# Hiker Heat Risk Study: The Relation Between Physiological Measurements And Self-Reported Risk Perception And Risk-Taking While Hiking In A Hot And Dry Environment

by

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ABSTRACT

The Phoenix area trail system rescues over 200 hikers every year due to extreme levels of heat. Although much is known about how hyperthermia and dehydration affect a person physically, little is known about how this affects an individual's risk-taking (RT) and risk perception (RP).

This study aimed to assess how individual fitness, hydration, body temperature, and subjective feelings of heat, thirst, and physical exertion affected their ability to perceive risk. Three-hundred-nineteen participants were recruited at the Piestewa Peak trailhead in Phoenix Arizona and an additional 21 were recruited as a less active cohort to hike A-Mountain, also in Phoenix (42.9% female, 40.1±12.9 years). Individuals who completed or hiked at least 30 minutes and were greater than eighteen years of age were considered for this study. Participants were asked to complete a 39-part questionnaire assessing their RP, RT behaviors, and the subjective feelings of thirst, heat, and exertion during their hike. Physiological measures, including VO2Max estimates (via submaximal step-tests), urine specific gravity (USG), and body temperature were taken. High and low RP groups were created based on the median RP score as were high and low VO2Max, body temperature and USG groups.

Individuals who were more fit reported lower RP scores $X^2$ (1, N = 132) = 7.758, p = 0.005. Those who reported more perceived heat or thirst reported higher RP scores F(3, 329) = 4.843, p = 0.003 and F(6, 626) = 2.635, p = 0.016. Body temperature results were significant for some tests but insignificant for others showing a trend towards an effect on RT F(1, 114) = 5.278, p = 0.023) and $X^2$ (1, N = 116) = 3.515, p = 0.061. These results show high fitness level may cause an individual to perceive less risk while

increased feelings of heat or thirst concomitantly increase an individual's RP score. Although insignificant ($p = 0.062$), thermal state (body temperature) may influence an individual's propensity for risk.

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CHAPTER 1

INTRODUCTION

## STATEMENT OF THE PROBLEM

Within the Phoenix Arizona hiking trail system, over 200 hikers are rescued each year due to heat injury or dehydration (City of Phoenix, n.d.). The Piestewa Peak Summit trail is a highly frequented trail among Phoenix locals and has been given a rating of "extremely difficult" by the city of Phoenix Park Rangers, reflecting the trails' steep incline, difficult terrain, and exposure to the heat without shade relief. To mitigate heat injury risk, the City of Phoenix launched the "Take a Hike, Do it Right" campaign to educate the public about the risks and signs of exertional heat illness and how to mitigate their onset. Although much is known about the physiology of heat stress and dehydration, little is known about how these processes affect hikers' risk perception (RP) and risk-taking (RT) behaviors during difficult hikes or in hot environments. Thus, the present study aims to investigate how physiological and subjective markers of stress affect RP and RT.

## OVERVIEW

The elements of RP and RT behaviors are multifaceted decision-making processes and are not inherently negative or positive perceptions (Megías-Robles, Cándido, Maldonado, Baltruschat, & Catena, 2022). Risk recreation, activities such as hiking or mountaineering, pose inherent risks but are driven by a sense of self-development, freedom, control, or thrill (Ewert, 1994). The motivations for engaging in activities where there is known risk are attributable to both inaccurate assessments of risk and the propensity to be attracted to risky behaviors, known as “risk proneness” (de-Juan-Ripoll, Chicchi Giglioli, Llanes-Jurado, Martin-Morales, & Alcañiz, 2021).

Thermoregulation is the homeostatic mechanism responsible for regulating internal body temperature. The human body is tightly controlled within a narrow normothermic temperature range of 36–38°C and can increase to 40°C during exercise or in hot environments (Cramer, Gagnon, Laitano, & Crandall, 2022). Internal temperatures above 40°C increase the risk of heat injury/illness which is higher when exercise is performed in hot environments and while dehydrated. The central nervous system is largely responsible for thermoregulation within the body with spinal structures and the brain stem regulating large temperature fluctuations within the body while the hypothalamus is responsible for small temperature changes within the body (Boulant, 2000). Thermoregulation occurs via efferent signaling from thermosensitive cells which send signals to the structures within the central nervous system. The central nervous system sends afferent signals for autonomic and behavioral actions such as increased sweating rates, increased blood perfusion, shade-seeking behaviors, or fluid intake (Zhao, Yang, Gao, & Shen, 2017). Fluid balance, the reabsorption of water and electrolytes, and the redistribution of blood flow throughout the body are major autonomic responses that occur in response to heat stress and aid in thermoregulation.

At the level of the kidney, the renin-aldosterone-angiotensin-system (RAAS) and antidiuretic hormone (ADH) are responsible for the reabsorption of water and electrolytes by responding to plasma osmolality and vascular pressure (Antunes-Rodrigues, de Castro, Elias, Valença, & McCann, 2004; Kuhnle, Lewicka, & Fuller, 2004). During exercise, fluid balance is also challenged by the induction of sweating. Sweat, a hypoosmotic fluid, draws fluid into the extracellular space, causing dehydration. Proper electrolyte and fluid intake must be initiated to mitigate the effects of dehydration (Convertino, 1987). If these components are not replaced, ADH and aldosterone will be stimulated to conserve water and electrolytes (Weitzman & Kleeman, 1979).

Continued exposure to heat stress leads to multiple metabolic alterations to better handle the heat; however, without proper hydration or cool-seeking behaviors, heat illness occurs. Exercise combined with heat stress leads to exertional heat illness, characterized by elevated body temperature, heat/muscle cramps, heat exhaustion, or heatstroke (American College of Sports Medicine, 2007). Heat stress presents a variety of problems to organ systems; during prolonged aerobic exercise, the cardiovascular system is tasked with redistributing blood flow to cutaneous vascular beds for heat loss while also supplying adequate perfusion to exercising muscles (Kenney, Stanhewicz, Bruning, & Alexander, 2014). Cerebral blood flow is reduced due, in part, to increased cutaneous blood flow, decreased cardiac output and arterial blood pressure, and hyperventilation-induced hypocapnia which causes cerebral vasoconstriction (Nybo & Nielsen, 2001). The decline in cerebral blood flow is accompanied by an increase in oxygen extraction (González-Alonso, Dalsgaard, & Osada, 2004) and cerebral metabolism (Trangmar, Chiesa, Stock, Kalsi, Secher, & González-Alonso, 2014) so that brain function is not impaired in hyperthermic environments. Repeated exposure to heat stress induces heat acclimation; metabolic and physiological adaptations that allow for better fluid balance, increased cardiovascular stability, improved skeletal muscle metabolism, and increased heat tolerance (Nielsen, 1998; Horowitz, 2014). Heat acclimation occurs relatively quickly with the initial phase of acclimation characterized by increased efferent excitation occurring within the first week and the final phase of acclimation characterized by enhanced metabolic efficiency occurring within 21 days or more (Horowitz & Meiri, 1993).

Dehydration presents unique metabolic and physiological problems that are distinct from heat stress. Dehydration increases the ionic concentration of extracellular compartments, forcing fluid from the intracellular space and causing cells to shrink, signaling for the initiation of drinking and the release of ADH from the hypothalamus to reabsorb water at the kidney (Arnaud, 1998). However, without replacing fluids, dehydration ensues and a concomitant rise in core body temperature occurs. This results in a loss of plasma volume, electrolytes, and increased plasma osmolality. These changes lead to lower sweat rates causing sweat to become insufficient for thermoregulation (Sawka, Latzka, Matott, & Montain, 1998). Detriments to physical and cognitive performance occur under relatively mild levels of dehydration of two percent body mass loss and include reduced endurance capacity, increased fatigue rate, and increased perceived effort (Cheuvront, Carter, & Sawka, 2003). During exercise and dehydration, cutaneous blood flow is reduced, venous return is compromised, stroke volume is stunted, and hyperthermia may ensue (Nadel, Fortney, & Wenger, 1980).

While the effects of heat stress and dehydration on physiological function are well documented (Cramer et al., 2022), the interaction between these physiological states and human psychology remains contentious. Two studies have evaluated how heat stress affects the parameters of risk; Ramsey described how elevated ambient temperatures increased the rate of unsafe behaviors (Ramsey, Burford, Youssef Beshir, Jensen, 1983). Chang and colleagues (2017) showed heat exposure decreased RP and increased RT behaviors. After a period of heat acclimation, RP returned to baseline levels while the propensity to take risks remained elevated (Chang, Bernard, & Logan, 2017). These two studies are the only available reports of RP and RT relating to thermal state while the remaining literature focuses on the interaction between thermal state and cognitive functioning. These studies highlight the complex interaction between heat stress and cognition which identifies a temperature threshold of ~38.5°C at which cognitive functioning declines (Taylor, Watkins, Marshall, Dascombe, & Foster, 2016). Tasks which are affected are identified as simple and complex tasks with complex tasks being affected to a greater extent than simple tasks (Saini, Srivastava, Agrawal, & Das, 2017; Ashworth, Cotter, & Kilding, 2021). These processes are explained by the conceptual framework coined the Maximal Adaptability Hypothesis (Hancock & Warm, 1989) which states physical and psychological stress act as a *tax* on the central nervous system and gradually degrade cognitive processes. Although cognitive processes and the Maximal Adaptability Hypothesis do not directly pertain to the parameters of risk, these processes provide an insight to the potential interactions between thermal state and risk.

Within the scope of dehydration, no available literature was found pertaining to RP and RT. Similar to thermal state, dehydration focuses mainly on its effects on cognitive processes. Mild to moderate dehydration has been shown to produce decrements in aspects of cognitive function such as perceptual discrimination, visuomotor tracking, and psychomotor skills (Gopinathan, Pichan, & Sharma, 1988; D'anci, Vibhakar, Kanter, Mahoney, & Taylor, 2009). However, cognitive functioning related to dehydration has not shown consistent results across studies (Cian, Barraud, Melin, & Raphel, 2001) and some studies show a null effect (Szinnai, Schachinger, Arnaud, Linder, & Keller, 2005). It should be noted the methodology of dehydration within these studies varies with some utilizing water deprivation and heat stress (Gopinathan et al., 1988; D'anci et al., 2009) while those with a null effect use water deprivation alone (Szinnai et al., 2005). Due to these various findings, it is suggested the affect on cognition should be attributed to its deleterious effects on mood rather than its effect on cognition (Benton, 2011; Armstrong, Ganio, Casa, Lee, McDermott, Klau, Jimenez, Le Bellego, Cheviollette, & Lieberman, 2012). It has been shown negative mood states can increase RP (Sobkow, Traczyk, & Zaleskiewicz, 2016), with increasing levels of RP also decreasing RT behaviors (Brewer, Chapman, Gibbons, Gerrard, McCaul, & Weinstein, 2007) indicating an indirect effect on the parameters of risk relating to dehydration. The Maximal Adaptability Hypothesis may also prove to be a useful framework to further understanding how dehydration affects risk.

**MEASURES**

Core body temperature is difficult to assess due to the low correlation between less invasive measurements and true core body temperature. The most accurate assessments utilize esophageal, rectal, or ingestible telemetric temperature pills. Non-contact infrared thermometry (NCIT) is an alternative method for assessment of core temperature which is both non-invasive and inexpensive. When assessing different areas of measurement, the inner-eye canthus or forehead are the most accurate but fail to replace more invasive methods of measurement (Foster, Lloyd, & Havenith, 2021). Submaximal $VO2_{MAX}$ tests assess fitness levels without the need for a metabolic cart and offer a safe, dependent, and accessible method to estimate $VO2_{MAX}$ and fitness levels in multiple populations (Bennett, Parfitt, Davison, & Eston, 2016). The YMCA three-minute step test protocol is a submaximal fitness protocol that assesses individuals at a standardized step height and step cadence which has also been validated against true maximal fitness testing on treadmills (Kieu, Jung S., Shin, Jung H., Jung E., Won, Kim, & Chae, 2020; Hong, Yang, Kim, Gonzales, Brage, & Jeon, 2019). The Borg scale is a measurement of perceived exertion (6-20) validated against objective measures of exertion or stress such as heart rate (Borg, 1982). Plasma osmolality is the most accurate measure of hydration status but can be expensive and invasive. (Cheuvront, Ely, Kenefick, & Sawka, 2010). Urinary osmolality and urine specific gravity are alternative methods of assessment that are more efficient, well correlated with plasma osmolality, and better suited for field studies (Baron, Courbebaisse, Lepicard, & Friedlander, 2015). Visual analog scales (VAS) assess subjective measures of hydration. VAS are reliable representations of subjective experiences and have been shown to be consistent across multiple subjective domains when compared to physiological measurements (Price, McGrath, Rafii, & Buckinham, 1983; Aitken, 1969).

Further research is needed to fully understand how dehydration, elevated core body temperature, fitness level, and subjective feelings of heat and hydration affect RP and RT behaviors. Within the literature is an apparent gap regarding RP and RT and how these various objective and subjective markers affect risk parameters. The current study highlights an important direction for research which can benefit individuals who regularly participate in risky behaviors through their occupation or recreational activity. Future research can further elucidate the interactions between these physiological and psychological states to better improve health outcomes for each respective population.

## RESEARCH AIMS

The current study aims to explore the relationship between RP, RT behaviors, and their relationship to the physiological responses of exercising in a hot and arid climate. To investigate this, the relationship between individual fitness levels, hydration state, body temperature, and subjective feelings of heat, thirst, and exertion was compared against RP among hikers in Phoenix, Arizona, during the summer.

## HYPOTHESES

Based on these aims, the primary hypothesis of this thesis is that individuals with higher fitness levels will exhibit diminished RP and RT behaviors compared to their less fit counterparts. Second, a correlation between physiological stress indicators and RP and RT behaviors exists, with increased stress associated with more RP and less RT behaviors.

# CHAPTER 2

# REVIEW OF THE LITERATURE

The following literature review focuses on the relevant information for thermoregulation, fluid balance, thirst, and heat stress and their effects and responses on the cardiovascular system, skeletomuscular system, and cerebral tissues. This review first examines the process of thermoregulation and fluid balance followed by the generation of thirst. Subsequently, a review of the effects of heat stress and hydration on blood redistribution, cardiovascular adjustments, sudomotor activity, and cerebral effects is conducted to better understand how these physiological states affect fluid compartments, heat dissipation, and differences in cerebral tissue function. A review of risk parameters and cognitive function associated with hyperthermia, exercise, and dehydration is then conducted to better understand the psychological aspects of these states. Lastly, a review of the measurements used for the present study is conducted to assess the applicability and validity of these measures.

## THERMOREGULATION

Thermoregulation is the homeostatic mechanism responsible for regulating internal body temperature and is tightly controlled within a narrow temperature range of 36–38°C (Cramer, Gagnon, Laitano, & Crandall, 2022). During exercise or in hot environments, internal temperature may reach 38–40°C. Internal temperatures above 40°C may cause heat injury/illness and the risk of this pathology is increased when exercise is performed in hot environments (Cramer et al., 2022).

**Neurological Signaling.** To maintain homeostatic control of bodily temperature, the central nervous system (CNS) receives feedback from the periphery via skin temperature and the internal core to protect vital organs from a hyperthermic environment (Tansey & Johnson, 2015). The CNS is primarily responsible for changes in body temperature and controls both discriminative and homeostatic thermoregulation (Romanovsky, 2007). Discriminative sensation of temperature is necessary for temperature avoidance and spatial awareness of temperature changes (Romanovsky, 2007). Homeostatic regulation occurs as a response to elevated core temperature or heat exchange between the skin and environment and triggers thermoeffector responses in an autonomic or behavioral fashion (Romanovsky, 2007). Both discriminative and homeostatic thermoregulation begin at thermosensitive endings on neurons where action potentials are generated which signals to the CNS to produce either of these actions

**Autonomic and Behavioral Thermoregulation**. Behavioral responses are conscious decisions that lower body temperature and include cool-seeking behaviors such as shade-seeking, fluid consumption, changing clothes, or cessation of exercise (Yahiro et al., 2023). Autonomic responses occur to cool internal body temperatures and include the induction of sweating, increased perfusion of blood to the skin for heat dissipation, and increased sense of thirst (Schlader & Vargas, 2019). Autonomic thermoeffector responses occur in proportion to the change in core body temperature and usually operate within a negative-feedback loop (Hammel, Jackson, Stolwijk, Hardy, & Stromme, 1963). These responses have been described in relation to a temperature "set-point" which is an abstract concept used to describe the magnitude of effector responses in relation to the change in temperature (Gisolfi & Wenger, 1984). Autonomic thermoregulation mechanisms have been well described, however, behavioral thermoregulation and how it operates alongside autonomic responses is unclear. It has been shown that thermoeffector responses, either behavioral or autonomic, that conserve energy are the first effectors evoked during heat stress (Kanosue, Crawshaw, Nagashima, & Yoda, 2010). Schlader et al. (2016) evaluated the behavioral and autonomic responses of participants who were passively cooled or heated and showed vasomotor function preceded behavioral thermoregulation but not metabolic alterations or the induction of sweating (Schlader, Coleman, Sackett, Sarker, Chapman, & Johnson, 2016). In a separate study by Schlader et al. (2013), behavioral and autonomic thermoregulatory responses were measured in relation to skin, esophageal, and rectal temperature. The results showed behavioral and autonomic responses such as thermal comfort seeking, sweating, and shivering occurred as a response to skin temperature changes with minimal deviations in rectal and esophageal temperature (Schlader, Perry, Jusoh, et al., 2013.).

The present literature suggests initial attempts by the body to thermoregulate are driven by skin temperature which initiates the initial thermoregulatory response. Additionally, behavioral thermoregulation is preceded by an increase in vasomotor function followed by more profound alterations in metabolic activity such as the induction of sweating, large alterations in blood flow distribution, and substrate utilization. These alterations likely occur in an energetically conservative manner where initial responses are the least costly physiologically followed by larger systemic alterations to defend core temperature.

**FLUID BALANCE**

Total body water accounts for 55% to 75% of total body mass in humans and accounts for approximately 76% of muscle mass and 10% of fat mass (Lorenzo, Serra-Prat, & Yébenes, 2019). Total body water can be defined as water in intracellular and extracellular compartments. Extracellular compartments include interstitial and intravascular compartments (Armstrong, 2005). These compartments are comprised of water permeable membranes which allow for the passive and continuous exchange of water between compartments. This enables various fluid shifts to occur as a response to the environment, exercise, or hydrostatic and oncotic pressures exerted on vascular walls (Antunes-Rodrigues et al., 2004). Extracellular fluid volume comprises about 24.9% of body mass whereas intracellular fluid volume comprises about 38.4% of body mass (Armstrong, 2005). Interstitial fluid is determined as the difference between extracellular fluid volume and plasma volume and accounts for about 21% of body mass (Armstrong, 2005).

Fluid flowing across cell membranes causes fluids to cross into or out of the cell, altering the osmolality and fluid volume of the cells. Osmolality can be defined as the amount of particles dissolved in a fluid and is expressed as osmoles of solutes of particles per kilogram of solvent whereas osmolarity, a similar measure, is the number of milliosmoles of solute per liter of solute. In humans, osmolality ranges from 275 to 295 mOsm/Kg (Rasouli, 2016). The importance of blood osmolality was first described by Verney (1947) who introduced the term "osmoreceptor" in an experiment involving dogs and their response to intracarotid sodium chloride injections (Verney, 1947).

Osmoreceptors are distributed throughout the body and categorized as central or peripheral receptors. Central osmoreceptors are present within the anterior hypothalamus and are highly concentrated in the organum vasculosum laminae terminalis (OVLT), supraoptic nuclei (SON), paraventricular nuclei (PVN), and subfornical organ (SFO) (Danzinger & Zeidel, 2015). Peripheral osmoreceptors exist in various tissues and connect to the CNS to induce anticipatory osmoregulatory responses (Lechner, Markworth, Poole, Smith, Lapatsina, Frahm, May, Pischke, Suzuki, Ibañez-Tallon, Luft, Jordan, & Lewin, 2011).

**THIRST**

**Neurological Signaling for Thirst Regulation.** Cells have a requirement for energy, nutrients, and oxygen which the cardiovascular system is responsible for distributing throughout the body. The cardiovascular system's ability to carry out this function is reliant on blood pressure, blood volume, and the constituents within the blood. When hypovolemia or hypotension due to lack of fluid or electrolyte replenishment occurs, thirst is induced to correct these imbalances (Hughes, Mythen, & Montgomery, 2018). Fluid balance is primarily regulated through autonomic responses; however, thirst is also perceptual; usually perceived at 1-2% of body mass loss due to dehydration (Adams, Vandermark, Belval, & Casa, 2019). Central neural control of thirst was first discovered in the 1950's during a series of studies by Andersson (1952, 1953, and 1955) showing infusion of hypertonic saline into the anterior hypothalamus of goats produced increased water drinking and antidiuresis (Andersson, 1952; Andersson, 1953; Andersson & McCann, 1955). Early murine models showed the importance of the lamina terminalis regarding osmotically induced drinking (Buggy & Johnson, 1977; Hosutt, Rowland, & Stricker, 1981; Gardiner & Stricker, 1985). Andersson conducted lesion studies in the anteroventral wall of the third ventricle which showed a decreased sense of thirst and increased blood osmolality (Andersson, 1978). These studies helped to identify the lamina terminalis as the primary area for the sensation of thirst which contain the OVLT and SFO, essential areas for fluid balance. Due to the presence of osmoreceptors in the OVLT and SFO and their communication with peripheral osmoreceptors and baroreceptors, these regions are integral in thirst sensation.

