05$) (Table 1.). Participant preferences are reported in Table 2. The was no statistical difference between the ranking of different trials (X^2 (4, N = 20) = 7.8, $P = 0.09$).

4. Discussion

The primary findings of this study were that a single 30-min hot tub session resulted in transient increases in heart rate, blood flow and shear rate in the superficial femoral artery, while reducing blood pressure, anxiety, and stress hormone levels. Underwater massage did not offer any additional effect on these responses and therefore our hypothesis can be rejected. Further, this is the first study to demonstrate that when massage was delivered by air jets, water temperature is considerably reduced, leading to blunted increases in superficial femoral artery blood flow and shear rate compared to control and water jet delivered massage.

Hot water immersion resulted in positive cardiovascular responses, as evidenced by transient increases in heart rate (≈31bpm), superficial femoral artery blood flow and shear rate (≈345%) and decreases in blood pressure (SBP≈ 9 mmHg, DBP≈19 mmHg). These responses are typical of what has previously been reported in the literature with similar interventions (Thomas et al., 2017) and demonstrate vascular

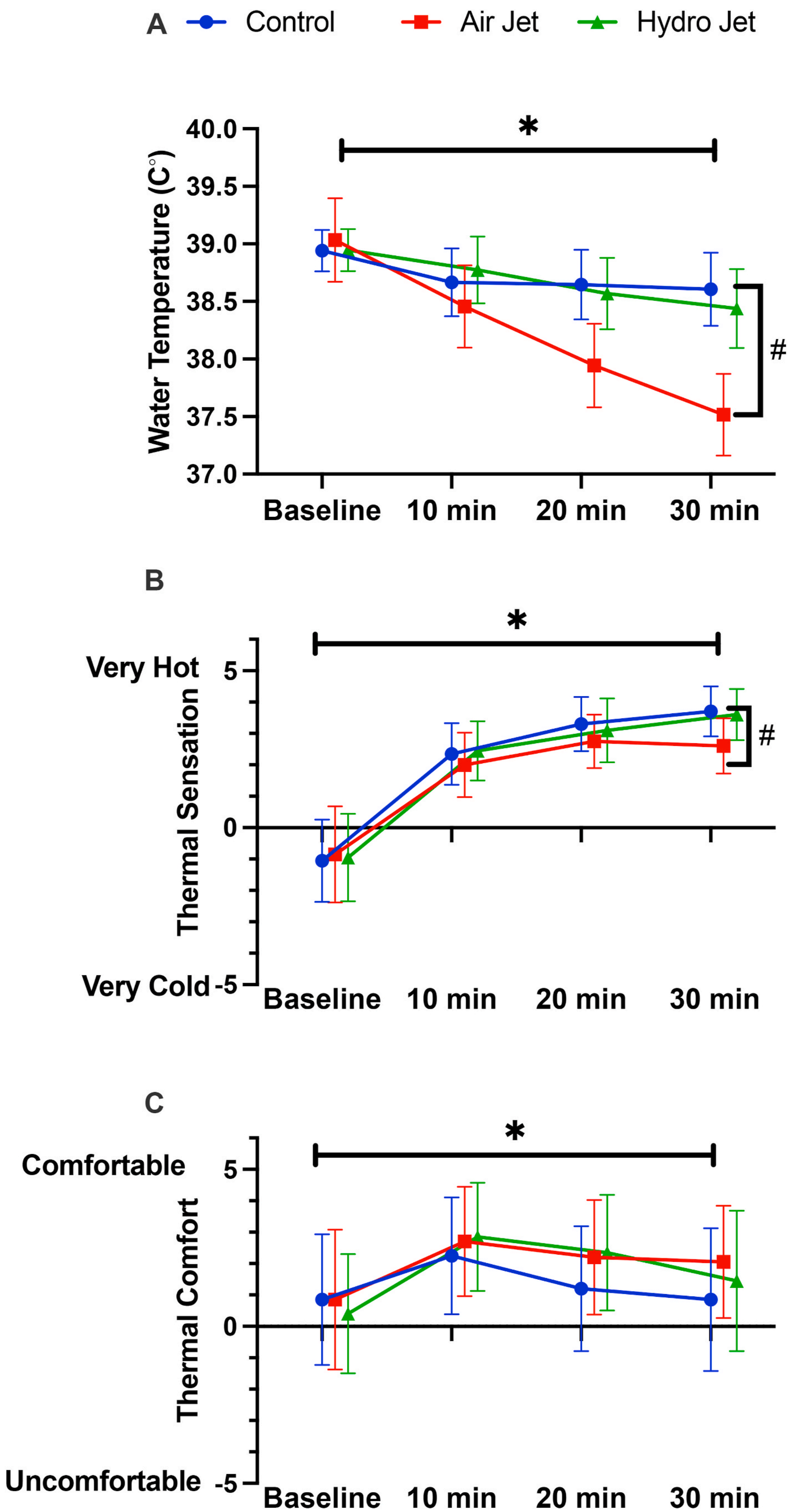

Fig. 1. Water temperature (A), Thermal sensation (B) and thermal comfort (C) during each experimental trial. * Represents a significant main effect of time in all conditions. # Represents a significant difference between Air Jet and the other two conditions at 30 min.

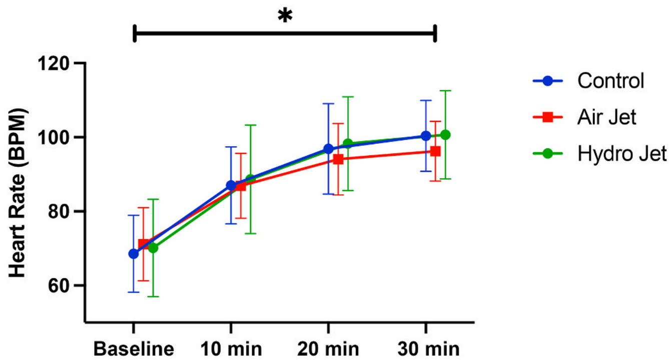

Fig. 2. Heart rate response throughout each experimental trial. * Represents a significant main effect of time in all conditions. ($P < 0.05$).

and psychological stress responses consistent with those known to elicit multifaceted cardiovascular and mental health benefits if repeated chronically (Brunt and Minson, 2021). Importantly, this study shows for the first time that underwater massage does not enhance these benefits. Indeed, the observed increases in superficial femoral artery blood flow and shear stress were blunted following the Air Jet condition. Therefore, if increasing blood flow and shear rate are to be considered important for the cardiovascular health benefits of water immersion, continuous air-based massage should be avoided. The observed blunting of shear rate and blood flow observed in the Air Jets condition appears to be due to the lower water temperature at the end of the Air Jet trial (≈1 °C lower Vs Control and Hydro Jet), rather than due