



## Original research

# Exacerbated heat strain during consecutive days of repeated exercise sessions in heat



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## ABSTRACT

**Objectives:** An exercise session in a hot environment may increase thermal strain during subsequent exercise sessions on the same and consecutive days. Therefore, this study was conducted to determine lasting physiological strain from moderate-high intensity, intermittent exercise in heat on subsequent exercise.

**Design:** Repeated measures laboratory study.

**Methods:** Seventeen healthy, recreationally active men (age:  $22 \pm 3$  y, maximal oxygen consumption:  $54.6 \pm 5.3$  mL kg<sup>-1</sup> min<sup>-1</sup>) underwent two intermittent moderate-high intensity aerobic exercise sessions separated by 2 h of rest one day, followed by one session 24 h later in a 40 °C, 40% relative humidity environment. Heart rate, rectal temperature, heat stress perception, and environmental symptoms were assessed.

**Results:** 100%, 35%, and 71% of participants completed the full exercise protocol during the first exercise session, second exercise session, and the following day, respectively. Exercising heart rate and rectal temperature were greater during the second exercise session ( $189 \pm 11$  bpm,  $38.80 \pm 0.47$  °C) than the first identical exercise session ( $180 \pm 17$  bpm,  $p=0.004$ ;  $38.41 \pm 0.52$  °C,  $p=0.001$ ), respectively. Immediate post-exercise heart rate, rectal temperature, thirst, thermal sensation, fatigue, and perceived exertion were similar among exercise sessions despite a shorter exercise duration during the second exercise session ( $93 \pm 27$  min,  $p=0.001$ ) and the following day ( $113 \pm 12$  min,  $p=0.032$ ) than the first exercise session ( $120 \pm 0$  min).

**Conclusions:** Moderate-high-intensity intermittent exercise in the heat resulted in greater heat strain during a second exercise session the same day, and exercise the subsequent day.

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## Practical implications

- Two hours of rest between moderate-high intensity exercise sessions is not sufficient to prevent the attainment of a critically high body temperature during a second exercise session the same day.
- Individuals perceive greater physical strain during subsequent exercise compared to a first exercise session in the heat.

- Medical personnel should be acutely aware of body temperature and signs and symptoms of heat illness during consecutive exercise sessions, and exercise the following day.

## 1. Introduction

Prolonged, physically demanding exercise in a hot environment is common for many athletes.<sup>1</sup> Many times these individuals are unable to self-pace their work due to coaching demands and experience dehydration, cardiovascular strain, and a dangerously high body temperature.<sup>2,3</sup> Additionally, many athletes wear protective equipment further limiting heat dissipation, causing uncompensated

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able heat stress which may increase the chance of suffering from an exertional heat illness (EHI).<sup>4–6</sup>

EHI rates are highest on days with multiple athletic practices,<sup>7</sup> therefore, heat acclimatization guidelines suggest delaying multiple practices on a single day until day six of heat acclimatization.<sup>8</sup> Unfortunately, this policy is not mandatory across all states and levels of sport, with only 2.5% of high schools following the guidelines.<sup>9</sup> Multiple exercise sessions on day one of practice may place athletes at risk of thermal strain and warrants investigation in a laboratory setting.

Short rest breaks of 15–30 min between consecutive exercise sessions are common athletic competitions (e.g., half time) and result in incomplete recovery from the first exercise session, indicated by elevated heart rate (HR)<sup>10</sup> and core temperature<sup>10</sup> during the second exercise session. Rest breaks 60 min in length allowed for full HR and rectal temperature ( $T_{re}$ ) recovery in a warm environment, however, perceived exertion was greater in the second exercise session.<sup>11</sup> Resting for 90 min after light intensity (30% maximal oxygen consumption ( $VO_{2max}$ )),<sup>12</sup> but not high intensity (70%  $VO_{2max}$ )<sup>13</sup> exercise in heat results in similar heat strain among exercise sessions. Collectively,  $T_{re}$  was only moderately elevated ( $\bar{3}8.5^{\circ}C$ ) in these studies due to warm conditions or light-moderate exercise intensities. Recovery from greater intensity exercise in hot conditions needs to be explored.