Hypovolemia causes a preference towards water and solutes to correct blood volume and is often coined extracellular dehydration (Pool, Wang, Stafford, Chance, Lee, Ngai, & Oka, 2020). Transcriptomic analyses have shown major overlap in the cell class and neuron types within the SFO and OVLT (Pool et al., 2020). However, astrocytes located specifically in the SFO have been found to be strongly activated in response to hyperosmolality (Pool et al., 2020). Other studies in mice have found similar results. When the sodium channel within circumventricular organs was blocked, only the mice which received a transduction of the sodium channel into the SFO recovered salt-avoiding behavior after hyperosmotic saline injections (Hiyama, Watanabe, Okado, & Noda, 2004). Recent studies have found contradictory results regarding the activation of neurons within the OVLT. Both *in vitro* and *in vivo* cells from the OVLT were found to be activated by NaCl when analyzed by optogenetics and electrophysiological identified cells (Kinsman, Simmonds, Browning, Wenner, Farquhar, Stocker, 2020). In another study by Kinsman et al. (2017) neurons were activated when NaCl was injected locally into the OVLT. Specifically, sympathetic tone was increased in the lumbar and adrenal sympathetic nerves and increased arterial blood pressure (Kinsman, Simmonds, Browning, & Stocker, 2017). Researchers also inhibited OVLT neurons via the GABA receptor agonist muscimol which decreased sympathetic activity and did not show arterial pressor effects (Kinsman et al., 2017). Another study by Kinsman compared NaCl and equiosmotic mannitol and observed greater sympathoexcitatory and pressor responses when NaCl was injected versus mannitol. (Kinsman, Browning, & Stocker, 2017).

Collectively, these results indicate both the SFO and OVLT respond to hyperosmolality, however, the mechanism by which this occurs is unknown. Interestingly, OVLT neurons seemed to respond to osmolality, but NaCl induced a greater effect indicating distinct processes to regulate thirst, hormones, and autonomic response when neurons detect NaCl or osmolality. A mechanism may exist in which hypertonicity induced by dehydration and hypovolemia is needed to activate OVLT neurons to signal volume and osmolality correction via thirst. The SFO may play a distinct role in correcting hypertonicity in the absence of hypovolemia, however, future research is needed at the cellular level to discover these mechanisms.

**Hormones Related to Thirst.** In the scenario where water cannot be replenished during a state of water deficit, hormonal systems are activated which increase the reabsorption of water and electrolytes at the kidneys, induce pressor effects, and stimulate the sensation of thirst. Multiple hormone systems are involved in the induction of thirst, the renin-angiotensin-aldosterone-system (RAAS) being one of the most important and well-studied. Within the cascade of peptides produced within the RAAS, angiotensin II

(ANG II) is highly important when responding to hypovolemia and hypotension (Leib, Zimmerman, & Knight., 2016). ANG II affects responses on several organ systems, fluid balance, vascular tonicity, and thirst. Within the vasculature, ANG II induces vasoconstriction of systemic and renal arterioles causing an increase in blood pressure and a subsequent increase in venous return, allowing for maintained delivery of nutrients to cells despite reduced blood volume (Vukelic & Griendling, 2014; Navar, Inscho, Majid, Imig, Harrison-Bernard, & Mitchell, 1996). Within the brain, ANG II receptors within the structures of the lamina terminalis, primarily the SFO, increase sympathetic output to the heart and smooth muscles of vascular walls, increasing cardiac output and total peripheral resistance concomitantly to elevate blood pressure (Reid, 1992; Kinsman et al., 2020). At the level of the kidney, ANG II acts to increase sodium reabsorption through a sodium-proton antiporter within the proximal convoluted tubule (Cano, Miller, Alpern, & Preisig, 1994). The role of ANG II on electrolytes also extends to potassium and its regulation by aldosterone. Aldosterone, a component of the RAAS, acts principally to increase excretion of potassium but also increases sodium reabsorption at the kidney (Gupta, Franco-Saenz, & Mulrow, 1995). Mechanistic studies show when an ANG II antagonist is introduced, aldosterone secretion is blunted in response to a potassium load (Gupta et al., 1995). Aldosterone and its production in the zona glomerulosa of the adrenal glands is regulated by ANG II and acts to acutely upregulate its production and chronically to increase the adrenal glands capacity to produce aldosterone (Nogueira, Xing, Morris, & Rainey, 2009). ANG II also signals for the release of arginine vasopressin (AVP) (also known as vasopressin or antidiuretic hormone) from the hypothalamus, specifically the posterior pituitary (Quadri, Culman, Veltmar, Maas, Rascher, & Unger, 1993). The release of AVP from the posterior pituitary affects fluid balance largely from its actions on the kidneys where it promotes fluid retention through the opening of aquaporins (Park & Kwon, 2015).

**Hormonal Signaling for Thirst.** Angiotensin II (ANG II) and its role as a dipsogenic stimulus was first discovered in the late 1970's during a series of studies by Fitzsimons and colleagues (Fitzsimons, 1979; Fitzsimons & Moore-Gillon, 1980). In one of these studies, venous return was compromised by inflating a balloon in the inferior vena cava of dogs leading to increased water intake and the development of a sodium appetite (Fitzsimons & Moore-Gillon, 1980). Following this obstruction, plasma renin levels rose indicating the activation of the RAAS. When a competitive ANG II antagonist (saralasin acetate) was infused, drinking was reduced but not abolished. Researchers also blocked the left vagosympathetic nerve concurrently as balloon inflation which enhanced the drinking response (Fitzsimons & Moore-Gillon, 1980). These results demonstrate the role of hypovolemia and the RAAS in generating thirst and sodium appetite. Similar to osmotically induced drinking, hormone induced drinking involves the structures of the lamina terminalis. Hormones such as ANG II reach the circumventricular organs where an electrical signal is integrated to correct arterial blood pressure and blood volume (Johnson, Cunningham, & Thunhorst, 1996).

Fluid balance is broadly controlled by two hormones: arginine vasopressin (AVP) and the renin angiotensin aldosterone system (RAAS) (Patel, Rauf, Khan, & Abu-Izneid, 2017). The RAAS is activated primarily by hypotension and electrolyte concentrations sensed within juxtaglomerular cells. Prorenin is converted into renin within the kidneys which is then able to convert angiotensinogen into angiotensin II through a cascade of reactions (Patel et al., 2017). Angiotensin II increases blood pressure, blood volume, stimulates aldosterone release from the adrenal cortex. and causes sodium reabsorption in the kidneys (Johnson et al., 1996). Aldosterone, while primarily released in response to angiotensin II, is also stimulated by potassium ion concentration (Fountain, Kaur, & Lappin, 2023). Aldosterone stimulates the excretion of potassium through the action of epithelial sodium channels in aldosterone sensitive distal nephrons (Fountain et al., 2023). These cells create an electrochemical gradient causing sodium to be driven into the cell in exchange for potassium which is forced into the luminal space for excretion. Due to the effects on intracellular and extracellular electrolyte concentrations, aldosterone has a major effect on fluid balance. This effect is made more pronounced by the pressor effects and blood volume increases of angiotensin II, the molecule which activates aldosterone (Fountain et al., 2023).

AVP is activated by hyperosmolar and hypotensive states within the blood and is produced within the hypothalamus where blood tonicity can be detected from the surrounding ventricles (Cuzzo, Padala, & Lappin, 2023). Once AVP is produced, it travels from the hypothalamus to the posterior pituitary via the hypothalamic hypophyseal tract, where it is stored (Reghunandanan, V., Reghunandanan, R., & Mahajan, 1998). When released ADH travels and acts on the distal convoluted tubule and collecting ducts within the nephrons of the kidneys. Here, ADH acts on vasopressin-2 receptors, activating aquaporins to allow water reabsorption to occur (Cuzzo et al., 2023). ADH is primarily responsible for facultative water reabsorption, reabsorption which occurs as a result of elevated blood osmolarity. Thus, the RAAS regulates the blood volume and electrolyte concentrations of the kidneys while ADH regulates the tonicity of the blood (Cuzzo et al., 2023).

## HEAT STRESS AND HYDRATION

Heat balance in the body is maintained at a relatively constant temperature and numerous metabolic and physiological alterations occur to maintain a homeostatic state (Kenny & Jay, 2013). High ambient temperatures or increased workload can cause an elevation in internal bodily temperatures above 40°C which may cause heat illness or heat stroke to occur (Cramer et al., 2022). Heat balance is disturbed to a greater extent when ambient temperatures exceed internal body temperatures, making heat dissipation difficult and a requirement for internal modes of heat loss necessary (Kenny & Jay, 2013). Under such conditions, blood is redistributed to the skin via vasodilation, sweat secretion is increased for evaporative heat loss, and cardiac alterations are made to adjust for the redistribution of blood flow (Kenny & Jay, 2013). The brain is the central regulator of these responses receiving input from thermosensitive cells on the skin, osmolality of the blood, baroreceptors, cytokines, and chemoreceptors which detect metabolic products from exercising muscles (Fealey, 2013)

**Effects on Skin Perfusion.** During the initial phases of heat stress, blood flow is redistributed to the skin via an efferent sympathetic signal to induce vasodilation (Rowell, 1974). The redistribution of blood flow causes a similar decrease in renal and splanchnic blood flow (Rowell, 1974). Blood flow redistribution begins with an elevation in skin temperature which causes small variations in sympathetic tone for vascular control. At rest and in a normothermic environment, sympathetic noradrenergic tone maintains basal tone within cutaneous vascular beds while cholinergic activity is relatively low or absent (Charkoudian, 2010). Elevated skin temperature results in the withdrawal of vasoconstrictor activity allowing for increased vasodilation and skin blood flow (Pérgola, Kellogg, Johnson, & Kosiba, 1994). Elevations of body temperature via exercise cause an increase in active cutaneous vasodilator activity in addition to withdrawal of vasoconstrictor activity (Pérgola et al., 1994). In a study by Savage and Brengelmann (1996), forearm skin blood flow, esophageal temperature, and skin temperature were observed during passive heating with thermoneutral (33°C - 35°C) water and showed a linear relationship between forearm blood flow and skin temperature but not esophageal temperature (Savage & Brengelmann, 1996). This research group suggests a feed forward mechanism in which skin blood flow is reflexively increased within the thermoneutral zone (33°C - 35°C). This response overcompensates for the effect of skin temperature on thermal balance, resulting in the inverse relationship between the equilibrium of core temperature and skin temperature (Savage & Brengelmann, 1996). As skin temperature increases, a threshold is met at which cholinergic vasodilator activity is at a maximum and noradrenergic vasoconstrictor activity is abolished (Yamijo, Lee, & Mack, 2005).

**Sudomotor Activity.** As core temperature begins to rise, sudomotor activity begins for evaporative heat loss (Yamijo, Lee, & Mack, 2005). The temperature which sweating occurs is controlled centrally at the hypothalamus and the temperature threshold for sweating can be reduced as a result of aerobic training, heat acclimation, or elevated skin temperatures due to high ambient temperature. The induction of sweating can also be altered by physiological states related to dehydration such as hyperosmolality which increases the threshold of sweating (Mack, Cordero & Peters, 2001; Armstrong &

Maresh, 1998). When regularly participating in aerobic training or regularly exposed to elevated temperatures, eccrine sweat gland sensitivity is increased so that sweating rate is increased relative to temperature. Factors such as hypovolemia decrease eccrine gland sensitivity (Nadel, 1979; Mack et al., 2001). Ambient temperatures also affect sweat rate; When ambient temperatures are high, but sweating is not present, skin temperatures increase closer to ambient temperatures due to increased perfusion. (Kenney & Johnson, 1992).

**Cardiovascular Effects.** Heat stress introduces a unique challenge to the heart as it is tasked with the redistribution of blood flow to the working muscles and to the skin for heat dissipation. Heat stress dilates cutaneous vasculature for heat dissipation, increases cutaneous venous compliance, increases blood transit time throughout the skin, and ultimately causes blood to pool in the periphery (Rowell, Marx, Bruce, Conn & Kusumi, 1966). Alterations in blood flow are necessary for heat dissipation but also inhibits cardiac filling by displacing central blood volume. The redistribution of blood towards the skin results in reduced diastolic filling and lower end-diastolic volume, requiring an increase in heart rate to compensate for the lack of cardiac filling (Rowell et al., 1966). These effects are described well in a study conducted by Rowell et al., (1969) where cardiac output, stroke volume, heart rate, central blood volume, aortic mean pressure, right atrial mean pressure, and total peripheral resistance were measured in 11 subjects while being progressively heated during light intensity exercise. Heating the skin to 38.3°C increased heart rate and cardiac output while stroke volume, central blood volume, aortic mean pressure, right atrial mean pressure, and total peripheral resistance declined (Rowell, Brengelmann, Murray, 1969). Increased heart rate was responsible for the increase in cardiac output, despite the reduction in stroke volume. Reduced diastolic filling is evidenced by reduced mean aortic pressure and right atrial mean pressure while decreased total peripheral resistance suggests vasodilation in the periphery. These changes are seemingly driven by skin temperature as heating of the skin almost immediately increased heart rate and cardiac output while stroke volume and central blood volume declined (Rowell et al., 1969). Therefore, as skin temperature increases, sympathetic cholinergic tone vasodilates cutaneous vasculature and redistributes blood flow towards the periphery. This redistribution causes central blood volume to decrease, causing stroke volume to decline and heart rate to increase to maintain cardiac output. Due to increased blood demands imbued on the body to dissipate heat, cardiac output increases as a result of increasing heart rate.

Compensatory mechanisms exist to attenuate peripheral pooling of blood. Splanchnic, renal, and gastrointestinal blood flow are gradually reduced during heat stress and during exercise in proportion to exercise intensity to compensate for the lack of central blood volume (Rowell, Brengelmann, Blackmon, Twiss, & Kusumi, 1968). Once again, the reduction in splanchnic and renal blood flow appears to rely on skin temperature. When heated at rest, splanchnic blood flow is reduced in proportion to skin temperature. During exercise, the vasoconstrictive effects of exercise and heat are additive so that the reduction in blood flow is greater at higher skin temperatures regardless of exercise intensity (Rowell et al., 1968). Shunting blood away from these organs allows for cardiac output to be diverted to the skin and muscles while also mobilizing blood to help recover stroke volume loss (Rowell et al., 1974). These compensatory mechanisms help to maintain cardiac output during exercise or during heat stress.

**Skeletomuscular Effects.** In relation to heat stress and its effects on organ systems, muscular function is of high importance. Muscle function is affected as a result of alterations in blood flow induced to dissipate heat from the skin. During low to moderate exercise, blood flow to exercising muscles is maintained (Savard, Nielsen, Laszczynska, Larsen, & Saltin, 1988), however, during high-intensity exercise with hyperthermia or concomitant dehydration and hyperthermia, a reduced cardiac output cannot maintain blood perfusion to working muscles for oxygen delivery (González-Alonso, Calbet, & Nielsen, 1998; González-Alonso & Calbet, 2003). Therefore, two mechanisms of muscular fatigue during heat stress exist for maximal and submaximal exercise.

Muscular performance is limited by the amount of oxygen delivered to muscles. Thus, muscular blood flow is an important indicator for the upper limits of muscular performance. Studies evaluating maximal blood flow in knee extensor muscles have shown a mean average blood flow of 2.5 L/kg/min and an oxygen uptake of 0.35 L/kg/min (Andersen & Saltin, 1985). However, maximal, whole-body exercise does not elicit such high levels of blood flow and is a result of recruiting a larger fraction of total muscle mass. Mortensen et al. (2005) conducted a study demonstrating an attenuation in blood flow and oxygen delivery to active leg musculature as cycling intensity increased beyond 50% of VO2Max (Mortensen, Dawson, Yoshiga, Dalsgaard, Damsgaard, Secher, & González-Alonso, 2005). They also showed a plateau in cardiac output at intensities above 90% of maximum capacity which was accompanied by a leveling off in vascular conductance (Mortensen et al., 2005). In the same study, both cardiac output and blood flow to active muscles increased in a linear manner during incremental exercise involving small muscle groups until exhaustion (one-legged knee-extensor exercise) (Mortensen et al., 2005). These findings suggest the limitations in blood flow to active muscles and the limitations of cardiac output restrict aerobic output. This is further supported by Secher and Volianitis (2006) who showed that during exercise, the body maintains blood pressure by increasing cardiac output, however, when cardiac output cannot maintain blood pressure, vascular peripheral resistance is increased via increased sympathetic activity and restricts blood flow to working muscles to maintain blood pressure (Secher & Volianitis, 2006). Thus, upper limits to aerobic capacity are likely determined by the need to maintain blood pressure at baroreceptor locations and the limitations of cardiac output. Additionally, these limitations will be increased during dehydration which will further lower blood volume, left diastolic filling, stroke volume, and cardiac output as a result.

Submaximal exercise elicits a less severe response in muscular blood flow and muscular function. Initial studies of muscular blood flow during submaximal exercise in the heat found extreme body heating (>40°C) had no measurable effect on muscular blood flow (Savard, et al., 1988; Nielsen, Savard, Richter, Hargreaves, & Saltin, 1990; Nielsen, Hales, Strange, Christensen, Warberg, & Saltin, 1993). This was observed during submaximal exercise using a small muscle mass (single-leg knee extensions) (Savard et al., 1988) as well as during submaximal exercise with large fractions of muscle mass (cycle ergometer) (Nielsen et al., 1990; Nielsen et al., 1993). As opposed to maximal exercise bouts, the maintenance of blood flow to active muscles was accompanied by increases in skin blood flow of 1 L/min – 3.2 L/min (Nielsen et al., 1990; Savard et al., 1988). These series of studies also show oxygen extraction is maintained during submaximal exercise in the heat (Nielsen et al., 1990; Savard et al., 1988). These studies point to an important conclusion; muscular blood flow is prioritized over skin blood flow, even when thermoregulatory demands are high, allowing for the continual function of active muscles. However, when dehydration or hypovolemia is present, cardiac output is reduced and the lack of available blood volume to be delivered to working muscles induces fatigue (González-Alonso et al., 1998). In the study by González-Alonso (1998), it was shown that despite the decrease in leg blood flow during dehydration, whole body and leg VO2 were maintained. Although leg blood flow was reduced, an even greater increase in arterial-venous oxygen difference attenuated this decrease allowing for VO2 to be maintained (González-Alonso et al., 1998). Therefore, dehydration or hypovolemia may not have as severe an impact on submaximal exercise as it does on maximal exercise.

**Cerebral Effects.** Historically, cerebral tissue has been studied to address how passive or exercise-induced hyperthermia affects fatigue. This question was first explored experimentally by Nybo and Nielsen (2001) who warmed participants to either 40°C (experimental condition) or 38°C (control) on a cycle ergometer before performing maximal voluntary contractions with exercised muscle groups (knee extensors) or non-exercised muscle groups (handgrip). The study found that in hyperthermia, the ability to generate force during sustained maximal voluntary contractions was similar between both trials. However, the ability to sustain this force was reduced during hyperthermic conditions, and this was associated with a decrease in voluntary muscle activation. Additionally, the force development curve was similar for the non-exercised group. Thus, the ability to sustain force was not dependent on whether the muscle group was used in the preceding exercise but rather was attenuated by the hyperthermic conditions (Nybo & Nielsen, 2001). In order to determine if the reduction in sustained force were due to central fatigue or blood flow redistribution, Todd et al. (2005) used transcortical magnetostimulation (TMS) to show passive hyperthermia (core temperature of 38.5℃) increased central fatigue, as indicated by increased amplitude of TMS-evoked twitch during a sustained maximal voluntary contraction (Todd, Butler, Taylor, & Gandevia, 2005). They also found peak relaxation rate of the muscle increased, suggesting hyperthermia-induced fatigue may be due to a failure of the brain's voluntary control to compensate for changes in muscle contractile properties due to the hyperthermic condition of the muscle (Todd et al., 2005). Thomas and colleagues (2006) demonstrated central fatigue occurs when core temperature is elevated regardless of local muscle temperature (Thomas, Cheung, Elder, & Sleivert, 2006). In their study, subjects' core temperature was raised from 37.2℃ to 39.5℃ and then cooled back to 37.9℃ using a liquid-conditioning garment, while maintaining muscle temperature below 36℃ in one leg and heating the other leg to a muscle temperature of 39℃. Passive heating led to significant decreases in torque for both legs, and voluntary activation was similarly impaired in the heated leg compared to the control leg. Cooling the heated leg did not immediately restore torque or voluntary activation but returning core temperature to normal levels restored both to baseline values (Thomas et al., 2006). Additionally, central fatigue was still present when the skin was rapidly cooled from 39℃ to 31℃ but core temperature remained high (>39°C) which also reduced cardiovascular strain as heart rate decreased from 64% to 29% of heart rate reserve. In contrast, when skin temperature was high (39°C) but core temperature was relatively low (38.5°C) MVC force was not affected (Thomas et al., 2006). These data indicate fatigue caused by hyperthermia is present when core temperature is high, regardless of muscle or skin temperature. An elevated core temperature independently affects central fatigue, leading to impaired voluntary muscle activation during sustained isometric contractions or repeated isokinetic contractions. These findings are supported by other groups (Morrison, Sleivert, & Cheung, 2004; Martin, Marino, Rattey, Kay, & Cannon, 2005; Brazaitis & Skurvydas, 2010).

