J Appl Physiol 129: 1304–1309, 2020.
First published October 1, 2020; doi:10.1152/japplphysiol.00608.2020.

MINI-REVIEW | *Physiology of Thermal Therapy*

The health benefits of passive heating and aerobic exercise: To what extent do the mechanisms overlap?

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Submitted 14 July 2020; accepted in final form 28 September 2020

Cullen T, Clarke ND, Hill M, Menzies C, Pugh CJ, Steward CJ, Thake CD. The health benefits of passive heating and aerobic exercise: To what extent do the mechanisms overlap? *J Appl Physiol* 129: 1304–1309, 2020. First published October 1, 2020; doi:10.1152/japplphysiol.00608.2020.—Exercise can induce numerous health benefits that can reduce the risk of chronic diseases and all-cause mortality, yet a significant percentage of the population do not meet minimal physical activity guidelines. Several recent studies have shown that passive heating can induce numerous health benefits, many of which are comparable with exercise, such as improvements to cardiorespiratory fitness, vascular health, glycemic control, and chronic low-grade inflammation. As such, passive heating is emerging as a promising therapy for populations who cannot perform sustained exercise or display poor exercise adherence. There appears to be some overlap between the cellular signaling responses that are regulated by temperature and the mechanisms that underpin beneficial adaptations to exercise, but detailed comparisons have not yet been made. Therefore, the purpose of this mini review is to assess the similarities and distinctions between adaptations to passive heating and exercise. Understanding the potential shared mechanisms of action between passive heating and exercise may help to direct future studies to implement passive heating more effectively and identify differences between passive heating and exercise-induced adaptations.

adaptation; exercise; health; heat; therapy

INTRODUCTION

Physical inactivity increases the risk of several chronic diseases, such as cardiovascular disease, type 2 diabetes, and obesity (4). In contrast, regular exercise elicits a variety of health benefits and attenuates traditional cardiovascular disease risk factors, including blood pressure and body weight/adiposity, as well as improved blood lipid profiles, insulin sensitivity, and cardiorespiratory fitness (43). More recently, this understanding has extended to include nontraditional factors such as antiatherogenic effects propagated by functional and structural adaptations within the vasculature (18) and the anti-inflammatory effects of exercise (48). Despite the overwhelming evidence for its efficacy, exercise is typically not well adhered to, with common self-reported barriers including lack of motivation, time, poor physical fitness, and low self-esteem (53). However, older populations also avoid exercise due to an increased fear of injury and pain (35). As such, alternative or adjunct therapies capable of eliciting similar systemic health benefits have considerable clinical implications and warrant further investigation.

In recent years, there has been a resurgence of interest in the potential health benefits of passive heating or "'thermal therapy," with some authors promoting heat therapy as a potential alternative to exercise for populations with physical disabilities and those who find adherence to exercise difficult (7, 26). Thus far, a range of different methods of passive heating have been used such as sauna bathing, hot water immersion, water-perfused suits, or microwave diathermy. Epidemiological studies from Finland, where sauna bathing is common, have demonstrated that regular sauna bathing and a high level of cardiorespiratory fitness (argued to be a surrogate of regular physical activity) independently reduce the risk of death by cardiovascular disease, but this risk is further reduced by a combination of high cardiorespiratory fitness and regular sauna bathing (33). If the protective effects of these therapies are complementary, it raises the question as to "how" these protective effects are conferred and to what extent these mechanisms overlap. A growing number of studies have begun to elucidate the mechanisms by which the protective effects of thermal therapy may be conferred, and the reader is directed to reviews on these topics (e.g., 9, 25, 28). Given that studies of passive heating are still in their relative infancy, understanding the potential shared mechanisms of action with exercise may help to direct future studies and the implementation of passive heating more effectively. To focus on the potential overlap of mechanisms, this review will primarily draw upon literature from nondiseased populations and will only make a reference to other

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populations where useful to do so. The purpose of this mini review is to assess the similarity and distinctions between the cardiovascular and metabolic health benefits induced by passive heating and exercise, to highlight any areas by which passive heating may lack some of the benefits of exercise, and to discuss important areas of future study.

