Sweat Rate and Electrolyte Concentration in Swimmers, Runners, and Nonathletes

Simone D. Henkin, Paulo L. Sehl, and Flavia Meyer

Because swimmers train in an aquatic environment, they probably do not need to sweat as much as runners who train on land and, therefore, should not develop the same magnitude of sweating adaptations. **Purpose:** To compare sweat rate and electrolyte concentration in swimmers, runners and nonathletes. **Methods:** Ten swimmers (22.9 ± 3.1 years old), 10 runners (25 ± 2.9 y) and 10 nonathletes (26.5 ± 2.2 y) cycled in the heat (32°C and 40% relative humidity) for 30 min at similar intensity relative to their maximal cycle test. Sweat volume was calculated from the difference of their body mass before and after cycling, since they were not allowed to drink. Sweat was collected from the scapula using absorbent patch placed on the skin that was cleaned with distilled water. After cycling, the patch was transferred to syringe and the sample was obtained when squeezing it to a tube. Concentration of sodium ([Na⁺]), chloride ([Cl⁻]) and potassium ([K⁺]) were analyzed using an ion selector analyzer. **Results:** The sweat volume, in liters, of swimmers (0.9 ± 0.3) was lower (*P* < .05) than that of runners (1.5 ± 0.2) and similar to that of nonathletes (0.6 ± 0.2). [Na⁺] and [Cl⁻], in mmol·L⁻¹, of swimmers (65.4 ± 5.5 and 61.2 ± 81), and nonathletes (67.3 ± 8.5 and 58.3 ± 9.6) were higher (*P* < .05) than those of runners (45.2 ± 7.5 and 38.9 ± 8.3). [K⁺] was similar among groups. **Conclusions:** The lower sweat volume and higher sweat [Na⁺] and [Cl⁻] of swimmers, as compared with runners, indicate that training in the water does not cause the same magnitude of sweating adaptations.

**Keywords:** sweat glands, sweat ion concentration, acclimatization, exercise in the heat

Aerobic training may change sweating responses as it was shown that overall trained men have a greater sweat rate compared with untrained men.¹ The heat acclimatization process due to repeated heat exposure while living under heat stress² also indicates increase in sweat rate and change in sweat electrolyte concentration, mainly a decrease in sweat [Na⁺].³,⁴ Thus, the combination of aerobic training and heat acclimatization could probably optimize these sweat adaptations of runners.

There are few studies on sweating responses of swimmers, and they all took place in the swimming pool.⁵⁻⁸ Swimmer athletes, even training aerobically, may not develop the same degree of sweat adaptations as runners. This is because swim-
mers exercise in the water, which helps dissipate the body heat production through convection and conduction.\textsuperscript{9,10} The facilitated body heat removal may reduce the need to sweat during swimming and thus attenuate those sweat adaptations that were shown in runners. Such differences in sweating responses could be demonstrated by using a study design in which swimmers and runners exercise outside the water, under similar environmental and exercise conditions.

We are unaware of any study that examined sweat rate and sweat electrolyte concentrations of swimmers in comparison with other athletes outside the water. We hypothesized that, as untrained individuals, swimmers present a lower sweat rate and a higher sweat $[\text{Na}^+]$ than runners when they exercise out of water under similar environmental and exercise conditions. If indeed the aquatic training spare sweating adaptations, swimmers may be at thermoregulatory disadvantages if they occasionally exercise out of water for a long time in the heat. Knowledge of such responses may have another practical implication regarding hydration needs. Therefore, the purpose of this study was to compare the sweat rate and sweat electrolyte concentration in swimmers, runners and nonathletes.

**Methods**

**Subjects**

Ten endurance runners, 10 endurance swimmers and 10 nonathletes, all males, gave written informed consent to participate in this study which was approved by the Ethical Committee of the Universidade Federal do Rio Grande do Sul. At the time of the experiment, runners and swimmers had been training in their respective sports for at least 5 y until the month before testing. For the swimmers, we chose those who competed distances of 400 and 800 m, and trained in the pool about 35 km per week. The runners competed 10 and 20 km and trained outdoors, about 92 km per week. Basically, runners and swimmers were training in their respective dry-land and aquatic environments for about 2 h, 5 d per week, and at the time of the experiment using their routine exercise intensity for a noncompetitive period.

The nonathlete group was active, practicing weight training three times a week but had not been participating in any kind of competitive or systematic training for the last 6 mo before the experiment. None of the subjects were taking medications or were smokers.

All subjects were living in similar environmental conditions (South Brazil) and experiments took place during late winter, when the air temperature ranged from 16°C to 24°C. Athletes were therefore at similar training seasons, and runners wore shorts and T-shirts while training. Subjects came first for the screening session and later for the experimental session.

