

Review

Importance of Electrolytes in Exercise Performance and Assessment Methodology After Heat Training: A Narrative Review

Marcos S. Keefe¹, Courtney L. Benjamin² , Douglas J. Casa³  and Yasuki Sekiguchi^{1,*}¹ Sports Performance Laboratory, Department of Kinesiology and Sport Management, Texas Tech University, Lubbock, TX 79409, USA; makeefe@ttu.edu² Department of Kinesiology, Samford University, Birmingham, AL 35229, USA; cbenjami@samford.edu³ Department of Kinesiology, Korey Stringer Institute, University of Connecticut, Storrs, CT 06269, USA; douglas.casa@uconn.edu

* Correspondence: yasuki.sekiguchi@ttu.edu

Abstract: Performing exercise in hot environmental conditions presents athletes with potential negative physiological and perceptual implications. Key constituents, such as fluid and electrolytes, are lost during sweating through the process of cooling the human body. The loss of electrolytes impairs exercise performance. Heat training is one strategy to combat sweat electrolyte loss, with decreased sweat electrolyte concentration being a main sudomotor adaptation. To measure sweat electrolyte concentration, two common assessment methods are typically utilized: whole-body washdown and regional sweat patch measurements. The effects of physiological adaptations and sweat electrolyte assessment methodology have been investigated; however, the importance of methodological differences between sweat electrolyte measurements following heat training has yet to be explored. This review explores the differences between sweat electrolyte measurement techniques following adaptations incurred with heat training. Future research directions are also provided.

Keywords: electrolyte; heat; exercise

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1. Introduction

Exercise performance in hot environmental conditions is compromised due to increased physiological strain, compared to when undertaken in temperate or cool conditions [1–3]. While exercising in the heat, central and peripheral thermosensitivity mechanisms control body temperature regulation [4]. Sensory thermoreceptors transmit signals to the preoptic anterior hypothalamus (POAH) in response to increased core temperature, thereby initiating independent thermoeffector loops to elicit thermoregulatory sweating in an effort to cool the body through heat dissipation [4,5]. However, this sudomotor response is accompanied by a loss of electrolytes (i.e., sodium [Na⁺], chloride [Cl[−]], and potassium [K⁺]) in the sweat [6]. Electrolytes are critical substances that aid with maintaining water balance by shifting fluid between intracellular and extracellular compartments, maintaining membrane electrochemical potentials, and transporting nutrients into and waste out of the cell [7]. The loss of electrolytes in sweat and subsequent fluid imbalances often lead to hypohydration, which negatively influences exercise performance, health, and thermoregulatory mechanisms [8–10] (Figure 1).

The physiological actions of electrolytes operate in both the extracellular compartments of the blood and intracellular compartments within the cell. During exercise in the heat, several physiological impairments occur as a result of reduced plasma electrolyte concentrations from the increased electrolyte concentrations lost in sweat [11]. For example, increases in plasma osmolality occur because plasma Na⁺ (Na⁺_p) and Cl[−] (Cl[−]_p) are directly associated with plasma osmolality, as they are the primary regulators of extracellular volume and function to maintain water absorption [11–13]. In addition, plasma

volume is partially regulated by Na^+ and Cl^- , as these electrolytes exert osmotic pressure and redistribute fluid between the blood and cells [11]. Consequently, plasma volume reductions may be observed due to the increased electrolyte concentration lost in sweat as opposed to circulating in plasma. Furthermore, it has been suggested that there may be a relationship between electrolytes and the neuromuscular properties associated with exercise performance (i.e., skeletal muscle membrane potential, exercise-induced muscle cramps [EIMC]) [14,15]. Indeed, muscle tissue is composed of approximately 76% water, with electrolytes being a primary modulator of water flux [16]; however, it is difficult to surmise the impact of this as it remains under contention amongst the scientific community and requires more research [15,17]. Collectively, electrolyte imbalances due to exercise in the heat can lead to various physiological impairments.



Figure 1. Impact of sweat electrolyte loss in sports performance across physiological and physical performance metrics.