to the physical pressure of the massage (Chiesa et al., 2016). Indeed, a similar blunting was not observed when using a water-based massage system in the Hydro Jet condition, which maintained temperature to a similar level to Control. However, the dose response relationship between temperature of water immersion and important vascular responses, such as shear stress and blood pressure, have not been established and future studies should systematically assess this.

Our results show that thermal comfort peaked at 10 min and subsequently declined thereafter, while thermal sensation continued to rise (Fig. 1B and C). It is notable that at the end of the 30-min immersion, mean thermal comfort was still positive. This is in contrast to more recently used protocols which are longer (>45 min) and hotter protocols (40 °C), where significant thermal discomfort has been reported (Hoekstra et al., 2018; Steward et al., 2023). Given that water temperature and the resulting thermal sensation were lower in the Air Jet condition at 30 min, it is plausible that Air Jet massage, may improve the tolerability of and adherence to longer hot water immersion protocols. However, this should be tempered with the apparent trade-off with reduced shear stress if this is the desired stimulus for adaptation.

Psychological responses to hot water immersion were generally very positive, with participants reporting it to be particularly enjoyable, scoring particularly highly in the sub scales "pleasurable", "pleasant" and "refreshing", but less well for "exhilarating". There were no statistically significant differences between trials for the scores in each of the categories, showing that neither Air Jets nor Hydro Jets were consistently more enjoyable than having no massage (Control). Given that there is consistent evidence that massage by manual therapy is considered to be enjoyable (Field, 1998), it was a surprising result that the addition of underwater massage did not enhance the enjoyment of hot tub bathing. Indeed, participant preferences (Table 2), show a similar pattern to enjoyment, as participants did not appear to consistently favour one condition over the other. These results suggest that people have highly individualised preferences in relation to the type of hot tub bathing they favour, and this should be an important consideration for long-term adherence. It is important to also acknowledge and consider that there is likely to be a trade-off between enjoyment and physiological efficacy. Similarly, there were significant reductions in anxiety

