REVIEW

Exercising in Stressful Environmental Conditions with Hypertension Versus Normal Blood Pressure

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ABSTRACT

Hypertension (high blood pressure [BP]) is the most common, costly, and preventable cardiovascular disease risk factor in the world. Regular aerobic exercise is universally recommended as a lifestyle therapeutic intervention for the prevention, treatment, and control of high blood pressure. However, the stressor response to exercise in extreme but commonly experienced stressful environments may be exacerbated in individuals with hypertension, a situation not fully described in the literature. Therefore, we performed a systematic search examining the potential adverse health effects of exercising in hot, humid, cold, or air-polluted environments among adults with hypertension. Studies included adults with hypertension compared to normal BP and that with at least one physiological marker in response to heat, humidity, cold, windchill, or air pollution. The present systematic review revealed few studies that explored differences between individuals with hypertension and normal BP while exercising in commonly experienced stressful environmental conditions. Our preliminary evidence suggests that adults with hypertension may be more vulnerable to adverse cardiovascular stressor responses while exercising in the heat. Future studies are required to better characterize these maladaptive responses to extreme heat or humidity to better identify potential countermeasures for this vulnerable population. *Journal of Clinical Exercise Physiology*. 2018;7(3):53–62.

Keywords: physical activity, extreme environments, adaptation

INTRODUCTION

Hypertension is the most common, costly, and modifiable cardiovascular disease (CVD) risk factor in the world, affecting ~874 million adults worldwide and resulting in US $46.4 billion in direct and indirect healthcare costs (1). Participation in regular exercise is a key modifiable determinant of hypertension and is recognized as a cornerstone therapy for the primary prevention, treatment, and control of high BP (2-5). The American College of Sports Medicine (ACSM) recommends that individuals with hypertension engage in moderate intensity aerobic exercise 5 to 7 days per week, supplemented by resistance exercise 2 to 3 days per week for a total of 150 minutes per week or 700-2000 calories per week (6). However, to the best of our knowledge, no formal guidelines exist for exercise prescription (ExR_x) modifications in response to stressful environmental conditions for individuals with hypertension. This is surprising, given the well-established acute and chronic effects that environmental factors (e.g., temperature, air pollution, noise) can have on BP (7,8).

Furthermore, the present and projected lasting consequences of global climate change—such as decreased air quality and extreme temperature variability—are considered by some to be inevitable, non-modifiable, and with the potential to prohibitively exclude exercise for individuals that stand to benefit from many of its associated health benefits, such as adults with hypertension (9). The US Global Change Research Program has declared individuals with hypertension as a population of concern (10) and more

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vulnerable in experiencing adverse health-related effects in response to outdoor air pollution or heat than the general population.

Accordingly, the overall goal of the present review is to appraise differences in the physiological responses between healthy adults with normal BP and individuals with hypertension during exposure to common environmental stressors, thereby informing ExR_x recommendations and future priorities for research. We hypothesize that individuals with hypertension performing exercise in stressful environmental conditions (such as excessive heat, humidity, cold, and air pollution) will experience augmented physiological responses compared to individuals with normal BP, warranting reevaluation of special considerations regarding exercise (Figure 1).

METHODS

With the assistance of a trained medical librarian, a systematic search with keywords was performed in PubMed from inception (late 1940s and selectively back to 1809) until May 1, 2018 (Appendix A). Randomized controlled trials were included with human, adult populations (≥18 years old) designed to examine individuals with hypertension in comparison to normal BP, including at least one physiological marker in response to heat, humidity, cold, windchill, or air pollution. Potential reports were screened by title only and, if deemed relevant, then by title and abstract, and lastly by full-text review (Appendix B).

Eligible studies were synthesized and presented with the following section format: (*a*) brief introduction of the environmental stressor (i.e., heat, cold, air pollution); (*b*) overview of the typical response to the stressor *at rest* in healthy adults with normal BP; (*c*) overview of the response to the stressor during *exercise* in healthy adults (Table 1); (*d*) presentation of the results from the systematic review (i.e., physiological response to the stressor during exercise in individuals with hypertension; Table 2).