Blood flow patterns experience significant alterations during exercise compared to resting conditions [18]. When an individual performs exercise, particularly under thermal stress, blood circulation to the skin can increase by as much as 30–40% in healthy young men as part of the body's efforts at temperature regulation [18]. This increased skin blood flow leads to a higher concentration of plasma electrolytes and blood in the dermis, which is the skin layer composed of collagen, elastic tissue, and extracellular components, including blood vessels, nerve endings, and eccrine glands [19]. The secretion of sweat occurs within the dermis in the secretory coils and proximal ducts, more precisely following the Na-K-2Cl cotransport model within the clear cells of the secretory coil [20]. When the POAH signals for sweating to occur, acetylcholine is released from sympathetic post-ganglionic neurons and binds to muscarinic receptors on the basolateral membrane of the clear cells [20]. This initiates the release of intracellular calcium (Ca^{2+}) stores and an influx of extracellular Ca^{2+} into the cell's cytoplasm [20]. Following this, an efflux of K^+ via K^+ channels on the basolateral membrane and Cl^- through Cl^- channels on the apical membrane occurs, thus causing cell shrinkage [20]. This cell shrinkage leads to an inflow of Na^+ , K^+ , and Cl^- through Na-K-2Cl cotransporters on the basolateral membrane and, subsequently, an efflux of Na^+ and K^+ through Na-K-ATPase and K^+ channels into the extracellular space, along with an efflux of Cl^- through Cl^- channels into the lumen [20]. The increased Cl^- concentration in the lumen creates an electrochemical gradient that promotes the movement of Na^+ across the cell junction [20–22]. In turn, this leads to a net efflux of K^+ and Cl^- from the cell, creating an osmotic gradient for the movement of water into the lumen via aquaporin-5 channels [20,23–25]. Lastly, the water and electrolytes transported into the lumen combine to form primary sweat. This entire process elucidates how electrolytes from the blood are utilized in the formation of sweat.

The homeostasis of body fluid regulation and electrolyte excretion via sweat glands during and after exercise in the heat is also impacted by aldosterone and antidiuretic hormone, as well as sympathetic nervous system activity. Aldosterone is a mineralocorticoid hormone whose primary function is water and Na^+ regulation via reabsorption in the kidney, specifically the late distal tubules and collecting ducts of nephrons [26]. The

antidiuretic hormone is typically co-released with aldosterone, whereby it supports the extracellular fluid reabsorption of water through the mobilization of aquaporin channels to the apical membrane of the collecting tubule [26]. During exercise in the heat, aldosterone and antidiuretic hormone secretions are increased, which promotes water and Na^+ reabsorption in the kidneys and counteracts the loss of fluids and electrolyte caused by sweating [27]. In contrast, sympathetic nervous system activity modulates fluid regulation during exercise in the heat by activating sweat glands to excrete fluid via sweating [28]. This function is imperative to allow for adequate heat dissipation, but it subsequently results in fluid and electrolyte losses. Therefore, the body is in a constant flux of fluid and electrolyte reabsorption (i.e., aldosterone and the antidiuretic hormone) and excretion (i.e., sympathetic nervous system activity).

The loss of electrolytes via sweating, along with several other decremental physiological responses from exercising in the heat, has been investigated in the hope of reducing these effects. A popular strategy that has been explored is the implementation of heat training, either via heat acclimation (HA; training in a hot artificial environment) or heat acclimatization (HAz; training in a naturally hot environment). One of the positive adaptations that occurs with heat training is reduced electrolyte concentrations in the sweat, inferring that more electrolytes are kept in the blood, possibly due to improved reabsorption within the proximal duct during sweat secretion. As primary sweat propagates in the lumen towards the skin surface, Na^+ and Cl^- are reabsorbed via the luminal and basal cells of the duct [20]. This results in the final form of sweat being hypotonic; however, there still remain electrolytes in the sweat that is then lost on the skin's surface. Investigation into the heat training adaptation of reduced electrolytes in the sweat has been carried out using various methodologies.