Cerebral blood flow is an important component to central fatigue as brain function relies on oxygen and substrate delivery. While at rest, the brain accounts for 20% of whole-body oxygen and glucose use while receiving approximately 15% of cardiac output (Lassen, 1985; Madsen, Holm, Herning, & Lassen, 1993). In relation to hyperthermia and exercise, circulatory stress and reductions in cardiac output influence cerebral blood flow as inadequate oxygen delivery to the brain and low levels of cerebral oxygen may contribute to fatigue (Ide, Pott, Van Lieshoutt, & Secher, 1998). The Kety-Schmidt method, which analyzes arterial and jugular venous inert gases, has consistently shown no change in cerebral flow (Madsen, Sperling, Warming, Schmidt, Secher, Wildschiødtz, Holm, & Lassen, 1993) whereas regional blood flow, or blood flow to specific areas of the brain, shows a distinct response to motor tasks associated with exercise. The variation in regional blood flow to the brain has been shown by near-infrared spectroscopy and further supported by $^{133}$Xe clearance and the transcranial Doppler ultrasound method (Olesen, 1971; Jørgensen, Perko, & Secher, 1992; Jørgensen, Perko, Hanel, Schroeder, & Secher, 1992). The increase in cerebral blood flow occurs even with minimal change in mean arterial pressure, indicating a significant increase in cerebral vascular conductance, mainly in the smaller vasculature within the brain as the diameter of the large cerebral arteries does not change (Giller, Bowman, Dyer, Mootz, & Krippner, 1993). Together, these results indicate no change in global blood flow to the brain but rather show a dynamic response of blood flow to specific regions of the brain as a response to exercise.

Another important aspect of cerebral blood flow and cerebral metabolism is carbon dioxide and oxygen tension within the cerebral vasculature. During hyperthermic conditions with a core temperature of 37-38°C or greater, minute ventilation increases linearly with rising core temperature (White & Cabanac, 1996; Katagiri, Fujii, Dobashi, Lai, Tsuji, & Nishiyasu, 2023). Hyperventilation has two important effects for cerebral tissue: first, hyperventilation causes arteriolar vasoconstriction, decreasing cerebral blood flow and cerebral blood volume as a result (Chin, Leigh, Heigenhauser, Rossiter, Paterson, & Kowalchuk, 2007). Second, hyperventilation induces hypocapnia as carbon dioxide is expelled from the lungs, disturbing the carbon dioxide-oxygen tension within the brain (Chin et al., 2007). The presence of carbon dioxide has different mechanisms with differing exercise intensities. At a moderate exercise intensity, arterial carbon dioxide concentrations increase causing vasodilation to further increase cerebral blood flow (Jørgensen et al., 1992). At high exercise intensities, carbon dioxide decreases due to the increased minute ventilation as well as causing a decrease in pH (Nielsen, Bredmose, Strømstad Voliantis, Quistorff, & Secher, 2002). Therefore, blood flow at high exercise intensities or with profound hyperventilation causes a decrease in cerebral flow, ultimately decreasing oxygen delivery to the brain and potentially affecting cerebral function. Nybo et al., (2002) evaluated the rates of oxygen extraction and glucose utilization to determine how lower rates of perfusion affected the brain. A control and hyperthermic exercise trial were conducted and cerebral blood flow and cerebral arterio-venous oxygen difference were measured. During exercise with hyperthermia, cerebral blood flow decreased by 18% from 51 to 43 mL/min/100g and was accompanied by an increased arterio-venous oxygen difference which increased 23% while the cerebral metabolic rate for oxygen increased (Nybo, Møller Volianitis, Nielsen, & Secher, 2002). Therefore, a decrease in cerebral blood flow is accompanied by an increase in oxygen extraction and metabolic rate for oxygen.

## PSYCHOLOGICAL ASPECTS OF RISK BEHAVIOR

The available literature pertaining to the psychological aspects of RT behavior during exercise in the heat is sparse. Instead, it is centered around describing cognitive processes affected during these states. Although this research does not pertain to RP and RT *per se*, the cognitive processes affected provide insight into how RP and RT may be affected.

**Defining Risk.** The literature on risk illuminates the fact that RT is largely determined by perceived risk. Two meta-analyses have concluded a higher perceived risk is associated with a lower likelihood of participating in the risky behavior (Brewer et al., 2007; Sheeran, Harris, & Epton, 2014). However, RP and RT are not linearly aligned. Such examples include adolescents engaging in sexual intercourse and perceived risk for contracting sexually transmitted diseases (Sneed, Morisky, Rotheram-Borus, Ebin, Malotte, Lyde, & Gill, 2001), risky driving behaviors and risk of fatal accidents (Ivers, Senserrick, Boufus, Stevenson, Chen, Woodward, & Norton, 2009), and smoking and perceived risk of lung cancer in high-school and college-aged students (Johnson, McCaul, & Klein, 2002). Beyond RP, research has indicated several other domains affecting one's ability to predict risk or engage in risky behaviors such as an individual's sensitivity to reward, risk propensity/proneness, closeness to peers or social context, current emotional state, perceived benefits of actions, and impulsivity levels are also effectors of RT decisions (Gerrard, Gibbons, Benthin, & Hessling, 1996; Baltruschat, Megías-Robles, Cándido, Maldonado, & Catena, 2021). Of the aforementioned factors, impulsivity has been shown to have the greatest impact on RT. In a study by Megías-Robles and colleagues (2022) which investigated if impulsivity causes those to partake in high-risk activities, three main findings were reported; first, higher impulsivity is associated with lower RP. Second, impulsivity was associated with lower RP and with lower avoidance of RT. Third, both RP and impulsivity were independent predictors of RT avoidance scores, with no interaction between the two factors (Megías-Robles et al., 2022). Thus, a greater propensity for impulsivity within individuals manifests in greater RT despite high perceived risk.

**Hyperthermia and Risk.** Several confounders exist which affect results in hyperthermia research. Although this makes interpreting the literature complicated, it also gives us further insight into how human physiology preserves itself. Both passive and active heat exposure are used to increase core temperature, however, it has been shown exercise can improve cognitive function and is dependent on fitness level, intensity, and duration of exercise (Brisswalter, Collardeau, & René, 2002; Grego, Vallier, Collardeau, Bermon, Ferrari, Candito, Bayer, Magnié, & Brisswalter, 2004). Low to moderate exercise performed for less than 60 minutes improves both simple and complex cognitive tasks (Chmura, Krysztofiak, Ziemba, Nazar, & aciuba-Uścilko, 1998). It is thought these improvements stem from increases in cerebral blood flow and arousal (Grego et al., 2004). Hydration status also plays a major role in thermoregulation and has been implicated in cognitive function. Although this is relatively well-known, many studies have not controlled this confounder. Duration of tasks is a confounder as prolonged periods of mental or physical exertion can lead to decreased cognitive function. While this effect is worsened during heat stress, how this aspect of cognitive tasks assigned to participants remains misunderstood (Schmit, Hausswirth, Le Meur, & Duffield, 2017).

Few studies have directly assessed how thermal strain impacts RP and RT. Although not evaluated directly, Ramsey et al. (1983) showed increased rates of unsafe behaviors after heat exposure (Ramsey et al., 1983). In one small study, participants perceived risky behaviors as less risky and engaged in more risk when exposed to thermal strain. When participants became heat acclimated, their perception of risk returned to baseline values, however, the propensity to engage in risky behavior remained at their heightened level (Chang et al., 2017). Other studies assessing RP and RT in the heat could not be found and highlights an apparent gap in the literature. Therefore, how hyperthermia affects the components of risk will be reviewed through its effect on other cognitive measures which may influence RP and RT.

Hyperthermia has been shown to influence cognitive function as demonstrated by Ramsey et al. (1983) who showed unsafe behavior increases in factory workers when ambient temperatures are high (Ramsey et al., 1983). Additionally, it was shown environmental temperatures which exceed 23℃ may lead to cognitive impairments (Ramsey et al., 1983). The Maximal Adaptability Model (Hancock & Warm, 1989) is a conceptual framework which presents heat stress as a *tax* on our ability to cope with stressors. When stress increases, more resources are needed to cope with the stress and ultimately decreases our available resources to maintain cognitive function (Hancock & Warm, 1989).

Multiple studies have demonstrated the usefulness of the Maximal Adaptability Model as a conceptual framework. Gaoua et al. (2018) showed heat stress may affect cognitive load by directly affecting the frontal cortex (Gaoua, Herrera, Périard, El Massioui, & Racinais, 2018). Another group investigated how heat stress affected vigilance (state of alertness) and found exposure to high ambient temperatures which produced high core temperatures negatively affected vigilance while decision making was unaffected (Faerevik & Reinertsen, 2003). A similar study found tasks involving visual perception and monitoring with manual responses were negatively affected at higher temperatures whereas tasks which involve memory were unaffected. Additionally, tasks were affected to a greater extent with higher humidity (Vasmatzidis, Schlegel, & Hancock, 2002). In an attempt to group cognitive processes together, Ramsey and Kwon (1992) categorized tasks as "simple" and "complex" tasks; simple tasks are simple perceptual motor tasks which require low mental effort such as basic arithmetic, reaction time tests, or simple decision making. Complex tasks require greater focus and attention and may require multiple cognitive processes such as complex motor tasks, working memory tasks, multitasking, problem-solving, vigilance, complex decision making, or sustained attention (Ramsey & Kwon, 1992).

Some studies have used attention network tests (ANT), a tool used to analyze distinct brain areas activated by alerting, orienting, and executive control activities. Alerting tasks are related to readiness and categorized as simple tasks, orienting tasks are related to proprioception and categorized as simple tasks, and executive control tasks are related to completing goals by initiating behaviors and categorized as complex tasks (Sun, Yang, Jiang, Liu, Li, L., Zhao, & Li, M., 2012). Using the ANT and fMRI, two studies have found alerting and orienting tasks are unaffected while executive function tasks were significantly affected during passive heating in 50°C and 40% relative humidity (Sun et al., 2012; Liu, K., Sun, Li, B., Jiang, Yang, Li, M., Li, L., Qian, Zhao, Zhou, von Deneen, & Liu, Y. 2013). As hypothesized in the Maximal Adaptability Model, complex tasks which involve greater cognitive load are shown to be affected when using the ANT to analyze brain areas, further illuminating how cognition is affected under heat stress.

Hyperthermia has been shown to improve cognitive performance at its onset but declines as core temperature increases (Taylor, et al., 2016). Early studies on this topic showed increases in core temperature above 38.5℃ improved simple task performance while complex tasks such as working memory, information retention, and information processing declined (Wilkinson, Fox, Goldsmith, Hampton, & Lewis, 1964; Hocking, Silberstein, Lau, Stough, & Roberts, 2001). Similarly, a 2011 study showed cognitive performance declined as core temperature reached 38.7℃ (Gaoua, Racinais, Grantham, & El Massioui, 2011). Bandelow et al. (2010) have suggested a temperature threshold for hyperthermia-induced cognitive improvements at 38.2℃ (Bandelow, Maughan, Shirreffs, Ozgünen, Kurdak, Ersöz, Binnet, & Dvorak, 2010). However, multiple studies have reported null effects when core temperature exceeded 38.2℃ (Holland, Sayers, Keatinge, Davis, & Peswani, 1985; Amos, Hansen, Lau, Michalski, 2000; Ashworth, Cotter, & Kilding, 2021). Notably, many of these studies have methodological differences such as short latency between heat exposure and testing (Holland et al., 1985), measuring of only simple tasks (Amos et al., 2000), or low to moderate exercise intensity concomitant with low environmental temperatures (Ashworth et al., 2021). Gaoua (2010) states variances in results can be explained by "the severity of temperature exposure, the methodology used to attain hyperthermia, the complexity and duration of the cognitive tasks utilized, the duration of exposure, and the skill level of the participants" (Gaoua, 2010). In agreement, several reviews have concluded the inconsistent results are due to cognition being affected by more than core temperature (Ramsey, 1995; Pilcher, Nadler, & Busch, 2002; Hancock & Vasmatzidis, 2003; Taylor et al., 2016). These results indicate a core temperature threshold of ~38.5℃ at which cognition declines. However, core temperature is not the only indicator for cognitive impairments and is dependent on temperature, complexity of tasks, and overall cognitive load. For example, selective skin cooling on the forehead was used to increase thermal comfort while maintaining elevated core temperatures which preserved short-term memory (Gaoua et al., 2011). In a separate study, thermal discomfort was measured and found greater impairments in cognition as comfort decreased independent of core temperature (Gaoua, Grantham, Racinais, & El Massioui, 2012). These results bring further precedence to the hypothesis that cognitive decline is not reliant on core temperature *per se* but instead a combination of stressors as suggested by the Maximum Adaptability Model (Hancock & Warm, 1989).

In an interesting study by Saini and colleagues (2017), 100 soldiers who had spent a minimum of 1 year in the desert were studied during the months of June and March. During the time of testing, temperature ranged from 25-27°C (March) to 42-43°C (June) creating a substantial temperature difference between both testing times (Saini, Srivastava, Agrawal, & Das, 2017). Multiple psychological tests were administered during this trial including the Post graduate institute memory scale (PGI), trail making test, reaction time, and the Wisconsin Card Sorting Test (WCST) (Saini et al., 2017). The results show that for the tasks attention and concentration, delayed recall, immediate recall, verbal retention for dissimilar pairs, visual retention, and recognition were significantly impaired in the hot environment compared to cool. Only for verbal retention of similar pairs, considered a simple task, was the difference between groups insignificant. The trail making test and WCST represent psychomotor dexterity, speed, and executive frontal lobe tasks. Both tests showed significant detriments in cognitive decline in the hot environment compared to the cool. Only the reaction time tests, representative of simple tasks, showed no statistical difference between hot and cool conditions (Saini et al., 2017). Of critical importance within this study are four factors: First, all soldiers were heat acclimated during the hot months. Second, humidity was relatively low (30% in March and 31% during June) and is likely not a confounder. Third, both complex tasks (trail making test, WCST, and select PGI measures) and simple tasks (reaction time and select PGI measures) were used in this study. Lastly, dehydration was controlled, and participants were maintained in a euhydrated state (Saini et al., 2017). This study uniquely demonstrates the additive effect of cognitive stressors on cognition. In other studies which use similarly high environmental temperatures but increase thermal comfort, attentional tasks are preserved (Racinais, Gaoua, & Grantham, 2008; Gaoua et al., 2011). These results support the idea that cognitive processes become inactive as thermal strain increases with more complex tasks being lost first and increasingly simpler tasks lost as heat stress increases. Likely, simple tasks are expended in an evolutionarily favorable manner with tasks such as attention being lost first (Racinais et al., 2008; Gaoua et al., 2011) and tasks such as reaction time (Saini et al., 2017) being preserved until heat stress becomes overwhelming and cognitive impairment ensues.

Taken together, the current literature indicates cognitive impairments due to heat stress result from a combination of stressors. In agreement with the Maximal Adaptability Model, cognitive processes which are the most demanding are affected first (e.g. Saini et al., 2017) and simpler cognitive processes (e.g. Ashworth et al., 2021) are affected to a lesser extent. During the onset of hyperthermia, cognitive processes improve until a core body temperature threshold, estimated to be ~38.5℃, is exceeded in which cognition has generally shown to decline. This marker of 38.5℃ can be modulated by additional stressors as previously mentioned, allowing cognitive impairment to begin at higher core temperatures if stressors are attenuated. Cognitive impairment is also dependent on several factors such as thermal comfort, complexity of tasks, intensity and duration of exercise, and duration and severity of heat exposure. Elements of cognition such as concentration, vigilance, decision-making, and memory are the first elements of cognition to become impaired, however, cognitive functions were not consistently affected across studies and are likely on a case-by-case basis. Ultimately, hyperthermia negatively affects cognition and, in the framework of exercise in the heat, can be expected to negatively affect an individual's vigilance, ability to make quick and favorable decisions, and ability to concentrate.

**Fitness and Risk.** Exercise relating to the parameters of risk is also limited within the literature. One study in adolescents describes the relationship between perceived risk and RT and shows adolescents with higher VO2Max values and handgrip strength also show higher levels of RP and more RT (González-Gálvez, Vaquero-Cristobal, Maciá-Andreu, García-Tascon, Soler-Marín, & Gallardo-Guerrero, 2023). However, it is also shown adolescents relationship to risk may deviate from older populations (Sneed et al., 2001). Perceptions of risk relating to disease have also been evaluated in relation to physical activity which has shown those who worry of future disease increase physical activity levels (Stephan, Boiche, Trouilloud, Deroche, & Sarrazin, 2011). Another study in college students shows those who are more anxious about their health also engage in positive health activities (Wang K., Liu, Yang, Wang, Y., 2024) These studies highlight an important factor within the present study; those who engage in physical activity may already have an increased level of RP compared to their less fit counterparts. This factor may act as a confounder for populations who are already highly fit. Studies which highlight how fitness affects perceptions of risk and the propensity to take risk are otherwise absent within the literature, further highlighting the importance to study how fitness level may affect how the parameters of risk are affected.

The effects of acute bouts of exercise on cognition and mood have been well documented (Berger, 1996; Stevens, Lieschke, Cruwys, Cárdenas, Platow, & Reynolds, 2021). The effects of exercise on cognition vary depending on the duration, intensity, and type of exercise performed. Research indicates short-term, moderate-intensity exercise can enhance cognitive processes such as attention, memory, and executive function. This enhancement is often attributed to increased cerebral blood flow, leading to improved oxygen and nutrient delivery to the brain, and the upregulation of neurotrophic factors like brain-derived neurotrophic factor (BDNF) (Tomporowski, 2003; McMorris, Sproule, Turner, & Hale, 2011).

Consistent with the Maximal Adaptability Model, increasing exercise duration has shown a detrimental effect on several cognitive processes. In one study, cyclists were given cognitive tasks before and every 20 minutes during a three-hour cycling trial with one group given fluids during exercise and another without. The results showed an initial improvement in reaction time and lower error rates, however, as exercise continued, error rate increased while reaction time remained consistent (Grego, Vallier, Collardeau, Rousseu, Cremieux, & Brisswalter, 2005).

**Dehydration and Risk.** Similar to hyperthermia, there is limited to no literature on RP and RT pertaining to dehydration and is therefore assessed through other cognitive measures. Although the effects of dehydration and physical performance are well known and have been previously described, how dehydration affects cognition is unclear. Similar to hyperthermia, the literature pertaining to dehydration and cognition is inconsistent and confounders must be considered to decipher its effects. Factors such as method of dehydration, exercise, hyperthermia, or task difficulty can affect results and must be accounted for. For example, exercise causes an increase in brain-derived neurotrophic factor (BDNF), cerebral glucose levels, oxygen uptake, and lactate which may sustain the level of cognitive performance (Secher, Seifert, & Van Lieshout, 2008). Therefore, how dehydration affects cognition must be evaluated in the context of dehydration alone and a further review of how these all these factors interact will be conducted in the following pages.

Dehydration is often attained in experimental trials via exercise, hyperthermic environments, water deprivation, and diuretics. Early studies evaluating dehydration and cognition used hyperthermic environments and/or exercise to attain dehydration. These studies show that a 2% or more body mass loss affects cognition (Cian et al., 2001; Baker, Conroy, & Kenney, 2007; Ganio, Armstrong, casa, McDermott, Lee, Yamamoto, Marzano, Lopez, Jimenez, Le Bellego, Chevillotte, & Lieberman, 2011). Although these results show an effect on cognition, confounders such as heat or exercise are not controlled. Systematic reviews have highlighted the importance of assessing dehydration and cognition in free-living participants. A systematic review of 12 separate studies suggests dehydration may impact cognitive capacities in sports with eight out of the studies showing significant effects. However, four articles did not find such effects (Casals Vázquez, Vázquez Sánchez, M., Sánchez, J., & Suárez-Cadenas, 2015). Rather than affecting cognition directly, it is suggested dehydration's effect on cognition should rather be attributed to its deleterious effect on mood state which has been extensively reported at 2% body mass loss (Benton, 2011; Armstrong et al., 2012; Pross, Demazières, Girard, Barnouin, Metzger, Klein, Perrier, Guelinckx, 2014; Suh, Lieberman, Jansen, Colburn, Adams, Seal, Butts, Kirkland, Melander, Vanhaecke, Dolci, Lemetais, Perrier, & Kavouras, 2021). As suggested by Armstrong et al. (2012), the effect on cognition is attributable to subjective feelings of reduced will, increased effort, and increased feelings of anxiety resulting in decreased desire to complete cognitive tasks (Armstrong et al., 2012). Therefore, dehydration during exercise and/or heat stress, which decrease cognition as previously discussed, should be prevented in order to mitigate decreases in mood. Dehydration should rather be assessed in the context of hyperthermia and exercise as hydration status is an important factor for thermoregulation and its' mechanisms. In accordance with the Maximal Adaptability Model, dehydration increases the number of stressors the nervous system can manage and preventing dehydration, especially 2% body mass loss or more, will allow complex cognitive tasks in the heat, such as vigilance or working memory, to be engaged.

