

SCIENTIFIC REPORT

UNDERSTANDING VARIABILITY IN MEASURING SWEAT SODIUM CONCENTRATION

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01

EXECUTIVE SUMMARY

Sweat sodium concentration is highly individual and can vary meaningfully within the same athlete depending on exercise, environmental exposure, heat adaptation and testing methodology. The available evidence indicates that some factors have a substantially greater influence than others, reinforcing the need to interpret each sweat test in the context in which it was performed.

Exercise Intensity

- Harder exercise can markedly increase sweat sodium concentration, with data demonstrating increases of up to ~920 mg/L between low and high intensity exercise.

Heat Adaptation Status

- 8 days of heat training can reduce sweat sodium concentration by ~470 mg/L.
- Seasonal heat exposure can reduce sweat sodium concentration by 30-60%.
- Acute heat exposure can increase sweat sodium concentration by ~15% compared to cooler conditions.

Testing Methodology and Biological Variability

- The ventral forearm closely reflects whole-body values on average.
- Day-to-day variation of 5-16% is still expected.
- MX3 analytical variation is low: CV ~5.6%.

KEY POINT

Sweat sodium concentration should not be treated as a fixed value. The most useful result is one obtained using a standardised method under conditions representative of the athlete's training or competition, with retesting considered when exercise demands, environmental exposure or heat adaptation status change substantially.

INTRODUCTION

Why Should I Measure Sweat Sodium Concentration?

Sweat contains both water and electrolytes, with sodium being the primary electrolyte lost in sweat [1]. During exercise, the amount of sodium lost is determined by two factors: 1) how much an individual sweats and 2) the sodium concentration of that sweat. Because both can vary substantially between people, two individuals completing the same exercise session can lose very different amounts of sodium [2]. Sweat sodium concentration is influenced by both modifiable (e.g., changes in exercise intensity) and non-modifiable (e.g., genetics) factors and is therefore highly individualised [3]. **Large published datasets have demonstrated considerable interindividual variation in sweat sodium concentration and total sodium losses, supporting the value of individual sweat testing [1].** Measuring sweat sodium concentration can therefore help estimate an individual's total sodium losses during training or competition and **inform more personalised hydration and electrolyte-replacement strategies.** This is particularly relevant when sweat losses are high, exercise is prolonged, or there is a limited recovery time between sessions. However, sweat sodium concentration should not be considered a completely fixed value [2]. The result obtained during a sweat test can be influenced by several physiological, environmental and methodological factors, which is why the conditions surrounding the test are important when interpreting the result.

How is Sweat Sodium Determined?

Most sweat produced during exercise comes from eccrine sweat glands, which are distributed across most of the body's skin surface. Each gland consists primarily of two functional regions: a secretory coil, where sweat is initially produced, and a duct, which modifies the sweat before it reaches the skin [2]. The fluid produced by the secretory coil contains a sodium concentration similar to blood plasma (~135-145 mmol/L). As this fluid travels through the sweat duct, sodium and chloride are reabsorbed back into the body. The amount of sodium reabsorbed is not constant; it depends on factors that influence sweat production and the sodium-reabsorbing capacity of the sweat gland. For example, as sweat rate increases, sodium secretion increases faster than sodium reabsorption, allowing more sodium to remain in the final sweat [3].

This document will help identify and explain why sweat sodium concentration may change with environmental conditions, heat adaptation status, exercise characteristics, dietary sodium intake and where on the body the sweat sample is collected.

03

ENVIRONMENTAL CONDITIONS

Environmental conditions can influence sweat sodium concentration because they affect how much and how quickly we sweat. When exercising in hotter conditions, the body generally needs to produce more sweat to dissipate heat. As sweat rate increases, less sodium is reabsorbed in the sweat gland, meaning a greater concentration of sodium remains in the sweat that reaches the skin. Please note that this section focuses on *acute heat exposure*, whilst adaptations pertaining to chronic heat exposure are discussed later.

Air Temperature

One study compared cyclists completing the same exercise protocol in 21°C and 32°C. Sweat rate increased from 0.8 L/h to 1.3 L/h. **Estimated sweat sodium concentration was significantly higher in the hot environment, increasing from 1380 mg/L to 1590 mg/L (~15%) [4].** A much larger analysis of 1944 sweat tests also identified air temperature as a significant predictor of whole-body sweat sodium concentration, even after accounting for factors such as energy expenditure [5].