Sweat electrolyte loss can be measured via two methods: (1) the whole-body wash-down (WBW) technique and (2) regional sweat patch measurements (Figure 2). WBW determines whole-body sweat electrolyte losses, whereas regional sweat patch measurements determine sweat electrolyte loss at specific anatomical sites [29]. The WBW technique is considered the gold standard and most accurate measure of whole-body sweat electrolyte loss, which is attributed to all sweat runoff being collected/accounted for and a lack of interference with the normal evaporative sweating process [30]. An itemized list, instructions, and an example document on proper execution of the WBW technique have previously been reported [31]. Although WBW is the gold standard for sweat electrolyte assessment, variations still remain in Na^+ sweat concentrations. The alternative assessment method, regional sweat patches, uses predictive equations to estimate whole-body sweat electrolyte losses from various anatomical sites [30,32]. Although these predictive equations have been validated [30], the validity of regional sweat patch measurements is limited due to sweat composition and sweat rate variations across regions of the body [33]. In addition, the patch suppresses sweat evaporation in that specific anatomical area and sweat collected from occlusive coverings may represent false increased electrolyte concentrations due to electrolyte leaching from the stratum corneum of the skin [30,34]. It has been noted that sweat patches usually overestimate sweat loss concentrations [30]. However, a recent cross-validation study conducted by Baker and colleagues (2019) confirmed the validity of predictive equations to predict whole-body sweat Na^+ concentrations from regional sweat patch measurements [6]. Another matter to note is that there are different methodological sweat patch assessments utilizing either single or multiple patch sites for collection [29,35–37]. This demonstrates the importance of considering which sites are being measured, and if those predictive equations have been validated in the literature. However, regional sweat patches are still utilized in research and professional settings as they provide the advantage of being more readily available for field settings and in situations where there is a limited budget.

Numerous original research studies and reviews have been conducted discussing sweat electrolyte concentration and losses during exercise, along with methodological assessments to measure sweat electrolytes (whole-body washdown vs. regional sweat

patches) [6,29,30,33,38–41]. However, there are no current reviews available, to the authors' knowledge, on electrolyte concentration adaptations from heat training and differences in assessment results dependent on the method employed. Therefore, the objective of this review was to explore the differences between sweat electrolyte measurement techniques from the adaptations incurred following heat training.

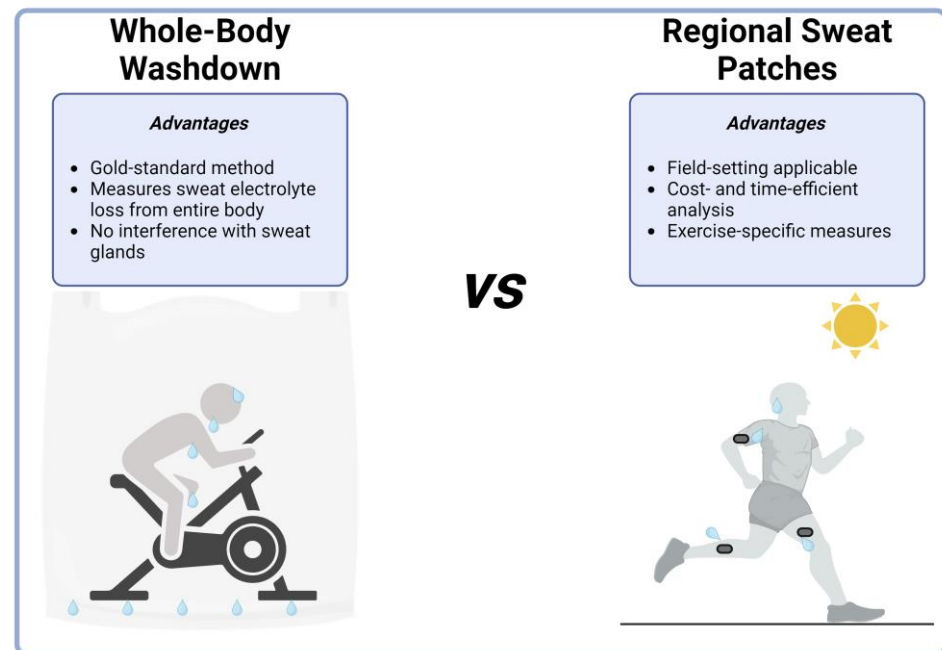


Figure 2. Whole-body washdown (WBW) vs. regional sweat patches, advantages for sweat electrolyte analysis. Created with [BioRender.com](https://www.biorender.com), accessed on 24 September 2024.

