Lactate–Sweat Relationships in Younger and Middle-Aged Men

James M. Green, Phil A. Bishop, Ian H. Muir, and Richard G. Lomax

Sweat lactate is at least partly derived from eccrine-gland metabolism. This study examined whether potential age-associated changes in sweat rate and skin blood flow influence sweat lactate. Six middle-aged (51.5 ± 3.8 years) and 6 younger (25.8 ± 1.5 years) men similar in VO_{2max}, height, weight, percent body fat, and surface area completed constant-load (CON) cycling and interval-cycling (INT) trials. During each trial, sweat and blood were analyzed for lactate concentration at 15, 25, 35, 45, and 60 min. Sweat rates and estimated total lactate secretion were not significantly different (p > .05) between trials or groups. Blood-lactate concentrations were not significantly different between groups during CON but were significantly higher in younger men at 35 min and 45 min during INT. Sweat-lactate concentrations were not significantly different (p > .05) between groups during CON or INT. These results suggest that differences in eccrine-gland metabolism between young and middle-aged men are minimal.

Key Words: eccrine sweat, thermoregulation, exercise

Sweat lactate results at least in part from anaerobic metabolism of eccrine sweat glands (Gordon, Thompson, Muenzer, & Thrasher, 1971; Wolfe et al., 1970). Sweat-lactate concentration is influenced by sweat rate (Astrand, 1963; Falk et al., 1991; Fellmann, Labbe, Gachon, & Coudert, 1985), and acute blood-flow occlusion decreases sweat rate and increases sweat-lactate concentration (Astrand; Weiner & Van Heyningen, 1952). Potential effects of aging are a lower sweat rate (Inoue, 1978; Inoue, Nakao, Araki, & Murakami, 1991) and decreased skin blood flow (Inoue et al., 1991; Kenney, 1997). It is possible that decreased sweat rates contribute to less dilute sweat (higher lactate concentrations) and that decreased skin blood flow might contribute to decreased oxygen delivery to eccrine glands, causing a greater reliance on anaerobic metabolism. Consequently, age-associated changes in sweat-lactate concentration might occur.

Aging, independent of chronic disease and a sedentary lifestyle, decreases heat tolerance minimally (Kenney, 1997). Peripheral sweat rates in older and younger men (matched for VO_{2max}) can be similar (Buono, McKenzie, & Kasch, 1991; Smolander, Korhonen, & Ilmarinen, 1990; Tankersley, Smolander, Kenney, ...
& Fortney, 1991). However, Inoue (1978) showed an age-associated decrease in sweat-gland output. Although results are mixed, potential age-associated changes in sweat response might occur and could alter sweat-lactate concentration; however, published research in this area is limited.

Eccrine glands rely primarily on aerobic metabolism to support secretory activity (Sato, 1977). Also, sweat glands rely on blood glucose and stored glycogen in eccrine glands as metabolic substrates (Gordon et al., 1971; Wolfe et al., 1970), but, because glycogen concentration in eccrine glands is insufficient to support the secretion of large volumes of sweat (Sato; Wolfe et al.), blood-glucose delivery becomes increasingly important. Older individuals (as early as age 50) might respond to exercise with a reduced skin vasodilation compared with younger individuals (Kenney & Johnson, 1992). A decrement in oxygen supply and reduced delivery of blood glucose consequent to this reduced skin blood flow could hinder aerobic metabolism of the eccrine glands. Increases in sweat-lactate concentration have been demonstrated on acute blood-flow occlusion (by inflation of a blood-pressure cuff), and a less pronounced decrease in skin blood flow caused by vascular changes associated with physiological aging might also influence sweat-lactate concentration.

From comparisons of five different age groups (6–15, 16–25, 26–35, 36–45, and 46–55 years), Al-Tamer and Hadi (1994) concluded that sweat-lactate concentration was not age dependent when sweating was thermally induced during rest. At rest, minimal metabolic activity in skeletal muscles likely reduced the competition for blood between muscles and skin that exists during exercise in the heat, and skin blood flow therefore might have been minimally compromised. Sweating induced as a result of metabolically produced heat and thermal exposure would possibly generate different results regarding sweat-lactate concentration.

Physiological variations in skin blood flow and sweat rate as a result of aging might result in changes in sweat-lactate concentration. This question, however, has not been adequately answered. The purpose of this study was to assess possible age-associated changes in sweat lactate during constant-load and interval cycling in the heat in young and middle-aged men. Based on the extant literature, we hypothesized that (a) sweat-lactate concentrations would be significantly higher in middle-aged participants at each time point but not significantly different between interval and constant-load cycling trials, (b) sweat rates would be significantly lower in middle-aged participants, (c) blood lactate would be significantly greater during interval-cycling trials (25, 35, 45, 60 min) but not significantly different between groups, and (d) total sweat-lactate secretion would be significantly lower in middle-aged participants.