Recent research has focused on physiological strain incurred over consecutive days of work in a warm environment. Field studies investigating fire suppression<sup>14</sup> and electric utilities work<sup>15</sup> reported greater physiological and perceptual heat strain during the second day of work in a warm environment. In older men, heat storage was increased on the second day of intermittent exercise in a hot environment,<sup>16</sup> although this relationship was not observed in young men.<sup>17</sup> Recent epidemiological evidence suggested increased thermal strain on the second day of collegiate pre-season American football practice.<sup>7</sup> Similarly, Marine Corps recruits were most likely to have EHI if they exercised in high temperatures the previous day, suggesting individuals are at greatest risk of thermal strain on the second of two consecutive days of exercise in a hot environment.<sup>18</sup> Although others have found no differences between consecutive exercise sessions in similar warm conditions.<sup>19,20</sup>

Higher intensity exercise such as that experienced during American football practices likely results in even greater heat strain than occupational work during consecutive exercise sessions due to greater work intensity which increases metabolic heat production, however, this has not been investigated. Additionally, work in a hot environment ( $>30^{\circ}C$  WBGT) is yet to be investigated. Therefore, the purposes of this study were to (1) determine how a strenuous exercise session in the heat (Bout 1) affects physiological and perceptual heat strain during a second exercise session on the same day (Bout 2), and (2) determine how two strenuous exercise sessions in the heat (Bout 1 and 2) affect physiological and perceptual strain during exercise the subsequent day (Day 2). We hypothesized that physiological and perceptual heat strain would be greater during both the second exercise session (Bout 2) and second day (Day 2) of exercise compared to the first exercise session (Bout 1).

## 2. Methods

Seventeen healthy men (Mean  $\pm$  SD, age:  $22 \pm 3$  y, height:  $179.5 \pm 5.8$  cm, weight:  $74.31 \pm 7.64$  kg, body fat:  $9.6 \pm 4.1\%$ , maximal oxygen consumption ( $VO_{2max}$ ):  $54.6 \pm 5.3$  mL  $kg^{-1}$   $min^{-1}$ ) provided written informed consent prior to participation in this study, which was approved by the university Institutional Review Board. All were recreationally active and in good health without

**Table 1**  
Exercise protocol each exercise session.

4 min	Jogging	(60% $VO_{2max}$ )
1 min	Running	(80% $VO_{2max}$ )
4 min	Walking	(4.83 km $h^{-1}$ )
1 min	Running	(80% $VO_{2max}$ )
4 min	Jogging	(60% $VO_{2max}$ )
1 min	Running	(80% $VO_{2max}$ )
5 min	Rest	

Note. Each 20 min exercise protocol was repeated six times, totaling 2 h of exercise. To ensure the first exercise session (Bout 1) was completed in its entirety, beginning at minute 40, jogging speed was lowered by 0.8 km  $h^{-1}$  for individuals who reached a  $T_{re} > 39^{\circ}C$ , indicating that they likely would reach the  $T_{re}$  termination criteria prior to the completion of 2 h of exercise.

current musculoskeletal, cardiovascular, metabolic and respiratory disease, and had no history of exertional heat stroke.

A study physician determined eligibility using preliminary tests and a medical history questionnaire. Participants refrained from alcohol and strenuous exercise 24 h and caffeine 8 h prior to testing. Height was measured to the nearest 0.5 cm using a wall mounted stadiometer. Nude body mass was measured to the nearest 0.01 kg (T51 P, Ohaus, Pine Brook, NJ). Body fat percentage was estimated using skinfold thickness measured at three sites (chest, abdomen, and thigh) in duplicate using a Lange skinfold caliper (BetaTechnology Inc, Cambridge, MD) as previously described.<sup>21</sup>

Participants performed a treadmill graded exercise test following a ramping protocol in a temperate environment to determine maximal oxygen consumption. Open circuit spirometry (TrueOne 2400 Metabolic Measurement System, Parvomedics, Sandy, UT) measured oxygen consumption. To mimic collegiate interscholastic athletes, individuals were approved to participate in the study if they achieved a  $VO_{2max} \geq 45.0$  mL  $kg^{-1}$   $min^{-1}$ , an average  $VO_{2max}$  of males in this age group.<sup>22</sup>