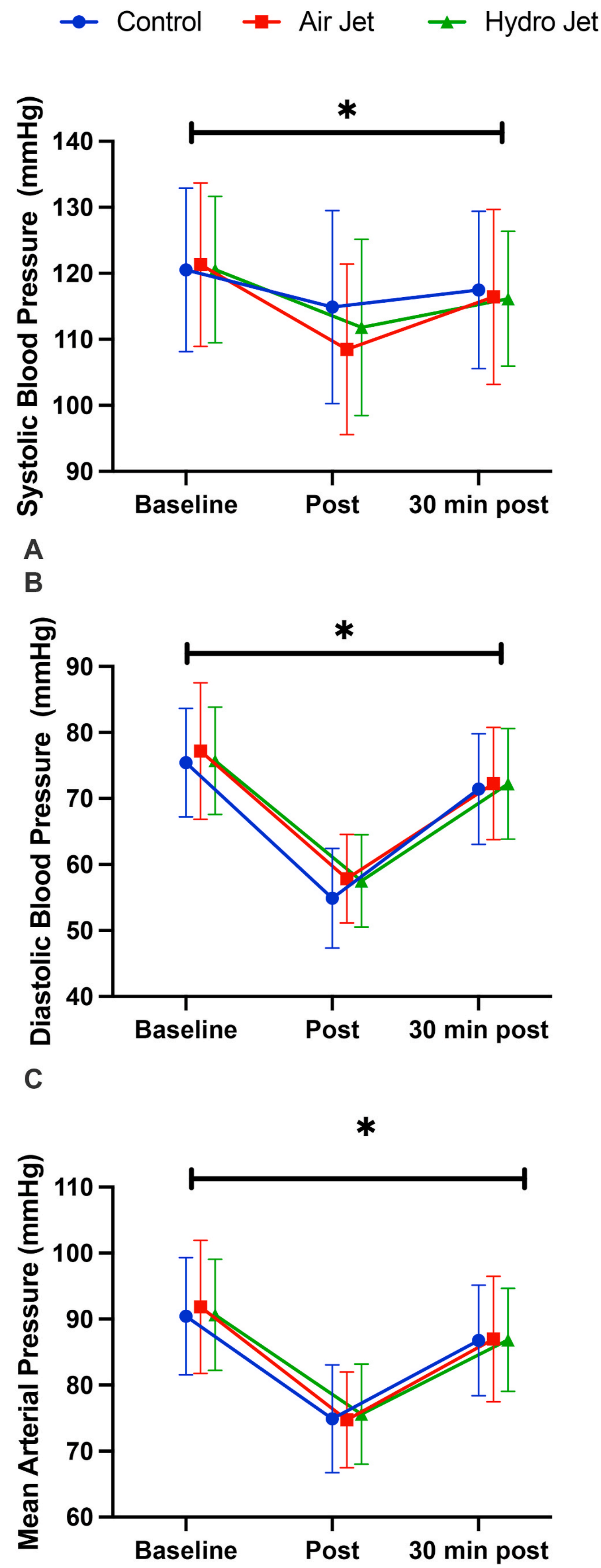

Fig. 3. Systolic (A) and diastolic (B) blood pressure, mean arterial pressure (C). * Represents a significant main effect of time in all conditions. ($P < 0.05$).