Humidity

Humidity appears to have a smaller or less consistent influence. A previous study compared exercise at ~32°C under low (26%) and moderate (49%) relative humidity and found no significant differences in whole-body or regional sweat sodium concentration [6]. Similarly, in the previously mentioned large dataset, relative humidity was not an independent predictor of sweat sodium concentration [5].

Practical Implications

A sweat sodium result obtained in cool conditions may not perfectly represent the concentration measured during harder exercise in a hotter environment. Where possible, **sweat testing should therefore be performed under conditions that are reasonably representative of the athlete's typical training or competitive environment.**

04

HEAT ADAPTATION STATUS

Repeated exposure to hot conditions causes the body to adapt so that it can regulate core temperature more effectively. An important adaptation is an improvement in the body's ability to conserve sodium in sweat, whilst concurrently increasing sweat rate. This adaptation occurs because repeated heat exposure increases the ability of the sweat gland duct to reabsorb sodium before sweat reaches the skin. Importantly, this effect is not simply explained by changes in how much a person sweats.

One study examined the relationship between sweat rate and sweat sodium concentration before and after 10 days of heat training. **Following heat training, sweat sodium concentration was lower at a given sweat rate, demonstrating a shift of ~345 mg/L.** This indicates that the sweat glands had become more effective at reabsorbing sodium, rather than the reduction simply being caused by a lower sweat rate [7]. A similar response was reported in a different study, **whereby sweat sodium concentration was reduced by 34% (~400 mg/L)** after 10 days of heat training, despite whole-body sweat rate being higher [8].

The effect is also apparent when results from multiple heat training studies are combined together. **A recent review pooled results from 14 studies and found that, after 8 days of repeated heat training, sweat sodium concentration decreased by ~460 mg/L [9]. Evidence from seasonal heat adaptation is also consistent with these findings, with one review reporting a reduction in sweat sodium concentration of 22% [10] and others reporting 30-60% [11,12].** These data indicate that when athletes or workers train repeatedly in naturally hot environments, such as the start of spring/summer, sweat sodium concentration will reduce as exposure increases.

Practical Implications

An athlete's sweat sodium concentration measured before a period of heat training or at the beginning of Summer may not fully represent their values after becoming heat adapted. Sweat testing may be worth repeating following a meaningful period of heat training, particularly before competition in a hot environment or following substantial seasonal changes in heat exposure.

05

EXERCISE DURATION AND INTENSITY

The characteristics of an exercise session can influence sweat sodium concentration, with exercise intensity appearing to have a clearer effect than exercise duration alone. Higher-intensity exercise produces more metabolic heat, increasing the requirement for sweating. As sweat flow through the gland increases, sodium secretion increases faster than sodium reabsorption, allowing a greater concentration of sodium to remain in the sweat reaching the skin.

Exercise Intensity

Sweat sodium concentration tends to increase as exercise intensity increases (Table 1). This is likely due to the accompanying increase in sweat rate. Although the sweat gland reabsorbs more sodium as sweat production increases, sodium secretion increases at a faster rate, meaning a greater proportion of sodium remains in the sweat reaching the skin.

Table 1. Summary of studies investigating the effect of exercise intensity on sweat sodium concentration.

Study	Participants and Protocol	Exercise Intensity Comparison	Sweat Sodium Concentration (mg/L)	Interpretation
Baker et al., 2019 [13]	11 recreational athletes; 90 min cycling at 30°C and 44% RH.	45% vs 65% $\text{VO}_{2\text{max}}$	750 -> 1210 mg/L Increase by ~460 mg/L	Strong direct evidence that increasing exercise intensity substantially increases whole-body sweat sodium concentration.
Buono et al., 2008 [14]	10 participants; 5 separate 30 min exercise bouts in 35°C and 40% RH	50%, 60%, 70%, 80% and 90% HR_{max}	440 -> 1360 mg/L Increase by ~920 mg/L	Higher exercise intensity increases sweat rate, causing sodium secretion to outpace ductal sodium reabsorption.
Baker et al., 2022 [5]	Retrospective dataset of 1944 sweat tests.	Wide range of exercise workloads and sports.	Energy expenditure was a significant predictor of sweat sodium concentration and was among the strongest variables in the models.	Large scale supporting evidence that greater exercise workload/energy expenditure is associated with higher sweat sodium concentration.