Methods

PARTICIPANTS

Six moderately active younger (24–28 years) and 6 very active middle-aged (47–58 years) men were recruited as participants. They self-reported engaging in moderate to vigorous physical activity (20 min minimum) 4.5 (±1.0) days/week (middle-aged) and 3.3 (±0.8) days/week (younger). The Physical Activity Readiness Ques-
tionnaire (American College of Sports Medicine [ACSM], 1995) and a health-status questionnaire were completed by each participant. Before data collection, participants were informed of the requirements and risks associated with participation and signed a written informed consent. All procedures were approved by the local institutional review board for the protection of human subjects.

DESCRIPTIVE DATA

Participants reported to the lab 3–4 hr postprandial and well rested (no heavy physical activity for 24 hr). Descriptive data were collected including age, height (cm), weight (kg), and skinfold thickness using Lange skinfold calipers (Cambridge, MD). Body composition was estimated according to Jackson and Pollock’s (1978) three-site method. Participants then completed a maximal-exertion cycle-ergometry trial on an 868 Monark Cycle Ergometer (Varberg, Sweden). Oxygen consumption (VO$_2$) was measured using an Aerosport Teem 100 Metabolic Measurement System (Ann Arbor, MI), which was calibrated before each test with a gas of known composition. Appropriate seat height was set, and participants pedaled at 60 rpm at 0 kp for 3 min. Resistance was increased 1.0 kp every 3 min until participants reached volitional exhaustion or could not maintain 60 rpm. Heart rate was monitored using a Polar heart-rate monitor (Stamford, CT), and ratings of perceived exertion according to Borg’s 15-point scale (ACSM, 1995) were recorded at the end of each stage.

CONSTANT-LOAD AND INTERVAL CYCLING

Participants reported to the lab on two other occasions well rested and 3–4 hr postprandial. On separate days each participant completed a constant-load low-intensity (CON) and a high-intensity interval (INT) cycling session in an environmental chamber (32 ± 1°C wet bulb globe temperature). For CON, participants warmed up (15 min at 0.5 kp, 60 rpm) and then cycled for 30 min at a load (predetermined from VO$_{2\text{max}}$ trials) requiring approximately 40% VO$_{2\max}$. For INT, participants completed an identical warm-up and then completed 15 one-min intervals (separated by 1-min rests) at 60 rpm and twice the resistance used during CON. CON and INT were designed to require the completion of similar volumes of total work, with the INT trial producing much higher blood-lactate levels. After each trial, participants remained seated for 15 min of passive rest in the environmental chamber. Trials were separated by a minimum of 36 hr and were counterbalanced to control for the effects of ordering. Participants were permitted to drink water ad libitum during each trial.

SWEAT AND BLOOD COLLECTION AND ANALYSIS

Sweat and blood samples were collected at 15, 25, 35, 45, and 60 min during CON and INT. Capillary blood was collected at the fingertip using a microhematocrit capillary tube (Fisher Scientific, Pittsburgh, PA). Sweat was collected using a modification of a disposable sweat-collection device developed by Brisson et al. (1991). An 8- × 9-cm piece of impermeable parafilm (American Can Co., Greenwich,
CT) was placed on the adhesive side of a 10- × 14-cm Opsite wound dressing (Smith & Nephew Inc., Largo, FL), and this device was transferred to the lumbar region of the back. Samples were collected at the desired time by peeling back the top corner of the device and using a microhematocrit capillary tube. After each sample was collected, the device was removed, the skin was cleansed with de-ionized water and dried with a cotton towel, and a new device was attached. This eliminated contamination of serial samples. Blood and sweat were immediately analyzed for lactate concentration using a YSI 1500 Sport lactate analyzer (Yellow Springs Instruments, Yellow Springs, OH), which was calibrated (at 5 mmol/L) and checked for linearity (at 15 and 30 mmol/L) with standards of known concentration. Ratings of perceived exertion, heart rate, and rectal temperature (Tre) were recorded every 5 min throughout testing. Heart rate was monitored using a Polar Heart Monitor (Polar Electro Inc., Woodbury, NY). Tre was monitored using a rectal thermistor (Physitemp, Clifton, NJ). Sweat rate (ml/hr) was determined using pre- and postexercise nude body weights corrected for water intake.