HEAT AND HUMIDITY

The relationship between temperature and BP in healthy adults is well established, given the role the cardiovascular system plays in thermoregulation (11). At rest, acute increases in temperature (e.g., passive heating) cause central and peripheral alterations that maintain core body temperature. Cutaneous or peripheral blood vessel dilation facilitates increased skin blood flow and evaporative (e.g., sweat) and dry heat loss. This reduction in total peripheral resistance (TPR) provokes an increase in heart rate (HR) and a slight increase in stroke volume (SV), such that overall cardiac output (CO) is increased and BP remains unchanged or is maintained (11).

During exercise, the metabolic heat produced by muscle increases the deep body temperature and elicits similar cardiovascular and thermal responses as at rest (Table 1). Baroreceptor resetting increases BP substantially to meet the circulatory demands of both muscle and skin (11). The addition of heat stress to the cardiovascular demands of exercise

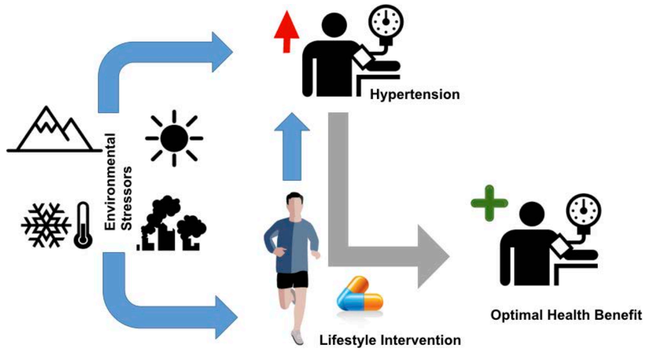

FIGURE 1. Hypothetical model of common environmental stressors, heat, cold, and air pollution and their moderating effect on the antihypertensive benefits of exercise. In this theoretical model, environmental stressors, in combination with hypertension, impose deleterious adaptations (i.e., maladaptations) to repeated exercise, and compromise the optimal health benefits gained from exercise.

results in an even greater allocation of CO to working skeletal muscles and skin, coupled with an increased peripheral resistance in the renal and splanchnic beds (11). Even under conditions of heat stress, BP is defended and maintained at a level determined by workload and at a level greater than at rest (11).

Individuals with hypertension are more likely to suffer from heat-related complications during exercise than those with normal BP (12-15). Structural and functional alterations that are associated with hypertension appear to impair thermoregulatory function during and after exercise in the heat. Kenney et al. were the first to examine the influence of exercise in the heat between individuals with normal BP and hypertension (16-18). The authors examined the influence of a single bout of light intensity, dynamic leg exercise (40% maximum oxygen consumption, VO_2max), performed for 1 hour in a hot environment (38°C dry-bulb, 28°C wet-bulb) among men with unmediated hypertension (150/97 mm Hg; *n* = 6) and men with normal BP (115/73 mm Hg; *n* = 6). Men with hypertension experienced greater vascular resistance and a 30% greater mean arterial pressure (MAP) response to exercise compared to men with normal BP (16,17). In addition, the men with hypertension experienced greater thermal strain, such that men with hypertension had 81% less skin blood flow and 56% less core-to-skin heat transfer than men with normal BP (18).

Ribeiro et al. (19) examined the influence of hydration on exercise performed in a hot environment, among men with unmediated hypertension (143/98 mm Hg; *n* = 8) and men with normal BP (113/78; *n* = 8). The men performed a single bout of light intensity exercise (40% VO_2max) on a cycle ergometer for 60 minutes while drinking water (500 mL 2 hours before and 115 mL every 15 minutes) or without water ingestion in a warm, humid environment (30°C, 85% humidity; 19). The authors reported that men with hypertension had higher HR (10%), systolic BP (SBP; 21%), diastolic BP (DBP; 20%), and skin temperature (1%) during both experimental conditions compared with men with normal

TABLE 1. Acute physiological responses of healthy adults to exercise in harsh environmental conditions.