Exercise Duration

Exercise duration appears to have a smaller and less consistent effect on sweat sodium concentration compared to exercise intensity (Table 2). Sweat samples collected early may produce somewhat lower values, but sweat sodium concentration does not appear to continually increase simply because exercise duration is increased.

Table 2. Summary of studies investigating the effect of exercise duration on sweat sodium concentration.

Study	Participants and Protocol	Exercise Duration Comparison	Sweat Sodium Concentration (mg/L)	Interpretation
McCubbin et al., 2019 [15]	15 male endurance athletes; 2 h running/cycling at 55% VO_{2max} in 35°C	1st hour v 2nd hour	940 -> 1125 mg/L Increase by ~185 mg/L	This suggests that sweat sodium concentration can increase during prolonged exercise even when exercise intensity is maintained.
Goulet et al., 2026 [16]	8 highly trained males; 5 h cycling at 61% VO_{2peak} in 30°C	40 v 130 v 220 v 290 min	At 40 v 130 min: increase by ~240-300 mg/L	Sweat sodium concentration appears to increase during the earlier part of prolonged exercise but then becomes stable rather than continuing to rise.
Baker et al., 2022 [5]	Retrospective analysis of 1944 sweat tests; exercise duration ranged from 0.4-4.1 h	Broad range of exercise durations	Exercise duration was not an independent predictor of whole-body sweat sodium concentration.	Suggests duration alone is not a major determinant of sweat sodium concentration once other factors such as workload, sweat rate and environmental conditions are considered.

Practical Implications

Sweat testing should ideally reflect the intensity of the activity for which the result will be used, particularly when comparing results across different training or competition demands. A value obtained during lower intensity training may underestimate the concentration observed during harder exercise. For duration, very early sweat samples may also produce somewhat lower values; however, once sweating is well established, sweat sodium concentration appears to be relatively stable during prolonged steady-state exercise.

DIETARY SODIUM INTAKE

Dietary sodium can influence sweat sodium concentration by altering the body's sodium-conservation response. In general, lower sodium availability can increase sodium conservation, whereas higher sodium intake may reduce the need to conserve sodium and therefore increase the amount appearing in sweat. However, the available evidence is mixed (summarised in Table 3).

Table 3. Summary of studies investigating the effect of dietary sodium intake on sweat sodium concentration.

Study	Participants and Protocol	Sweat Sodium Concentration (mg/L)	Interpretation
McCubbin et al., 2019 [15]	15 endurance athletes completed 3 days of low, usual or high sodium intake before 2 h exercise in 35°C	Low: 1010 mg/L Usual: 1125 mg/L High: 1265 mg/L	Higher dietary sodium was associated with higher sweat sodium concentrations.
Braconnier et al., 2020 [17]	Healthy adults completed 5 days of high-salt and low-salt diets, sweat measured using pilocarpine iontophoresis	Low: 790 mg/L High: 1000 mg/L	Supports an increase in sweat sodium concentration during high sodium intake, although sweat was pharmacologically induced rather than exercise-induced.
Koenders et al., 2016 [18]	9 endurance-trained men completed 9 days of low- and high-sodium diets before 3 h cycling in the heat.	~1250 mg/L in both conditions.	Despite clear differences in sodium intake and urinary sodium excretion, sweat sodium concentration was unchanged.
Hamouti et al., 2014 [19]	Sodium-containing fluid consumed before exercise: water alone vs low or high sodium.	~830-900 mg/L across all conditions.	An <i>acute</i> sodium load before exercise did not meaningfully alter sweat sodium concentration.

Practical Implications

Substantial changes in habitual sodium intake maintained for several days may shift sweat sodium concentration, but a single high-sodium meal or drink is unlikely to dramatically alter a sweat test result. For repeat testing, athletes should therefore ideally maintain their usual dietary pattern, rather than deliberately restricting or increasing sodium intake before the test.