2. Search Strategy

All literature examining sweat electrolyte adaptations, following heat training utilizing the WBW technique and/or regional sweat patches, was searched between December 2022 and May 2024 in PubMed, Scopus, and Google Scholar. Keywords included 'heat training', 'heat acclimation', 'acclimatization', 'heat adaptation', 'thermal adaptation', 'passive heating', 'electrolyte', 'sodium', 'potassium', 'chloride', and 'sweat'. Subject headings were used independently and in combination. With the initial article search, only full-text, peer-reviewed articles with human participants and published in the English language were selected. Furthermore, review articles, abstracts, case/single studies, unpublished theses, conference papers, and editorials were not included. During abstract and full-text reviewing, only articles utilizing the WBW technique or regional sweat patches to analyze sweat electrolyte adaptation from heat training were included for discussion.

3. Whole-Body Washdown

Four studies investigated sweat electrolyte adaptations following heat training using the WBW method [42–45] (Table 1). Of these four studies, two were part of the same larger cohort study [42,43]. One of these two investigated sweat electrolyte adaptations following HAz and HA + HAz [42], whereas the other study investigated sweat electrolyte adaptations after an intermittent heat training protocol following an HA protocol [43]. Another study investigated sweat electrolyte adaptations following an HAz period of summer running in the northeastern United States [44]. Lastly, the other study measured sweat electrolyte adaptations when testing the effects of bromocriptine on sweat gland function following an HA protocol, but also included a control group that did not ingest the bromocriptine [45]. All four of these studies measured Na^+ and K^+ , whereas only the two Benjamin et al. (2021 and 2022) studies additionally measured Cl^- .

Table 1. Summary of heat acclimation/acclimatization and electrolyte concentration (conc.) investigations. Arrows signify a reduction or no change in sweat electrolyte concentration following HA.

Study	Participant Characteristics	HA Classification	Sweat Electrolyte Assessment	Na ⁺ Sweat Conc.	Cl [−] Sweat Conc.	K ⁺ Sweat Conc.
Buono et al. (2018) [40]	4 healthy individuals (<i>f</i> = 1)	7-day HA	Forearm regional sweat collector	↓	--	--
Benjamin et al. (2021) [42]	24 male endurance athletes	4-month HAZ + 5-days HA	WBW	↓	↓	↔
Benjamin et al. (2022) [43]	24 male endurance athletes	4- and 8-wk IHT after 5-day HA	WBW	↔	↔	↔
Armstrong (1987) [44]	5 highly trained distance runners (<i>f</i> = 1)	14.5-wk HAZ	WBW	↔	--	↔
Kaufman et al. (1988) [45]	8 healthy males	10-day HA	WBW	↓	--	↔
Buono et al. (2007) [46]	8 healthy males	10-day HA	Chest regional sweat collector	↓	--	--
Inoue et al. (1999) [47]	5 young, 4 highly fit old, and 5 normally fit old males	8-day HA	Chest, back, forearm, & thigh sweat patch	↓	--	--
Karlsen et al. (2015) [48]	9 trained cyclists	2-wk HAZ	Back sweat patch	↓	--	--
Kirby and Convertino (1986) [49]	10 healthy males	10-day HA	Chest regional sweat patch	↓	--	--
Klous et al. (2020b) [50]	15 healthy participants (<i>f</i> = 5)	10-day HA	Back and arm sweat patch	↓	↓	↔
Klous et al. (2020a) [51]	8 healthy participants (<i>f</i> = 2)	10-day HA	Back and arm sweat patch	↓	↓	↔
Magalhães et al. (2010) [52]	9 male tropical natives	11-day HA	Forehead, chest, arm, forearm, and thigh sweat patch	↔	--	--
Marshall et al. (2007) [53]	7 healthy males	3-day HA	Forearm sweat patch	↓	↓	--
McCleave et al. (2019) [54]	9 trained male and female runners (<i>f</i> = 3)	3-wk heat training	Back sweat patch	↓	--	--
Mikkelsen et al. (2019) [55]	12 male sub-elite cyclists	5.5-wk HA	Back sweat patch	↓	--	--
Petersen et al. (2010) [56]	6 male cricket players	4-day HA	Upper forearm sweat patch	↓	↓	↓
Rendell et al. (2017) [57]	8 healthy males	11-day HA	Back sweat patch	↓	--	--
Saat et al. (2005) [58]	16 Malaysian-Malay males	2-wk HA	Back sweat patch	↔	--	↔
Willmott et al. (2019) [59]	20 healthy males	5- and 10-day HA	Unspecified regional sweat patch	↓	--	--
Roussey et al. (2021) [60]	17 male competitive-level athletes	5-day HA	Back sweat patch	↔	--	--
Racinais et al. (2012) [61]	19 male semiprofessional soccer players	6-day HAZ	Back sweat patch	↓	--	--
Racinais et al. (2014) [62]	18 male Australian football players	2-wk HAZ	Back sweat patch	↓	--	--
Tan et al. (2022) [63]	51 untrained tropical native males	10-day HA	Thigh sweat patch	↓	--	--