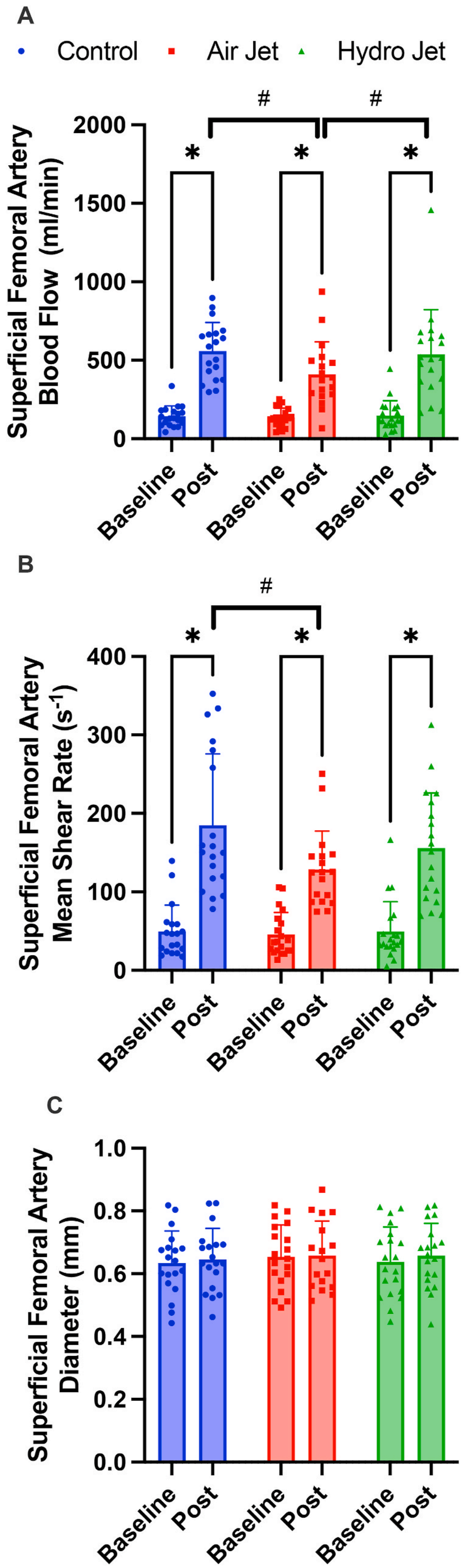

Fig. 4. Superficial femoral artery blood flow (A) and mean shear rate (B) before and immediately after each experimental trial. * Represents a significant increase from Pre to Post ($P < 0.05$). # Represents significant difference between the Control and Air Jet conditions ($P < 0.05$).

(≈10%) and salivary cortisol (≈22%) due to hot tub bathing but with no additional benefit (or detrimental effects) of underwater massage. In the case of salivary cortisol, these findings are in agreement with those reported in a recent systematic review of the effects of balneotherapy (Antonelli and Donelli, 2018). It is also important to highlight that the majority (15 out of 20) of participants in the current study were classified as having no or low anxiety (scoring between 20 and 37 on the state trait anxiety inventory), and greater reductions in stress and anxiety are likely in people with greater stress levels (Toda et al., 2006). Nonetheless, these are particularly important results given that chronic stress is highly prevalent in modern society, and that persistent stress can lead to a number of health issues, such as high blood pressure, disruptions to immunoendocrine function and depression (Schneiderman et al., 2005). As such, hot water immersion offers a potentially easily accessible and enjoyable method of reducing stress and anxiety.

The study does have some limitations. Firstly, we did not obtain vascular measurements throughout the immersion period, and this would have proved useful to better understanding the time course of changes and may have provided more detail on the potential impact of changing water temperature. Indeed, some acute studies have controlled for changes in water temperature by closely monitoring the temperature and adding in additional hot water when temperature decreases. In contrast, we chose to treat water temperature as an outcome measure rather than control it throughout each trial by manually manipulating the temperature. While our approach could be considered a limitation; we felt this approach significantly increases the ecological validity of our findings and, importantly, allowed us to demonstrate the blunting effects caused by the decrease in water temperature observed in the Air Jet condition. Secondly, we did not control for the phase of the menstrual cycle in which females attended for each of their test sessions. It could be argued that this may have increased the variability in our data to small degree, however, it increases the ecological validity of our findings which are not specific to one phase of the menstrual cycle (Stanhewicz and Wong, 2020). Finally, it is important to emphasise that the responses measured in this study may have been different if the temperature of the water and duration of immersion were different and the findings of this study should not necessarily be applied to other scenarios.

5. Conclusion

This study demonstrated that 30 min of hot water immersion resulted in large increases in superficial femoral artery shear rate and decreased blood pressure, anxiety, and salivary cortisol. However, underwater massage did not enhance these benefits, and in the case of massage by air jets, caused a decrease in water temperature which blunted some of the beneficial vascular responses.

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CRediT authorship contribution statement

Tom Cullen: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Charles J. Steward:** Writing – review & editing, Investigation. **Campbell Menzies:** Writing – review & editing, Investigation. **Christopher J.A. Pugh:** Writing – review & editing. **C. Douglas Thake:** Methodology, Conceptualization.