**Screening Session**

Subjects came to the laboratory to evaluate physical characteristics (age, height, weight and sum of skinfolds) and maximal oxygen uptake ($\text{VO}_2\text{max}$) to standardize exercise intensity for the experimental session. $\text{VO}_2\text{max}$ was measured using online, breath-by-breath, open-circuit spirometry ($\text{O}_2$ and $\text{CO}_2$ analyzer Medgraphics model CPX/D) on a cycle ergometer (Cybex, The Bike) using a progressive protocol.\textsuperscript{11}
Subjects cycled for 3 min at a self-selected pace at an initial load of 50 W, and then the load was increased by 25 W each minute. During the test, subjects were instructed to cycle at a rate ≥ 60 rpm. Heart rate (HR; Polar, S610, Polar Electro Oy, Finland) was monitored continuously. Subjects were given verbal encouragement throughout the test, which ended when they were unable to maintain the rhythm or when HR exceeded 200 bpm. The second ventilatory threshold was set using increases of $O_2$ and $CO_2$ ventilatory equivalent ($VE\cdot VO_2^{-1}$ and $VE\cdot VCO_2^{-1}$).

Subjects were instructed to drink 500 mL of water 2 h before the next session (experimental)\textsuperscript{12} and to refrain from caffeine and alcoholic beverages as well as physical activities the prior 24 h.

**Experimental Session**

On arrival at the laboratory, we confirmed that subjects had followed the instructions, and we then assumed they were euhydrated. Afterward, subjects emptied their bladder, and their body weight was assessed (Fillizola) wearing only shorts.

At the site of sweat collection, the skin was cleaned with distilled water. A gauze patch (Tegaderm 3582, 3M) was attached to the right side of the scapula (approx. 7 cm lateral from the vertebral column) to absorb the local sweat as described by Patterson et al.\textsuperscript{13} Before attaching the patch, the site was washed with distilled water and dried with sterilized gauze to avoid contamination. Following cycling, as described bellow, the patch was removed with tweezers (cleansed with distilled water) and placed into a disposable syringe that was squeezed into a tube (Eppendorf) to obtain the sweat sample for later analysis.

Wearing only shorts, subjects cycled on a friction-braked ergometer (Ergo Fit 167, Spain, 5 W). They cycled for 30 min and the power output was calculated to be approximately 10% below the second ventilatory threshold from their individual $VO_2$\textsubscript{max} measured in the screening session. The corresponding means ± SD (in watts) were 125 ± 26.8 for swimmers, 171 ± 10.3 for runners and 91.7 ± 14.4 for nonathletes. Heart rate (Polar, S610, Polar Electro Oy, Finland) was monitored throughout the exercise session, corresponding to 65 to 75% of maximal HR. Subjects cycled in the heat of an environmental chamber (Russels, 3.63 m wide × 2.39 m high × 3.81 m deep) with an air temperature of 32°C and relative humidity of 40%.

After cycling, each subject toweled dry, voided, and the body mass was recorded again with subjects wearing a dry short.

**Sweat Analyses and Calculations**

Sweat was analyzed for [Na\textsuperscript{+}], [Cl\textsuperscript{−}], and [K\textsuperscript{+}] using an ion selector analyzer (AVL, 9180, Roche), in duplicate. We considered the mean value since results were similar within samples.

Body mass loss was determined by change in body mass. This difference between pre- and postexercise body mass represented the 30-min sweat volume, since subjects did not drink any fluid during cycling. We corrected to 1 h (by multiplying by 2) and also divided by the body mass and minutes to express the sweat rate in mL·kg\textsuperscript{-1}·min\textsuperscript{-1}.

The amount of sodium loss was calculated by multiplying the sweat electrolyte concentration obtaining from sample of the scapula by the total sweat volume.
Statistical Analysis

Data were tested for normality of distribution and are presented as mean ± SD. To compare the variables among groups, analysis of variance (ANOVA) with Tukey post hoc test were used. Differences were considered significant when $P < .05$. Data were analyzed using SPSS 13.0.

Results

As shown in Table 1, the three groups were similar in height, body mass, and sum of skinfolds, but they were different in VO$_2$max. Runners had the highest VO$_2$max.