f, female; HA, heat acclimation; HAZ, heat acclimatization; WBW, whole-body washdown; IHT, intermittent heat training.

From the Benjamin et al. (2021 and 2022) study, participants performed both an HAz and HA protocol, resulting in two separate time points of adaptation measurements: post-HAz and post-HAz + HA. The HAz protocol involved self-directed summer training for approximately 109 ± 9 days. Following this, participants completed a 5-day HA protocol. Significant reductions were noted in Na^+ and Cl^- post-HAz + HA compared to both baseline and post-HAz measurements, demonstrating adaptations from HA [42]. However, no significant differences were seen between the baseline and post-HAz, suggesting HAz may not be a strong enough stimulus by itself to induce sweat electrolyte adaptation. Indeed, the HAz protocol involved participants performing self-directed summer training and average WBGT temperatures were $\sim 22.5^\circ\text{C}$, thus potentially not being a strong enough stimulus [42].

From the same overall study, intermittent heat training (IHT) was implemented to combat decay and maintain physiological adaptations following HAz + HA [43]. Participants completed 0, 1, or 2 days of heat training per week for a total of 8 weeks, with adaptations being measured after 4 and 8 weeks. Interestingly, there was no sweat electrolyte concentration maintenance for Na^+ or Cl^- with both IHT protocols [43]. K^+ was maintained throughout the 8 weeks; however, this conservation did not seem to be because of the IHT as even the control group experienced the same K^+ maintenance. At the week 4 and 8 time points, Na^+ and Cl^- concentrations were higher compared to post-HAz + HA across all conditions. These findings suggest that IHT may not be effective in maintaining sweat electrolyte adaptations, but K^+ may be maintained after HA even without IHT [43].

Armstrong et al. (1987) found no adaptations following a summer HAz protocol, for both sweat and plasma electrolyte concentrations [44]. Highly trained distance runners trained during the summer months in the northeastern United States for 14.5 weeks. Although no adaptations were noticed, this was likely due to the moderate temperature conditions not being hot enough to induce appropriate stimulus for adaptation to occur. Indeed, only 3 days of the 14.5 weeks HAz had a maximum daily temperature above 30.3°C , with most of the mean maximum temperatures ranging between ~ 20 and 30°C . Most HA research utilizes temperatures above 35°C in order to induce adequate stimulus for adaptation [64]. Extended time with an internal body temperature above 38.5°C is suggested to be a factor in inducing physiological adaptations for performance in the heat [64]. This may partly explain why no physiological adaptations, including sweat and plasma electrolyte concentrations, were seen in this study. In contrast, Kaufman et al. (1988) saw a decreased concentration of sweat Na^+ following a 10-day HA protocol, but no significant decrease in K^+ [45]. The sweat electrolyte adaptation is likely linked to the improved core temperature that the control group experienced from the HA protocol.