CARDIORESPIRATORY FITNESS

Cardiorespiratory fitness [typically measured by maximal oxygen uptake, ($\dot{V}O_{2max}$)] is a strong predictor of all-cause mortality and death by cardiovascular disease (52), with some authors suggesting that cardiorespiratory fitness is in fact a better predictor of all-cause mortality than established cardiovascular disease risk factors (44). Despite its apparent importance, a limited number of studies have reported the cardiorespiratory fitness responses to thermal therapy, but results thus far are positive, with several studies reporting improvements of ~2–3 mL/kg/min over 6–8 wk (2, 24, 40).

Given that the beneficial health effects of exercise are thought to be due to the diverse physiological adaptations that underpin improved cardiorespiratory fitness, the precise nature of adaptations to both passive heating and exercise should be carefully considered. Even when focusing solely on aerobic exercise, the mechanisms of adaptation are incredibly broad and span both the cardiovascular and musculoskeletal systems (see Fig. 1). Following aerobic training in untrained populations, increases in cardiac output and stroke volume are considered to be among the largest contributing adaptations to improvements in cardiorespiratory fitness (50), and these adaptations are thought to be due to increases in left ventricular dimensions, increased myocardial contractility, and an increased blood volume (23). There is also a wealth of evidence from the heat acclimation literature that heating induces an expansion of plasma volume (19), which contributes to enhanced cardiorespiratory fitness via subsequent increases in blood volume, cardiac filling, and stroke volume (22). Somewhat surprisingly, few studies documenting increased cardiorespiratory fitness following passive heating have assessed hematological or cardiac adaptations, and this warrants further consideration. Given the dearth of evidence from longitudinal studies, discussion of the acute physiological responses to passive heating and exercise may help to understand the "potential" chronic adaptations.

During maximal aerobic exercise, cardiac output can increase by ~18–25 L/min, whereas more modest increases up to ~10 L/min are observed when core temperature is increased by ~1.5°C during passive heating using a water-perfused suit (16). However, it should be noted that there will be subtle differences in the acute physiological responses dependent on the method of heating; for example, water immersion will cause an increase in hydrostatic pressure and subsequent preload (38). During exercise, the increase in cardiac output primarily facilitates an increase in blood flow to the active muscle, whereas during passive heating, a significantly greater proportion of blood is distributed to the skin to facilitate thermoregulation (10). The increase in cardiac output during heating is primarily facilitated by an increased heart rate, which has been shown to increase by ~20–40 beats·min^{-1} depending on the duration and intensity of the heat stimulus, yet this is considerably less than that observed during moderate-intensity exercise (15, 54). Furthermore, the increase in heart rate during heating does not coincide with a concomitant increase in stroke volume, as is the case during exercise (11). As such, thermal therapy does induce some cardiac stress, albeit modest compared with exercise. Nevertheless, in heart failure patients, the magnitude of stimulus appears sufficient to improve cardiac function and cardiorespiratory fitness. For example, daily sauna bathing (15–20 min at 60°C) for 4 wk has been shown to improve cardiorespiratory fitness in heart failure patients by ~3 mL/kg/min (40). This is similar to what is seen with moderate-intensity exercise interventions in heart failure patients but lower than the reported benefits seen with higher-intensity exercise (increase of ~6 mL/kg/min) (58). Perhaps more importantly for this particular cohort, Wisløff et al. only reported beneficial left ventricular remodeling and improved cardiac function in the higher-intensity exercise group, suggesting that a relatively increased degree of cardiac stress may be required for subsequent beneficial cardiac adaptations. However, it remains unclear if cardiac adaptations