	Environmental Condition and Stressor Response		
Body System	**Heat and Humidity**	**Air Pollution***	**Cold and Windchill**
Cardiovascular System	↑CO, ↑SV, ↑HR, ↑BP, ↑skin and muscle blood flow, ↓blood plasma volume, ↓ splanchnic blood flow, ↓SV in extreme cases (i.e., heat illness)	↑or ↔HR, ↑or ↔BP, ↑ blood coagulability, ↑inflammation, ↓decreased flow-mediated dilatation response	↔CO, ↑SV, ↓ or ↔ HR, ↔BP, ↓skin blood flow, ↔inner organ blood flow
Muscular System	↑metabolic activity, ↑blood flow	↓reoxygenation of muscle microcirculation	↑shivering to produce metabolic heat, ↑lactate production
Endocrine System	↑water and NaCl retention	NR	↑water and NaCl retention, ↑thyroid/adrenal hormones to increase metabolism
Respiratory System	↑breathing rate, ↓VO_2max, ↓endurance capacity	↑breathing rate, ↓VO_2max, ↓pulmonary function, ↓exercise performance	↑breathing rate, ↓VO_2max, ↓endurance capacity
Nervous System	↑efferent output from hypothalamus to maintain temperature homeostasis	↑ or ↔ efferent output from the hypothalamus, to maintain homeostasis of blood CO_2 and O_2 partial pressure, pH	↑efferent output from hypothalamus to maintain temperature homeostasis, ↓sweat rate, ↓heat loss via radiation and convection, ↑respiratory heat loss
Thermoregulatory System	↑skin blood flow, ↓urine output, ↑heat dissipation via skin evaporation, ↑sweat rate	NR	↑urine volume, ↓sweat rate

CO_2 = carbon dioxide; NO_2 = nitrogen dioxide; CO = cardiac output; SV = stroke volume; HR = heart rate; BP = blood pressure; VO_2max = maximum oxygen consumption; NaCl = sodium chloride; NR = not reported.
*Physiological stressor response may vary by pollutant.

BP. Ribeiro et al. attributed this response to an increase in sympathetic activity required to maintain the same muscle power during exercise among men with hypertension (19). Interestingly, exercise-induced cardiac work and skin temperature were greater among men with hypertension compared to those with normal BP, and the magnitude of this difference was even greater after water ingestion. These results suggest that hydration protocols prescribed for those with normal BP may induce an overload effect in those with hypertension; however, future studies are required to confirm these provocative findings (19).

More recently, Fonseca et al. (20) examined the thermoregulatory responses of men with hypertension on medication for high BP (MAP, 98 mm Hg; n = 9) and men with normal BP (MAP, 86 mm Hg; n = 8) after moderate intensity (50% VO_2max) aerobic exercise on a treadmill for 1 hour, followed by 1 hour of resting recovery in a hot and humid environment (38°C, 60% humidity). Similar to Kenney et al. (16,17), the authors reported that MAP was higher in the men with hypertension compared to those with normal BP (20). In addition, men with hypertension appeared to store less heat and had more evaporated sweat during recovery than did men with normal BP, suggesting that men with hypertension appear to have greater heat dissipation and body cooling than men with normal BP, immediately following moderate-intensity aerobic exercise in hot and humid conditions (20). However, the generalizability of these results are limited because the individuals were taking antihypertensive medications (e.g., diuretics and ACE inhibitors), which may have resulted in greater cutaneous vasodilation and increased sweat evaporation (20).

COLD AND WINDCHILL

Epidemiological studies have consistently shown that CVD events are more likely to occur in the winter, with the relative risk for myocardial infarction increasing 1.1× for each decrease in 5-day average temperature of 1°C (15). In addition, CVD-related events (e.g., myocardial infarction, sudden cardiac death, stroke) are more likely to occur in the early morning awakening period; this peak incidence occurs in parallel with otherwise normal circadian surges in catecholamines and morning BP (21). At rest, acute cold exposure evokes thermoregulatory, cardiovascular, and metabolic responses that diminish heat loss to maintain body temperature. In contrast to passive heating, cold air exposure lowers skin blood flow through constriction of cutaneous blood vessels, causing warm blood to be shunted to the deep body to reduce heat loss. This redistribution of blood flow to the deep body results in an increase in BP, CO, and central blood volume (SV), with little or no change to HR (22).