Mean (± SD) HR over the 30-min cycling session was lower in nonathletes (127 ± 3 bpm) than in runners (154 ± 11 bpm) and swimmers (162 ± 8 bpm). Swimmers’ sweat rates (absolute and relative body mass) were lower than runners’ and similar to nonathletes’ (Table 2). As a result, runners lost significantly more body mass than swimmers and nonathletes. Considering the body mass measured just before exercise, the loss in kilograms and the respective percentage dehydration were 0.46 ± 0.1 and 0.61 ± 0.17 in swimmers, 0.73 ± 0.1 and 0.98 ± 0.17 in runners, and 0.27± 0.1 and 0.33 ± 0.12 in nonathletes.

As shown in Table 2, sweat [Na$^+$] and [Cl$^-$] in swimmers and nonathletes were higher than in runners. Sweat [K$^+$] was similar across the three groups. Estimated

Table 1  Physical and physiological characteristics of runners, swimmers, and nonathletes

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>∑ of nine skinfolds$^*$ (mm)</th>
<th>VO$_2$max (mL·kg$^{-1}$·min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swimmers</td>
<td>22.9 ± 3.1</td>
<td>178 ± 5.8</td>
<td>75 ± 10.0</td>
<td>116 ± 44.8</td>
<td>54.2 ± 5.7$^b$</td>
</tr>
<tr>
<td>Runners</td>
<td>25.4 ± 2.9</td>
<td>178 ± 5.8</td>
<td>74 ± 7.8</td>
<td>106 ± 19.8</td>
<td>60.5 ± 5.8$^a$</td>
</tr>
<tr>
<td>Nonathletes</td>
<td>26.5 ± 2.4</td>
<td>176 ± 5.6</td>
<td>80 ± 11.8</td>
<td>131 ± 39.5</td>
<td>45.2 ± 2.9$^c$</td>
</tr>
</tbody>
</table>

$^*$ Triceps, biceps, chest, axilla, iliac crest, subscapular, abdominal, front thigh, and medial calf. Data are mean ± SD.

$^a$ Greater than in swimmers and nonathletes, $P < .001$. $^b$ Greater than in nonathletes, lower than in runners, $P < .001$. $^c$ Lower than in swimmers and runners.

Table 2  Sweat rate (L·h$^{-1}$ and mL·kg$^{-1}$·min$^{-1}$) and electrolyte concentration (mmol·L$^{-1}$) in swimmers, runners, and nonathletes

<table>
<thead>
<tr>
<th></th>
<th>Sweat rate</th>
<th>Electrolyte concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L·h$^{-1}$</td>
<td>mL·kg$^{-1}$·min$^{-1}$</td>
</tr>
<tr>
<td>Swimmers</td>
<td>0.9 ± 0.3</td>
<td>0.20 ± 0.57</td>
</tr>
<tr>
<td>Runners</td>
<td>1.5 ± 0.2$^a$</td>
<td>0.33 ± 0.06$^a$</td>
</tr>
<tr>
<td>Nonathletes</td>
<td>0.6 ± 0.2</td>
<td>0.11 ± 0.04</td>
</tr>
</tbody>
</table>

Data are mean ± SD. $^a$ Greater than in swimmers and nonathletes ($P < .05$). $^b$ Greater than in runners ($P < .05$).
sweat sodium loss (in mmol·kg⁻¹·h⁻¹) of swimmers (0.79 ± 0.24) was similar to that of runners (0.88 ± 0.18), and higher than that of nonathletes (0.44 ± 0.14).

**Discussion**

The main findings of the current study were that, when exercising out of water, swimmers and nonathletes did not sweat as much as runners; and their sweat [Na⁺] and [Cl⁻] were higher than those of runners, confirming our hypothesis. These findings indicate that sweat responses are dependent on the training environment (land vs water). The aquatic environment may facilitate body heat transfer through conduction and convection, limiting sweating. We purposely used an environmental condition to stimulate swimmers to sweat out of their usual training environment (on land). Further, this design enabled us to compare sweating responses among swimmers, runners and nonathletes under similar exercise conditions. On the other hand, more studies are necessary to explain the mechanisms of the observed findings.

Some studies⁵–⁸ have investigated the thermoregulatory responses of swimmers and runners in the water, making it impossible to compare these with the responses of our study. Swimmers’ sweat rate in the current study (0.9 L·h⁻¹) was greater than that previously reported for swimmers in the literature (0.4 L·h⁻¹ and 0.7 L·h⁻¹).⁵,⁸ The estimated mean sweat volume per hour (1.5 L·h⁻¹) in runners in the current study was similar to previously reported values for runners under similar exercise conditions.¹⁴,¹⁵