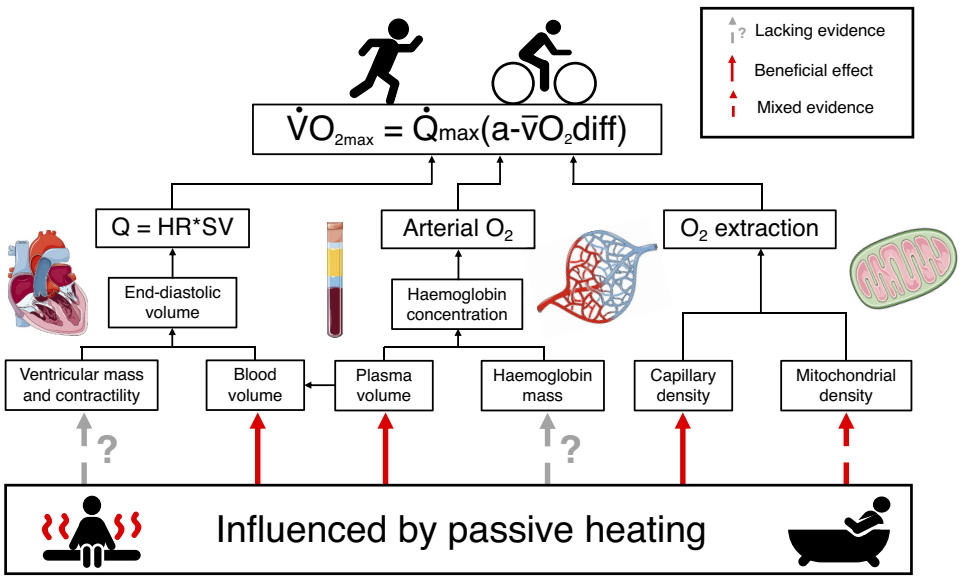

Fig. 1. Summary of the determinants of cardiorespiratory fitness measured by $\dot{V}O_{2max}$ and the "potential" influence of passive heating on those determinants. a-vO_2diff is the difference in oxygen content between a (arterial blood) and v (venous blood). Scientific illustrations produced by Servier Medical Art (https://smart.servier.com) and used under the terms of the Creative Commons 3.0 license.

following passive heating extend to populations without severe limitations to their cardiac function, and this should be investigated further.

Two recent studies in healthy populations have shown that passive heating, consisting of thrice weekly 30–50-min sessions for 6–8 wk, improved cardiorespiratory fitness to a similar extent (~5–8%) as time-matched moderate-intensity aerobic exercise (2, 24). However, cardiorespiratory fitness was not the primary outcome variable upon which the sample size was calculated in these studies, and therefore, larger studies are required before it can be firmly concluded that passive heating and exercise induce similar adaptations to aerobic fitness. Interestingly, Hesketh et al. reported adaptations within the skeletal muscle that likely contributed to the observed increase in cardiorespiratory fitness (as described in Fig. 1), but there were some differences between the response to exercise and passive heating. Specifically, passive heating enhanced muscle endothelial nitric oxide synthase (eNOS) content and capillary density to a similar extent as exercise, but only exercise enhanced markers of mitochondrial density (24). However, the thermal stimulus used was relatively low (40–50 min heat chamber exposure at 40°C and ~40% humidity), and in fact, core temperature was not elevated by passive heating but was significantly increased by the exercise intervention. The current available evidence suggests that angiogenic adaptations to passive heating require a relatively lower heat stimulus than mitochondrial adaptations, which are not always evident (24, 32), and appear to require a more prolonged increase in intramuscular temperatures, which can be achieved more easily with local than whole body heating (20). Taken together, passive heating does appear to improve cardiorespiratory fitness in healthy sedentary and diseased populations, but as with exercise, the exact nature and extent of these adaptations are likely determined by the duration, intensity, mode, and location of heating. For a detailed review of the skeletal muscle adaptations to heat therapy, the reader is directed to the recent review by Kim et al. (31).

VASCULAR HEALTH

It is widely accepted that most cardiometabolic diseases are characterized by vascular dysfunction, which can include impaired endothelial function, arterial stiffening, and increased arterial wall thickness of both peripheral and central arteries. The protective effects of exercise on the vasculature have been extensively reviewed elsewhere (18), and recent evidence suggests that thermal therapy may also elicit a range of vascular benefits (10).

In response to exercise training, it is thought that there is an initial improvement in endothelial function, as measured by brachial artery flow-mediated dilation (FMD), which over time may be superseded by structural adaptations, such as an increased lumen diameter and reduced arterial wall thickness (56). Several studies have shown that passive heating can also enhance brachial artery endothelial function (2, 7, 9); however, it remains unclear whether longer-term heat therapy can elicit any structural remodeling to peripheral vessels.