4. Regional Sweat Patches

When investigating the effects of HA on electrolyte preservation, most studies examine these adaptations using regional sweat patch measurement, which may demonstrate differences in sweat responses depending on regional body area [65]. Traditional HA protocols are typically characterized by either endurance-based cycling or running exercises. Although both are endurance-based types of exercise, running utilizes more whole-body movement compared to cycling. Thus, regional sweat rates may differ between exercise types, with more sweat potentially being lost in the lower extremities during cycling compared to running since most movement occurs in the leg musculature [66]. However, there seem to be limited to no differences in sweat electrolyte adaptation between HA protocols of cycling versus running [40,42,45–59].

From one of the earlier studies that investigated sweat electrolyte adaptations and HA, Kirby and Convertino (1986) found increases in sweat Na^+ reabsorption via sweat patches at the chest site, explained by the authors as eccrine gland responsiveness to plasma aldosterone, following a 10-day cycling HA protocol [49]. Significant reductions in sweat Na^+ were noted after the 10 days during both the first and second hour of exercise [49]. In addition, plasma aldosterone concentrations were reduced following HA, which partially

demonstrates the sweat Na^+ adaptation. As the chest regional site has been shown to be one of the best sites for predicting whole-body sweat, deductions from this study can be deemed accurate for the determination of sweat electrolyte concentration adaptations. Other investigations have also chosen the chest site for sweat patch placement [47]. Following an 8-day HA cycling protocol, young males, highly fit old males, and normally fit old males collectively experienced sweat Na^+ reductions at several regional sites (chest, back, forearm, and thigh) [47]. The younger males experienced these adaptations at all four sites, whereas the highly fit older males did not experience these reductions at the forearm and thigh sites, nor did the normally fit older males experience these reductions at the back and forearm sites [47].

Several investigations have determined sweat electrolyte adaptation from HA using the upper back and upper arm regional sites [48,50,51,54,55,57,60], with all but one demonstrating positive adaptation [60]. Although significant differences were not seen overall, the researchers did note that a pre–post-training reduction in sweat Na^+ was observed in 13 of the total 17 participants, suggesting some changes had occurred [60]. Additionally, another study utilized regional sweat patches for electrolyte assessment and observed conserved Na^+ following HA; however, the authors did not specify where the patch was regionally located [59].

In field or laboratory settings when skin sites might be restricted due to clothing, a forearm single-site measurement is typically attained. Petersen et al. (2010) measured sweat electrolyte loss with sweat patches at a single site, the upper forearm [56]. Following a short-term 4-day HA protocol, male cricket club players exhibited substantial decreases in sweat Na^+ , K^+ , and Cl^- concentrations [56]. Although this study involved only 4 days of HA, reductions were still noted, providing evidence that sweat electrolyte adaptations may begin within the first couple of days. Similarly, reduced sweat Na^+ was noted following 3 consecutive days of cycling-based heat training from sweat collected at the forearm site [53]. Thus, the forearm is likely a valid location for sweat electrolyte assessment in settings where clothing hinders other sites.

Non-traditional forms of heat training have also resulted in positive electrolyte adaptations via regional patch measurement [61,62]. In Australian football players, 2 weeks of traditional sport training in hot conditions improved sweat Na^+ reductions [62]. Likewise, semi-professional soccer players completed a 6-day HAz protocol of their usual training cycle in the heat and also experienced decreases in sweat Na^+ [61]. The practical application of regional sweat patches is highlighted by studies like these, where although the testing sessions were performed in laboratory settings, the protocols were field-based. Thus, it is surmisable that regional patches may also be utilized during actual training sessions to measure sweat electrolyte loss, allowing for more evidence-informed decisions regarding nutritional and hydration strategies.