Participants drank 500 mL water the night before and 250 mL the morning of each laboratory visit. The morning of testing participants provided a urine sample to measure urine specific gravity (USG) via refractometer (A300CL, Atago, Bellevue, WA). If participants were hypohydrated (USG  $> 1.020$ ) participants consumed 500 mL water prior to proceeding with the protocol. Participants privately inserted a rectal thermistor (YSI 400 series probe, Measurement Specialties, Beavercreek, OH) 10–12 cm beyond the anal sphincter and nude body mass was recorded. Sweat rate was calculated using pre- and post-exercise nude body mass accounting for fluid intake and urine output. A heart rate (HR) monitor (Race Trainer, Timex, Middlebury, CT) with chest strap, shorts, a t-shirt, and athletic shoes were donned.

Participants entered an environmental chamber (4284-2L-W, Minute-Eleven, Weymouth, MA) ( $40^{\circ}C$ , 40% relative humidity (RH)) and sat quietly for a 20 min equilibration period. A modified Environmental Symptoms Questionnaire (ESQ) determined signs and symptoms of heat illness.<sup>23,24</sup> Immediately prior to exercise,  $T_{re}$ , HR, and perceptual scales were recorded. Perceptual scales included 11-point perceived exertion OMNI run-walk<sup>25</sup> and fatigue scales, a 9-point thirst scale,<sup>26</sup> and 17-point thermal sensation scale,<sup>27</sup> with greater numbers indicating an exaggerated response.

Exercise sessions were 2 h in length and consisted of walking at 4.83 km  $h^{-1}$ , jogging at 60%  $VO_{2max}$  ( $9.2 \pm 1.1$  km  $h^{-1}$ ), running at 80%  $VO_{2max}$  ( $12.1 \pm 1.4$  km  $h^{-1}$ ) at a 1% grade, and rest (Table 1). Intensities mimicked typical pre-season American football intensities.<sup>1</sup> To ensure the first exercise session (Bout 1) was completed in its entirety, beginning at min 40, jogging speed was lowered by 0.8 km  $h^{-1}$  for individuals who reached a  $T_{re} > 39^{\circ}C$ , indicating that they likely would reach the  $T_{re}$  termination criteria prior to the completion of 2 h of exercise. The following exercise session protocols (Bout 2 and Day 2) were adjusted to be identical to the speeds of Bout 1. Laboratory termination criteria were: (1)

$T_{re} \geq 40.0^\circ\text{C}$ , (2) unsteady gait making exercise unsafe, (3) signs or symptoms of heat illness, or (4) participant request. Throughout exercise,  $T_{re}$ , HR, and perceptual scales were recorded at minutes 15, 35, 55, 75, 95, and 115 and participants drank  $23^\circ\text{C}$  tap water ad libitum throughout.

Upon the completion of 2 h of exercise, participants completed an ESQ and rested quietly in a temperate environment ( $24^\circ\text{C}$ , 21% RH) for 2 h. Participants replenished fluids with water ad libitum and consumed a 20 oz carbohydrate-electrolyte drink and a small standardized meal (800 kcal) within 30 min. Following the rest period, an ESQ was administered, nude body mass was recorded, and participants completed Bout 2. Upon exercise completion, participants completed an ESQ, nude body mass, and provided a urine sample. Twenty-four hours later Day 2 was completed.

Serum was collected through an antecubital venipuncture immediately after exercise. Samples sat for 15 min before 10 min of centrifugation and storage at  $-80^\circ\text{C}$  until analysis. Cortisol concentration was determined by ELISA in duplicate (CalBiotech, Spring Valley, CA) with an intra-assay CV of  $\leq 4.9\%$ .