STATISTICS

One-way ANOVAs were used to examine between-group differences in age, height, weight, percent body fat, surface area (Dubois & Dubois, 1916), and VO₂max. With respect to hypotheses, each was tested as follows. Hypotheses A and C and sweat- and blood-lactate concentrations between groups were analyzed for CON and INT trials using a one-way repeated-measures (time of sample) ANOVA and a Bonferroni follow-up procedure when necessary. Results were considered significant at p ≤ .05. Hypothesis B, sweat rates, was evaluated using a one-way repeated-measures (trial) ANOVA between groups. Estimated total lactate secretion (mmol) was calculated by multiplying mean sweat-lactate concentration in mmol/L (for 25-, 35-, 45-, and 60-min samples) for each individual and multiplying by that individual’s volume of sweat produced. The initial 15-min time period was excluded because of minimal sweating (visually observed) and a considerably higher sweat-lactate concentration that would have inaccurately biased this calculation. Hypothesis D, estimated lactate secretion, was analyzed using a one-way repeated-measures (trial) ANOVA between groups. Delta values for rectal temperature (delta Tre) were calculated (Tre at 45 min to Tre at 0 min) and compared between trials and within participants using a one-way repeated-measures ANOVA.

Results

The younger and middle-aged groups were very similar in all descriptive variables (except age), in sweat rates, and in estimated total lactate secretion in sweat. Age was significantly different, F(1,4) = 240.04, p = .0009, between groups; however, there were no significant differences (p > .05) for height, weight, percent body fat, surface area, or VO₂max (Table 1). Sweat rates were not significantly different (p > .05) between CON and INT or between groups (Table 2). Estimated total lactate secretion was not significantly different (p > .05) between groups or trials (Table 3). Mean workload was not significantly different between younger and middle-aged participants for CON (1.75 ± .27 kp and 1.83 ± .26 kp, respectively) or INT (3.67 ±
<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yr)</th>
<th>Ht (cm)</th>
<th>Wt (kg)</th>
<th>Body fat (%)</th>
<th>Surface area (m²)</th>
<th>VO₂max (ml · kg⁻¹ · min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>25.8 ± 1.5</td>
<td>176.4 ± 10.0</td>
<td>81.9 ± 9.2</td>
<td>15.3 ± 3.4</td>
<td>1.99 ± 0.17</td>
<td>47.9 ± 6.7</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>51.5 ± 3.8*</td>
<td>177.9 ± 5.6</td>
<td>76.5 ± 8.9</td>
<td>15.6 ± 3.1</td>
<td>1.94 ± 0.13</td>
<td>52.6 ± 8.7</td>
</tr>
<tr>
<td>All</td>
<td>38.7 ± 13.7</td>
<td>177.2 ± 7.6</td>
<td>79.2 ± 9.1</td>
<td>15.5 ± 3.1</td>
<td>1.96 ± 0.15</td>
<td>51.4 ± 8.6</td>
</tr>
</tbody>
</table>

*p ≤ .05 between groups.
Table 2  Sweat Rates (ml/hr) for Younger (n = 6) and Middle-Aged (n = 6) Men (M ± SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>CON</th>
<th>INT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>779.7 ± 292.6</td>
<td>798.0 ± 268.3</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>795.9 ± 258.5</td>
<td>763.6 ± 178.7</td>
</tr>
</tbody>
</table>

Note. No significant differences between groups or trials.

Table 3  Estimated Total Sweat-Lactate Excretion (mmol) for Younger (n = 6) and Middle-Aged (n = 6) Participants

<table>
<thead>
<tr>
<th>Group</th>
<th>CON</th>
<th>INT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>7.8 ± 2.4</td>
<td>7.5 ± 1.5</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>7.6 ± 2.2</td>
<td>7.3 ± 1.5</td>
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</table>

Note. No significant differences between groups.

Figure 1.  Sweat and blood-lactate concentrations for younger (YG) and middle-aged (MA) participants during CON. (No significant differences between groups.)

.52 kp and 3.50 ± .55 kp, respectively). In addition, heat gain (indicated by delta Tre) was not significantly different between groups for CON (younger = 0.56 ± 0.15°C, middle-aged = 0.54 ± 0.19°C) or INT (younger = 0.83 ± 0.25°C, middle-aged = 0.89 ± 0.11°C). Blood-lactate concentrations were not significantly different (p > .05) between groups at any time for CON (Figure 1). During INT, blood lactate was not significantly different between groups at 15, 25, or 60 min but was significantly
greater in younger participants at 35 min, \(F(1,4) = 4.88, p = .002\), and 45 min, \(F(1,4) = 4.29, p = .002\) (Figure 2). Blood-lactate concentrations (CON vs. INT) were not significantly different \((p > .05)\) at 15 min \(CON = 1.23 + 0.34, INT = 1.51 + 0.71\) but were significantly different \((p < .05)\) at 25 min \(CON = 2.0 + 0.93, INT = 4.0 + 1.55\), 35 min \(CON = 2.10 + 1.19, INT = 4.93 + 1.92\), 45 min \(CON = 2.04 + 1.32, INT = 5.55 + 2.0\), and 60 min \(CON = 1.11 + 0.62, INT = 3.42 + 1.77\). Sweat-lactate concentrations were not significantly different \((p > .05)\) between groups at any time for CON or INT (Figures 1 and 2).