SWEAT PATCH LOCATION

Sweat sodium concentration is not uniform across the body, with regional differences in sweat rate and sweat-gland sodium reabsorption producing different concentrations at different anatomical sites (Table 4). MX3 recommends placement on the ventral forearm, a site that has demonstrated close agreement with whole-body sweat sodium concentration and provides a practical, standardised location for repeat testing [20].

Table 4. Summary of studies investigating regional differences in sweat sodium concentration.

Study	Participants and Protocol	Sweat Sodium Concentration (mg/L)	Interpretation
Patterson et al., 2000 [21]	10 males; 90 min cycling	Whole-body: 554 mg/L Dorsal forearm: 970 mg/L Forehead: 1304 mg/L Chest: 1094 mg/L Thigh: 621 mg/L Calf: 724 mg/L Foot: 559 mg/L	Demonstrates substantial regional variation in sweat sodium concentration. This study did not assess the ventral forearm.
Baker et al., 2018 [20]	26 recreational endurance athletes; 90 min cycling in 30°C	Whole-Body: 993 mg/L Ventral forearm: 890 mg/L Dorsal forearm: 1129 mg/L Ventral thigh: 871 mg/L Calf: 821 mg/L Chest: 1363 mg/L Scapula: 1651 mg/L Forehead: 1653 mg/L	Ventral forearm was not significantly different from whole-body sweat sodium concentration and correlated strongly with it: $r = 0.85$; $R^2 = 0.73$.
Baker et al., 2020 [6]	49 participants; 90 min cycling	Whole body: 945 mg/L Ventral forearm: 947 mg/L Dorsal forearm: 1179 mg/L Thigh: 938 mg/L Calf: 864 mg/L Upper arm: 1166 mg/L Chest: 1437 mg/L Upper back: 1474 mg/L	Sweat sodium concentration assessed using the ventral forearm was almost identical to whole-body sweat sodium concentration. Significant correlation between ventral forearm and whole-body sweat sodium concentration: $r = 0.89$.

Practical Implications

Collectively, the available evidence indicates that the location of a sweat patch can influence the result obtained even when the athlete, exercise session and environmental conditions remain unchanged. **Therefore, sweat patches should be placed consistently on the ventral forearm for sweat testing (Fig. 1).** Changing anatomical location between tests can introduce variation unrelated to a true change in the athlete's sweat sodium concentration, making longitudinal comparisons more difficult.