Brunt et al. have provided the most robust evidence of systemic vascular adaptation following thermal therapy, showing improvements in peripheral artery endothelial function and compliance, alongside reductions in central artery stiffness and wall thickness. Encouragingly, this comprehensive work indicates that the magnitudes of peripheral and central artery adaptations following heat therapy are comparable with those typically observed following exercise training. Indeed, Bailey demonstrated that for a similar acute increase in core temperature (0.6°C–0.8°C) per session, 8 wk of passive heating elicited the same improvement in brachial artery FMD (1.7%) as continuous moderate-intensity exercise training. Nevertheless, it is probable that both the magnitude and time course of adaptation will differ between peripheral and central vessels and will likely be influenced by the magnitude of heat stress. For instance, the considerable vascular adaptations reported by Brunt et al. were in response to a 90-min protocol (aiming to increase core temperature by 1.5°C), whereas others (2, 9) used a 30-min protocol that increased core temperature by only ~0.6°C.

Episodic increases in shear stress is an essential stimulus for enhanced endothelial function (18). Indeed, removing shear stress via the use of an inflatable cuff prevents the beneficial effects of both exercise (56) and passive heating (9) on endothelial function. Interestingly, there is evidence that an acute bout of passive heating can induce greater shear stress than dynamic exercise (55); however, this finding is likely dependent on the individual nature of each stressor (i.e., magnitude and duration of heat stress and intensity of exercise), and direct comparisons should be carefully considered within this specific context. Shear stress is thought to induce a cascade of signaling factors, including eNOS, VEGF, and multiple heat shock proteins (HSPs), which contribute to angiogenesis following exercise (18) and passive heating (10). Recent evidence suggests that nitric oxide appears essential to angiogenic adaptations following passive heating (7, 8); however, the role of other circulating factors including HSPs and VEGF appears less clear and indeed in some cases display distinct responses to exercise and heat (41, 42).

CARDIOMETABOLIC HEALTH

Regular exercise elicits a range of beneficial effects on cardiometabolic health, with previous research historically focusing on improvements to classic cardiovascular risk factors, such as blood pressure, insulin sensitivity, blood lipid profiles, and fat mass (43).

In response to acute exercise (49) and passive heating (39), glucose tolerance is reduced, but once these interventions are repeated for several weeks, glucose tolerance is increased. One of the earliest studies of heat therapy reported daily hot water immersion (38°C–41°C) for 3 wk reduced fasting blood glucose and glycated hemoglobin (HbA_{1c}) (28). Several subsequent studies have since reported reductions in fasting glucose and insulin concentration (14, 25, 47) and improved glucose tolerance (e.g., 13, 23). Some studies have also reported beneficial changes in blood lipid profiles following heat therapy in healthy active (19) and sedentary obese populations (13) that are similar in magnitude to what is reported by large-scale meta-analyses of aerobic exercise interventions (30). Relatively large-scale meta-analyses including 54 randomized control trials in normotensive and hypertensive populations have shown that regular aerobic exercise chronically reduces systolic and diastolic blood pressure by 3.8 and 2.6 mmHg, respectively (57). In comparison, reductions in blood pressure are also consistently reported following chronic thermal therapy. Importantly, these reductions may indeed be of a larger magnitude than is seen following

exercise training, with some studies reporting decreases of systolic and diastolic blood pressure in the region of ~10 and ~5 mmHg, respectively (1, 6, 13, 25). Further studies are required to investigate these potential effects in more detail and in conjunction with other complementary therapies such as dietary and exercise interventions.