## PHYSIOLOGICAL MEASUREMENTS

**Core Body Temperature.** Core body temperature measurements are a useful tool to quantify the thermoregulatory state of the body. Core temperature is a reflection of the thermal state of the internal organs and is a necessary measurement to accurately assess how an elevated internal bodily temperature affects variables such as RP or RT. The current methods to measure core body temperature are often invasive, expensive, or inaccurate. Skin temperature was initially thought to correlate with core temperature but later on was not found to reflect the thermal state of the internal organs (Moran & Mendal, 2002). The nasopharynx and tympanic membrane are sites chosen due to their proximity to essential areas such as the hypothalamus or internal carotid artery. However, both sites are subject to error due to environmental conditions, smoking, or drinking hot or cold beverages (Moran & Mendal, 2002; Roth, Verdile, Grollman, & Stone, 1996). The tympanic membrane in particular has been shown to correlate with rectal temperature but can be heavily influenced by physical effort in the heat making it unsuitable for field studies (Roth et al., 1996). These methods are often compared against invasive methods which prove to be the most accurate. Esophageal and rectal temperature are common methods used to measure core body temperature due to their position near internal organs (Lefrant, Muller, de La Coussae, Benbabaali, Lebris, Zeitoun, Mari, Saïssi, Ripart, Eledjam, 2003). The most accurate assessment of core body temperature is pulmonary artery measurements since it supplies blood flow directly to the core. This measurement is conducted using a catheter making it highly invasive and impractical for many research studies (Brengelmann, 1987). While invasive measures (esophageal, rectal, and pulmonary artery) are the most accurate in comparison to the less invasive methods, they are unsuitable for field studies with large amounts of participants evaluated each trial period.

Non-contact infrared thermometry (NCIT) has arisen as an alternative to more invasive measures of core body temperature estimates. Estimation of core body temperature through this measure involves assessing the skin surface temperature and measuring the emitted radiation within the infrared waveband. During the COVID-19 pandemic, infrared screening became a popular choice for assessing body temperature for fever diagnosis as it required minimal human contact and could be conducted quickly (Foster, Lloyd, & Havenith, 2021). The sensitivity of these measurements to detect fever is relatively low with one report stating only 5.2% of cases being detected (Mouchtouri, Bogogiannidou, Dirksen-Fischer, Tsiodras, & Hadjichristodoulou, 2020). The International Standardization Organization have stated these errors are due to screening groups of people instead of individually, not facing the camera directly, and faces being obstructed by masks (Howell, Mercer, & Smith, 2020). The forehead has been commonly used as a site of temperature measurements to assess fever, but have been shown to be inaccurate in low body temperature ranges (Ng, Chan, Lee, & Leung, 2005), affected by environmental conditions (Liu, Chang R.E., & Chang W. C., 2004), or cannot accurately predict core temperature values after physical activity (Pryor, Seitz, Morley, Suyama, Guyette, Reis, & Hostler, 2012). The inner eye canthus is a preferred site for measurement and is considered to be the most accurate at estimating core temperature (Mercer & Ring, 2009) and has been validated across in ambient temperature ranges of

21°C and 26°C with previously accepted core temperature measurements (International Standardization Organization, 2020). However, it has been shown to be inaccurate during dynamic exercise but performs better than forehead measurements (Fernandes, Moreira, Brito, da Silva, Sillero-Quintana, Pimenta, Bach, Garcia, & Bouzas Marins, 2016). Overall, the inner eye canthus has shown to be the most accurate site for estimating core body temperature under dynamic conditions and serves as a reasonable indicator of core body temperature when more accurate and invasive measures are unavailable.

Recommendations for NCIT measurements state the measurements should be taken indoors with an ambient temperature of 18°C-24°C, relative humidity between 10% and 75%, have limited airflow between the subject and the camera, and limit radiation from windows, lights or the sun (Foster et al., 2021). Emissivity, the ratio of emitted thermal energy relative to a perfect emitter, should also be considered. The emissivity of human skin with long wavelengths, such as infrared, is 0.98 and is recommended the infrared camera be set at this emissivity (Foster et al., 2021). The camera must also be positioned at an appropriate distance from the subject. Larger distances between the subject and the camera will increase the area measured and thus increases error in measurements. Thus, 0.3 meters is the recommended measurement distance with a 3 x 3 pixel area to analyze pictures (Foster et al., 2021). Utilizing these recommendations and specifications, a reasonably accurate estimate of core temperature can be attained and serves as a useful tool to measure multiple subjects within a short time period.

**Submaximal VO2Max Tests.** Cardiorespiratory fitness is a measure of health and is a direct reflection of the body's ability to supply oxygen to working muscles during aerobic and anaerobic exercise. VO2 is typically measured in milliliters of oxygen per kilogram of body weight per minute (mL/kg/min) and expresses the capacity of the lungs to uptake oxygen and distribute it to bodily tissues. $VO2_{MAX}$ represents the highest oxygen uptake that can be attained regardless of increasing exercise intensity. Therefore, higher $VO2_{MAX}$ values represent fitter individuals and are desirable for endurance events. Measurement of these values typically involves a graded exercise test with participants exercising on a cycle ergometer or a treadmill. Subjects wear a mouthpiece which captures all expired gases while a flow sensor analyzes the rate and volume of gases expired. Gas analyzers then quantify the concentration of oxygen and carbon dioxide and determine the amount of oxygen used by subtracting the amount of oxygen measured in the flow sensor from the amount exhaled. Although these tests provide a direct measurement of how much oxygen a subject can uptake, these tests are difficult and time consuming, making them not well suited for field studies with many participants.

Submaximal $VO2_{MAX}$ tests are an alternative method used to determine ones fitness levels. These tests do not directly measure maximal oxygen uptake but rather have participants perform submaximal exercise at an established intensity and work rate and then predicting $VO2_{MAX}$ using age-predicted maximal heart rate (Astrand, 1976). Due to their inexpensive requirements and ability to be performed by many people, submaximal $VO2_{MAX}$ tests are commonly used in place of maximal testing to predict $VO2_{MAX}$ values. Step tests are often the preferred test as they are a safe, portable, and inexpensive mode to measure this important variable (Peroy-Badal, Sevillano-Castaño, Núñez-Cortés, García-Fernández, Torres-Castro, Vilaró, Blanco, & Gimeno-Santos, 2022). A wide variety of step tests have been developed and validated against maximal testing with varying intensities, durations, and stages of the test. The Chester Step Test, Astrand-Rhyming, and Modified YMCA 3-minute Step Test are tests that have been validated against maximal testing and have been shown to correlate well with actual $VO2_{MAX}$ values (Bennett et al., 2016). The Modified YMCA 3-minute step test in particular showed a correlational value of 0.75 showing a strong relationship between predicted and measured $VO2_{MAX}$ (Santo & Golding, 2003). Overall, submaximal step tests provide an effective way to predict $VO2_{MAX}$ when the gold standard is unavailable or improbable.

**Urine Specific Gravity.** Measuring hydration status can be conducted through several methods such as plasma osmolality, urine osmolality, body weight changes, hematocrit, or urine specific gravity (USG). USG measurements rely on refractometers; manual or digital devices which measure the refractive index of liquids, providing insight into a subjects' hydration status. As a person becomes more hydrated, their urine becomes diluted, decreasing its' refractive index and lowering USG values. In a euhydrated individual, it is generally accepted a USG value of less than 1.020 indicates a euhydrated individual while values above this indicate dehydration (Popowski, Oppliger, Patrick Lambert, Johnson, Kim Johnson, & Gisolf, 2001).

Compared to plasma osmolality (POsm), the gold standard for hydration assessment, USG provides a less invasive and more accessible means of evaluating hydration status as measuring osmolality of fluids can be expensive and inefficient for large amounts of samples. Studies comparing USG against POsm have validated its effectiveness in various settings and have shown strong correlational values (r=0.86-0.97)

(Perrier, Rondeau, Poupin, Le Bellego, Armstrong, Lang, Stookey, Tack, Vergne, & Klein, 2013). However, it may not consistently reflect the body's true hydration state due to its susceptibility to external factors. Studies have shown discrepancies between USG and plasma osmolality, particularly in athletic and field settings, highlighting the importance of considering context when interpreting USG results and emphasizing the importance of standardized testing conditions to enhance its accuracy (Oppliger, Magnes, Popowski, & Gisolf, 2005; Cheuvront, Kenefick, Montain, & Sawka, 2010). Although USG measurements can have discrepancies compared to plasma osmolality, the low-cost and accessibility of its measurements make USG a preferred method to quantify hydration status.

**SUMMARY**

The current state of the literature describes the physiological and physical manifestations of hyperthermia and dehydration well. This includes how organ systems are affected by these states and how compensatory mechanisms respond to attenuate the effects of hyperthermia and dehydration. Additionally, cognitive function related to hyperthermia, fitness, and dehydration is well described and has a plethora of studies which assess how factors such as reaction time, memory, or attention span are affected. However, to date, studies which directly assess how RP and RT are affected relating to these factors are absent within the literature. The current study examines an important gap within the literature relating to the parameters of risk which can be used to further direct research on how fitness, hydration state, and thermal state affect how an individual perceives or takes risks.

# CHAPTER 3

# METHODS AND MATERIALS

This study was conducted during the summer of 2021 at Piestewa Peak (year 1, considered an extremely difficult trail) and in 2022 at the ASU campus including a hike at A-Mountain (year 2, considered a moderately difficult trail). The first summer targeted fit hikers and the second summer targeted sedentary participants. To ensure sedentary participants could finish the hike, a route from a lab facility North of the ASU campus toward A-Mountain was chosen. During Year 1, trained survey administrators randomly approached potential participants after returning from their hike between July 17 and October 3, 2021. Random weekends and weekdays were selected between the hours of 0600 and 1100 as well as 1700 and 2100 to approach participants. During year 2, participants were recruited before hiking the designated trail and assessed for eligibility with PAR-Q and YOU questionnaires.

This study was divided into two parts: Part I consists of a whole-body heat picture to assess core body temperature, an estimation of foods and fluids participants brought on their hike, and a 10-minute questionnaire via personal mobile devices or a tablet provided by the survey team. While completing the questionnaire, a pulse oximeter recorded the participant's heart rate and blood oxygen saturation levels. Participants who completed the questionnaire were asked if they would like to participate in Part II of the study. Part II consists of a three-minute YMCA step test while simultaneously recording heart rate up to one minute after the step test is completed. Cardiorespiratory fitness was determined using heart rate reserve, heart rate recovery, and an estimate of maximal oxygen uptake (VO2max). All participants were asked to provide an all-out urine sample regardless of whether they participated in Part II of the study.

Both Part I and Part II are identical in Year 1 and Year 2. Those who completed part two at Piestewa Peak in Year 1 of the study received a $5.00 Tango gift card for their participation. For participants who were recruited to participate in the A-mountain hike in Year 2, a $20.00 Tango gift card was awarded.

**PARTICIPANTS**

To achieve the desired statistical power, a minimum of 289 participants were needed to achieve a confidence level of 95% with a margin of error of 5%. Each participant was given an informed consent form and provided with pertinent information including potential risks and benefits associated with the study. Eligibility criteria for the 2021 cohort included being at least 18 years of age and having hiked for greater than 60 minutes or completed the entire trail. The 2022 eligibility criteria included being 18 years of age, non-exercising, and without contraindications for increasing activity levels as determined by PAR-Q and YOU questionnaires. This study received approval from the Institutional Review Board (IRB) at Arizona State University (STUDYXXXX). The IRB approval included a review of the research design, methodology, informed consent procedures, and data management protocols. IRB approval displays ethical design for participant safety and data management.

**PROCEDURES**

During the summer of 2021, participants in the Piestewa Peak cohort were randomly selected by survey administrators at the trailhead. A sign indicating an ongoing research study was the only form of recruitment for this phase.

During the summer of 2022, participants in the A-Mountain cohort were recruited by hanging posters on the Arizona State University (ASU) Tempe and Downtown Phoenix campuses. Posters were also distributed via email to ASU-based organizations. Additionally, social media ads were ran for approximately 2.5 weeks using Facebook ads to target the desired population.

After the recruitment phase, the study design was identical for all cohorts. Participants were given informed consent forms which asked participants if they would like to participate in part two of the study. After signing the IRB-approved informed consent form, participants were instructed to abstain from drinking or eating anything during Part I of measurements (~10 minutes) to not interfere with subjective measurements. After completion of informed consent, participants were given a subject ID to allow for anonymity within the data set. Two primary outcomes were measured and assessed for this study: the socio-psychological heat-related risks of hiking and RT behaviors of hikers and physiological measurements of fitness and core temperature. The socio-psychological aspect of this study assessed participants' perception of thirst, heat, exertion, hiking risk, hiking experience, socio-demographic information, and participants' knowledge of Phoenix's "Take a Hike, do it Right" campaign. The physiological outcomes estimated are VO2 max, core temperature, hydration status, heart rate, and oxygen saturation.

**Part I.** A whole-body heat camera picture was taken from the front and back to assess body surface temperature. Participants were asked to share the food and fluid containers brought with them to the trail, allowing the research team to estimate the volume and size of items brought to the trail. During this time, participants completed a

10-minute questionnaire that measured perceived exertion using the Borg scale (6-20 rating scale), RP (using multiple questions and quantified for a total score), heat perception (1-10 rating scale), thirst sensation (1-100 scale based on the following question: If you had a glass of water right now, would you feel the need to drink water from it?), hiking experience, and sociodemographic data including relationship to Piestewa Peak in the Piestewa Peak cohort. During this process, oxygen saturation and heart rate were measured for five to 10 minutes. All participants were asked to refrain from drinking or eating during these measurements to not affect temperature measurements.

**Part II.** For the modified YMCA step test, step heights were set at 12 inches for every participant and a 96 beats per-minute cadence was adopted. Instructions were given to step in time with each beat, stepping one foot up on the bench (beat one) followed by the other foot (beat two) and subsequently step down with one foot (beat three) followed by the other foot (beat 4). This rhythm is to be maintained throughout the entire three-minute step test. If perfect cadence is maintained throughout the test, 24 cycles of steps are to be completed each minute. During the test and for one minute after the test, heart rate was recorded. Cardiorespiratory fitness was assessed based on heart rate reserve and estimating maximum oxygen consumption. Those who completed the step-test were asked to provide an all-out urine sample in a 990 mL container within the trailhead restroom facilities. Urine collection cups were weighed before and after sample collection and the difference between these measurements was used to determine urine volume. Urine specific gravity (USG) measurements were performed to quantify hydration status.

## MATERIALS

**Questionnaire.** An online 39-question questionnaire (Appendix ‘A’) was used to collect self-reported socio-psychological data. Questions included how many years they have hiked Piestewa Peak, the number of times they participate in this hike per year, the duration of their hike, and their attachment to Piestewa Peak. To assess attachment, participants were given various statements such as “I am very attached to Piestewa Peak” or “I will bring my children to Piestewa Peak” and asked to rate these statements on a 1-5 scale or from “Strongly Disagree” (“1”) to “Strongly Agree” (“5”). Modifications to these questions were used during Year 2 to reflect hiking at A-Mountain instead of Piestewa Peak. Participants were asked what factors they consider when deciding how much fluid to bring on their hike, their satisfaction with the amount of fluid they had brought, and if they had used any of the fluid to pour over their head/body. Thirst sensation was based on the following question: “If there were a glass of water in front of you, would you drink it?” and quantified on a 1-100 scale. During the questionnaire, pulse oximeters were placed on participants' wrists to measure oxygen saturation and heart rate. Additionally, participants were asked to rate their perceived exertion of the hike on the Borg Scale (6-20). Participants were asked about their perceptions heat and how they prepared for the heat. These parameters will be assessed using a sliding scale, a 1-5 rating scale, or a fill-in-the-blank question. Participants were assessed on their knowledge of Phoenix’s heat warning system “Take a Hike, do it Right” campaign and their favorability on methods to attenuate the rise in heat-related injury during heatwaves. Finally, participants' self-perceived risk was assessed by rating how dangerous the

Phoenix heat is for them (scale of 1-5), personal safety concerns, and complaints during hikes.

**Physiological measurements.** ***Heart rate*.** Participants were instructed to remain seated as soon as they arrived at the trailhead facility and asked to complete the questionnaire. During the questionnaire, a pulse oximeter (Zacurate 500BL Fingertip Pulse Oximeter Blood Saturation Monitor, Stafford Texas) was placed on each participant's index finger to measure heart rate. Two measurements were recorded; one measurement after being seated and another after five minutes. Oxygen saturation was recorded at each of these time points.

***Thermal Imaging.*** Core body temperature was estimated using NCIT. A handheld FLIR infrared camera (FLIR E95, Teledyne FLIR, FLIR Systems, Wilson Oregon, USA) imaged whole-body temperature (front and back) and estimated core body temperature by measuring the temperature of the internal canthus of the eye. NCIT measurements were taken indoors where temperature and environment were more stable (26°C). Each participant was seated on a stool and the NCIT camera was placed 30 cm from the participant’s face. Infrared headshots were taken of participants and, from the heat map of the headshots, a 3x3 pixel area was selected using the free FLIR Thermal Studio Starter Program, at the inner-eye canthus (i.e. inside part of the eyelid between the nose and the eye). This area of the head is considered to reasonably reflect core temperature (Foster, Lloyd, & Havenith, 2021). The program reports the maximum, minimum, and average temperature of the measured area. The whole emissivity was set at 0.98 for human skin. In addition, reflected temperature, atmospheric temperature, and relative humidity was set for the appropriate date.

***Cardiorespiratory fitness.*** $VO2_{MAX}$ was assessed by using a modified YMCA step test protocol. A 12-inch step height was used for all participants and a 96 beats-per-minute cadence was adopted for the test. Heart rate was measured during the test and for one minute after the test using the pulse oximeter (Zacurate 500BL Fingertip Pulse Oximeter Blood Saturation Monitor, Stafford Texas).

***Hydration status.*** Urine volume was measured by calculating the difference between the bottle with the urine sample and the empty bottle (measured before urine collection). Each measurement was performed on a precision scale (Amazon Basics, 2021, Electronic Kitchen Scale, Amazon) and performed twice. If the difference between measurements was greater than 0.5 mL, a third measurement was taken, and the median volume value accepted. Hydration status and urine temperature was quantified by analyzing the urine sample via urine specific gravity refractometry (Atago 4410 PAL-10S Digital Handheld Pocket Urine S.G. Refractometer, 1 to 1.06 Urine Specific Gravity Range, Bellevue Washington). Urine was transferred to the refractometer's measurement prism using a transfer pipette and each sample measured twice. If the measurements differ by more than 0.005, a third measurement was taken, and the median value accepted.

**Environmental conditions.** Environmental assessments of temperature, humidity, and wind speed were taken during each trial period using a Kestrel 5400 Heat Stress Tracker (Nielsen-Kellerman, Boothwyn, PA, USA).

**Calculations.** $VO2_{MAX}$ was calculated using the following equations (Kieu NTV, 2020):

$$Males: VO2_{MAX} = 70.597 - 0.246 \times (Age) + 0.077 \times (Height) - 0.222 \times (Weight) - 0.147 \times (HR)$$

$$Females: VO2_{MAX} = 70.597 - 0.185 \times (Age) + 0.097 \times (Height) - 0.246 \times (Weight) - 0.122 \times (HR)$$

VO2Max equations for Males and females can be found in Figure 1:

| Equation | Formula |
|---|---|
| VO2Max, Males | VO2max = 70.597 - 0.246 × (Age) + 0.077 × (Height) - 0.222 × (Weight) - 0.147 × (HR) |
| VO2Max, Females | VO2max = 70.597 - 0.185 × (Age) + 0.097 × (Height) - 0.246 × (Weight) - 0.122 × (HR) |

*Figure 1. Equations used to calculate VO2Max for males and females.*

**Grouping.** Participant cardiovascular fitness data was separated into high and low groups based on the median estimated VO2Max values. High and low VO2Max categories were also created based on the median VO2Max value for male and female genders respectively to evaluate if gender is a confounding variable within the dataset. Hydration levels will be categorized as euhydrated (USG $< 1.020$) and dehydrated (USG $\geq 1.020$). Skin temperature data was divided into high and low groups as defined by the median value within the data set. Heat perception data was divided into quartiles based on the median value within the data set. Thirst perception data was divided into quartiles as defined by the median value within the data set. Exertional data was not split into groups as the values did not vary enough to create meaningful categories. Participants RP will be quantified by adding scores from RP questions from questions 16 and 17 (Appendix ‘A’) which are assessed on a five-point Likert scale and quantified as 1-5 points. The total amount of individual questions for RP was 15 with a maximum possible score of 75 and a minimum score of 15 where higher scores indicate higher RP. Scores for RT were quantified by summing the number of preparatory actions indicated on questions 15, 18, 19, 25, 26, and 27 (Appendix ‘A’). For questions 15 and 27, answers were assessed on a five-point scale and quantified as 1-5 points. Questions 18, 19, 25, and 26 were asked in a “yes” or “no” format with “yes” answers equating to one point and less RT behaviors and “no” answers equating to zero points and more RT behaviors. A total of 37 RT questions were asked with a maximum score of 122 and a minimum score of 20 with higher scores indicating lower RT behaviors. The RP groups were created based on the median value and split into high-risk perception (HRP) groups and low-risk perception (LRP) groups. Similarly, high and low RP groups were created for male and female genders based on the median value within each respective gender.