A few studies within the same research group have used Macroduct sweat collectors on chest [46] and forearm [40] sites to assess sweat electrolyte concentration following medium-term HA (7 and 10 days) in healthy individuals. These sweat collectors function in the same manner as patches, being placed in the same sites for sample collection. Buono et al. (2007) assessed sweat electrolyte concentration while controlling for the effect of changes in sweat rate on sweat Na^+ [46]. In doing so, sweat Na^+ concentrations still decreased over the 10-day HA protocol, signifying that the adaptation is not attributable only to elevated sweat rate [46]. Similarly, this group again demonstrated that HA significantly reduces sweat Na^+ concentration via improvements in Na^+ ion reabsorption from eccrine sweat gland ducts [40].

Sweat electrolyte adaptation has also been investigated in tropical populations following HA using regional patches [52,58,63]. Previous research has demonstrated that tropical natives exhibit greater thermoregulation efficiency through less reliance on evaporative cooling mechanisms (i.e., sweating) [52,67,68]; thus, it is important to understand if this population experiences similar sudomotor adaptations as a result of HA. When accounting for tropical climates, Rivera-Brown and Quinones-Gonzalez (2020) provided sweat Na^+

concentration normative values for athletes indigenous to these hot and humid climates, explaining ranges for low, low-average, average-high, and high [69]. From three known studies to the authors' knowledge, two investigations noted reductions in sweat Na^+ concentrations following medium-term HA protocols (10 and 11 days) [52,63]. In contrast, Saat et al. (2005) saw no differences in sweat Na^+ or K^+ from a 14-day HA protocol [58]. The lack of sweat electrolyte adaptation may partly be explained by the environmental conditions, specifically the relatively high 70% humidity level. During exercise in humid-hot conditions, characterized by reduced evaporative potential, heat loss mechanisms are altered by reduced heat loss through sweating compared to dry-hot conditions [70]. Subsequently, there was also no adaptation in the increased sweat rate. In the absence of an increased sweat rate, limited opportunity exists for electrolytes to be reabsorbed via sweat gland ducts as the final form of sweat is produced.

5. Future Directions and Limitations

The accuracy and application of the WBW technique has been well established as the gold standard for sweat electrolyte measurement. However, the use of this method has been less investigated in correspondence with HA protocols because of the limitations of field setting functionality. Therefore, future research should investigate sweat electrolyte concentration adaptations following HA comparing the WBW method to regional sweat patches. In addition, sex and age differences between WBW and regional sweat patches need to be explored due to the underrepresentation of females in exercise thermoregulation research and differences in thermoregulation between young and older individuals. Lastly, other electrolyte assessment modalities have been gaining attention due to emerging technology, such as microfluidic systems, and commercially available wearables [71–74]. Third-party reliability and validity studies should be conducted to compare these modalities to the WBW technique.

This review has summarized the current literature on sweat electrolyte adaptations following heat training utilizing either the WBW technique or regional sweat patches. However, this study was not without limitations. Narrative reviews inherently contain limitations regarding the objectivity of study selection and the interpretation of results [75]. Furthermore, no statistical analysis was executed to compare findings between studies that used the WBW technique to those that used regional sweat patches. We considered performing a meta-analysis but deemed it not appropriate as there is a large disparity in the number of studies between methodologies. However, this does result in a bias in the studies' interpretation. Even so, we chose to include all studies from our search strategy and aimed to present this review in the most objective way possible.

6. Conclusions

Sweat electrolytes play a pivotal role in maintaining various physiological functions, optimizing exercise performance, and ensuring athlete safety. These electrolytes, mainly Na^+ , Cl^- , and K^+ , help regulate fluid balance and aid in cardiovascular and neuromuscular functionality. Therefore, it is essential to accurately measure sweat electrolyte loss during exercise to understand how to properly replace sweat electrolytes during and after exercise. While regional sweat patches are convenient in field settings, the WBW technique is the gold standard method for sweat electrolyte measurement, providing more precise and accurate readings. Using the WBW method ensures the accuracy of the data collected. Further research is needed to investigate the adaptations of sweat electrolyte concentrations induced by HA using the WBW method. This knowledge can provide valuable information to athletes, coaches, and sports scientists for the improved creation of individualized electrolyte replacement plans for optimal performance and safety during exercise.

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