The purpose of this study was to examine differences in variables among three exercise sessions. Although all participants completed the full exercise session during Bout 1, many participants terminated Bout 2 and Day 2 prematurely. All participants completed at least 35 min of exercise during all sessions, therefore, Minute 0, Minute 35, and immediate post-exercise (IPE) data were compared among exercise sessions. One way repeated measures ANOVA were used to compare physiological responses to exercise, hydration, and exercise time among exercise sessions. Perceptual responses to exercise and ESQ were analyzed using Friedman ANOVA. Greenhouse-Geisser corrections were implemented when sphericity was violated. Significant F-values were subsequently analyzed using dependent t-tests or Wilcoxon signed-rank tests. An  $\alpha$ -level of 0.05 determined significance without adjustment for multiple comparisons. An a priori power analysis indicated that based on a previous study with a  $0.5^\circ\text{C}$  difference in core temperature between trials with a standard deviation of  $0.6^\circ\text{C}$ , 12 participants were required to detect between-trial differences in heat strain with at least 80% statistical power.<sup>28</sup> Our sample of 17 participants adequately powered our analyses. Data are presented as mean  $\pm$  SD. Statistical analyses were performed with SPSS software version 21.0 (IBM SPSS Statistics, Chicago, IL).

### 3. Results

All participants completed the full 120 min Bout 1 but averaged less time during Bout 2 ( $93 \pm 27$  min,  $p=0.001$ ) and Day 2 ( $113 \pm 12$  min,  $p=0.032$ ). 100%, 35%, and 71% of participants completed the full exercise protocol during Bout 1, Bout 2, and Day 2, respectively (Fig. 1). Eleven participants were unable to complete Bout 2 due to:  $T_{re}$  reaching the laboratory cut-off ( $n=5$ ), symptoms of EHI (e.g., lightheadedness, nausea, tingling in the extremities making exercise dangerous;  $n=4$ ), and subject request due to joint pain ( $n=1$ ) and fatigue ( $n=1$ ). All five who ended exercise early on Day 2 also ended exercise early during Bout 2 and terminated exercise due to:  $T_{re}$  reaching the laboratory cut-off ( $n=3$ ), symptoms of EHI ( $n=1$ ), and subject request due to fatigue ( $n=1$ ) on Day 2.

Despite a 2 h rest break, resting HR ( $104 \pm 17$  bpm) and Minute 35 HR ( $189 \pm 11$  bpm) were higher during Bout 2 than Bout 1 ( $79 \pm 12$  bpm,  $p<0.001$ ;  $180 \pm 17$  bpm,  $p=0.004$ ) (Fig. 2). While resting  $T_{re}$  was similar among exercise sessions (Bout 1:  $36.82 \pm 0.44^\circ\text{C}$ ; Bout 2:  $37.08 \pm 0.51^\circ\text{C}$ ; Day 2:  $36.83 \pm 0.30^\circ\text{C}$ ,  $p=0.051$ ), Minute 35  $T_{re}$  was highest during Bout 2 ( $38.80 \pm 0.47^\circ\text{C}$ ) compared to Bout 1 ( $38.41 \pm 0.52^\circ\text{C}$ ,  $p=0.001$ ) and Day 2 ( $38.31 \pm 0.35^\circ\text{C}$ ,  $p<0.001$ ). Immediate post-exercise HR (Bout 1:  $172 \pm 15$  bpm, Bout 2:  $178 \pm 19$  bpm, Day 2:  $173 \pm 14$  bpm,

$p=0.393$ ) and  $T_{re}$  (Bout 1:  $39.49 \pm 0.31^\circ\text{C}$ , Bout 2:  $39.60 \pm 0.43^\circ\text{C}$ , Day 2:  $39.46 \pm 0.46^\circ\text{C}$ ,  $p=0.494$ ) were similar among exercise sessions despite a shorter exercise duration during Bout 2 and Day 2 compared to Bout 1, indicating an equal level of heat strain occurred in a shorter period of time during the subsequent exercise sessions. Similarly, serum cortisol concentration was similar IPE among Bout 1 ( $447.3 \pm 172.3$  nmol L<sup>-1</sup>), Bout 2 ( $499.3 \pm 238.6$  nmol L<sup>-1</sup>), and Day 2 ( $422.7 \pm 203.1$  nmol L<sup>-1</sup>,  $p=0.328$ ). One participant reached  $40^\circ\text{C}$  at the final measurement during Bout 1, while six and three participants reached this laboratory cut-off during Bout 2 and Day 2, respectively.