**Data Analysis.** SPSS version 25 and Excel were used for statistical analyses. Variables within the data set are presented as mean ±SD, median, interquartile range, or as a percentage. Questions for RP and RT were assessed based on high and low RP groups. Mann-Whitney U tests were employed for questions which used the Likert scale, while questions with a “yes” or “no” format were assessed with Chi-Square tests of independence to discover statistical differences between RP groups and evaluate the median differences. Complaints experienced were assessed with Chi-Square tests of independence to discover median differences between RP groups. The variables of fitness, hydration state (USG), and body temperature, were assessed as continuous variables against RP groups. These variables were also assessed as dichotomous groups and compared with Chi-Square tests of independence and Mann-Whitney U tests were employed for statistically significant tests. Multivariate and one-way ANOVA tests were used to compare cardiorespiratory fitness, hydration data (USG), body temperature, Borg scale values, feelings of heat, and feelings of thirst groups to the variables of RP and RT respectively. Tukey's post hoc test was employed if a statistical difference was found for any of the independent variables with degrees of freedom greater than one. Self-perceived exertion, objective and subjective heat stress, thirst sensation, RP, cardiorespiratory fitness, and hydration status were correlated against each other using Spearman correlations which include a 95% confidence interval based on Fisher's Z transformation. All significance levels are set at $P \leq 0.05$.

CHAPTER 4

RESULTS

**PARTICIPANTS**

In total, 880 hikers were approached and *n* = 319 participants, aged 16 to 75 years, agreed to participate in the study (36.3% response rate). Additionally, *n* = 21 subjects were recruited during year 2 as less active participants, resulting in a total of *n* = 340 participants. Of the respondents, 54.4% of participants were male, 42.9% were female, and 0.9% were non-binary/third gender. Participants reported 80.0% Caucasian/white, 20.6% Hispanic or Latino descent, 10.9% Asian, 4.1% black or African American, 2.9% American Indian or Alaskan Native, and 1.2% Native Hawaiian or other Pacific Islander. Participants were allowed to select multiple options and thus the total percentage exceeded 100%. Other participant characteristics include an average 175±9.3 cm in height, 74.3±14.8 kg in weight, and aged 40.6±12.9 years. When classifying participants for perceived risk, the LRP group were 35.9% female and aged 41.4±13.4 years. Those within the HRP group were 51.3% female and aged 39.7±12.2 years. Only gender was found to be significantly different between RP groups ($p = 0.015$). Other sample characteristics can be found in Table 1.

Table 1

*Demographic Distribution of the Sample*

| Descriptives | Sample | High Risk Perception | Low Risk Perception | P Value |
|---|---|---|---|---|
| Height (cm), Mean (STD) | 174.45 (9.26) | 171.40 (9.03) | 173.25 (9.39) | 0.077 |
| Weight (kg), Mean (STD) | 74.32 (14.80) | 73.18 (14.62) | 74.93 (14.97) | 0.417 |
| BMI | 24.80 (3.79) | 24.87 (3.86) | 24.74 (3.75) | 0.859 |
| Age (yrs) | 40.61 (12.85) | 39.72 (12.16) | 41.39 (13.40) | 0.235 |

| Descriptives | % (n) | Group % (n) | | P Value |
|---|---|---|---|---|
| | | High Risk Perception | Low Risk Perception | |
| Gender | | | | 0.015 |
| Male | 54.4% (185) | 47.4% (74) | 60.3% (111) | |
| Female | 42.9% (146) | 51.3% (80) | 35.9% (66) | |
| Non-Binary/ Third Gender | 0.9% (3) | 1.3% (2) | 0.5% (1) | |
| Prefer Not to say | 0.3% (1) | 0 (0%) | 0.5% (1) | |
| Missing | 1.5% (5) | 0% (0) | 2.7% (5) | |
| Race | | | | |
| Hispanic or Latino | 20.6% (70) | 21.2% (33) | 20.1% (37) | 0.866 |
| American Indian or Alaskan Native | 2.9% (10) | 3.8% (6) | 2.2% (4) | 0.351 |
| Asian | 10.9% (37) | 12.2% (19) | 9.8% (18) | 0.465 |
| Black or African American | 4.1% (14) | 3.2% (5) | 4.9% (9) | 0.452 |
| Native Hawaiian / Pacific Islander | 1.2% (4) | 1.3% (2) | 1.1% (2) | 0.857 |
| White | 80.0% (272) | 78.8% (123) | 81.0% (149) | 0.201 |
| Employment Status | | | | 0.546 |
| Education | | | | 0.241 |
| Income | | | | 0.328 |

*Note. This table displays the demographic distribution of the sample population, percentage of participants within a specific demographic, and significant difference* *between high and low risk perception groups (p value). P values were calculated using an independent T-test.*

The normality of the data was assessed using the Kolmogorov-Smirnov test. The results show distributions for VO2Max (D = 0.106, p < 0.001), body temperature (D = 0.207, p < 0.001), the Borg Scale (D = .331, p < 0.001), feelings of heat (D = 0.285, p < 0.001), and feelings of thirst (D = .072, p < 0.001) significantly deviated from normality while USG did not significantly deviate from normality (D = 0.075, p = 0.077) (Table 2).

Table 2

*Normality Distribution for Independent Variables.*

| Variable | Kolmogorov-Smirnov | | |
|---|---|---|---|
| | Statistic | df | P value |
| VO2Max | 0.106 | 132 | <0.001 |
| USG | 0.075 | 130 | 0.077 |
| Body Temperature | 0.207 | 116 | <0.001 |
| Borg Scale | 0.374 | 306 | <0.001 |
| How hot do you feel now? | 0.285 | 333 | <0.001 |
| How thirsty do you feel now? | 0.071 | 317 | <0.001 |

*Note. This table summarizes the results of a Kolmogorov-Smirnov (K-S) test, which evaluates the normality of distributions for selected physiological and perceptual variables in the study. The 'Statistic' column reports the K-S statistic, which measures the discrepancy between the empirical distribution of the sample and the expected cumulative normal distribution. Column labeled 'df' indicates degrees of freedom associated with each test. The 'P value' provides the probability of observing the given* *result under the null hypothesis, which assumes that the data follow a normal distribution. P values below 0.05 suggest a statistically significant departure from normality, indicating that the data does not follow a normal distribution.*

**Correlations between physiological variables.** Nonparametric correlational analyses were conducted to explore the relationships between physiological measurements, subjective perceptions of heat and thirst, fluid intake, RP, and RT behaviors among participants (n=340) (Table 6). Spearman's rank-order correlations were computed due to the non-normal distribution of the data as indicated by the Kolmogorov-Smirnov test.

A significant positive correlation was found between the volume of fluid brought by hikers and the volume consumed ($r(288) = 0.767$, $p < 0.01$). Participants' self-reported heat perception during the hike was moderately correlated with their thirst levels ($r(315) = 0.424$, $p < 0.01$), indicating as hikers felt hotter, they also report feeling thirstier. RP was significantly correlated with self-reported heat perception ($r(331) = 0.230$, $p < 0.01$) and RT behaviors ($r(338) = 0.308$, $p < 0.01$) suggesting individuals who perceived higher levels of risk were more likely to report feeling hot during the hike and engage in more RT behaviors. Additionally, a weak but significant correlation between VO2Max and RT ($r(130) = 0.180$, $p < 0.05$) was found implying those with higher fitness levels may be inclined to take more risks. However, no other significant correlations were observed between the aforementioned variables ($p > 0.05$).

Table 3

*Spearman Correlation Matrix for Physiological and Subjective Measures*

| Variable | n | Mean (STD) | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. VO2Max | 132 | 50.01 (10.67) | | | | | | | | | |
| 2. USG | 128 | 1.021 (0.009) | 0.071 | | | | | | | | |
| 3. Body Temp. (°C) | 116 | 34.65 (2.08) | 0.021 | 0.074 | | | | | | | |
| 4. Borg Scale | 281 | 8.56 (3.66) | 0.073 | 0.006 | 0.156 | | | | | | |
| 5. Fluid Brought (mL) | 290 | 1343 (1169) | 0.164 | 0.088 | 0.071 | 0.009 | | | | | |
| 6. Fluid Consumed (mL) | 290 | 752.4 (617.7) | 0.040 | 0.021 | 0.163 | 0.039 | 0.767** | | | | |
| 7. Feelings of Heat | 333 | 3.54 (1.86) | 0.138 | 0.013 | 0.126 | 0.131* | 0.077 | 0.003 | | | |
| 8. Feelings of Thirst | 317 | 36.89 (21.09) | 0.010 | 0.081 | 0.079 | 0.083 | 0.033 | 0.018 | 0.424** | | |
| 9. Risk Perception | 340 | 47.07 (10.16) | 0.154 | 0.061 | 0.028 | 0.094 | 0.053 | 0.024 | 0.230** | 0.159** | |
| 10. Risk-Taking | 340 | 46.36 (15.61) | 0.180* | 0.035 | 0.159 | 0.096 | 0.037 | 0.027 | 0.056 | 0.041 | 0.308** |

*Note. This table presents the Spearman rank-order correlation coefficients among various physiological subjective measures within the study cohort. Correlational coefficient values are shown in the table above. Values with (*) indicate significance at the $p < 0.05$ level while values with (**) indicate significance at the $p < 0.01$ level.*

**Risk Perception.** The median RP score for the sample was 48.0±10.2, the LRP group median score was 42.0±7.20, and the HRP group median score was 55.0±5.35 (minimum possible score is 18 and maximum possible score is 90). The internal consistency of RP questions was assessed using Cronbach's alpha. For the 18 questions used to determine RP score, the Cronbach alpha was found to be 0.876, indicating a high level of reliability. Table 4 displays the results from Mann-Whitney U tests to determine differences between RP groups across RP questions as well as median and interquartile ranges for RP questions. Results show those in the HRP group were more likely to perceive more risk compared to the LRP group (p>0.001).

Table 4

*Median Responses for Risk Perception Questions (n=340)*

| Questionnaire Question | Median (IQR) | Risk Perception Group | N | Median (IQR) | P Value (Effect Size) |
|---|---|---|---|---|---|
| How dangerous do you think the Phoenix heat is for you? | 3.00 (3.0-4.0) | Low | 184 | 3.0 (2.0-4.0) | <0.001 (-0.41) |
| | | High | 156 | 4.0 (3.0-4.0) | |
| Sudden change in weather conditions | 3.0 (2.0-4.0) | Low | 184 | 3.0 (2.0-3.0) | <0.001 (-0.44) |
| | | High | 156 | 4.0 (3.0-4.0) | |
| Outdoor medical assistance is not accessible when in need | 3.0 (2.0-4.0) | Low | 184 | 2.0 (2.0-3.0) | <0.001 (-0.45) |
| | | High | 156 | 4.0 (3.0-4.0) | |
| Poor communication with the outside world | 3.0 (2.0-4.0) | Low | 184 | 2.0 (2.0-3.0) | <0.001 (-0.46) |
| | | High | 156 | 3.0 (3.0-4.0) | |
| Wildlife invasion, insect bites, snake bites | 3.0 (2.0-4.0) | Low | 184 | 3.0 (2.0-3.0) | <0.001 (-0.40) |
| | | High | 156 | 4.0 (3.0-4.0) | |
| Accidents such as falling, slips, injuries, etc. | 4.0 (3.0-4.0) | Low | 184 | 3.0 (3.0-4.0) | <0.001 (-0.43) |
| | | High | 156 | 4.0 (4.0-5.0) | |
| Insufficient and inadequate peers would affect the team | 3.0 (2.25-4.0) | Low | 184 | 3.0 (2.0-4.0) | <0.001 (-0.35) |
| | | High | 156 | 4.0 (3.0-4.0) | |

| Questionnaire Question | Median (IQR) | Risk Perception Group | N | Median (IQR) | P Value (Effect Size) |
|---|---|---|---|---|---|
| Loss of property during hiking | 2.0 (2.0-3.0) | Low | 184 | 2.0 (1.0-2.75) | <0.001 (-0.35) |
| | | High | 156 | 3.0 (2.0-3.0) | |
| Hiking experience falling short of expectations | 2.0 (2.0-3.0) | Low | 184 | 2.0 (1.0-2.0) | <0.001 -0.39 |
| | | High | 156 | 3.0 (2.0-3.0) | |
| Exertional heat illness (fever, nausea) | 3.0 (2.0-4.0) | Low | 184 | 3.0 (2.0-3.75) | <0.001 (-0.50) |
| | | High | 156 | 4.0 (3.0-4.0) | |
| Physical exhaustion | 3.0 (2.0-4.0) | Low | 184 | 3.0 (2.0-3.0) | <0.001 (-0.51) |
| | | High | 156 | 4.0 (3.0-4.0) | |
| Getting lost during the hike | 2.0 (2.0-4.0) | Low | 184 | 2.0 (1.0-3.0) | <0.001 (-0.50) |
| | | High | 156 | 3.0 (2.0-4.0) | |
| Lack of shade | 3.0 (2.0-4.0) | Low | 184 | 3.0 (2.0-4.0) | <0.001 (-0.45) |
| | | High | 156 | 4.0 (3.0-4.0) | |
| Feeling uncomfortable in unfamiliar surroundings | 2.0 (2.0-3.0) | Low | 184 | 2.0 (1.0-2.0) | <0.001 (-0.52) |
| | | High | 156 | 3.0 (2.0-4.0) | |
| Carrying insufficient fluid | 3.0 (2.0-4.0) | Low | 184 | 2.0 (1.0-4.0) | <0.001 (-0.52) |
| | | High | 156 | 4.0 (3.0-5.0) | |
| Carrying insufficient snacks/ food | 3.0 (2.0-4.0) | Low | 184 | 2.0 (2.0-3.0) | <0.001 (-0.53) |
| | | High | 156 | 4.0 (3.0-4.0) | |

*Note. This table displays responses to risk perception questions with associated medians and interquartile ranges, stratified by risk perception groups (Low vs. High). Each question prompts participants to rate their concerns about various hiking-related risks on a scale from 1 ("Strongly Disagree") to 5 ("Strongly Agree"). Responses were numerically scored as 1, 2, 3, 4, and 5 points respectively, representing increasing levels of concern. The statistical significance of differences between the groups is reported with* *p-values, derived from Mann-Whitney U tests, indicating the probability that such differences could arise by chance. Biserial effect sizes, calculated using the formula 'Effect Size =*$\frac{z}{\sqrt{n}}$*', quantify the strength and direction of these differences, with negative values suggesting higher concern in the High-risk group.*

The median RT score for the sample was 43.0±15.6, the median score for the LRP was 40.0±15.4, and the median score for the HRP group was 48.0±14.6, with lower values indicating a higher likelihood to take risk (minimum possible score is 17 and maximum possible score is 112). Total RT scores were compared across RP groups using Mann-Whitney U tests and biserial effect sizes which showed RT scores were significantly different across RP groups ($p < 0.001$, $r = -0.272$). Those who perceive more risk are also less likely to take more risk.

Differences in RT question responses from Table 5 which questioned participants which elements of the "Take a Hike, Do it Right" campaign they consider when hiking were assessed across RP groups using Mann-Whitney U tests and biserial effect sizes. Participants in the HRP group were more likely to consider the importance of watching the weather (LRP: Median = 1.0, IQR = 1.0-3.0; HRP: Median = 1.0, IQR = 1.0-4.0; p = 0.016, r = -0.130), dressing appropriately for the hike (LRP: Median = 1.0, IQR = 1.0-3.0; HRP: Median = 1.0, IQR = 1.0-4.0; p = 0.004, r = -0.155), bringing water (LRP: Median = 1.0, IQR = 1.0-4.0; HRP: Median = 1.0, IQR = 1.0-5.0; p = 0.012, r = -0.137), keeping in contact with others (LRP: Median = 1.0, IQR = 1.0-3.0; HRP: Median = 1.0, IQR = 1.0-4.0; p = 0.001, r = -0.175), teaming up with others (LRP: Median = 1.0, IQR = 1.0-3.0; HRP: Median = 1.0, IQR = 1.0-4.0; p = 0.005, r = -0.152), being honest about their physical and medical condition prior to hiking (LRP: Median = 1.0, IQR = 1.0-4.0;

HRP: Median = 1.0, IQR = 1.0-4.0; p = 0.007, r = -0.147), and taking responsibility (LRP: Median = 1.0, IQR = 1.0-4.0; HRP: Median = 1.0, IQR = 1.0-4.0; p = 0.009, r = -0.142). The question “Don’t trailblaze” did not reach statistical significance between RP groups (LRP: Median = 1.0, IQR = 0.0-4.0; HRP: Median = 1.0, IQR = 0.0-4.0; p = 0.098). The internal consistency of RT questions from Table 5 was assessed using Cronbach’s alpha. For the 8 questions found on Table 5, the Cronbach alpha was found to be 0.980, indicating a high level of reliability.

Table 5

*Safety Measures During Hiking Stratified by Group (n=340).*

| Risk-Taking Question | Risk Perception Group | N | Median (IQR) | P Value (Effect Size) |
|---|---|---|---|---|
| Watch the weather | Low | 184 | 1.0 (1.0-3.0) | 0.016 (-0.130) |
| | High | 156 | 1.0 (1.0-4.0) | |
| Dress appropriately | Low | 184 | 1.0 (1.0-3.0) | 0.004 (-0.155) |
| | High | 156 | 1.0 (1.0-4.0) | |
| Bring water | Low | 184 | 1.0 (1.0-4.0) | 0.012 (-0.137) |
| | High | 156 | 1.0 (1.0-5.0) | |
| Keep in contact | Low | 184 | 1.0 (1.0-3.0) | 0.001 (-0.175) |
| | High | 156 | 1.0 (1.0-4.0) | |
| Team up | Low | 184 | 1.0 (1.0-3.0) | 0.005 (-0.152) |
| | High | 156 | 1.0 (1.0-4.0) | |
| Be honest about your physical and medical condition | Low | 184 | 1.0 (1.0-4.0) | 0.007 (-0.147) |
| | High | 156 | 1.0 (1.0-4.0) | |
| Don't trailblaze | Low | 184 | 1.0 (1.0-4.0) | 0.098 (-0.090) |
| | High | 156 | 1.0 (1.0-4.0) | |
| Take responsibility | Low | 184 | 1.0 (1.0-4.0) | 0.009 (-0.142) |
| | High | 156 | 1.0 (1.0-4.0) | |

*Note. This table presents the results of questions with the prompt "Did you consider the following" which assesses the extent to which participants considered various safety measures while hiking stratified by risk perception group (Low vs high). The medians and interquartile ranges (IQR) for each safety measure are provided. The p-values, derived from Mann-Whitney U tests, indicate the probability that observed differences between* *the two groups occur by chance. Biserial effect sizes, calculated using the formula 'Effect Size =*$\frac{z}{\sqrt{n}}$*', quantify the strength and direction of these differences, with negative values suggesting higher concern in the High-risk group.*

The RT questions from Table 6 which questioned participants which factors they considered when planning how much fluid to take with them was assessed across RP groups using Chi square test of independence with phi effect sizes. Participants in the HRP group were more likely to consider the daily temperature (LRP: 31.8%, HRP: 34.1%, p = 0.002, r = -0.165) and the planned duration of the hike (LRP: 32.4%, HRP: 33.8%, p = 0.007, r = -0.147). Although not statistically significant, there was a tendency for those in the HRP group to more frequently consider the amount of fluid they can carry (LRP: 19.7%, HRP: 21.2%, p = 0.069, r = 0.099), and a tendency for those in the LRP to not consider any factors when hiking (LRP: 2.1%, HRP: 0.3%, p = 0.055, r = -0.104). Other factors such as financial situation or lack of planning fluid intake did not show significant differences (p = 0.109 or greater).

Table 6

*Hydration Strategies Among Hikers Stratified by Group (n=340)*

| Risk-Taking Question | Total group % (n) | Risk Perception Group | % (n) | P Value (Effect Size) |
|---|---|---|---|---|
| None | 2.4% (8) | Low | 2.1% (7) | 0.055 (-0.104) |
| | | High | 0.3% (1) | |
| Today's temperature | 65.9% (224) | Low | 31.8% (108) | 0.002 (-0.165) |
| | | High | 34.1% (116) | |
| Planned duration of the hike | 66.2% (225) | Low | 32.4% (110) | 0.007 (-0.147) |
| | | High | 33.8% (115) | |
| The amount of fluid that I am able to carry | 40.9% (139) | Low | 19.7% (67) | 0.069 (0.099) |
| | | High | 21.2% (72) | |
| Available bottle or container size | 24.1% (82) | Low | 12.4% (42) | 0.545 (0.033) |
| | | High | 11.8% (40) | |
| The water/restroom facilities on this trail | 16.8% (57) | Low | 8.8% (30) | 0.805 (0.013) |
| | | High | 7.9% (27) | |
| My financial situation | 0.9% (3) | Low | 0.9% (3) | 0.109 (-0.087) |
| | | High | 0.0% (0) | |
| I did not really plan my fluid intake | 5.0% (17) | Low | 3.2% (11) | 0.369 (-0.049) |
| | | High | 1.8% (6) | |
| Other | 5.9% (20) | Low | 3.5% (12) | 0.586 (-0.030) |
| | | High | 2.4% (8) | |

*Note. This table displays the percentage of participants who considered various factors when deciding how much fluid to bring on a hike, stratified by low and high risk perception groups. The total group percentage reflects the proportion of all participants that considered each factor, while subgroup percentages reflect responses within each risk perception group. Statistical significance was tested using chi-square tests, and effect sizes were determined using Phi coefficients, which measure the strength of association between categorical variables.*

The RT questions listed in Table 7, asking participants which risk-mitigating strategies they use during excessive heat warnings were assessed across RP groups using Mann-Whitney U tests and biserial effect sizes. Participants in the HRP group showed a greater acceptance for signing in at the trailhead with the option to be tracked via phone or tracking device (LRP: Median = 3.0, IQR = 2.0-4.0; HRP: Median = 4.0, IQR = 3.0-4.0; $p < 0.001$, $r = -0.200$), access to trails being limited only to those who have completed a self-paced short online course focused on heat related injury (LRP: Median = 3.0, IQR = 2.0-4.0; HRP: Median = 3.0, IQR = 2.0-4.0; $p = 0.008$, $r = -0.143$), access to trails being limited only to those who have sufficient fluids (LRP: Median = 3.0, IQR = 2.0-4.0; HRP: Median = 4.0, IQR = 3.0-4.0; $p < 0.001$, $r = -0.225$), access only to those with appropriate heat-related clothing (e.g. hats) (LRP: Median = 3.0, IQR = 2.0-4.0; HRP: Median = 3.0, IQR = 3.0-4.0; $p = 0.005$, $r = -0.145$), closing public access to trails rated difficult or extremely difficult during specific times (LRP: Median = 2.0, IQR = 1.0-3.0; HRP: Median = 3.0, IQR = 2.0-4.0; $p < 0.001$, $r = -0.203$), closing public access to all trails (LRP: Median = 1.0, IQR = 1.0-2.0; HRP: Median = 2.0, IQR = 1.0-3.0; $p = 0.005$, $r = -0.151$), closing public access during select times to trails rated difficult or extremely difficult (LRP: Median = 3.0, IQR = 1.0-4.0; HRP: Median = 4.0, IQR = 2.25-4.0; $p < 0.001$, $r = -0.239$), banning hiking alone (LRP: Median = 1.0, IQR = 1.0-2.0;

HRP: Median = 2.0, IQR = 1.0-3.0; $p < 0.001$, $r = -0.225$), closure of the highest fire department rescue location of Piestewa Peak (LRP: Median = 2.0, IQR = 1.0-3.0; HRP: Median = 2.0, IQR = 1.0-3.0; $p = 0.048$, $r = -0.107$), and having a permit for hiking during excessive heat (LRP: Median = 2.0, IQR = 1.0-4.0; HRP: Median 3.0, IQR = 2.0-4.0; $p < 0.001$, $r = -0.227$). Signing in at the trailhead and banning pets on the trail did not reach significance ($p = 0.082$ and $p = 0.086$ respectively). The internal consistency of RT questions from Table 7 was assessed using Cronbach's alpha. For the 12 questions found on Table 7, the Cronbach alpha was found to be 0.831, indicating a high level of reliability.