In agreement with the current study, swimmers showed a lower sweating rate during heat stress. It has been reported that swimmers have a reduced sweat rate.⁵–⁷ This lower sweating rate in water-trained individuals may be explained by the fact that swimmers do not experience marked daily increases in core or skin temperature because of the increased heat transfer characteristics of the water environment (increases that have been reported to be necessary to initiate sweating).¹⁶ The lower sweat rate in swimmers has also been attributed to an inhibition in the sweat gland activity due to training in the water.¹⁷ This may cause a depression in sweat response which was named as chronic hidromeiosis.¹⁸

Sweat rate in athletes is markedly higher than in sedentary subjects.¹⁹–²¹ In this study, however, the sweat rate in swimmers was not higher than in nonathletes, which is in disagreement with earlier studies.²² The similar sweat rates found in swimmers and nonathletes might be due to the relative low degree of thermal stress that induces sweating. At low levels of thermal stress, it may be difficult to find a difference in sweat rate between groups due to the lower sweating rate of the limbs.⁷ Such differences could become clearer with an increase in the stimulus to sweat at higher levels of thermal stress and sweating.

Aerobic conditioning and heat acclimatization are factors that affect sweat rate induced by exercise.¹,³,⁴ They could explain a higher sweat rate in runners as they presented a greater VO₂max. A high level of cardiorespiratory fitness is associated with an improved exercise-heat tolerance including increases in sweat rate.²⁰ It is known that endurance training in high air temperate conditions with significant increases of VO₂max contributes to heat acclimatization.²² For example, Piwonka et al.¹⁹ reported that trained distance runners showed a decreased physiological strain compared with untrained individuals during exercise-heat stress. In addition, because runners train in conditions that facilitate heat gain, they develop a greater
evaporative heat capacity that is more efficient than convection in an air environment. In the current study, although all athletes were competitive, relative VO₂ max was about 10% higher in runners than in swimmers. In this case, we do not know how much the VO₂ max affected the results; but it could explain them only partially, since the relative sweat rate was about 40% higher in runners than in swimmers. VO₂ was not measured during exercise; but subjects’ workload was individually estimated at the same relative intensity from their maximal.

Body size also affects the sweat rate during exercise; however, the three groups assessed here were similar in height, weight, and sum of skinfolds. Thus, differences in body mass could not account for the greater sweat rate in runners.

The density of heat-activated sweat glands is also associated with a greater sweat rate. Ogawa et al observed that the number of heat-activated sweat glands, which may be indicative of sudomotor neural activity, increased after heat acclimatization, suggesting that heat acclimatization may alter central modulation of the sweating response. In the current study, to avoid variations of heat acclimatization, all subjects were tested at the same time of the year (late winter). Nevertheless, we cannot guarantee that all subjects were equally acclimatized.

Another factor is that the sweating threshold at a given core temperature may be decreased by training and acclimatization. We did not measure this relation to determine how much it affected the sweat rate among groups. It is possible that a delayed onset of sweating in swimmers and nonathletes could have underestimated their sweat rate over the 30 min cycling. We used a relatively short exercise in the heat protocol (30 min at 32°C, 40% relative humidity), but it was sufficient to show some differences in sweating volumes and to obtain samples for electrolyte analyses.

The novel data of the current study concern the sweat electrolyte concentration in swimmers. Sweat [Na⁺] and [Cl⁻] were higher in swimmers and nonathletes. Sweat [Na⁺] and [Cl⁻] have decreased with heat acclimatization even for a given increase in sweating rate. Thus, although heat-acclimatized individuals sweat more—as observed in the greater sweat rate in runners—there is lower [Na⁺] and [Cl⁻] in that sweat. Another significant finding was that sweat Na⁺ loss was higher in swimmers and runners than in nonathletes. This was due to the somewhat higher sweat [Na⁺] in swimmers despite their lower sweat rate as compared with runners. One limitation of the current study was that sweat was collected from one region only (scapula). The sweat electrolyte concentration may vary at different sites, and sweating distribution across the limbs and trunk changes with acclimatization. Future studies should evaluate sweat electrolyte loss using an estimation of different body areas.

Conclusions and Practical Applications

Swimmers as well as the nonathletic group did not sweat as much as runners; neither did they have a lower NaCl sweat concentration. These sweating responses induced by a 30-min cycling in the heat, out of the water, suggest that sweating adaptations may be influenced by the sport training environment. This lower sweat rate of swimmers, in relation to runners, may represent a thermoregulatory disadvantage and they, just like nonathletes, may need special care to avoid hyperthermia and other heat-related disorders if they start running or training in a warm environment out of the water. More experimental studies, including measurements such as core
temperature, sweating threshold and heat-activated sweat glands could clarify such findings. Another practical implication is related to the fluid intake needs. The usual volume, but not the amount of sodium, recommended for a swimmer to maintain euhydration may be lower than that of a runner athlete.

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References