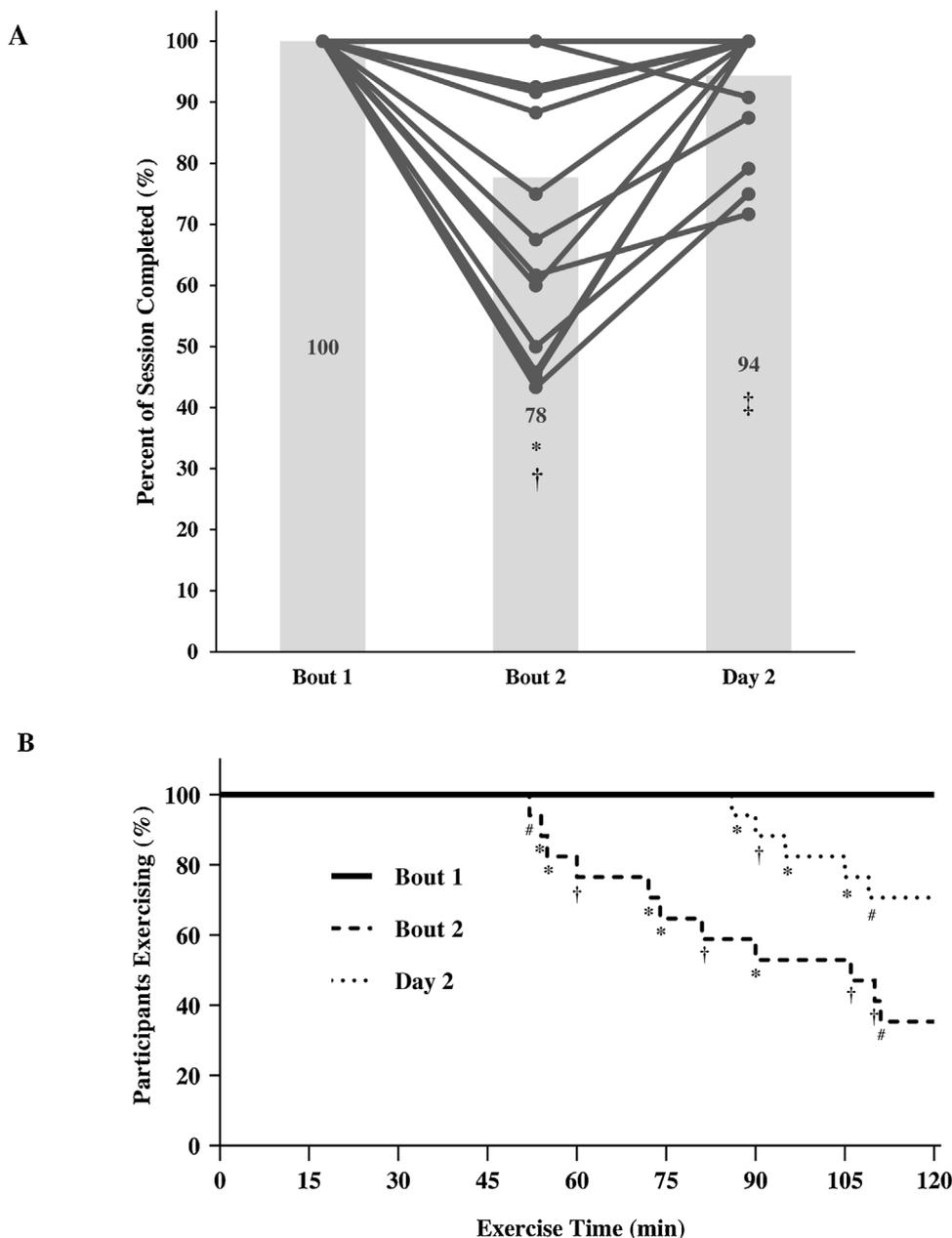
Markers of hydration status were similar among exercise sessions. Urine specific gravity indicated euhydration before ( $1.015 \pm 0.008$ ) and after ( $1.016 \pm 0.009$ ) exercise on the first day of exercise, but slight hypohydration both before ( $1.021 \pm 0.010$ ) and after ( $1.021 \pm 0.006$ ) Day 2. Sweat rate was similar among exercise sessions for Bout 1 ( $1.41 \pm 0.36$  L h<sup>-1</sup>), Bout 2 ( $1.51 \pm 0.45$  L h<sup>-1</sup>) and Day 2 ( $1.35 \pm 0.33$  L h<sup>-1</sup>,  $p=0.260$ ). Participants drank a similar volume of water ad libitum during exercise ( $1.96 \pm 0.91$  L,  $1.62 \pm 0.86$  L,  $2.10 \pm 0.88$  L,  $p=0.073$ ) and replaced similar percentages of sweat lost ( $71.7 \pm 31\%$ ;  $76.9 \pm 46.9\%$ ;  $89.4 \pm 48.8\%$ ;  $p=0.079$ ) during Bout 1, Bout 2, and Day 2 exercise, respectively. This water replacement strategy resulted in similar dehydration ( $1.14 \pm 0.01\%$ ,  $1.0 \pm 1.4\%$ , and  $0.63 \pm 1.3\%$ ,  $p=0.241$ ), by the end of Bout 1, Bout 2, and Day 2, respectively.