Table 7

*Favorability of Risk Mitigation Actions During Excessive Heat (n=340)*

| Risk-Taking Question | Risk Perception Group | N | Median Score (IQR) | P Value (Effect Size) |
|---|---|---|---|---|
| Sign-in at the trail head | Low | 184 | 4.0 (3.0-4.0) | 0.082 (-0.094) |
| | High | 156 | 4.0 (3.0-4.0) | |
| Sign-in at the trail head including the option to be tracked via a phone or other tracking device | Low | 184 | 3.0 (2.0-4.0) | <0.001 (-0.200) |
| | High | 156 | 4.0 (3.0-4.0) | |
| Access to trails limited to only those who have completed a self-paced short online course focused on heat related injury | Low | 184 | 3.0 (2.0-4.0) | 0.008 (-0.143) |
| | High | 156 | 3.0 (2.0-4.0) | |
| Access to trails limited to only those who have sufficient fluids | Low | 184 | 3.0 (2.0-4.0) | <0.001 (-0.225) |
| | High | 156 | 4.0 (3.0-4.0) | |
| Access to trails limited to only those who have appropriate heat related clothing (e.g. hats) | Low | 184 | 3.0 (2.0-4.0) | 0.005 (-0.154) |
| | High | 156 | 3.0 (3.0-4.0) | |
| Close public access to trails rated difficult or extremely difficult | Low | 184 | 2.0 (1.0-3.0) | <0.001 (-0.203) |
| | High | 156 | 3.0 (2.0-4.0) | |
| Close public access to all trails | Low | 184 | 1.0 (1.0-2.0) | 0.005 (-0.151) |
| | High | 156 | 2.0 (1.0-3.0) | |
| Close public access during select times to trails rated difficult or extremely difficult | Low | 184 | 3.0 (1.0-4.0) | <0.001 (-0.239) |
| | High | 156 | 4.0 (2.25-4.0) | |
| Ban hiking alone | Low | 184 | 1.0 (1.0-2.0) | <0.001 (-0.225) |
| | High | 156 | 2.0 (1.0-3.0) | |

| Risk-Taking Question | Risk Perception Group | N | Median Score (IQR) | P Value (Effect Size) |
|---|---|---|---|---|
| Ban pets on trails | Low | 184 | 3.0 (2.0-4.0) | 0.086 (-0.093) |
| | High | 156 | 3.0 (3.0-4.0) | |
| Close the highest fire department rescue location of Piestewa Peak | Low | 184 | 2.0 (1.0-3.0) | 0.048 (-0.107) |
| | High | 156 | 2.0 (1.0-3.0) | |
| Have a permit for hiking during excessive heat | Low | 184 | 2.0 (1.0-4.0) | <0.001 (-0.227) |
| | High | 156 | 3.0 (2.0-4.0) | |

*Note. This table presents responses to various potential risk mitigation strategies during excessive heat warnings, stratified by risk perception group (Low vs. High). The responses are summarized as medians and interquartile ranges (IQRs) for each group. Participants rated each management action on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree), with these scores numerically reflecting increasing levels of acceptance. P-values are calculated using the Mann-Whitney U tests to determine the statistical significance of differences between the two groups, indicating the probability that such differences are due to chance. Biserial effect sizes, calculated using the formula 'Effect Size =*$\frac{z}{\sqrt{n}}$*', quantify the strength and direction of these differences,. where negative values suggest greater acceptance of management actions in the high-risk perception group.*

The RT questions from Table 8 assesses what types of cooling clothing articles participants brought on their hike were assessed across RP groups using Chi square test of independence and phi effect sizes. Participants in the HRP group were more likely to bring a cool scarf or bandana with them on their hike (LRP: 5.4%, HRP: 12.8%, $p = 0.013$, $r = -0.450$). All other options such as a cool shirt or a cool vest did not reach statistical significance ($p \geq 0.087$).

Table 8

*Clothing Choices to Manage Heat Stratified by Group (n=275)*

| Risk Mitigating Strategy | Percentage Answered (n) | Risk Perception Group | % (n) | P Value (Effect Size) |
|---|---|---|---|---|
| Hat | 54.4% (185) | Low | 52.2% (96) | 0.474 (-0.053) |
| | | High | 57.1% (89) | |
| Sun glasses | 47.9% (163) | Low | 44.6% (82) | 0.187 (-0.103) |
| | | High | 51.9% (81) | |
| Cool scarf/bandana | 8.8% (30) | Low | 5.4% (10) | 0.013 (-0.450) |
| | | High | 12.8% (20) | |
| Cool shirt | 45.6% (155) | Low | 43.5% (80) | 0.332 (-0.078) |
| | | High | 48.1% (75) | |
| Cool vest | 2.4% (8) | Low | 1.1% (2) | 0.087 (-0.633) |
| | | High | 3.8% (6) | |
| Clothes soaked in water before the start of the hike | 2.1% (7) | Low | 2.2% (4) | 0.898 (-0.049) |
| | | High | 1.9% (3) | |
| None of these options | 14.1% (48) | Low | 16.8% (31) | 0.145 (-0.211) |
| | | High | 10.9% (17) | |
| Other | 8.2% (28) | Low | 9.8% (18) | 0.298 (-0.197) |
| | | High | 6.4% (10) | |

*Note. This table presents the results of how participants prepared for heat during hikes, stratified by risk perception group (Low vs. High). Each row details the proportion of individuals within each group that employed a specific risk-mitigating strategy Statistical* *significance was tested using chi-square tests, and effect sizes were determined using Phi coefficients, which measure the strength of association between categorical variables (Yes or 'No' to each question and Low vs. High risk perception group).*

The prevalence of complaints experienced by participants during their hikes were assessed across RP groups using the Chi square test of independence with phi effect sizes (Table 9). Although the absolute prevalence was low, a significantly higher percentage of participants in the HRP group reported having stomach cramps (LRP: 0.0%, HRP: 3.3%, $p = 0.023$, $r = 0.137$), being lightheaded or dizzy (LRP: 4.5%, HRP: 15.7%, $p = 0.002$, $r = 0.189$), and feeling like passing out (LRP: 0.6%, HRP: 4.1%, $p = 0.05$, $r = 0.118$). Other complaints such as headaches, muscle cramps, and urges to urinate did not show significant differences between RP groups ($p > 0.077$ or greater). These results suggest an association between high perceived risk and the manifestation of certain physical symptoms while hiking in the heat (Table 9).

Table 9

*Complaints Experienced by Hikers During Hiking Stratified by Group.*

| Questionnaire Question | Total group % (n) | Risk Perception Group | % (n) | P Value (Effect Size) |
|---|---|---|---|---|
| None | 73.1% (201) | Low | 77.3% (119) | 0.078 (-0.106) |
| | | High | 67.8% (82) | |
| Headache | 3.3% (9) | Low | 3.2% (5) | 0.978 (0.002) |
| | | High | 3.3% (4) | |
| Muscle cramp | 5.1% (14) | Low | 3.9% (6) | 0.309 (0.061) |
| | | High | 6.6% (8) | |
| Urge to urinate | 4.4% (12) | Low | 3.9% (6) | 0.669 (0.026) |
| | | High | 5.0% (6) | |
| Belch, burp or having a bloated feeling | 2.2% (6) | Low | 1.3% (2) | 0.258 (0.068) |
| | | High | 3.3% (4) | |
| Nausea | 3.6% (10) | Low | 3.2% (5) | 0.697 (0.023) |
| | | High | 4.1% (5) | |
| Diarrhea, loose stool or bloody stool | 0.0% (0) | Low | 0.0% (0) | NA |
| | | High | 0.0% (0) | |
| Heartburn | 0.4% (1) | Low | 0.6% (1) | 0.375 (-0.054) |
| | | High | 0.0% (0) | |
| Stomach cramp | 1.5% (4) | Low | 0.0% (0) | 0.023 (0.137) |
| | | High | 3.3% (4) | |

| Questionnaire Question | Total group % (n) | Risk Perception Group | % (n) | P Value (Effect Size) |
|---|---|---|---|---|
| Abdominal pain | 0.7% (2) | Low | 0.6% (1) | 0.864 (0.010) |
| | | High | 0.8% (1) | |
| Being light headed or dizzy | 9.5% (26) | Low | 4.5% (7) | 0.002 (0.189) |
| | | High | 15.7% (19) | |
| Feeling like passing out | 2.2% (6) | Low | 0.6% (1) | 0.050 (0.118) |
| | | High | 4.1% (5) | |
| Truly passing out | 0.0% (0) | Low | 0.0% (0) | NA |
| | | High | 0.0% (0) | |
| Other | 4.4% (12) | Low | 5.2% (8) | 0.447 (-0.046) |
| | | High | 3.3% (4) | |

*Note. This table outlines the distribution and comparison of self-reported health complaints during hiking activities, stratified by risk perception (Low vs. High). Participants were asked to report health issues experienced, with the results expressed as percentages of the total and respective subgroups. Statistical significance was tested using chi-square tests, and effect sizes were determined using Phi coefficients, which measure the strength of association between categorical variables(Yes or 'No' to each complaint listed and Low vs. High risk perception group).*

The physiological variables VO2Max, USG, and estimated body temperature were assessed across RP groups using Mann-Whitney U tests (Table 10) and found no significant differences in VO2Max (LRP: Median = 53.40, IQR = 41.50-58.50; HRP: Median = 44.90, IQR = 41.95-56.00; p = 0.121, r = -0.135), USG values (LRP: Median = 1.021, IQR = 1.014-1.026; HRP: Median = 1.021, IQR = 1.015-1.024; p = 0.998, r <- 0.001), or estimated body temperature (LRP: Median = 35.20, IQR = 34.45-35.85; HRP:

Median = 35.40, IQR = 33.40-36.20; p = 0.722, r = -0.033) suggesting these outcomes were not different across RP groups. Subjective measures were also assessed across RP groups using Mann-Whitney U tests (Table 10) which showed ratings of perceived exertion via the Borg Scale did not differ significantly between low and high RP groups (LRP: Median = 6.0, IQR = 6.0-11.0; HRP: Median = 6.0, IQR = 6.0-12.0; p = 0.100, r = -0.098). Significant differences were found in self-perceived heat (LRP: Median = 3.0, IQR = 2.0-4.0; HRP: Median = 2.0, IQR = 3.0-5.25; p = 0.001, r = -0.179) and self-perceived thirst (LRP: Median = 31.0, IQR = 19.0-47.75; HRP: Median = 38.0, IQR = 23.0-52.00; p = 0.039, r = -0.116) suggesting as feelings of thirst and heat increase, risk is perceived at a higher rate. Finally, hydration strategies were assessed across RP groups using Mann-Whitney U tests (Table 7). No statistical difference was found in fluids brought on the hike (LRP: Median = 1000.0, IQR = 500.75-1999.0; HRP: Median = 946.0, IQR = 500.0-1893.0; p = 0.399, r = -0.050) or fluids consumed during the hike (LRP: Median = 600.0, IQR = 400.0-1000.0; HRP: Median = 550.0, IQR = 336.0-1000.0; U = 164, p = 0.556, r = -0.035) when compared across RP groups.

Table 10

*Analysis of Physiological and Subjective Measures by Group.*

| Variable | Median (IQR) | Risk Perception Group | Median (IQR) | P Value (Effect Size) |
|---|---|---|---|---|
| VO2Max (mL/kg/min) (n=132) | 48.55 (41.85-56.70) | Low (n=66) | 53.40 (41.50-58.50) | 0.121 (-0.135) |
| | | High (n=66) | 44.9 (41.95-56.00) | |
| USG (n=126) | 1.021 (1.015-1.026) | Low (n=66) | 1.021 (1.014-1.026) | 0.998 (-0.000) |
| | | High (n=64) | 1.021 (1.015-1.024) | |
| Body Temp (°C) (n=116) | 35.25 (34.15-36.00) | Low (n=65) | 35.20 (34.45-35.85) | 0.722 (-0.033) |
| | | High (n=51) | 35.40 (33.40-36.20) | |
| Borg Scale (6-20) (n=281) | 6.0 (6.0-12.00) | Low (n=155) | 6.0 (6.0-11.0) | 0.100 (-0.098) |
| | | High (n=126) | 6.0 (6.0-12.0) | |
| Self-perceived Heat (1-10) (n=333) | 3.0 (2.0-5.0) | Low (n=179) | 3.0 (2.0-4.0) | 0.001 (-0.179) |
| | | High (n=154) | 3.0 (3.0-5.25) | |
| Self-perceived Thirst (1-100 (n=319) | 34.0 (21.0-50.0) | Low (n=167) | 31.0 (19.0-47.75) | 0.039 (-0.116) |
| | | High (n=150) | 38.0 (23.0-52.00) | |
| Fluid Brought (mL) (n=290) | 1000.0 (500.0-1999.0) | Low (n=164) | 1000.0 (500.75-1999.0) | 0.399 (-0.050) |
| | | High (n=126) | 946.0 (500.0-1893.0) | |
| Fluid Consumed (mL) (n=290) | 591.0 (355.0-1000.0) | Low (n=164) | 600.0 (400.0-1000.0) | 0.556 (-0.035) |
| | | High (n=164) | 550.0 (336.0-1000.0) | |

*Note. This table presents a comparison of subjective and objective measures related to fitness, hydration, and body temperature, stratified by risk perception groups (Low vs. High). Each row reports the median and interquartile range (IQR) for variables, with the differences between the groups tested using Mann-Whitney U tests. P-values and biserial* *effect sizes, calculated using the formula 'Effect Size =$\frac{z}{\sqrt{n}}$', are provided to denote the statistical significance and the magnitude of differences, respectively. Negative effect size values suggest higher values in the High-risk group, indicating more pronounced perceptions or behaviors related to the risk factors assessed.*

The physiological variables VO2Max, USG, and body temperature were assessed categorically across RP groups using Chi-Square tests of independence and phi effect sizes (Table 11). When comparing high and low VO2Max groups against RP groups, significant differences were found between groups $X^2$ (1, N = 132) = 7.758, p = 0.005. For the variables of USG and body temperature, no significant differences were found $X^2$ (1, N = 130) = 0.136, p = 0.712 and $X^2$ (1, N = 116) = 0.035, p = 0.852 respectively. Chi-Square tests of independence were used to evaluate whether the differences between groups were driven by gender differences. When comparing high and low female VO2Max groups against the median female RP score, no significant differences were found $X^2$ (1, N = 55) = 1.569, p = 0.277 (not shown on tables). Similarly, when male high and low VO2Max groups were compared against male RP groups, no significant differences were found $X^2$ (1, N = 73) = 0.096, p = 0.816 (not shown on tables), suggesting the effect of fitness level on RP was driven by gender and not fitness as most of the females were categorized in the lower category while males were in the higher VO2Max category.

Mann-Whitney U tests were employed as post hoc tests to determine differences between each group for VO2Max (groups shown in superscripts as A, B, C, and D on Table 4b). Within the low VO2Max groups, group A was significantly different from groups B, C, and D respectively (p = 0.048). Similarly, group B was significantly different from groups A, C, and D respectively ($p = 0.048$). In the high VO2Max groups, group C was significantly different from groups A and B ($p < 0.001$). Similarly, group D was significantly different from groups A and B ($p <0.001$). These results indicate the significance found in the chi square test of independence were driven mainly by those in the low VO2Max group. No significant differences were found for the variables of USG ($p = 0.712$, $r = 0.032$) or body temperature ($p = 0.852$, $r = 0.017$).

Table 11

*Analysis of High and Low Physiological Measures Groups.*

| Variable, High and Low Groups | Risk Perception Group, % (n) | Median (IQR) | P Value (Effect Size) |
|---|---|---|---|
| Low VO2Max (mL/kg/min) | Low[a] 37.9% (25) | 39.20 (37.60-42.90) [b, c, d] | 0.005 (-0.242) |
| | High[b] 62.1% (41) | 42.20 (40.00-44.10) [a, c, d] | |
| High VO2Max (mL/kg/min) | Low[c] 62.1% (41) | 56.70 (54.20-62.60) [a, b] | |
| | High[d] 37.9% (25) | 57.60 (54.65-63.05) [a, b] | |
| Euhydrated | Low 52.5% (31) | 1.014 (1.008-1.018) | 0.712 (0.032) |
| | High 47.5% (28) | 1.015 (1.011-1.019) | |
| Dehydrated | Low 49.3% (35) | 1.026 (1.024-1.030) | |
| | High 50.7% (36) | 1.024 (1.022-1.028) | |
| Low Body Temp (°C) | Low 56.9% (33) | 34.50 (32.40-35.10) | 0.852 (0.017) |
| | High 43.1% (25) | 33.40 (31.55-34.80) | |
| High Body Temp (°C) | Low 55.2% (32) | 35.85 (35.60-36.20) | |
| | High 44.8% (26) | 36.15 (35.60-36.33) | |

*Note. This table provides a comparative analysis of physiological variables across risk perception groups (Low vs. High). Groups are stratified by low and high risk perception groups and low and high groups for physiological variables. Statistical significance was tested using chi-square tests, and effect sizes were determined using Phi coefficients, which measure the strength of association between the aforementioned categories. Subgroups within significant terms are denoted with superscripts (a, b, c, and d) and Mann-Whitney U tests were employed as post hoc tests to test interactions between subgroups at the $p < 0.05$ level. Significant interactions are shown as superscripts in the 'Median (IQR)' column.*

A multivariate analysis of variance (MANOVA) was conducted to investigate how various physiological and perceptual measures impact participants' RP scores and RT scores (Table 12). The measures investigated included VO2Max, USG, body temperature, Borg Scale values, feelings of heat, and feelings of thirst. Box's Test of Equality of Covariance Matrices was used to test the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups. Results showed covariances were equal across groups for VO2Max ($p = 0.702$), USG data ($p = 0.454$), body temperature ($p = 0.177$), perception of thirst ($p = 0.766$), perceptions of heat ($p = 0.471$), and Borg scale data ($p = 0.098$) satisfying the assumption of homogeneity for MANOVA tests.

VO2Max showed a significant multivariate effect on the dependent variables, $F(2, 129) = 3.425$, $p = 0.036$, with a small effect size ($r = 0.050$). When evaluating the multivariate effect within the female participants, no effect was found on the dependent variables $F(2, 52) = 1.247$, $p = 0.296$. Similarly, there was no multivariate effect within the male participants on the dependent variable $F(2, 70) = 0.633$, $p = 0.534$. USG measures did not show a significant multivariate effect on the dependent variables, $F(2, 127) = 0.223$, $p = 0.800$. Body temperature showed a significant multivariate effect on the dependent variables, $F(2, 113) = 3.690$, $p = 0.028$, with a small effect size ($r = 0.061$). The Borg scale measures did not show a multivariate effect on the dependent variables, $F(24, 536) = 1.054$, $p = 0.394$. Feelings of heat during the hike showed a significant multivariate effect on the dependent variables, $F(18, 646) = 2.227$, $p = 0.003$, with a small effect size ($r = 0.058$). Finally, feelings of thirst showed a significant multivariate effect on the dependent variables, F(6, 626) = 2.635, p = 0.016, with a small effect size (r = 0.025).