Declaration of competing interest

The authors declare they have no competing interests.

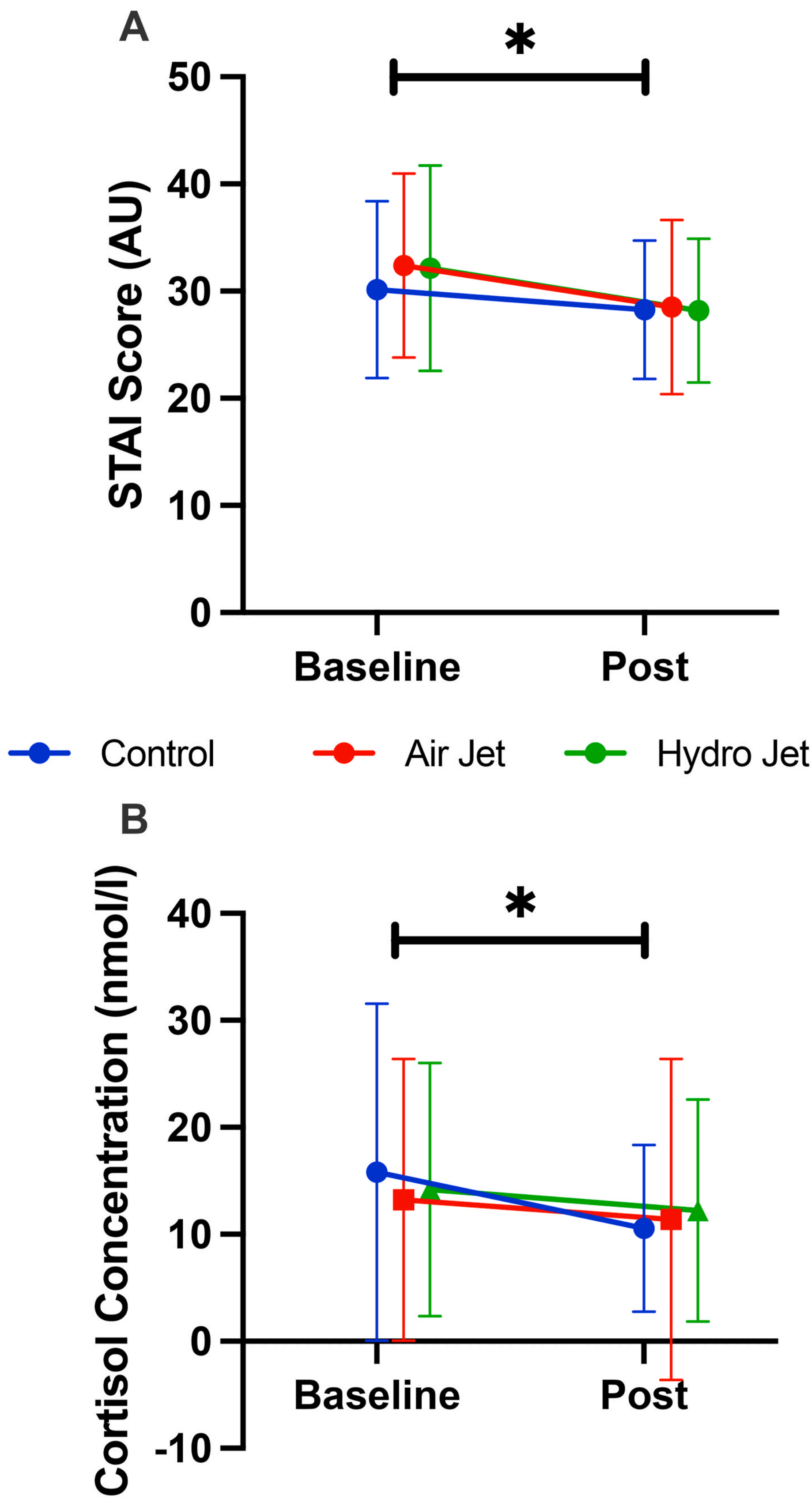

Fig. 5. State-Trait Anxiety Inventory (STIA) (A) and salivary cortisol (B) at baseline and after each experimental trial. AU=Arbitrary units. * Represents a significant difference decrease in all conditions.