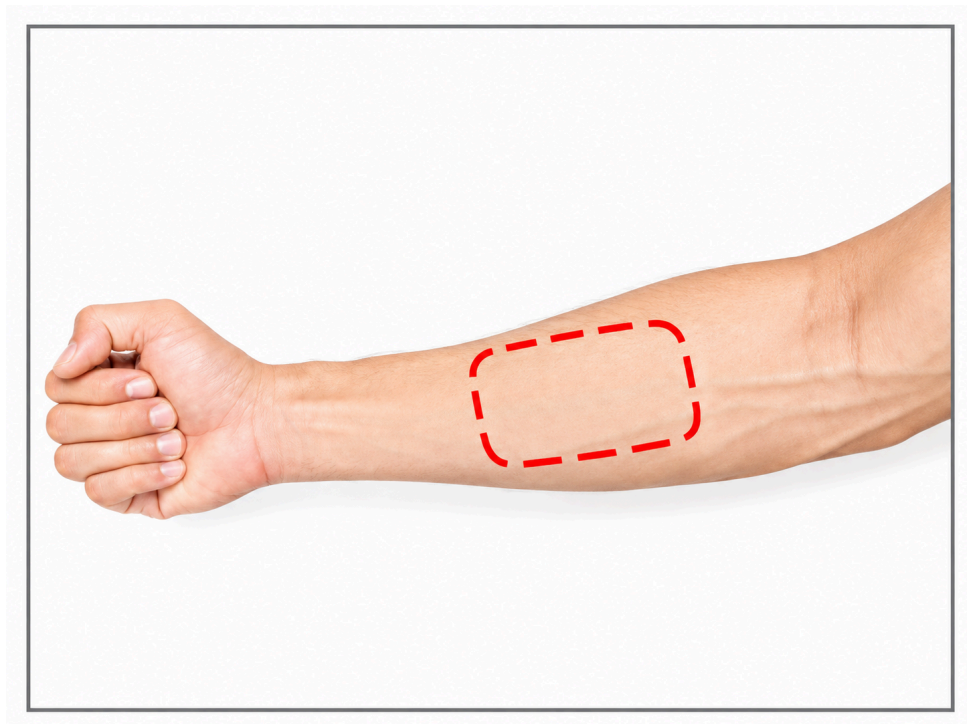


Fig. 1. Place the MX3 sweat patch on the ventral forearm, indicated by the red box.

HYDRATION STATUS

Hydration status may influence sweat sodium concentration, but the available evidence is mixed and less consistent than for factors such as exercise intensity or heat acclimation. Progressive dehydration can increase extracellular fluid sodium concentration and alter cardiovascular and thermoregulatory strain, which may in turn affect the sodium concentration in sweat. **One study demonstrated that after 2 h, forearm sweat sodium concentration was ~230 mg/L higher when participants consumed no fluid compared with when sweat losses were replaced [22].** Importantly, whole-body and local sweat rates were similar, suggesting the difference in sweat sodium concentration was not simply caused by a higher sweat rate.

The broader literature is inconsistent; studies have reported increases, decreases and no change in sweat sodium concentration with dehydration [2]. In addition, analysis of a large dataset found **no independent relationship between either pre-exercise hydration status or fluid balance during exercise and whole-body sweat sodium concentration [5].** Furthermore, there were no significant differences in sweat sodium concentrations during 90 min of exercise in the heat under mild dehydration (~2.4% BML) compared to euhydration in recreationally and moderately trained males and females [25].

Practical Implications

Athletes should ideally begin sweat tests in a hydrated state, particularly when repeat sweat test results are compared over time. However, normal day-to-day differences in hydration are unlikely to be a major source of variation in sweat sodium concentration.

GENETICS

Sweat Sodium Concentration

Genetics may contribute to some of the large differences in sweat sodium concentration observed between individuals. The clearest example involves the CFTR gene, which plays an important role in chloride and sodium reabsorption within the sweat gland duct. Individuals with cystic fibrosis who inherit two defective CFTR genes can have sweat sodium and chloride concentrations ~3-5 times higher than normal [3, 26].

Individuals who carry only one defective CFTR gene may also experience elevated sweat electrolyte concentration.

- Approximately 1 in 20 White individuals are heterozygous carriers of a defective CFTR gene and may have elevated sweat sodium and chloride concentrations [26, 27].

Sweat Loss and Rate

Genetic factors may also influence the amount of sweat produced. Hyperhidrosis is excessive sweating that exceeds the amount required for normal body temperature regulation. Primary focal hyperhidrosis affects ~3% of the population and has a strong familial component, with 30-65% of affected individuals reporting a positive family history [28].

Practical Implications

Genetic factors may help explain why some individuals consistently demonstrate unusually high sweat sodium concentrations or very high sweat losses despite otherwise similar exercise and environmental conditions. In particular, CFTR-related differences in sweat-gland sodium reabsorption may contribute to persistently 'salty' sweat.

For practitioners, this means that repeatedly unusually high sweat sodium concentrations or exceptionally high sweat losses could be due to a genetic predisposition. Genetics is therefore most useful for explaining persistent between-person differences, while changes within the same athlete over time are more likely to reflect modifiable factors.

TESTING METHODOLOGY AND DAY-TO-DAY VARIABILITY

Sweat sodium concentration can vary between tests because of both true physiological variation and differences in how sweat is collected and analysed. Methodological factors such as skin preparation, patch saturation and sample handling can introduce variation that is unrelated to a genuine change in the athlete's sweat sodium concentration (Table 5). Even when testing procedures are well standardised, some day-to-day biological variability should still be expected (Table 6; [3]).

Testing Methodology

Table 5. Summary of methodological considerations for sweat collection.