**Discussion**

This study examined potential differences in sweat-lactate concentrations during cycling in the heat between young and middle-aged men having similar relative aerobic fitness (\(VO_{2\text{max}}\)), height, weight, percent body fat, and surface area. Sweat lactate is thought to reflect eccrine-gland metabolism (Gordon et al., 1971; Sato, 1977; Weiner & Van Heyningen, 1952; Wolfe et al., 1970), and sweat rate might influence sweat-lactate concentrations (Astrand, 1963; Falk et al., 1991; Fellmann et al., 1985; Lamont, 1987). Because of possible age-associated changes in sweat response and skin blood flow, we hypothesized that sweat-lactate concentration differences might also exist. Mean age for middle-aged participants (51.5 years) was approximately twice that of younger participants (25.8 years). A mean difference of 25 years between groups should have permitted the detection of age-associated changes. Furthermore, the age group of our middle-aged participants depicts a group that is well represented in the exercising population.

Although sweat rate might diminish with age (Inoue, 1978; Inoue et al., 1991), the current results show sweat rates that were very similar between younger and middle-aged participants during CON, as well as INT (Table 2). These results are consistent with Kenney (1988) and Buono et al. (1991), who suggested that chronic exercise participation attenuates decreases in peripheral sweat production. Had sweat rates differed significantly between groups, sweat-lactate concentrations might have been greater in the group demonstrating the lower sweat rate. This possibility deserves further attention.
There are several alternative designs for studying the effects of age on physiological function. We chose to recruit young and middle-aged participants having similar relative aerobic fitness (VO$_{2\text{max}}$) because cardiovascular function could influence sweat lactate. This presented the problem, however, of having very fit middle-aged participants and moderately fit younger participants. Had participants been matched according to activity- or age-adjusted VO$_{2\text{max}}$, differences between groups (in VO$_{2\text{max}}$) would have resulted but these would have been confounders. Note that similar VO$_{2\text{max}}$ values between groups did not indicate similar activity levels. In fact, middle-aged participants reported being more active than younger participants (4.5 ± 1.0 days/week). We believe that adequate attention has been given to participants’ fitness status in past studies and suggest readers take into account this variable in interpreting this and other studies. In selecting participants with similar aerobic fitness, we were fortunate in that the two groups were similar in several other key characteristics. We think the similarity between groups in height, weight, fatness, and surface area provides for a useful comparison between two groups who mainly differ in age.

Because lactate in sweat results from eccrine-gland metabolism (Astrand, 1963; Falk et al., 1991; Gordon et al., 1971; Sato, 1977; Wolfe et al., 1970), it is not surprising that relationships have been found between sweat-lactate concentration and sweat rate. For example, sweat-lactate excretion might increase as sweat rate increases because of a greater volume of work by eccrine glands (Astrand; Fellmann et al., 1985). Lamont (1987) showed a greater lactate excretion with a lower sweat rate in sedentary than in fit women. Some studies suggest that sweat-lactate concentration decreases as sweat rate increases (Astrand; Falk et al.; Fellmann et al.). In contrast, Pilardeau et al. (1988) showed that a greater sweat-lactate concentration is associated with a higher sweat rate. Intergroup differences in fitness in their study might have caused variations in sweat-gland metabolism and, therefore, sweat-lactate concentrations. In the current study there were no significant differences in sweat rates between groups, and the potential variation in sweat-lactate concentrations resulting from such a difference could not be evaluated. Although sweat rates were not significantly different, sweat-lactate concentrations might have been affected by other factors.

Although lactate in sweat reflects anaerobic metabolism, the primary metabolic pathway of eccrine glands is aerobic metabolism (Sato, 1977). Eccrine glands contain abundant mitochondria and varying amounts of glycogen (Sagawa, Shiraki, Yousef, & Miki, 1988). In vitro evidence, however, suggests that the quantity of glycogen contained in eccrine glands is insufficient to support significant volumes of sweat secretion (Wolfe et al., 1970). An in vivo follow-up study using tracer metabolites provided evidence that the primary energy substrate for eccrine glands is blood glucose (Gordon et al., 1971). Studies involving blood-flow occlusion also support the dominance of aerobic metabolism by eccrine glands. In these studies (Astrand, 1963; Weiner & Van Heyningen, 1952), forearm blood-flow occlusion attenuated sweat rate and increased sweat-lactate concentrations. This was likely the result of decreased substrate and oxygen delivery to eccrine glands. These results show that adequate oxygen and glucose supply are imperative in supporting eccrine-gland metabolism.