The physiological responses to exercise in the cold are complicated, multifaceted, and vary depending on individual and environmental factors, such as exercise intensity, quality of insulative clothing, or the presence of additional stressful

TABLE 2. Major findings from trials that examined adults with hypertension versus normal BP exercising in extreme environmental conditions.

Author (Year)	Subject Sample	Environmental Condition	Exercise Intervention	Major Findings
Heat and Humidity				
Kenney et al. (1984)	Men with hypertension (*n* = 6, 150/97) vs. normal BP (*n* = 6, 115/73)	Warm environment (38°C dry-bulb, 28°C wet-bulb)	F: single bout I: 40% of VO_2max T: 60 min T: dynamic leg exercise	Men with hypertension had 81% lower skin blood flow and 56% less core-to-skin heat transfer during exercise in the heat, versus men with normal BP
Ribiero et al. (2004)	Men with hypertension (*n* = 8,143/98 mm Hg) vs. normal BP (*n* = 8, 113/78 mm Hg)	Hot, humid environment (30°C and 85% humidity)	F: single bout I: 40% of VO_2peak T: 60 min T: aerobic, cycle ergometer	Men with hypertension had higher HR (10%), SBP (21%), DBP (20%), and skin temperature (1%) during exercise in the heat than did men with normal BP
Fonesca et al. (2015)	Men with medicated hypertension (*n* = 0, MAP, 98 mm Hg) vs. normal BP (*n* = 8, MAP, 86 mm Hg)	Hot, humid environment (38°C and 60% humidity)	F: single bout I: 50% of VO_2max T: 60 min T: aerobic, treadmill	Men with hypertension had higher MAP during exercise than those with normal BP but evaporated more sweat during recovery than did men with normal BP
Cold and Windchill				
No studies exist				
Air Pollution				
Gong et al. (1998)	Adults with hypertension (*n* = 10, 147/74 mm Hg) vs. normal BP (*n* = 6, 119/74 mm Hg)	0.3 ppm ozone exposure vs. filtered air	F: single bout I: 30-40 L/min T: 60 min (intermittent, 15 min) T: aerobic, cycle ergometer	Both groups experienced an increase of HR ~8 bpm and decrease in lung function ~6%, with no differences between groups. Men with hypertension experienced greater increases in BP (169/88 mm Hg) compared to subjects with normal BP (145/80 mm Hg)

FITT = frequency, intensity, time, type; BP = blood pressure; MAP = mean arterial pressure; SBP = systolic BP; DBP = diastolic BP; VO_2 = oxygen consumption; HR = heart rate; ppm = parts per million.

conditions (e.g., windchill, rain). In general, the metabolic cost of exercise in the cold is greater than exercise in thermoneutral conditions so that ventilation, oxygen consumption, muscle glycogen utilization, and lactate production are higher when exposed to cold environments (22). During exercise, active working muscles produce metabolic heat that may or may not counteract cold-induced shivering. Similar to exercise in mild or hot/humid environments, baroreceptor resetting increases BP to meet the circulatory demands of both muscle and skin (11). However, CO and HR may be lower than mild or warm conditions due to increased TPR and SV, while exercising BP may be higher (22).

Individuals with hypertension are more likely to suffer from cold-related complications than are those with normal BP both at rest and during physical exertion (15,23). However, the mechanisms underlying these adverse responses are not well understood. Studies of individuals with hypertension exercising in cold environments are surprisingly rare. Individuals with hypertension experience exercise-induced increases in BP from baseline that are greater than those with normal BP. Perturbations that further increase BP, such as cold temperature, may elicit elevations in BP that supersede those levels experienced by individuals with hypertension exercising in mild environments. To the best of our knowledge, this has not been directly explored in humans; however, there is preliminary evidence to support this hypothesis.