Sedentary behavior or physical inactivity can lead to chronic low-grade inflammation, characterized by twofold to fourfold elevations in inflammatory markers, such as C-reactive protein (CRP), TNF-α and IL-6, which are thought to underpin several aspects of metabolic dysfunction including insulin resistance and atherosclerosis (51). For example, TNF-α has been shown to directly induce insulin resistance (29), is actively involved in the development of atherosclerotic lesions (5), and also increases the production of reactive oxygen species that are thought to play a role in endothelial dysfunction (37). Exercise can reduce chronic low-grade inflammation via a reduction in visceral fat mass and subsequent reduction in adipokine release from adipocytes and via the transient induction of an anti-inflammatory state with each bout of exercise (17). During exercise, IL-6 is released from the skeletal muscle and is thought to drive the subsequent increase in anti-inflammatory cytokines, such as IL-1Ra, IL-4, and IL-10, and reduce the resting concentration of pro-inflammatory mediators, such as CRP and TNF-α (48). Multiple passive heating studies have consistently reported an increase in the circulating concentration of IL-6, whereas the evidence for acute elevations in other inflammatory mediators such as HSPs is somewhat equivocal (26). However, when exercise and passive heating are matched for the increase in core temperature, the increase in circulating IL-6 is threefold greater following exercise (15). This may be important because the modest increases in IL-6 observed during shorter bouts of exercise (30–45 min) may not be sufficient to induce downstream potent anti-inflammatory mediators such as IL-10 and IL-4 (12), which are important for improving insulin sensitivity and glucose metabolism (27). Future studies should attempt to establish an exercise dose response for a wider array of anti-inflammatory mediators.

Despite some convincing epidemiological data supporting the anti-inflammatory effects of thermal therapy (34), there have been few controlled trials assessing chronic inflammatory responses to passive heating, and indeed, some of these were of only a short duration (~2 wk) (25). In this regard, longer-term studies should be encouraged. Generally, the most beneficial effects have been seen in diseased populations with elevated levels of chronic inflammation (14, 46), which is indeed similar to what is seen with exercise interventions (3). Interestingly, Ely et al. reported no change in body composition or BMI following passive heating, suggesting that the anti-inflammatory effects are more likely due to the transient induction of an anti-inflammatory state rather than a reduction in adipose tissue per se.

In a broader context, it is now widely appreciated that improvements in cardiovascular and metabolic health can be seen in the absence of changes in fat mass (21). However, weight loss remains an important goal for many who exercise and often represents a significant barrier to exercise whether this be due to low self-esteem regarding their body image or due to the perceived difficulty of exercising while being overweight (53). From a simplistic perspective, weight loss is dependent on a deficit of energy intake versus energy expenditure and, when matched for the thermal load and duration, exercise results in ~10 times greater energy expenditure than passive heating (15). Indeed, Bailey et al. (2) reported that 8 wk of moderate-intensity exercise reduced body weight, whereas time-matched hot water immersion did not. Initial evidence also suggests that gut hormone and hunger hormone responses are not altered in response to passive heating, suggesting that as an independent therapy,