Participants had the greatest perception of heat strain during Bout 2. Fatigue was greater at rest before Bout 2 ( $2 \pm 1$ ,  $p=0.005$ ) and Day 2 ( $2 \pm 1$ ,  $p=0.031$ ) compared to Bout 1 ( $1 \pm 1$ ). Thermal sensation, fatigue, and perceived exertion were greatest during Minute 35 of Bout 2 ( $7.0 \pm 1$ ,  $6 \pm 2$ ,  $6 \pm 2$ ) compared to Bout 1 ( $6.0 \pm 0.5$ ,  $p=0.003$ ;  $3 \pm 2$ ,  $p=0.001$ ;  $5 \pm 1$ ,  $p=0.010$ ) and Day 2 ( $6.5 \pm 0.5$ ,  $p=0.010$ ;  $4 \pm 2$ ,  $p=0.002$ ;  $5 \pm 2$ ,  $p=0.003$ ), respectively. Participants reported similar changes in ESQ scores among the three exercise sessions ( $p=0.282$ ).

### 4. Discussion

The purpose of this investigation was to determine if a single exercise session impacted heat strain during a second exercise session the same day, and if two same-day exercise sessions impacted heat strain during an exercise session the subsequent day. This was the first study to investigate heat strain during consecutive exercise sessions emulating an athletic setting. Our findings revealed that participants achieved similar physiological heat strain in a shorter exercise duration during a subsequent exercise session the same day. Additionally, heat strain was greater during the second of two consecutive days of exercise, with only 71% of participants completing exercise that was successfully completed the previous day. Our findings support previous studies that found many individuals unable to complete a subsequent exercise session of moderate intensity exercise in warm environmental conditions<sup>19</sup> and greater heat strain on the second of consecutive days of fire suppression.<sup>14</sup> Together, these studies demonstrate that prior exercise in a warm to hot environment predisposes individuals to premature exercise cessation and thermal strain the subsequent day.

One area of concern is the applicability of these data to double practice days in the athletic setting when  $T_{re}$  could reach dangerous levels. While no participants ended exercise prematurely due to reaching  $40^\circ\text{C}$  during the first exercise session, identical exercise during a second exercise session led to five participants reaching a  $T_{re}$  of  $40^\circ\text{C}$  thereby terminating the trial. Similar IPE  $T_{re}$  was attained during the two exercise sessions despite shorter total exercise time during Bout 2 (93 min) compared to Bout 1 (120 min). Had all participants continued to exercise at the given rate for the full 120 min protocol during Bout 2, additional symptoms of EHI and