Table 12

*Effects of Physiological and Subjective Measures on the Parameters of Risk.*

| Effect | F | DF | Effect size | P Value |
|---|---|---|---|---|
| VO2Max | 3.425 | 2 | 0.050 | 0.036 |
| USG | 0.223 | 2 | 0.004 | 0.800 |
| Body Temperature | 3.690 | 2 | 0.061 | 0.028 |
| Borg Scale | 1.054 | 24 | 0.045 | 0.394 |
| Feelings of Heat | 2.875 | 6 | 0.026 | 0.009 |
| Feelings of Thirst | 2.635 | 6 | 0.025 | 0.016 |

*Note. This table presents the results of a multivariate analysis of variance (MANOVA), evaluating the influence of physiological variables on risk perception and risk-taking The table presents Pillai's Trace, F-statistics (F), degrees of Freedom (DF), and their associated p-values for each tested variable and partial eta squared effect sizes to quantify the strength of the relationship.*

An analysis of variance (ANOVA) was conducted to further explore how various physiological and perceptual measures predict participants' RP (Table 13). The measures investigated included VO2Max, USG, body temperature, Borg Scale values, feelings of heat, and feelings of thirst. The ANOVA revealed high and low VO2Max groups significantly predicted RP score, F(1, 130) = 5.514, p = 0.020, with a small effect size (r

= 0.041). When males and females were assessed separately, VO2Max did not predict RP scores in females F(1, 53) = 0.177, p = 0.676 or males F(1, 71) = 0.031, p = 0.860. USG values categorized as euhydrated (< 1.020) and dehydrated (≥ 1.020) did not show significant effects on RP scores, F(1, 128) = 0.364, p = 0.547. When analyzing the impact of body temperature, high and low groups did not show a significant effect on RP score, F(1, 114) = 0.061, p = 0.806. Analysis of Borg scale measures did not show a significant effect on RP scores F(12, 268) = 0.692, p = 0.759. Feelings of heat during the hike significantly predicted RP scores, F(3, 329), 4.843, p = 0.003, with a small effect size (r = 0.088). Finally, feelings of thirst significantly predicted RP scores, F(3, 313) = 3.923, p = 0.009, with a small effect size (r = 0.036).

Post hoc tests were employed to test significant differences between groups for variables with degrees of freedom > 1 using Tukey's HSD test. For feelings of heat, Tukey's HSD indicated quartile 1 had significantly lower RP scores compared to quartile 3 (MD = -5.12, SE = 1.72, p = 0.017, 95% CI -9.5716, -0.6684]) and quartile 4 (MD = -4.95, SE = 1.53, p = 0.007, 95% CI [-8.9019, -0.9996]). No other pairwise comparisons reached statistical significance. These findings suggest that individuals who reported higher levels of self-perceived heat also reported higher RP scores. For feelings of thirst, Tukey's HSD indicated quartile 1 had significantly lower RP scores than quartile 3 (MD = -5.12, SE = 1.72, p = 0.017, 95% CI [-9.57, -0.67]) and quartile 4 (MD = -4.95, SE = 1.53, p = 0.007, 95% CI [-8.90, -0.99) suggesting those who reported higher levels of self-perceived thirst also reported higher RP scores.

Table 13

*Effects of Physiological and Subjective Measures on Risk Perception.*

| Fixed Factors | df | F | Effect Size | P Value |
|---|---|---|---|---|
| VO2Max | 1 | 5.514 | 0.041 | 0.020 |
| USG | 1 | 0.364 | 0.003 | 0.547 |
| Body Temperature | 1 | 0.061 | 0.061 | 0.806 |
| Borg Scale | 12 | 0.692 | 0.030 | 0.759 |
| Feelings of Heat | 3 | 4.843 | 0.042 | 0.003 |
| Feelings of Thirst | 3 | 3.923 | 0.036 | 0.009 |

*Note. This table examines the impact of physiological and perceptual measures on risk perception through univariate ANOVA tests. The table presents degrees of freedom (df), F-statistics (F), effect sizes, and their associated p-values for each tested variable.*

Similarly, an ANOVA was conducted to further explore how various physiological and perceptual measures predict participants' RT scores (Table 14). The measures investigated included VO2Max, USG, body temperature, Borg Scale values, feelings of heat, and feelings of thirst. VO2Max scores showed a trend towards predicting RP scores but did not reach statistical significance, $F(1, 130) = 3.383$, $p = 0.068$. When males and females were assessed separately, VO2Max did not predict RT scores in females $F(1, 53) = 1.664$, $p = 0.203$ or males $F(1, 71) = 1.137$, $p = 0.290$. USG values did not show a significant effect on RT scores, $F(1, 128) = 0.011$, $p = 0.915$. Body temperature significantly predicted RT scores, $F(1, 114) = 5.278$, $p = 0.023$, with a small effect size ($r = 0.044$). Borg scale values showed a trend towards predicting RP scores but did not reach statistical significance, F(12, 268) = 1.596, p = 0.092. Feelings of heat while hiking did not show a significant effect on RT scores, F(9, 323) = 1.446, p = 0.167. Finally, feelings of thirst did not show a significant effect on RT scores, F(3, 313) = 1.052, p = 0.370.

There were no variables with degrees of freedom > 1 which reached statistical significance; therefore, no post hoc tests were employed.

Table 14

*Effects of Physiological and Subjective Measures on Risk-Taking.*

| Fixed Factors | DF | F | Effect Size | P Value |
|---|---|---|---|---|
| VO2Max | 1 | 3.383 | 0.025 | 0.068 |
| USG | 1 | 0.11 | <0.001 | 0.915 |
| Body Temperature | 1 | 5.278 | 0.044 | 0.023 |
| Borg Scale | 12 | 1.596 | 0.067 | 0.092 |
| Feelings of Heat | 3 | 1.446 | 0.011 | 0.321 |
| Feelings of Thirst | 3 | 1.052 | 0.010 | 0.370 |

*Note. This table examines the impact of physiological and perceptual measures on risk-taking through univariate ANOVA tests. The table presents degrees of freedom (df), F-statistics (F), and their associated p-values for each tested variable.*

# CHAPTER 5
# DISCUSSION

This data indicated fitness level significantly affects RP, where those who are more fit perceive lower levels of risk. Hydration state did not appear to affect RP or RT, however, although body temperature results were not statistically significant, the results appeared to show a trend where body temperature affected RT only, pointing towards a potential relationship between elevated body temperature and the propensity to take risk. In addition, those who felt hotter and felt thirstier showed increased levels of RP. Finally, RP and RT were associated so that as perceptions of risk increased, the likelihood of taking risks decreased. The findings of this study fill an important gap within the literature of how fitness affects the parameters of risk. The lack of association between hydration state and the parameters of risk is also a novel finding which should be investigated further to elucidate the effects of hydration on risk.

One of the main results of this study was a positive association between feeling hot or feeling thirsty related with individuals perceiving more risk. This finding appears to agree with the Maximal Adaptability hypothesis (Hancock & Warm, 1989) which suggests physical and psychological stressors can limit cognitive functioning. Although this hypothesis is applied to cognitive tasks such as reaction time or ability to focus, the same mechanism may exist within RP. Elevations in RP when feeling hot or thirsty may also serve as a protective mechanism which decreases the likelihood of taking more risks and thereby protecting the individual during an already stressful state (Ceccato, Kudielka, Schwieren, 2016). This last statement is in concordance with both our correlational data, which showed RP and RT were associated, and our data for RT questions. The results of

RT questions showed those in the HRP group were more likely to score highly for RT questions, indicating a lower likelihood to take risks. These findings are generally expected; individuals who perceive higher levels of risk are less likely to engage in these risky behaviors (Brewer, Chapman, Gibbons, Gerrard, McCaul, & Weinstein, 2007; Sheeran, Harris, & Epton, 2014) and those who experience higher levels of subjective stress (heat and thirst) are more likely to experience higher RP (Popovic, Bentele, Pruessner, Moussaïd, & Gaissmaier, 2020) which then limits their propensity to take further risks and potentially exacerbate the physiological and subjective stressors.

The complaints experienced by participants during their hikes were assessed by RP group. Despite some significant differences between RP groups (i.e. being lightheaded or dizzy and having stomach cramps), the overall complaints experienced within our cohort were relatively low ranging from zero to 26 complaints. Overall, the high-risk group reported complaints more frequently suggesting a possible relationship between perceiving higher levels of risk and physical manifestations of illness, while the LRP group reported no complaints more frequently. Although the current study analyzes the complaints experienced by RP group, other studies have shown less fit individuals experience more physiological complaints than fitter individuals (Linsell, Pelham, Hondula, & Wardenaar, 2020). As shown in our results, those in the LRP group were also more fit, suggesting these differences in complaints may be due to participants' fitness levels. Other studies have shown those who are heat acclimated experience less complaints (Matsee, Charoensakulchai, & Khatib, 2023), indicating an individual's tolerance for heat and the physiological response of heat acclimation (i.e. earlier sweating onset, increased skin blood flow, and decreased sweat electrolyte content) may also play a role in the complaints experienced by hikers between RP groups. Due to the low number of reported complaints, the interpretation of these results is difficult but aligns with previous studies which found similar findings with higher response rates.

The study results indicated the cohort studied was highly fit, indicated by an average estimated VO2Max of 50 mL/kg/min for the sample, which is classified by the American College of Sport Medicine as excellent for the average age of the cohort (40 years of age) (*ACSM's* Guidelines for Exercise Testing and Prescription, 2018, p. 151-156). This level of fitness is expected; Piestewa Peak is a hike rated extremely difficult by the City of Phoenix and characterized by sun exposed trails and a 1,200-foot elevation gain. Individuals who hike these trails during the summer are more likely to be physically fit, heat acclimated, and familiarized with the trails which may influence RP and RT scores. Additionally, the modified YMCA step test used for this assessment did not correct for men and women, as indicated in the original protocol (Kieu et al., 2020) introducing further error into these measurements. Furthermore, fitness testing was conducted after participants returned from their hike, bringing into question the accuracy of the VO2Max results. However, Borg scale measures indicated 61.57% (n = 281) of participants reported the lowest level of perceived exertion for the hike, indicating less physical strain from participants and also agrees with our VO2Max results. Other studies which investigate the fitness level of hikers directly are absent further highlighting an important gap within the literature. To date, there are no studies which assess how fitness levels affect the parameters of risk in adults and rather focus on how those who perceive higher levels of health risks engage in more health activities (Stephan et al., 2011; Wang et al., 2024). In order to better elucidate the effects of fitness on the parameters of risk, a more diverse set of fitness levels will need to be studied to better understand how the lower ends of the fitness spectrum assess risk in a hiking context or other context which demands physical exertion and some level of increased risk. Future research should aim to define fitness categories more clearly in order to better assess whether fitness affects the parameters of risk.

Differences between VO2Max levels between genders may confound RP scores. Females generally have smaller hearts, lungs, and lower hemoglobin mass compared to their male counterparts which minimizes the amount of oxygen delivered to working muscles (Santisteban, Lovering, Halliwill, & Minson, 2022). As a result, more female participants were in the low VO2Max group compared to their male counterparts. In the current data set, estimated median VO2Max levels were lower for females compared to males (42.40 mL/kg/min and 55.50 mL/kg/min, $p < 0.001$). Additionally, levels of RP have been shown to differ between males and females in certain domains such as health protective behaviors and the COVID-19 pandemic (Tan, Yoshida, Ma, Mauvais-Jarvis, & Lee, 2022; Ferrín, 2022). Females also score higher in trait neuroticism at the Big Five Trait level (Costa, Terracciano, & McCrae, 2001; Weisberg, Deyoung, & Hirsh, 2011) and indices of anxiety (Feingold, 1994), suggesting perceived risk may be higher in females. The current data is in accordance with this conjecture; females reported a higher median RP score compared to men (50.0 and 47.0 respectively, $p = 0.010$). Our results showed female participants had a lower median VO2Max compared to the sample median (42.40 versus 48.55) and a higher median RP compared to the sample median (50.0 versus 48.0). When the effect of fitness on RP was assessed with the median VO2Max and RP score for males and females, no effect was found showing the effect of fitness on RP was mainly driven by inflated RP scores within the lower fitness category. As mentioned prior, step heights were not adjusted between men and women as indicated within the original modified YMCA step-test protocol, further increasing gender as a confounder. It is possible RP may be affected by fitness status at the lower ends of the fitness spectrum when compared to highly fit individuals, however, within the current data set, fitness does not show an effect on RP once gender is considered as a factor. Although no other studies assess how fitness effects RP, future studies should evaluate how fitness effects males and females separately to elucidate potential differences between genders regarding RP.

The assessment of body temperature via infrared thermal imaging showed a low association between thermal state and perceived risk. However, the results suggest variations in body temperature may have a modest influence on RT behaviors, where individuals with elevated body temperatures take less risks, although these results are not conclusive. When assessing these results alongside of the perceptual data, it was shown that individuals who felt hotter reported higher levels of perceived risk. These findings are directly applicable to other populations such as firefighters or manual labor workers which routinely work in hot environments and potentially become acclimatized to high levels of heat (Ramsey et al., 1983). In these conditions, these populations may have a lower level of perceived risk where an elevated level of RP may prove beneficial to prevent harm such as working with heavy machinery or on dangerously high surfaces such as construction workers (Ramsey et al., 1983). These findings may be used to direct research in these areas to improve safety of workers or inform hiking populations as the present study suggests each of these domains affects RP and RT separately. Chang et al.

(2017) has shown high ambient temperatures do decrease RP but also showed an affect on RT behaviors (Chang et al., 2017). Contrary to the methods of the current study, only ambient temperature was assessed rather than body temperature directly. Thus, these results may experience confounding from elevated body temperature which trended towards on effect on RT in the current study. Future research should assess how heat acclimation affects the parameters of risk and how these factors also interact with hyperthermic bodily states concomitantly with perceptions of heat.

The methodology of estimating body temperature via infrared thermal imaging may introduce error into measurements. Infrared thermal imaging was shown to have relatively low sensitivity to detect fever and therefore an elevated bodily temperature (Mouchtouri, Bogogiannidou, Dirksen-Fischer, Tsiodras, & Hadjichristodoulou, 2020) and has been shown to be stable with ambient temperatures of 21°C to 26°C (International Standardization Organization, 2020). The average ambient temperature within the room where measurements were conducted was 26.4°C. Therefore, the measurements were being conducted in the upper-limits of ambient temperatures shown to correlate with true core temperature. Other studies have assessed the efficacy of infrared thermal imaging in an exercise setting and have found low reliability when compared to more the gold standard measures of core temperature (Fernandes, Amorim, Brito, de Moura, Moreira, Costa, Sillero-Quintana, & Marins, 2014). Other studies have shown infrared imaging may be able to provide a measure which quantifies body temperature changes but can be affected by measurement technique, variations in skin blood flow, and environment (Zaproudina, Varmavuo, Airaksinen, & Närhi, 2008). Future research should attempt to measure core temperature with more accurate methods such as rectal temperature or esophageal. Furthermore, a larger sample size may be needed to further elucidate the effects of thermal state on RT behaviors as well as a more specific measure for RT behaviors, designed specifically to analyze an individual's propensity towards risk.

When hydration state (USG) was assessed, no significant association was found between RP or RT and USG. When comparing the hydration results of the current study to past studies, similar hydration markers were found (Rozier, 1998; Linsell, Pelham, Hondula, & Wardenaar, 2020). Due to the similarities of hydration status between studies, it is reasonable to conclude these results are most likely not due to abnormalities within these data. Additionally, these results are in alignment with studies assessing cognitive function which show dehydration alone is insufficient to cause decrements in cognitive function but rather affect mood state (Armstrong et al., 2012). It has been shown mood state can increase perceptions of risk (Sobkow, Traczyk, & Zaleskiewicz, 2016) which our results indicate would also affect RT. However, our results do not show any affect of hydration state on RP or RT. However, when thirst is assessed, those who report higher levels of thirst also report higher levels of RP. These findings are similar to feelings of heat and may indicate applicability to the Maximal Adaptability Hypothesis (Hancock & Warm, 1989) which states physical or psychological stressors increasingly degrade cognitive functions. Although this conceptual framework was not intended to be applied to variables such as risk, the data from the subjective feelings of thirst and heat indicate a similar framework may exist. Alternatively, it may also be a protective mechanism which serves to lower the individual’s propensity to take risk during physiological stress or to prevent further stress. This may relate to mood state which may affect perceptions of risk. (Sobkow, Traczyk, & Zaleskiewicz, 2016) However, USG data and feelings of thirst did not appear to be associated with each other according to our correlational data. An analysis of mood state alongside the parameters of risk would need to be conducted to analyze these effects more directly as these questions are outside of the scope of this study. Future research should be conducted to directly assess the effect of hydration state on the parameters of risk alongside mood state. Additionally, feelings of thirst and how it relates to RP should be further studied.

# CHAPTER 6

# CONCLUSIONS

This study examined how fitness level, hydration status, body temperature, perceived exertion, feelings of heat, and feelings of thirst affect how an individual perceives risk and takes risk. The findings of the current study show an association between high levels of perceived heat and thirst and higher perceived risk and a trend towards higher body temperature leading to more RT behaviors. Although fitness level appears to affect RP, this effect is likely driven by gender as a result of differences in fitness levels and RP between males and females included in this study. The findings for perceived heat and thirst may point to an effect between psychological stress and the parameters of risk as the findings for body temperature are inconclusive while hydration status showed no relation. Symptoms of illness experienced by participants during their hikes were sometimes experienced more frequently by those who perceive more risk; however, the data was inconclusive. Overall, this study provides insight into how hikers assess and respond to risks based on their physical and psychological states but also suggests avenues for further research. Future research could expand on these findings by exploring additional variables and employing a broader demographic to generalize the results more effectively. Additionally, more accurate measures for fitness and body temperature, such as maximal fitness testing and rectal thermometry, could expand on these results to give a more conclusive result.

## LIMITATIONS

Regarding limitations for the current study, fitness measures were estimates of VO2Max based on standardized submaximal fitness tests and validated equations. The accuracy of these tests may be limited. Body temperature measures do not directly reflect core body temperatures and only correlate with core body temperatures. However, such large fluctuations in core temperature are unlikely. RP and RT responses were indirect measures of these variables and more precise measures should be used. Additionally, participants were able to choose if they wanted to participate in tests such as the submaximal VO2Max test, meaning not all measures were conducted on each participant. Finally, a highly fit populous was studied and limits the applicability to lower fitness individuals.

## DELIMITATIONS

Only hikers who hiked at Piestewa Peak were randomly selected, narrowing our sample to individuals who regularly use the trails in question. Only hikers who hiked in the early morning hours (earlier than 10:00 am) or late afternoon hours (later than 5:00 pm) were studied in this sample to limit time spent in the intense heat. Finally, only those who completed the trail or hiked greater than 60 minutes were selected for this study to specify our sample towards those who most likely have experienced dehydration, elevated body temperatures, and fatigue.

# CHAPTER 8

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# APPENDIX A

# QUESTIONNAIRE GIVEN TO PARTICIPANTS

# Hiker Heat Risk study (HHR)

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Start of Block: Informed consent

Q1
**Assessing physiological and socio-psychological heat-related risk perceptions and behavior among Phoenix metropolitan area hikers.**

**INTRODUCTION**
The purposes of this form are to provide you information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study.

**RESEARCHERS**
Dr. Floris Wardenaar, an Assistant Professor in the College of Health Solutions at ASU, and Dr. Megha Budruk, an Associate Professor in the School of Community Resources and Development at ASU and Dr. Frank LoVecchio, Medical Director in the College of Health Solutions at ASU, have invited you to participate in a research study to assess self-reported behaviors towards hiking as well as testing your body temperature (part I), fitness, and hydration status (part II).

**STUDY PURPOSE**
Our overarching goal is to better understand the risk behaviors of hikers to limit the need for hiking-related rescues.

**DESCRIPTION OF RESEARCH STUDY**
If you decide to participate in this study, you will be asked to take a headshot picture with a heat camera to obtain an estimation of your body core temperature and fill out a web-based questionnaire using a tablet or your phone while we measure oxygen saturation and heart rate with an oximeter attached to your non-dominant index finger. While filling out the questionnaire we will have a look at the fluid/bottles brought (Part I). After completion of the questionnaire, you will be invited to perform a fitness test (3-min step test) and provide a urine sample (Part II). RISKS We anticipate that there are no risks to the participate in this study other than the risks that you experienced by walking the hike as the fitness test involves stepping up and down a 12-inch step.

**BENEFITS**
The results of this study are intended as pilot data for a grant proposal and the results will be published in peer-reviewed journal(s). Participants of Part II will be provided with a $5 digital Gift Card and can receive the result of their step test on a paper sheet directly after rounding up this test.

**NEW INFORMATION**
If the researchers find new information during the study that would reasonably change your decision about participating, then they will provide this information to you.

**CONFIDENTIALITY**
All information obtained in this study is strictly confidential unless disclosure is required by law. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. After data collection ends to maintain the confidentiality of your records, we will assign you a participant number. This digitally signed consent form will not be printed, the digital file will be held private as part of Dr. Wardenaar's password-protected Qualtrics account.

**WITHDRAWAL PRIVILEGE**
It is OK for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time. Your decision will not affect your relationship with Arizona State University or otherwise cause a loss of benefits to which you might otherwise be entitled.

**COSTS AND PAYMENTS**
The researchers want your decision about participating in the study to be absolutely voluntary. Gift card incentives will be distributed per email to participants upon completing the study within a week after completion of Part II.

**VOLUNTARY CONSENT**
Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Floris Wardenaar, floris.wardenaar@asu.edu or (480) 599 5945. If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk; you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at 480-965 6788. This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be offered to you.