Table 1
Comparisons of enjoyment subcategories between different experimental conditions. Each subcategory is scored on a 1–7 scale, with a score of 1 being positive and 7 negative). Data are displayed as median and interquartile range.

	Control	Air Jet	Hydro Jet	P Value
Pleasurable	2 (1–2)	2 (1–3)	2 (1–2)	0.87
Fun	3 (2–4)	3 (1.25–3.75)	3 (2–4)	0.46
Pleasant	2 (1–3)	2 (1–3)	2 (1–2)	0.99
Invigorating	3 (2–4)	3 (1–4)	2 (1–3)	0.11
Gratifying	3 (1–3)	3 (1.25–4)	2.5 (1–3)	0.71
Exhilarating	4 (3–5)	4 (3–5)	4 (2.25–5)	0.94
Stimulating	3 (2–4)	3 (1–4)	3.5 (2–4.75)	0.46
Refreshing	2 (2–3)	2 (1–3.75)	2 (1.25–3.75)	0.96

Table 2
The distribution of participant preferences between experimental conditions.

	Control	Air Jet	Hydro Jet
Most favourite	6	8	6
Intermediate	9	2	9
Least favourite	5	10	5
Total	20	20	20

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtherbio.2024.103858.

References

Antonelli, M., Donelli, D., 2018. Effects of balneotherapy and spa therapy on levels of cortisol as a stress biomarker: a systematic review. Int. J. Biometeorol. 62, 913–924. https://doi.org/10.1007/S00484-018-1504-8.

Brunt, V.E., Minson, C.T., 2021. Heat therapy: mechanistic underpinnings and applications to cardiovascular health. J. Appl. Physiol. 130, 1684–1704. https://doi.org/10.1152/JAPPLPHYSIOL.00141.2020.

Brunt, V.E., Eymann, T.M., Francisco, M.A., Howard, M.J., Minson, C.T., 2016a. Passive heat therapy improves cutaneous microvascular function in sedentary humans via improved nitric oxide-dependent dilation. J. Appl. Physiol. 121, 716–723. https://doi.org/10.1152/japplphysiol.00424.2016.

Brunt, V.E., Howard, M.J., Francisco, M.A., Ely, B.R., Minson, C.T., 2016b. Passive heat therapy improves endothelial function, arterial stiffness and blood pressure in sedentary humans. J. Physiol. 594, 5329–5342. https://doi.org/10.1113/JP272453.

Carter, H.H., Spence, A.L., Atkinson, C.L., Pugh, C.J.A., Naylor, L.H., Green, D.J., 2014. Repeated core temperature elevation induces conduit artery adaptation in humans. Eur. J. Appl. Physiol. 114, 859–865. https://doi.org/10.1007/s00421-013-2817-2.

Chiesa, S.T., Trangmar, S.J., González-Alonso, J., 2016. Temperature and blood flow distribution in the human leg during passive heat stress. J. Appl. Physiol. 120, 1047–1058. https://doi.org/10.1152/JAPPLPHYSIOL.00965.2015.

Cullen, T., Clarke, N.D., Hill, M., Menzies, C., Pugh, C.J.A., Steward, C.J., Thake, C.D., 2020. The health benefits of passive heating and aerobic exercise: to what extent do the mechanisms overlap? J. Appl. Physiol. 129, 1304–1309. https://doi.org/10.1152/japplphysiol.00608.2020.

American College of Sports Medicine, Ehrman, J.K., Liguori, G., Magal, M., Riebe, D., 2018. ACSM's Guidelines for Exercise Testing and Prescription. Wolters Kluwer – Medknow Publications, Tenth.

Epstein, Y., Moran, D.S., 2006. Thermal comfort and the heat stress indices. Ind. Health 44, 388–398. https://doi.org/10.2486/INDHEALTH.44.388.

Field, T.M., 1998. Massage therapy effects. Am. Psychol. 53, 1270–1281. https://doi.org/10.1037//0003-066X.53.12.1270.

Francisco, M.A., Colbert, C., Larson, E.A., Sieck, D.C., Halliwill, J.R., Minson, C.T., 2021. Hemodynamics of post-exercise vs. post hot water immersion recovery. J. Appl. Physiol. 130, 1362–1372. https://doi.org/10.1152/JAPPLPHYSIOL.00260.2020.