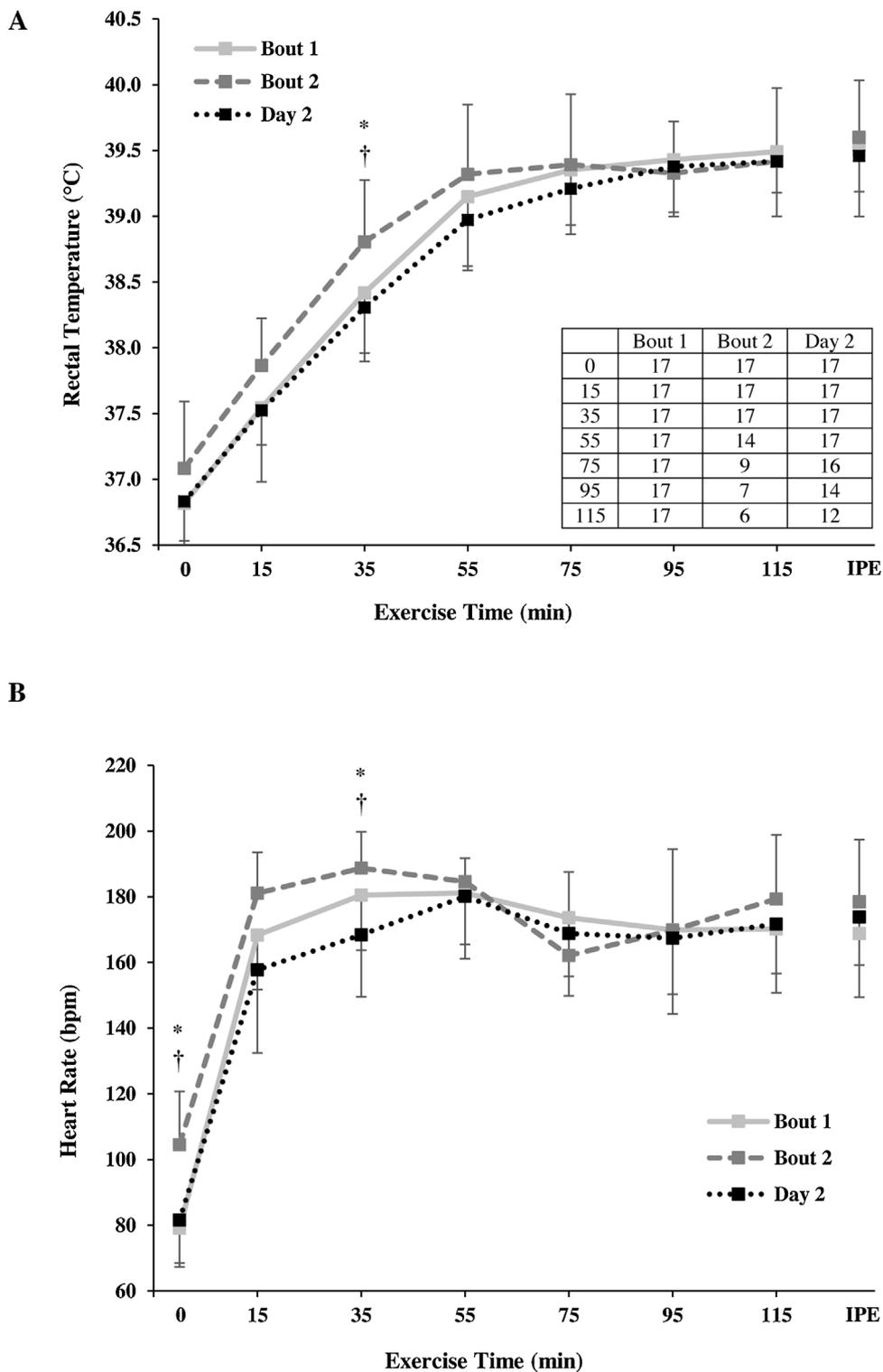
**Fig. 1.** (A) Percent of each exercise session completed. Bars indicate the average percent of each session completed. \*Bout 2 is significantly different than Bout 1 ( $p \leq 0.05$ ). †Bout 2 is significantly different than Day 2 ( $p \leq 0.05$ ). ‡Day 2 is significantly different than Bout 1 ( $p \leq 0.05$ ). (B) Survival graph indicating time at which participants stopped exercising among exercise sessions. The number and type of symbol represent the reason for trial termination at that time point. \*Trial ended due to rectal temperature  $\geq 40.0^\circ\text{C}$ . †Trial ended due to signs and symptoms of exertional heat illness. #Trial ended due to subject request caused by fatigue or joint pain.

possibly exertional heat stroke may have resulted in some of our participants.