Otsuki et al. (24) examined exercise-induced changes in SBP during low-intensity, self-paced, outdoor walking in cold (11.6-14.3°C), intermediate (15.1-16.7°C), and warm (17.0-19.6°C) conditions among middle-aged to older adults (*n* = 109, 66.8 ± 6.5 y, 124 ± 14 mm Hg). The researchers reported that, among all subjects, light intensity walking in the cold elicited increases in SBP from baseline (+22 mm Hg) compared to intermediate (+15 mm Hg) and warm (+14 mm Hg) weather conditions. While the study was not designed to directly examine the BP response between those with hypertension and normal BP, multivariate regression models revealed that baseline BP explained ~60% of the BP response to exercise in the cold. This study provides preliminary evidence to support a rationale for future studies that characterize the BP responses to exercise in cold environments for those with hypertension versus normal BP during exercise in cold environments.

AIR POLLUTION

Airborne contaminates are categorized as primary pollutants (e.g., carbon monoxide [CO], nitrogen dioxide [NO_2], sulfur dioxide [SO_2], and fine particulates) or secondary pollutants. Secondary pollutants are generated when a primary pollutant(s) interacts with other compounds such as sulfur oxide, nitrogen oxides (aerosols), or ultraviolet light from the earth's atmosphere to form gases such as ozone (O_3) and paroxyacetyl nitrate (PAN; 22). Primary and secondary air pollutants negatively influence health at rest and during exercise via different mechanisms and to varying degrees. These adverse effects can be magnified by warm weather fronts and atmospheric conditions, which can be particularly detrimental to individuals with preexisting conditions such as asthma or hypertension (10). Air pollutants predominately affect the respiratory and cardiovascular systems by decreasing blood oxygen–carrying capacity and increasing bronchoconstriction and airway resistance, resulting in decreased VO_2max or physical performance (22). Exercise augments physiological effects due to increased ventilation and pollutant uptake of primary and secondary pollutants. In addition, increased respiratory rate causes a shift from nasal breathing to predominately mouth breathing, resulting in less nasal scrubbing that is a beneficial protective mechanism at rest. Therefore, the adverse effects of each pollutant are magnified during physical work, often resulting in compromised exercise performance and greater myocardial demands for a given workload (Table 1; 25). A comprehensive review of the complex and synergistic effects of each pollutant in healthy populations can be found elsewhere (22).

A meta-analysis of 17 trials found that acute exposure to SO_2 and particulate matter (PM2.5 and PM10) and chronic exposure to NO_2 and PM10 are associated with an increased risk of hypertension (26). Subsequently, the largest cohort study to date confirmed these findings in 41,072 participants who were free of self-reported hypertension at baseline (27). After a 5- to 9- year follow-up, the incidence of self-reported hypertension was positively associated with PM2.5, such that for every 5 $\mu g/m^3$ of PM2.5, the risk of hypertension increased by 22% (27). Further, Peel et al. (28) examined >4 million emergency department visits from 31 hospitals in Atlanta, Georgia, between January 1993 and August 2000. They reported that patients with hypertension were more likely to experience dysrhythmia in relation to ambient levels of NO_2 (per 20 parts per billion [ppb]: odds ratio (OR) = 1.095, 95%CI: 1.030-1.165) and CO (per 1 part per million [ppm]: OR = 1.065, 95%CI: 1.015-1.118) than those with normal BP (28).

It is commonly believed that individuals with hypertension experience more adverse health-related effects from air pollutant exposure than do those with normal BP. However, few primary level studies have investigated this topic. Our literature search indicated that only one study aimed to examine physiological responses to exercise in air-polluted environments between individuals with hypertension and normal BP (29). Gong et al. (29) examined the influence of an acute, 3-hour, 0.3-ppm O_3 exposure, that is, administered within an environmentally controlled chamber versus filtered air, on individuals with hypertension (*n* = 10, 147/74 mm Hg) and with normal BP (*n* = 6, 119/74 mm Hg). Throughout the exposure, the subjects performed exercise on a cycle ergometer for 15 min (target ventilation, 30-40 $L \cdot min^{-1}$), alternated with 15 min rest. Central and peripheral hemodynamics were assessed via right heart catheterization (using radial artery access), and cardiac blood biomarkers were measured. Compared to filtered air, all subjects appeared to respond in a similar fashion to acute O_3 exposure, with no changes in BP, cardiac index, and pulmonary pressure. However, all individuals experienced increased HR relative to baseline (~+8 $b \cdot min^{-1}$) after the O_3 exposure, with no difference between those with hypertension versus normal BP. Similarly, average exercise BP increased during both conditions, with no differences in the change from baseline between those with hypertension (169/88 mm Hg) compared to normal BP (145/80 mm Hg). The authors concluded that with the exception of increased HR, there were no major cardiovascular effects experienced during exercise in O_3 exposure and no differential effects between individuals with hypertension and normal BP (29). However, the generalizability of these findings is limited as the sample size was quite small (*n* = 16) and O_3 is more likely to affect respiratory, not hemodynamic, function.