Goats, G.C., 1994. Massage–the scientific basis of an ancient art: Part 2. Physiological and therapeutic effects. Br. J. Sports Med. 28, 153. https://doi.org/10.1136/BJSM.28.3.153.

Hoekstra, S.P., Bishop, N.C., Faulkner, S.H., Bailey, S.J., Leicht, C.A., 2018. Acute and chronic effects of hot water immersion on inflammation and metabolism in sedentary, overweight adults. J. Appl. Physiol. 125, 2008–2018. https://doi.org/10.1152/japplphysiol.00407.2018.

Hoekstra, S.P., Bishop, N.C., Leicht, C.A., 2020. Elevating body termperature to reduce low-grade inflammation: a welcome strategy for those unable to exercise? Exerc. Immunol. Rev. 26, 42–55.

Mansfield, R.G., Hoekstra, S.P., Bill, J.J., Leicht, C.A., 2021. Local cooling during hot water immersion improves perceptions without inhibiting the acute interleukin-6 response. Eur. J. Appl. Physiol. 121, 1581. https://doi.org/10.1007/S00421-021-04616-5.

Mullen, S.P., Olson, E.A., Phillips, S.M., Szabo, A.N., Wójcicki, T.R., Mailey, E.L., Gothe, N.P., Fanning, J.T., Kramer, A.F., McAuley, E., 2011. Measuring enjoyment of physical activity in older adults: invariance of the physical activity enjoyment scale (paces) across groups and time. Int. J. Behav. Nutr. Phys. Activ. 81 (8), 1–9. https://doi.org/10.1186/1479-5868-8-103.

Ntoumani, M., Dugué, B., Rivas, E., Gongaki, K., 2023. Thermoregulation and thermal sensation during whole-body water immersion at different water temperatures in healthy individuals: a scoping review. J. Therm. Biol. 112 https://doi.org/10.1016/J.JTHERBIO.2022.103430.

Schneiderman, N., Ironson, G., Siegel, S.D., 2005. Stress and health: psychological, behavioral, and biological determinants. Annu. Rev. Clin. Psychol. 1, 607. https://doi.org/10.1146/ANNUREV.CLINPSY.1.102803.144141.

Spielberger, C.D., 1983. Manual for the State-Trait Anxiety Inventory. Consulting Psychologists Press, Palo Alto.

Stanhewicz, A.E., Wong, B.J., 2020. Counterpoint: investigators should not control for menstrual cycle phase when performing studies of vascular control that include women. J. Appl. Physiol. 129, 1117–1119. https://doi.org/10.1152/JAPPLPHYSIOL.00427.2020.

Steward, C.J., Menzies, C., Clarke, N.D., Harwood, A.E., Hill, M., Pugh, C.J.A., Thake, C.D., Cullen, T., 2023. The effect of age and mitigation strategies during hot water immersion on orthostatic intolerance and thermal stress. Exp. Physiol. 108, 554–567. https://doi.org/10.1113/EP090993.

Thomas, K.N., van Rij, A.M., Lucas, S.J.E., Cotter, J.D., 2017. Lower-limb hot-water immersion acutely induces beneficial hemodynamic and cardiovascular responses in peripheral arterial disease and healthy, elderly controls. Am. J. Physiol. Regul. Integr. Comp. Physiol. 312, R281–R291. https://doi.org/10.1152/AJPREGU.00404.2016/ASSET/IMAGES/LARGE/ZH60021792030005.JPEG.

Toda, M., Morimoto, K., Nagasawa, S., Kitamura, K., 2006. Change in salivary physiological stress markers by spa bathing. Biomed. Res. 27, 11–14. https://doi.org/10.2220/BIOMEDRES.27.11.

Williams, D.M., Dunsiger, S., Ciccolo, J.T., Lewis, B.A., Albrecht, A.E., Marcus, B.H., 2008. Acute affective response to a moderate-intensity exercise stimulus predicts physical activity participation 6 and 12 months later. Psychol. Sport Exerc. 9, 231–245. https://doi.org/10.1016/j.psychsport.2007.04.002.