Factor	Recommendation	Why it Matters
Testing conditions	Test during exercise, and under conditions, representative of the athlete's training or competition.	The environment, exercise intensity and heat adaptation status can independently alter sweat sodium concentration, making comparisons difficult when test conditions differ substantially.
Skin preparation	Clean and dry the skin immediately before applying the patch.	Helps minimise potential contamination from substances present on the skin surface. MX3 provides an alcohol swab to clean the skin prior to patch application.
Patch saturation	Remove the patch once sufficient sweat has been collected and before it becomes saturated as determined by visual inspection.	Excessive moisture accumulation can alter the measured sweat sodium concentration.
Patch location	Use the same anatomical location for every test; MX3 recommends the ventral forearm.	Sweat sodium concentration differs considerably between anatomical sites. The ventral forearm significantly correlates with whole-body sweat sodium concentration.
Sample handling	Analyse samples promptly and consistently where possible.	Storage conditions can alter measured sweat sodium concentration through processes such as evaporation.

Day-to-Day Variability

Table 6. Summary of studies investigating day-to-day variability in sweat sodium concentration.

Study	What was Compared?	Variability	Interpretation
Baker et al., 2017 [3]	Review of repeated sweat testing studies	Local sweat sodium concentration day-to-day CV: ~5-16% Whole-body sweat sodium concentration: ~11-17%	This suggests that ~15% variation can occur naturally even when there has been no meaningful physiological change.
Baker et al., 2018 [20]	Repeated exercise trials under matched conditions	Ventral forearm sweat sodium concentration: Trial 1: 692 ± 274 mg/L Trial 2: 720 ± 267 mg/L CV: 13.3%	Supports the presence of moderate biological and collection-related variation between repeated regional sweat tests.
Brown et al., 2024 [23]	The same sweat sample measured twice using the MX3 LAB Pro.	Mean difference: ~2 mg/L CV: 5.6%	Indicates relatively small analytical variation when using the MX3 LAB Pro on the same sweat sample.
Zhao et al., 2026 [24]	Two separate matched exercise trials measured using the MX3 LAB Pro.	CV: 23% ICC: 0.826	Between-trial variability is considerably greater than same-sample analytical variability.

Practical Implications

An important distinction is the difference between measurement variability and true day-to-day test variability. This distinction is important when monitoring an athlete longitudinally. A small difference between two sweat tests does not necessarily indicate that the athlete's physiology has changed. A review of studies suggests that **local sweat sodium concentration varies by 5-16% between days, with changes greater than this likely to have practical significance** when comparing otherwise similar tests.

Repeat sweat tests should be conducted using the same patch location, similar exercise and environmental conditions, consistent skin preparation and collection procedures. Small differences between tests should be interpreted cautiously and in the context of expected day-to-day variability rather than as evidence of a meaningful physiological change.

CONCLUSION AND PRACTICAL SUMMARY

Sweat sodium concentration is highly individual, but it should not be considered a fixed physiological value. The literature shows that an athlete's measured sweat sodium concentration can change with exercise intensity and sweat rate, environmental temperature, heat adaptation status, dietary sodium intake, hydration status and the anatomical site used for sweat collection. Of these, exercise workload/sweat rate and heat adaptation status appear to be the more important influences on sweat sodium concentration.

- Even when factors are well controlled, some natural day-to-day variability remains with previous work suggesting 5-16% variation between repeated tests.

Practical Summary

- **Exercise Intensity:** Harder exercise and higher sweat rates can produce substantially higher sweat sodium concentrations than lower-intensity exercise, so testing should ideally reflect the demands of the activity for which the result will be used.
- **Heat Adaptation Status:** Seasonal heat exposure or heat training can meaningfully reduce sweat sodium concentrations, so a result obtained before a heat training block or Summer, may not fully represent an athlete after adaptation.
- **Standardise Repeat Testing:** Where comparisons within an athlete are of interest, use a similar exercise intensity, duration, environment, anatomical site and consistent collection procedures.
- **Diet and Hydration:** Large changes in dietary sodium over several days may alter sweat sodium concentration, while the effect of hydration is less consistent. Normal pre-test habits are therefore preferable to deliberate sodium loading, sodium restriction or unusual fluid practices.
- **Interpretation of Small Changes:** A modest difference between tests may simply reflect normal biological and measurement variability. Changes should be interpreted alongside the test conditions and the athlete's recent training, environmental exposure and diet.

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