PHARMALOGICAL AND ENVIRONMENTAL INTERACTIONS

When lifestyle interventions such as exercise are not effective in achieving treatment BP goals, antihypertensive therapy may be initiated. Antihypertensive medications in conjunction with exercise facilitate greater improvements in health outcomes and risk factors than with medication use alone (30). Understanding potential interactions between antihypertensive therapy, exercise, and the environment is imperative to guide clinical recommendations and patient care.

Following the most recent treatment recommendations the most commonly prescribed antihypertensive medications are: thiazide-type diuretics, calcium channel blockers (CCB), angiotensin-converting enzyme inhibitors (ACEI), angiotensin receptor blockers (ARB), or β-blockers (31). It is well established that β-blockers and diuretics adversely affect thermoregulation or increase the predisposition to hypoglycemia in certain individuals; therefore, appropriate exercise modifications (i.e., intensity, duration), nutritional counseling, and hydration precautions should be taken in these situations (6).

The literature on the combined influence of environment and antihypertensive medications on the physiological responses to exercise among individuals with hypertension is limited. Pescatello et al. (32) examined the influence of β-blockers on cutaneous blood flow and sweat responses in men with hypertension (*n* = 6) during 40 minutes of moderate intensity (60% VO_2max) cycle ergometer exercise at 22°C and 32°C and were among the first to demonstrate that men taking β-blockers experience excess heat storage during exercise in the heat. Since then, few published studies have examined the influence of antihypertensive medication on the physiological responses to exercise in stressful environmental conditions. Due to the presence of β-2 receptors in the respiratory tree, β-agonists can increase the risk of severe bronchoconstriction, particularly in patients with asthma or in the general population exposed to cold or air polluted environments (33). As such, individuals with concomitant hypertension and asthma requiring β-blockers should be prescribed cardioselective agents, which do not act on bronchial β-receptors (34).

Common sense recommendations may call for an adequate warm-up or use of a heat exchange face mask to reduce the risk of exercise-induced bronchoconstriction or coughing during exercise. Similarly, exposure to PM or other air pollutants may precipitate the need for medications to counteract symptoms associated with airway irritation, such as inhaled corticosteroids, bronchodilators, or antihistamines. While the existing research is limited, these medications may exaggerate the pressor response to exercise among individuals with hypertension and may require additional clinical oversight.

DISCUSSION

The primary goal of this systematic review was to appraise differences between individuals with hypertension and normal BP in the physiological responses to exercise performed in stressful environments. Individuals with hypertension possess deleterious pathophysiological alterations that may manifest as increased sympathetic nervous system output, enhanced vasoconstriction, or decreased endothelial function (5,35). Furthermore, individuals with hypertension are more likely to experience an exaggerated response to exercise (e.g., exercise-induced changes in SBP that exceed Δ40 mm Hg), a clinical finding that is associated with negative CVD-related health outcomes (36). For these reasons, we hypothesized that exercise performed under stressful environmental conditions confers additional risk to those with hypertension compared to adults with normal BP. The present systematic review revealed few studies that explored differences between individuals with hypertension and normal BP while exercising in cold, hot, or air-polluted environments (Table 2). Nevertheless, from the current level of evidence, it appears that during exercise individuals with hypertension may exhibit reduced skin blood flow, less core-to-skin heat transfer (18), and an exaggerated BP response to exercise in the heat compared to those with normal BP (16,17,20), a finding also demonstrated in animal models (37).