Williams, B., Mancia, G., Spiering, W., Agabiti Rosei, E., Azizi, M., Burnier, M., Clement, D.L., Coca, A., de Simone, G., Dominiczak, A., Kahan, T., Mahfoud, F., Redon, J., Ruilope, L., Zanchetti, A., Kerins, M., Kjeldsen, S.E., Kreutz, R., Laurent, S., Lip, G.Y.H., McManus, R., Narkiewicz, K., Ruschitzka, F., Schmieder, R. E., Shlyakhto, E., Tsioufis, C., Aboyans, V., Desormais, I., Group, E.S.D., De Backer, G., Heagerty, A.M., Agewall, S., Bochud, M., Borghi, C., Boutouyrie, P., Brguljan, J., Bueno, H., Caiani, E.G., Carlberg, B., Chapman, N., Cífková, R., Cleland, J.G.F., Collet, J.-P., Coman, I.M., de Leeuw, P.W., Delgado, V., Dendale, P., Diener, H.-C., Dorobantu, M., Fagard, R., Farsang, C., Ferrini, M., Graham, I.M., Grassi, G., Haller, H., Hobbs, F.D.R., Jelakovic, B., Jennings, C., Katus, H.A., Kroon, A.A., Leclercq, C., Lovic, D., Lurbe, E., Manolis, A.J., McDonagh, T.A., Messerli, F., Muiesan, M.L., Nixdorff, U., Olsen, M.H., Parati, G., Perk, J., Piepoli, M. F., Polonia, J., Ponikowski, P., Richter, D.J., Rimoldi, S.F., Roffi, M., Sattar, N., Seferovic, P.M., Simpson, I.A., Sousa-Uva, M., Stanton, A.V., van de Borne, P., Vardas, P., Volpe, M., Wassmann, S., Windecker, S., Zamorano, J.L., Windecker, S., Aboyans, V., Agewall, S., Barbato, E., Bueno, H., Coca, A., Collet, J.-P., Coman, I.M., Dean, V., Delgado, V., Fitzsimons, D., Gaemperli, O., Hindricks, G., Iung, B., Jüni, P., Katus, H.A., Knuuti, J., Lancellotti, P., Leclercq, C., McDonagh, T.A., Piepoli, M.F., Ponikowski, P., Richter, D.J., Roffi, M., Shlyakhto, E., Simpson, I.A., Sousa-Uva, M., Zamorano, J.L., Tsioufis, C., Lurbe, E., Kreutz, R., Bochud, M., Rosei, E.A., Jelakovic, B., Azizi, M., Januszewics, A., Kahan, T., Polonia, J., van de Borne, P., Williams, B., Borghi, C., Mancia, G., Parati, G., Clement, D.L., Coca, A., Manolis, A., Lovic, D., Benkhedda, S., Zelveian, P., Siostrzonek, P., Najafov, R., Pavlova, O., De Pauw, M., Dizdarevic-Hudic, L., Raev, D., Karpettas, N., Linhart, A., Olsen, M.H., Shaker, A.F., Viigimaa, M., Metsärinne, K., Vavlukis, M., Halimi, J.-M., Pagava, Z., Schunkert, H., Thomopoulos, C., Páll, D., Andersen, K., Shechter, M., Mercuro, G., Bajraktari, G., Romanova, T., Trušinskis, K., Saade, G.A., Sakalyte, G., Noppe, S., DeMarco, D.C., Caraus, A., Wittekoek, J., Aksnes, T.A., Jankowski, P., Polonia, J., Vinereanu, D., Baranova, E.I., Foscoli, M., Dikic, A.D., Filipova, S., Fras, Z., Bertomeu-Martínez, V., Carlberg, B., Burkard, T., Sdiri, W., Aydogdu, S., Sirenko, Y., Brady, A., Weber, T., Lazareva, I., Backer, T. De, Sokolovic, S., Jelakovic, B., Widimsky, J., Viigimaa, M., Pörsti, I., Denolle, T., Krämer, B.K., Stergiou, G.S., Parati, G., Trušinskis, K., Miglinas, M., Gerdts, E., Tykarski, A., de Carvalho Rodrigues, M., Dorobantu, M., Chazova, I., Lovic, D., Filipova, S., Brguljan, J., Segura, J., Gottsäter, A., Pechère-Bertschi, A., Erdine, S., Sirenko, Y., Brady, A., 2018. 2018 ESC/ESH guidelines for the management of arterial hypertension the task force for the management of arterial hypertension of the European society of Cardiology (ESC) and the European society of hypertension (ESH). Eur. Heart J. 39, 3021–3104. https://doi.org/10.1093/EURHEARTJ/EHY339.