Kenney (1988) found lower blood flow in the arm during exercise in older (55–68 years) than in younger (19–30 years) participants matched on sweat rates.
and attributed the difference to diminished cardiac output (CO₂ rebreathing) in older participants. He concluded that older individuals demonstrated a modified vasodilatory response at the skin during exercise in the heat. Furthermore, the diminished forearm blood flow could not be attributed to fitness because participants were matched for VO₂max. Sweat-lactate concentrations were not measured in these studies. Al-Tamer and Hadi (1994), however, concluded that sweat-lactate concentrations at rest under thermal exposure were not related to age. These results cannot be transferred to exercise because skin blood flow during exercise and rest might not be similar because of greater competition for blood between muscles and skin. In the current study sweat-lactate concentrations were not significantly different between young and middle-aged participants (Figures 1 and 2), which supports results on resting participants (Al-Tamer & Hadi). Although blood flow was not measured in the current study, it is possible that (a) there were no skin blood flow differences between our groups, decreasing the probability of sweat-lactate-concentration differences, or (b) skin blood flow differences (and therefore oxygen delivery) were not large enough to generate a shift in eccrine-gland metabolism that would have caused a noticeable change in sweat-lactate concentration.

Kenney and Johnson (1992) note that maintaining a high VO₂max can offset the decreased vasodilatory response typical in older participants. In a review, Johnson (1998) also suggested that training improves skin blood flow. Participants in the current study were extremely similar regarding physical characteristics and VO₂max (Table 1), and therefore skin blood flow might also have been similar between groups. In addition, estimated total lactate secretion was not significantly different between groups (Table 3), which supports this speculation. Future studies should closely examine skin blood flow to determine whether possible differences affect sweat-lactate concentrations.

It should be noted that, although blood-lactate concentrations were very similar between groups during CON (Figure 1), they were significantly higher in younger men during INT at 35 and 45 min (Figure 2). It could be speculated that higher blood lactate systematically increased sweat-lactate concentrations of younger men to a level artificially matching levels observed in middle-aged men. The possible clearance of blood lactate through sweat has been investigated, however, and most results suggest no association between blood lactate and sweat lactate (Ament, Huizenga, Mook, Gips, & Verkerke, 1997; Gordon et al., 1971; Weiner & Van Heyningen, 1952). Furthermore, although our sample size is somewhat small, the similarity observed between sweat-lactate concentrations when blood lactate was high (INT) and low (CON) suggests that lactate was not cleared from blood to sweat.

Cutaneous vascular supply decreases with age (Balin & Pratt, 1989). In addition, aging is associated with a lower quantity of eccrine secretion. Fenske and Lober’s review (1986) states that the number of eccrine glands declines with age and both eccrine and apocrine glands undergo attenuation. These possibilities were beyond the scope of the current study, but future inquiry should examine the potential of these age-associated variations to influence sweat rates, sweat-lactate secretion, and sweat-lactate concentrations.

In conclusion, results of the current study suggest that younger and middle-aged individuals having similar VO₂max values and physical characteristics produce similar volumes of sweat. These results support those of Kenney (1988), Sagawa et
al. (1988), Buono et al. (1991), Tankersley et al. (1991), and Smolander et al. (1990). Results also suggest that estimated total sweat-lactate secretion (sweat volume × mean sweat-lactate concentration) is not different between younger and middle-aged individuals (Table 3). Although the small sample size for each group could have limited statistical power, the strong similarity in mean sweat-lactate concentrations between younger and middle-aged participants suggests that there is not an age-associated change in sweat-lactate concentration. It should be noted that possible changes in skin blood flow between groups or potential alterations in eccrine-gland density or size were not evaluated. Physiological differences in these variables might alter eccrine-gland metabolism, which could affect sweat-lactate concentrations. Within the limitations of the current study, however, results suggest that sweat rates, sweat-lactate secretion, and sweat-lactate concentrations are independent of age in younger and middle-aged men having similar aerobic fitness and physical characteristics.

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References
Dubois, D., & Dubois, E.F. (1916). A formula to estimate the approximate surface area if height and weight be known. Archives of Environmental Medicine, 17, 863-871.