Limitations

Few controlled studies have examined the combined influence of environmental stressors and exercise in individuals with hypertension (Table 2). The available studies to date are small, with a majority of participants being men, thus limiting the generalizability of our results. Nevertheless, our review highlights notable gaps in the literature and will hopefully serve to inform future research priorities. Specifically, a key literature gap exists due to the lack of adequately powered, randomized controlled trials examining the physiological response to exercise during exposure to (*a*) cold and (*b*) air pollution among individuals with hypertension (Table 1). Additionally, the role of other factors such as patient-level characteristics, exercise intervention features (i.e., frequency, intensity, type, time [FITT]), level of cardiorespiratory fitness, and acclimatization or habituation status remains unknown but may influence the stressor response to exercise. For example, the stressor response to resistance or flexibility exercise performed in stressful environments have not yet been characterized for individuals with hypertension but could have significant implications for patients who regularly engage in popular exercise modalities in extreme temperature such as Bikram (aka, “hot”) yoga, isometric training in a heated environment, or swimming in a heated pool.

It is important to mention that the BP thresholds and classifications for hypertension were recently reappraised. These changes represent a significant departure from the BP thresholds that were used as inclusion criteria for the classification of hypertension and normal BP within the studies examined in the present review. Since the inception in 1977, the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC 1-7) previously defined hypertension as having resting SBP ≥140 mm Hg or resting DBP ≥90 mm Hg (38). The report also defined an additional class of patients with SBP 120-129 mm Hg or DBP 80-89 mm Hg as having *prehypertension*—a term no longer used—and a heightened risk of developing hypertension in the future (38). The 2017 American College of Cardiology (ACC)/American Heart Association (AHA) Task Force on Clinical Practice Guidelines update has since lowered these thresholds by 10 mm Hg and, as a result, hypertension is now defined as having resting SBP ≥130 mm Hg, a resting DBP ≥80 mm Hg, taking antihypertensive medication, being told by a physician or health professional on at least two occasions that one has high BP, or any combination of these criteria (31). The report defines patients with SBP 120-129 mm Hg and DBP ≤80 mm Hg as having *elevated BP* and at heightened risk of developing hypertension in the future (38). In the present review, the average SBP and DBP of those classified as having hypertension was 146.7 ± 3.5 mm Hg (range: 143-150 mm Hg) and 89.7 ± 13.6 mm Hg (range: 74-98 mm Hg). The average SBP and DBP of the individuals considered to have normal BP was 115.7 ± 3.1 mm Hg (range: 113-119 mm Hg) and 75.0 ± 2.6 mm Hg (range: 73-78 mm Hg). Although these means are a crude estimate and do not represent individual level data for which study inclusion was defined, it is reassuring that these overall data are still relevant and clinically useful under the new BP thresholds and classifications.

Further, among the studies in this current review, BP assessment methods and equipment varied greatly—ranging from mercury sphygmomanometer, automated BP monitor, and ambulatory BP monitors. Such variability in the assessment of BP may contribute to heterogeneity in the literature and limit the generalizability of our findings. Future trials can significantly reduce this limitation by adhering to standard BP assessment protocols. According to AHA standards, BP should be measured three times in each arm, separated by at least 1 minute, and then averaged (39). Classification of BP for adults is based on the average of two or more properly measured, seated BP readings on each of two or more office visits (31).

Finally, the present review did not address potential synergistic effects of multiple environmental stressors (e.g., heat and air pollution, cold and altitude), which could potentially result in a combined adverse effect greater in magnitude than the sum of their separate influences. A “syndemics” approach examines pathways or mechanism of interactions between certain coexisting disease states and socioenvironmental conditions (40). For example, rising sea water levels due to climate change have contributed to increased salinity intrusion in certain coastal areas of the world (e.g., Bangladesh); this salinity is positively correlated with an increased incidence of hypertension (41). Certain populations may be disproportionately vulnerable to environmentally triggered hypertension, which may then be exacerbated by repeated exposures during outdoor exercise (Figure 1).