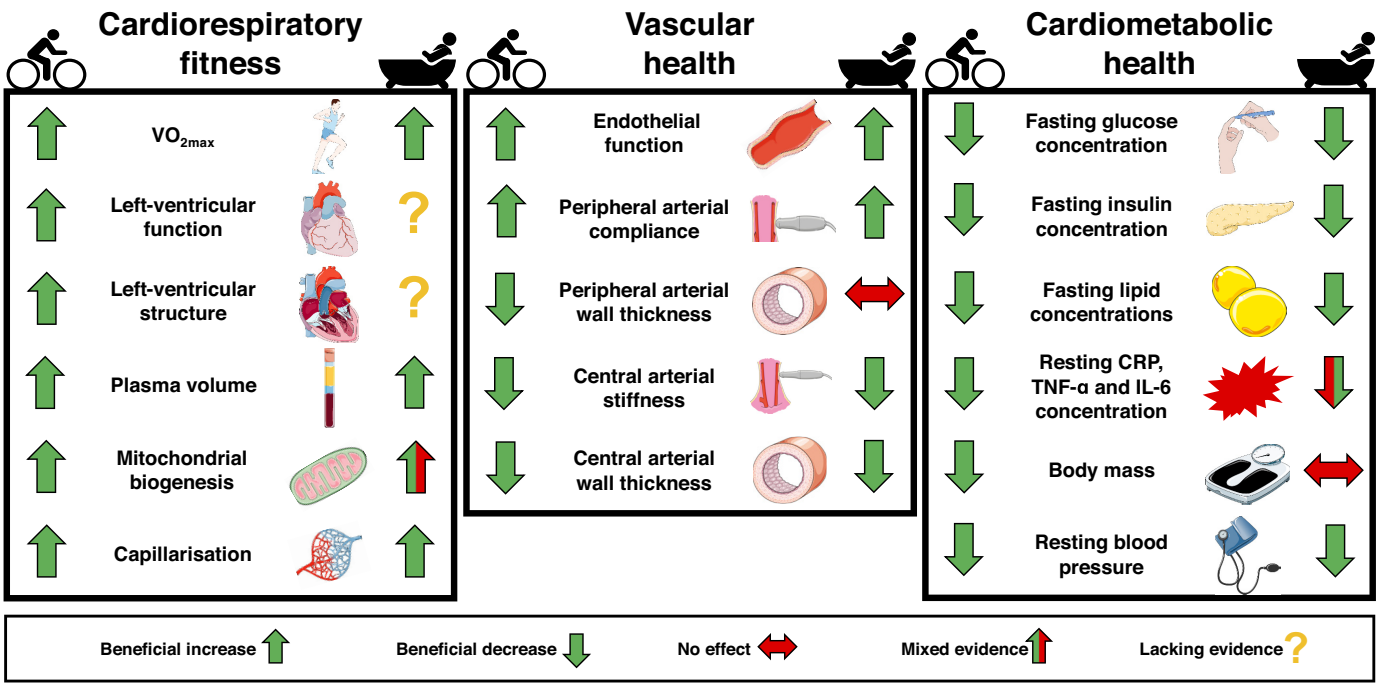

Fig. 2. Summary of chronic adaptations to exercise and passive heating. Where evidence is indicted as "mixed," this may be due to different results observed depending on the population studied or the nature of the heating stimulus. Scientific illustrations produced by Servier Medical Art (https://smart.servier.com) and used under the terms of the Creative Commons 3.0 license.

passive heating is likely to have minimal impact on long-term weight management (36). In populations for whom weight loss is particularly important, it may be beneficial to consider passive heating as a complementary therapy to existing strategies of exercise and/or diet modification.

CONCLUSION AND FUTURE DIRECTIONS

There is considerable overlap between the protective effect of passive heating and exercise, with beneficial adaptations reported in cardiorespiratory fitness, vascular function, and metabolism. Yet, heating does not appear to confer all the important benefits of exercise and potentially not to the same degree in all cases (see Fig. 2 for a summary). It is important to consider that our understanding of the health benefits of exercise has developed over several decades, providing considerable detail and nuance to how different populations respond to different forms of exercise, while the study of passive heating is still in its relative infancy. In this regard, exercise should be considered as the primary route for maintaining and improving health. Having said this, the health benefits of passive heating have been observed in healthy sedentary and some diseased populations, supporting the supposition that passive heating may be a promising therapy in those who display poor exercise adherence. In this regard, research should continue to focus on those specific populations who may benefit most, and a wide range of populations remain unstudied. It will be hugely important to investigate the risks and potential adverse outcomes associated with passive heating. These remain relatively unexplored but include potential heat illness, orthostatic intolerance, and an increased risk of falling, especially in older individuals (28, 45). Similarly, the physiological basis of these events and any subsequent mitigating strategies should be developed as they have been with exercise.

A limitation of the current comparison between passive heating and exercise is that passive heating interventions are often designed to induce the largest tolerable dose of heating and then subsequently compared with a bout of exercise. Although often similar in terms of the time required, significantly larger volumes of exercise could be tolerated (motivation and time availability notwithstanding). Future studies should also consider the perceptual stress and enjoyment of different interventions with a view to better understanding the potential impact on long-term adherence. If passive heating is to be promoted as an alternative to exercise, future studies should take a systematic approach to understanding the optimal method and dose responses for different health-related adaptations. These studies should carefully consider different durations, frequencies, intensities, mode of heating (i.e., sauna vs. water immersion), and degree of body exposure (i.e., whole body vs. peripheral), as each factor may well impact subsequent chronic adaptations. Finally, it remains to be seen whether passive heating may be used in conjunction with exercise, either before or after, to enhance or supplement the subsequent health benefits of either intervention when performed in isolation.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

T.C. conceived and designed research; T.C., C.M., and C.J.S. prepared figures; T.C. drafted manuscript; T.C., N.D.C., M.H., C.M., C.J.A.P., C.J.S., and C.D.T. edited and revised manuscript; T.C., N.D.C., M.H., C.M., C.J.A.P., C.J.S., and C.D.T. approved final version of manuscript.

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