Two hours of rest did not allow for HR or fatigue to return to resting values following Bout 1. Additionally, thermal sensation, fatigue, and perceived exertion were higher during Bout 2 compared to Bout 1 and two participants requested to prematurely terminate exercise, while four others developed symptoms of heat illness. Incomplete recovery previously has been shown between repeated bouts of 30 min of cycling in less stressful environments with 30 or 60 min of recovery.<sup>10,29</sup> Sawka et al. reported no differences in starting HR or  $T_{re}$  after 90 min of rest following 80 min of treadmill running at 70%  $\text{VO}_{2\text{max}}$ , although this was completed in less oppressive ambient conditions ( $22\text{--}25^\circ\text{C}$ , 45–60% RH).<sup>13</sup> These differing results are likely due to the latter study testing marathon runners instead of recreationally active men as

in the present study, as athletes of higher aerobic fitness have a more rapid HR recovery.<sup>30</sup> McLellan et al. investigated consecutive exercise sessions of walking in a mild environment ( $30^\circ\text{C}$ , 35% RH) and found no differences in heat strain.<sup>19</sup> Perhaps more challenging environments of greater temperature and humidity and/or greater exercise intensity is needed to see exacerbated heat strain during subsequent exercise sessions. Additional research into the effectiveness of extended rest breaks between exercise sessions is warranted to determine if the current National Athletic Trainers' Association heat acclimatization guidelines that suggest 3 h of rest between exercise sessions is sufficient to mitigate thermal strain.<sup>8</sup>

The present study determined individuals were hydrated before and after the first exercise session, but arrived to the lab hypohydrated on Day 2 and did not return to a hydrated state that day.



**Fig. 2.** Changes in rectal temperature (A) and heart rate (B) among exercise sessions. The table reports the number of participants exercising at each time point during each exercise session. Only Minute 0, Minute 35, and Immediate Post-Exercise (IPE) measures were analyzed for statistical differences. Bpm = beats per minute. \*Bout 2 is significantly different than Bout 1 ( $p \leq 0.05$ ). †Bout 2 is significantly different than Day 2 ( $p \leq 0.05$ ).

Ad libitum drinking was sufficient to maintain hydration status throughout each exercise session. A study of collegiate American football athletes reported dehydration both before and after every preseason practice with inadequate fluid replacement during practices, exacerbating dehydration.<sup>31</sup> One must remember that study participants had unlimited water access throughout each exercise session, which is not always true in athletic settings

that have structured rest and hydration breaks such as American football. Additionally, athletes do not always commence activity in a hydrated state during consecutive days of activity in a hot environment,<sup>31,32</sup> as observed in the present study. Beginning exercise hypohydrated exacerbates exercising core temperature by reducing sweat rate and skin blood flow, leading to a greater heart rate at a given temperature.<sup>33,34</sup> Even greater heat strain could be

observed when exercising in a hypohydrated state and warrants future investigation.

The current study is not without limitations. It should be noted that exercise intensity was predetermined and participants could not self-select or change intensity during or among exercise sessions. Treadmill intensities were chosen to mimic typical work rates during National Collegiate Athletic Association Division I American football preseason sport practices and may not be relevant to other exercise intensities.<sup>1</sup> Future studies should investigate self-paced exercise during consecutive days of exercise in varying levels of heat stress, as seen during individual sports such as cross country throughout a sport season. Additionally, environmental conditions in the present were oppressive (40 °C, 40% RH) and the results may not apply to more mild environments. Although heat acclimatization guidelines suggest 3 h of rest between practices,<sup>8</sup> we studied 2 h of rest, possibly limiting the direct applicability of our results to current heat acclimatization guidelines.

## 5. Conclusion

Intermittent, moderate-high intensity exercise in oppressive heat negatively impacts exercise during subsequent exercise sessions. End of exercise physiological and perceptual strain were similar among exercise sessions despite a shorter exercise duration during the subsequent sessions. Multiple exercise sessions should be avoided on the first day of physical activity in a hot environment as this may increase risk of attaining a critical core temperature.

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