CONCLUSION

Hypertension is the most common and costly CVD risk factor in the world, affecting ~874 million adults worldwide. Participation in regular exercise is universally recommended for the prevention, treatment, and control of high BP. Therefore, identifying exercise-associated risks unique to individuals with hypertension is important. The present systematic review has revealed preliminary evidence to suggest that individuals with hypertension may be more susceptible to augmented cardiovascular and thermoregulatory strain during exercise in some (e.g., hot, humid) but not all harsh environments. We failed to identify any evidence that hypertension is a beneficial or protective pathophysiological state that responds favorably to exercise in harsh environments.

Our systematic review established the need for primary level studies that better characterize the maladaptive responses of individuals with hypertension to exercise performed in stressful environments. Until then, evidence-based recommendations for additional modifications to an ExR_x are limited in those with hypertension. Clinicians and clinical exercise physiologists alike should consider potential interactions between commonly used medications and the environment and provide education to modify individual behaviors, prescribing FITT accordingly. Ultimately, identifying an ExR_x and associated special considerations that buffers unknown or potential maladaptive responses to environmental stressors will preserve physical activity as a safe and effective antihypertensive lifestyle therapy.

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APPENDIX A: SUMMARY OF KEYWORDS SEARCHED

Search Hedges:

Hypertension

(“Hypertension”[Mesh] OR hypertens*[tiab] OR “high blood pressure” OR “high blood pressures” OR “high arterial pressure” OR “high arterial pressures” OR “high systolic pressure” OR “high diastolic pressure” OR “high pulse pressure” OR “high venous pressure” OR “elevated blood pressure” OR “elevated blood pressures” OR “elevated arterial pressure” OR “elevated arterial pressures” OR “antihypertensive” OR “elevated systolic pressure” OR “elevated diastolic pressure” OR “elevated pulse pressure” OR “elevated venous pressure” OR “Prehypertension”[Mesh] OR prehypertens* OR “pre hypertension” OR “pre-hypertension”)

Exercise

(“exercise”[majr] OR exercise[ti] OR exercises[ti] OR exercising[ti] OR postexercise[ti] OR running[mesh] OR running[ti] OR bicycling[mesh] OR bicycling OR bicycle* OR cycling[ti] OR treadmill* OR ergometer* OR “weight lifting” OR “weight training” OR “resistance training” OR “strength training” OR “endurance training” OR “speed training” OR “circuit training” OR “training duration” OR “training frequency” OR “training intensity” OR “aerobic endurance” OR “aerobic training” OR “interval training” OR “combination training” OR “combined training” OR plyometric* OR “HIIT” OR walking[mesh] OR walking[ti] OR swimming)

Clinical trial

((“clinical”[tiab] AND “trial”[tiab]) OR “clinical trials as topic”[mesh] OR “clinical trial”[pt] OR random*[tiab] OR “random allocation”[mesh] OR “therapeutic use”[sh])

General Weather Terms

Environmental/air temperature

Weather OR “Weather”[Mesh] OR temperature OR “environmental condition” OR “environmental conditions” OR “ambient air” OR climate

Heat/Humidity

heat[ti] OR “radiant heat” OR “hot weather” OR “warm weather” OR “heat wave” OR “heat stress” OR “heat index” OR “hot temperature” OR “Hot Temperature”[Mesh] OR “wet bulb” OR “wetbulb” OR “globe temperature” OR WBGT OR humidity OR humid OR muggy OR “Humidity”[Mesh]

Cold/Windchill

cold[ti] OR “cold temperature” OR “Cold Temperature”[Mesh] OR freezing OR “cold weather” OR “cold front” OR windchill OR “wind chill”

Air Pollution

pollution OR “Air Pollution”[Mesh] OR “particulate matter” OR “Particulate Matter”[Mesh] OR “air sampling” OR smog OR carbon monoxide OR nitrogen dioxide OR sulfur dioxide OR aerosol OR aerosols OR sulfur oxides OR nitrogen oxides OR paroxyacetyl nitrate

APPENDIX B: SELECTION PROCESS FOR ARTICLES INCLUDED IN SYSTEMATIC REVIEW