Q2 Check the box indicating that you consent to participate in the above study.

◯ I consent to participate in Part I of this study (Heat picture and questionnaire). (1)

◯ I consent to participate in Part I and II of this study (Heat picture, questionnaire, step test and urine sample). (2)

◯ I do not want to be part of this study. (3)

*Skip To: End of Survey If Check the box indicating that you consent to participate in the above study. = I do not want to be part of this study.*

Q3 Add your individual ID number (provided by researcher)

________________________________________________________________

Q4 INVESTIGATOR'S STATEMENT
"I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. These elements of Informed Consent conform to the Assurance given by Arizona State University to the Office for Human Research Protections to protect the rights of human subjects. I have provided (offered) the subject/participant a copy of this signed consent document."

Signed by Floris Wardenaar, Principal Investigator

End of Block: Informed consent

Start of Block: Infrared picture and heart rate

Q5 Before you answer the questions we want to ask you to take a head shot infrared picture to assess your body temperature at the Ranger office. Additionally we ask permission to place an oximeter to measure oxygen saturation and heart rate on your non-dominant index finger for 5-10 minutes while you fill out this questionnaire.

End of Block: Infrared picture and heart rate

Start of Block: Experience use history

Q6 For how many years have you been hiking Piestewa Peak?
(Write number of years; If this is your first hike, write 0)

________________________________________________________________

Q7 How many times have you hiked Piestewa Peak in the past 12 months?
(Write the number of times; If this is your first visit, write 1)

________________________________________________________________

Q8 What was the duration of your current hike?
(Write the answer in minutes)

________________________________________________________________

End of Block: Experience use history

Start of Block: Hiking perception using scales

Q9 We want you to rate your perception of exertion as you experienced this during your hike. (Borg scale)

This feeling should reflect how heavy and strenuous the exercise feels to you as a whole, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion.

Choose the number from below that best describes your level of exertion.

Your own feeling of effort and exertion is important, not how it compares to other people's. Look at the scales and the expressions and then select a number.

| | Select the number that best describes your level of exertion during the hike. (1) |
|---|---|
| Score 6 -- No exertion at all (1) | ○ |
| Score 7 -- Extremely light (2) | ○ |
| Score 8 -- Extremely light (3) | ○ |
| Score 9 -- Very light (4) | ○ |
| Score 10 (5) | ○ |
| Score 11 -- Light (6) | ○ |
| Score 12 (7) | ○ |
| Score 13 -- Somewhat hard (8) | ○ |
| Score 14 (9) | ○ |
| Score 15 -- Hard (10) | ○ |
| Score 16 (11) | ○ |
| Score 17 -- Very hard (12) | ○ |
| Score 18 (13) | ○ |
| Score 19 -- Extremely hard (14) | ○ |
| Score 20 -- Maximal exertion (15) | ○ |

Q10 We want you to rate how hot you felt during the hike.

| | Very mild | | Tolerable | | | Very distressing | | Very intense | | Excruciating unbearable | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Click to write Choice 1 () | | | | | | | | | | | |

Q11 We want you to rate how thirsty you feel now?
(Analogue scale to assess thirst perception)

| | not at all | extremely thirsty |
|---|---|---|
| | 0 | 100 |
| Click to write Choice 1 () | | |

End of Block: Hiking perception using scales

Start of Block: Place attachment questions

Q12 Click to write the question text

| | Strongly disagree (1) | Disagree (2) | Neutral (3) | Agree (4) | Strongly agree (5) |
|---|---|---|---|---|---|
| I am very attached to Piestewa Peak (1) | ○ | ○ | ○ | ○ | ○ |
| Piestewa Peak is very special to me (11) | ○ | ○ | ○ | ○ | ○ |
| I identify strongly with Piestewa peak (12) | ○ | ○ | ○ | ○ | ○ |
| Piestewa Peak is the best place for hiking (13) | ○ | ○ | ○ | ○ | ○ |
| No other place can compare to Piestewa Peak (14) | ○ | ○ | ○ | ○ | ○ |
| I would not substitute any other place for Piestewa Peak (15) | ○ | ○ | ○ | ○ | ○ |
| I have a lot of fond memories about Piestewa Peak (16) | ○ | ○ | ○ | ○ | ○ |
| I have a special connection to Piestewa Peak and the people who recreate here (17) | ○ | ○ | ○ | ○ | ○ |
| I tell many people about Piestewa Peak (18) | ○ | ○ | ○ | ○ | ○ |
| I will bring my children to Piestewa Peak (19) | ○ | ○ | ○ | ○ | ○ |

End of Block: Place attachment questions

Start of Block: Risk behavior related questions

Q13 Are you aware of the Phoenix heat warning system?

◯ Yes (1)

◯ No (2)

X→

Q14 Are you aware of the City of Phoenix Parks and Recreation department's "Take a Hike Do it Right" campaign?

◯ Yes (1)

◯ No (2)

*Display This Question:*

*If Are you aware of the City of Phoenix Parks and Recreation department's "Take a Hike Do it Right"... = Yes*

X→

Q15 If yes, how familiar are you with the following elements of the "Take a Hike Do it Right" campaign?

| | Not familiar at all (1) | Slightly familiar (2) | Moderately familiar (3) | Very familiar (4) | Extremely familiar (5) |
|---|---|---|---|---|---|
| Watch the weather (1) | ○ | ○ | ○ | ○ | ○ |
| Dress appropriately (2) | ○ | ○ | ○ | ○ | ○ |
| Bring water (3) | ○ | ○ | ○ | ○ | ○ |
| Keep in contact (4) | ○ | ○ | ○ | ○ | ○ |
| Team up (5) | ○ | ○ | ○ | ○ | ○ |
| Be honest about your physical and medical condition (6) | ○ | ○ | ○ | ○ | ○ |
| Don't trailblaze (7) | ○ | ○ | ○ | ○ | ○ |
| Take responsibility (8) | ○ | ○ | ○ | ○ | ○ |

---

X→

Q16 This question is about how dangerous you feel the Phoenix heat is for you.

| | Not at all dangerous (1) | Slightly dangerous (2) | Somewhat dangerous (3) | Very dangerous (4) | Extremely dangerous (5) |
|---|---|---|---|---|---|
| How dangerous do you think the Phoenix heat is for you? (1) | ○ | ○ | ○ | ○ | ○ |

---

Q17 When hiking, I worry about:

| | Strongly disagree (1) | Disagree (2) | Neutral (3) | Agree (4) | Strongly agree (5) |
|---|---|---|---|---|---|
| Sudden change in weather conditions (warmer than expected, unexpected storm) (1) | ○ | ○ | ○ | ○ | ○ |
| Outdoor medical assistance is not accessible when in need (2) | ○ | ○ | ○ | ○ | ○ |
| Poor communication with the outside world (3) | ○ | ○ | ○ | ○ | ○ |
| Wildlife invasion, insect bites, snake bites (4) | ○ | ○ | ○ | ○ | ○ |
| Accidents such as falling, slips, injuries, etc. (5) | ○ | ○ | ○ | ○ | ○ |
| Insufficient and inadequate peers would affect the team (6) | ○ | ○ | ○ | ○ | ○ |
| Loss of property during hiking (7) | ○ | ○ | ○ | ○ | ○ |
| Contaminated food (8) | ○ | ○ | ○ | ○ | ○ |
| Infectious disease (9) | ○ | ○ | ○ | ○ | ○ |
| Hiking experience falling short of expectations (10) | ○ | ○ | ○ | ○ | ○ |
| Exertional heat illness (fever, nausea) (11) | ○ | ○ | ○ | ○ | ○ |
| Physical exhaustion (12) | ○ | ○ | ○ | ○ | ○ |
| Getting lost during the hike (13) | ○ | ○ | ○ | ○ | ○ |
| Lack of shade (14) | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| Feeling uncomfortable in unfamiliar surroundings (15) | ○ | ○ | ○ | ○ | ○ |
| Carrying insufficient fluid (16) | ○ | ○ | ○ | ○ | ○ |
| Carrying insufficient snacks/ food (17) | ○ | ○ | ○ | ○ | ○ |

---

Q18 What factors did you take into consideration while deciding how much fluid to bring on this hike?
(Check all that apply)

- ▢ None (1)
- ▢ Today's temperature (2)
- ▢ Planned duration of the hike (3)
- ▢ The amount of fluid that I am able to carry (4)
- ▢ Available bottle or container size (5)
- ▢ The (water and restroom) facilities on this trail (6)
- ▢ My financial situation (7)
- ▢ I did not really plan my fluid intake (8)
- ▢ Other (9)

---

*Display This Question:*

*If What factors did you take into consideration while deciding how much fluid to bring on this hike?... = Other*

Q19 What other factors did you take into consideration while deciding how much fluid to bring on this hike?

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

Q20 This question is about how satisfied you were about the amount of fluid brought.

| | Very dissatisfied (1) | Dissatisfied (2) | Neutral (3) | Satisfied (4) | Very satisfied (5) |
|---|---|---|---|---|---|
| How satisfied were you with the amount of fluid you brought on the hike? (1) | ○ | ○ | ○ | ○ | ○ |

Q21 Did you experience any complaints?
(Check any of the following complaints that you experienced on your hike today)

- ☐ None (1)
- ☐ Headache (2)
- ☐ Muscle cramp (3)
- ☐ Urge to urinate (4)
- ☐ Belch, burp or having a bloated feeling (5)
- ☐ Nausea (6)
- ☐ Diarrhea, loose stool or bloody stool (7)
- ☐ Heartburn (8)
- ☐ Stomach cramp (9)
- ☐ Abdominal pain (10)
- ☐ Being light headed or dizzy (11)
- ☐ Feeling like passing out (12)
- ☐ Truly passing out (13)
- ☐ Other (14)

---

*Display This Question:*

*If Did you experience any complaints? (Check any of the following complaints that you experienced on... = Other*

Q22 What other complaints did you experienced on your hike today?

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

X→

Q23 Did you pour some of the fluid you brought over your head/body?

◯ Yes (1)

◯ no (2)

*Display This Question:*

*If Did you pour some of the fluid you brought over your head/body? = Yes*

X→

Q24 Please quantify the volume that poured over your head/body.

◯ Less than or similar to 8 fluid ounces (1)

◯ 8-16 fluid ounces (2)

◯ 16-24 fluid ounces (3)

◯ 24-32 fluid ounces (4)

◯ More than 32 fluid ounces (5)

Q25 How did you prepare for the heat?

- ☐ Hat (1)
- ☐ Sun glasses (2)
- ☐ Cool scarf/bandana (3)
- ☐ Cool shirt (4)
- ☐ Cool vest (5)
- ☐ Clothes soaked in water before the start of the hike (6)
- ☐ None of these options (7)
- ☐ Other (8)

---

*Display This Question:*

*If Did you experience any complaints? (Check any of the following complaints that you experienced on... = Other*

Q26 What other ways did you use to prepare for the heat?

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

**End of Block: Risk behavior related questions**

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**Start of Block: Management alternatives question**

Q27 Given the increasing number of heat related injuries on trails, some management alternatives listed below are options that have been suggested. Indicate how acceptable or unacceptable each of the following potential management actions is for the days that an excessive heat warning has been declared. The list of items are not necessarily actions that are going to occur but we are interested in your opinions about these potential actions. (please select one response for each statement).

| | Very unacceptable (1) | Unacceptable (2) | Neither unacceptable nor acceptable (3) | Acceptable (4) | Very acceptable (5) |
|---|---|---|---|---|---|
| Sign-in at the trail head (1) | ○ | ○ | ○ | ○ | ○ |
| Sign-in at the trail head including the option to be tracked via a phone or other tracking device (13) | ○ | ○ | ○ | ○ | ○ |
| Access to trails limited to only those who have completed a self-paced short online course focused on heat related injury (14) | ○ | ○ | ○ | ○ | ○ |
| Access to trails limited to only those who have sufficient fluids (15) | ○ | ○ | ○ | ○ | ○ |
| Access to trails limited to only those who have appropriate heat related clothing (e.g. hats) (16) | ○ | ○ | ○ | ○ | ○ |
| Close public access to trails rated difficult or extremely difficult (17) | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| Close public access to all trails (18) | ○ | ○ | ○ | ○ | ○ |
| Close public access during select times to trails rated difficult or extremely difficult (22) | ○ | ○ | ○ | ○ | ○ |
| Ban hiking alone (19) | ○ | ○ | ○ | ○ | ○ |
| Ban pets on trails (20) | ○ | ○ | ○ | ○ | ○ |
| Close the highest fire department rescue location of Piestewa Peak (21) | ○ | ○ | ○ | ○ | ○ |
| Have a permit for hiking during excessive heat (11) | ○ | ○ | ○ | ○ | ○ |

End of Block: Management alternatives question

Start of Block: Personal demographics

X→

Q28 What is your gender?

○ Male (1)

○ Female (2)

○ Non-binary / third gender (3)

○ Prefer not to say (4)

Q29 What is your height? (ft and in)

________________________________________________________________

Q30 What is your body weight? (lbs)

________________________________________________________________

Q31 What is your age? (years)

________________________________________________________________

Q32 What is the ZIP Code of your primary residence?

________________________________________________________________

# APPENDIX B

# DEMOGRAPHICS OF THE SAMPLE – EXTENDED

| Descriptives | Sample | High Risk Perception | Low Risk Perception | P Value |
|---|---|---|---|---|
| Height (cm), Mean (STD) | 174.45 (9.26) | 171.40 (9.03) | 173.25 (9.39) | 0.077 |
| Weight (kg), Mean (STD) | 74.32 (14.80) | 73.18 (14.62) | 74.93 (14.97) | 0.417 |
| BMI | 24.80 (3.79) | 24.87 (3.86) | 24.74 (3.75) | 0.859 |

| Descriptives | % (n) | Group % (n) | | P Value |
|---|---|---|---|---|
| | | High Risk Perception | Low Risk Perception | |
| Gender | | | | 0.015 |
| Male | 54.4% (185) | 47.4% (74) | 60.3% (111) | |
| Female | 42.9% (146) | 51.3% (80) | 35.9% (66) | |
| Non-Binary/ Third Gender | 0.9% (3) | 1.3% (2) | 0.5% (1) | |
| Prefer Not to say | 0.3% (1) | 0 (0%) | 0.5% (1) | |
| Missing | 1.5% (5) | 0% (0) | 2.7% (5) | |
| Age, yrs. | | | | 0.235 |
| 18-29 | 23.5% (80) | 23.1% (36) | 23.9 (44) | |
| 30-49 | 46.8% (159) | 50.0% (78) | 44.0% (81) | |
| 50-64 | 25.3% (86) | 23.7% (37) | 26.6% (49) | |
| 65+ | 2.1% (7) | 1.3% (2) | 2.7% (5) | |
| Missing | 2.4% (8) | 1.9% (3) | 2.7% (5) | |
| Education | | | | 0.241 |
| Some High School | 1.5% (5) | 1.9% (3) | 1.1% (2) | |
| High School Graduate | 6.8% (23) | 3.8% (6) | 9.2% (17) | |
| Vocational/trade school | 2.9% (10) | 2.6% (4) | 3.3% (6) | |

| | | | | |
|---|---|---|---|---|
| Some College | 13.8% (47) | 12.8% (20) | 14.7% (27) | |
| Two Year College Degree | 9.1% (31) | 9.6% (15) | 8.7% (16) | |
| Four Year College Degree | 36.2% (123) | 39.7% (62) | 33.2% (61) | |
| Master's Degree | 21.2% (72) | 24.4% (38) | 18.5% (34) | |
| Ph.D., M.D., J.D., or equiv. | 7.4% (25) | 5.1% (8) | 9.2% (17) | |
| Missing | 1.2% (4) | 0% (0) | 2.2% (4) | |
| Employment Status | | | | 0.546 |
| Employed for Wages | 68.8% (234) | 69.9% (109) | 67.9% (125) | |
| Self Employed | 10.6% (36) | 11.5% (18) | 9.8% (18) | |
| Out of work, looking | 2.6% (9) | 2.6% (4) | 2.7% (5) | |
| Out of work, not looking | 1.2% (4) | 1.3% (2) | 1.1% (2) | |
| Student | 7.9% (27) | 9.6% (15) | 6.5% (12) | |
| Homemaker | 1.8% (6) | 2.6% (4) | 1.1% (2) | |
| Retired | 3.2% (11) | 0.6% (1) | 5.4% (10) | |
| Military | 0.9% (3) | 1.3% (2) | 0.5% (1) | |
| Unable to work | 0.9% (3) | 0.6% (1) | 1.1% (2) | |
| Missing | 2.1% (7) | 0% (0) | 3.8% (7) | |
| Race | | | | |
| Hispanic or Latino | 20.6% (70) | 21.2% (33) | 20.1% (37) | 0.866 |
| American Indian or Alaskan Native | 2.9% (10) | 3.8% (6) | 2.2% (4) | 0.351 |
| Asian | 10.9% (37) | 12.2% (19) | 9.8% (18) | 0.465 |
| Black or African American | 4.1% (14) | 3.2% (5) | 4.9% (9) | 0.452 |

| | | | | |
|---|---|---|---|---|
| Native Hawaiian/Pacific Islander | 1.2% (4) | 1.3% (2) | 1.1% (2) | 0.857 |
| White | 80.0% (272) | 78.8% (123) | 81.0% (149) | 0.201 |
| Income | | | | 0.328 |
| <$25,000 | 10% (34) | 13.5% (21) | 7.1% (13) | |
| $25,001-$50,000 | 15.9% (54) | 16.7% (26) | 15.2% (28) | |
| $50,001-$75,000 | 12.6% (43) | 10.3% (16) | 14.7% (27) | |
| $75,001-$100,000 | 15.9% (54) | 15.4% (24) | 16.3% (30) | |
| $100,001-$125,000 | 11.2% (38) | 10.9% (17) | 11.4% (21) | |
| $125,001-$150,000 | 7.1% (24) | 7.1% (11) | 7.1% (13) | |
| >$150,000 | 25% (85) | 24.4% (38) | 25.5% (47) | |
| Missing | 2.4% (8) | 1.9% (3) | 2.7% (5) | |

APPENDIX C

IRB APPROVAL FORM FOR THE SUMMER OF 2021

APPROVAL: EXPEDITED REVIEW

Floris Wardenaar
Nutrition
(602) 827-2841 Floris.Wardenaar@asu.edu

Dear Floris Wardenaar:

On 6/20/2021 the ASU IRB reviewed the following protocol:

| | |
|---|---|
| Type of Review: | Initial Study |
| Title: | Assessing physiological and socio-psychological heat related risk perceptions and behavior among Phoenix metropolitan area hikers. |
| Investigator: | Floris Wardenaar |
| IRB ID: | STUDY00014107 |
| Category of review: | |
| Funding: | Name: ISSR - Research Support Team |
| Grant Title: | |
| Grant ID: | |
| Documents Reviewed: | • Award approval, Category: Sponsor Attachment;<br>• Bioscience-Protocol Wardenaar 06182021.docx, Category: IRB Protocol;<br>• CITI TRAINING PROOF LoVecchio, Category: Vitaes/resumes of study team;<br>• City of Phoenix approval to partner at ISSR study - Hiker Heat Risk study.pdf, Category: Off-site authorizations (school permission, other IRB approvals, Tribal permission etc);<br>• Consent Form Wardenaar 06182021.pdf, Category: Consent Form;<br>• ISSR proposal Wardenaar Budruk LoVecchio |

| | |
|---|---|
| | • Survey, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); |
| | 02282021.pdf, Category: Sponsor Attachment;<br>• Result sheet, Category: Participant materials (specific directions for them);<br>• Results waiver, Category: Participant materials (specific directions for them); |

The IRB approved the protocol from 6/20/2021 to 6/19/2022 inclusive. Three weeks before 6/19/2022 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 6/19/2022 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the

INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc:

Megha Budruk

Frank LoVecchio

Sonia Navarro

# APPENDIX D

# IRB APPROVAL FORM FOR THE SUMMER OF 2022

APPROVAL: MODIFICATION

Floris Wardenaar
Nutrition
(602) 827-2841
Floris.Wardenaar@asu.edu

Dear Floris Wardenaar:

On 4/26/2022 the ASU IRB reviewed the following protocol:

| | |
|---|---|
| Type of Review: | Modification / Update |
| Title: | Assessing physiological and socio-psychological heat related risk perceptions and behavior among Phoenix metropolitan area hikers. |
| Investigator: | Floris Wardenaar |
| IRB ID: | STUDY00014107 |
| Funding: | Name: ISSR - Research Support Team |
| Grant Title: | None |
| Grant ID: | None |
| Documents Reviewed: | • Approval Frank LoVecchio.JPG, Category: Other;<br>• HHR Recruitment poster 04122022.pdf, Category: Recruitment Materials;<br>• Par-QandYou.pdf, Category: Screening forms;<br>• REVISED Bioscience-Protocol Wardenaar 04262022.docx, Category: IRB Protocol;<br>• REVISED Consent Form Wardenaar 04262022.pdf, Category: Consent Form; |

The IRB approved the modification.

When consent is appropriate, you must use final, watermarked versions available under the “Documents” tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

REMINDER - - Effective January 12, 2022, in-person interactions with human subjects require adherence to all current policies for ASU faculty, staff, students and visitors. Up-to-date information regarding ASU's COVID-19 Management Strategy can be found here. IRB approval is related to the research activity involving human subjects, all other protocols related to COVID-19 management including face coverings, health checks, facility access, etc. are governed by current ASU policy.

Sincerely,

IRB Administrator