Heat Strain Is Exacerbated on the Second of Consecutive Days of Fire Suppression

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ABSTRACT

SCHLADER, Z. J., D. COLBURN, and D. HOSTLER. Heat Strain Is Exacerbated on the Second of Consecutive Days of Fire Suppression. *Med. Sci. Sports Exerc.*, Vol. 49, No. 5, pp. 999–1005, 2017. **Purpose**: We tested the hypothesis that physiological and perceptual heat strain is exacerbated on the second of back-to-back days of fire suppression work despite evidence of full recovery. **Methods**: Twenty-six career and volunteer firefighters (age = 31 ± 8 yr) completed 20 min of near maximal fire suppression work on consecutive days. Dependent variables were core temperature, heart rate, perceived exertion, and thermal sensation, which were measured before and after fire suppression. Urine specific gravity and body mass were also measured upon arrival at the fire academy as an index of hydration and recovery between days. **Results**: Urine specific gravity (1.007 ± 0.006 vs 1.005 ± 0.006), body mass (87.7 ± 16.1 vs 87.8 ± 16.0 kg), heart rate (77 ± 14 vs 76 ± 14 bpm), and core temperature (37.2°C ± 0.4°C vs 37.1°C ± 0.7°C) were not different upon arrival on day 1 compared with day 2 ($P \geq 0.26$). The increase in core temperature during fire suppression was higher on day 2 (0.7°C ± 0.3°C vs 1.1°C ± 0.5°C, $P < 0.01$). Heart rate did not differ (after fire suppression: day 1 = 174 ± 19, day 2 = 169 ± 30 bpm, $P = 0.60$). The magnitude of increase in perceived exertion during fire suppression was greater on day 2 (6.7 ± 1.6 vs 7.4 ± 1.6 a.u., $P < 0.01$). Absolute thermal sensation at the end of fire suppression was greater on day 2 (3.8 ± 0.8 vs 4.3 ± 0.6 a.u., $P < 0.01$). **Conclusions**: Physiological and perceptual heat strain is higher on the second of back-to-back days of fire suppression work. **Key Words:** HEAT STRAIN, HEAT STRESS, FIREFIGHTERS, RECOVERY

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Workers often must perform physical work in the heat on consecutive days. Epidemiological data indicate that the risk of exertional heat illness is elevated on the second of back-to-back days of physical work in the heat (17,27,28). These findings suggest that physiological (e.g., increased core temperature, heart rate, etc.) and/or perceptual (e.g., perceived exertion, thermal discomfort, etc.) heat strain incurred by conducting physical work in the heat is likely greater on the second of two consecutive days.

To our knowledge, three studies have examined the carryover effects of a prior work or exercise heat exposure on heat strain during the second day. McLellan et al. (19) found that after complete recovery between days, physiological and perceptual heat strain during exercise in the heat was not different on the second day compared with the first day. By contrast, Pryor (20) found that despite no differences between physiological and perceptual heat strain on the second of two consecutive days of exercise in the heat, exercise tolerance was reduced by ~6% on the second day. Finally, a field study by Raines et al. (21) found that physiological and perceptual heat strain was greater on the first day of wildland fire suppression work compared with the second day, an observation that was largely attributed to the hypohydrated state that was observed upon arrival on day 1. Upon closer inspection of those data, however, the magnitude of the increase in core temperature (baseline to highest observed on the fireground) was greater than fivefold higher on the second day despite lower intensity of work, but this finding may be partially attributed to higher ambient temperatures on the second day (21). Collectively therefore, to date, studies examining the carryover effects of physical work in the heat provide little explanation for the aforementioned epidemiological observations (17,27,28).

The combination of protective clothing, intense physical work, and heat generated from a live fire often means that structural firefighters are exposed to uncompensably hot conditions during fire suppression (13,18). Firefighters may also have more than one job in the public safety sector or they may work overtime shifts, both of which subject the firefighter to risk of consecutive day heat exposures (7). Furthermore, shifts ranging from 10 to 48 h in duration are common in the fire service and firefighters may be exposed to heat stress multiple times within a single shift. Therefore,

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the purpose of this study was to test the hypothesis that physiological and perceptual heat strain is exacerbated on the second of consecutive days of structural fire suppression work.

METHODS

Subjects. Twenty-six career and volunteer firefighters were recruited from the community (Table 1). Each subject was fully informed of the experimental procedures and possible risks before giving informed, written consent. After providing informed consent, subjects completed a medical history questionnaire and were examined by a physician to identify any medical conditions that would exclude them from participation. All subjects were nonsmokers, not taking medications, and reported to be free from any known cardiovascular, metabolic, neurological, or psychological diseases. Female subjects were not pregnant, which was confirmed via a urine pregnancy test. Menstrual cycle phase and time of day were not controlled. The study was approved by the Institutional Review Board at the University of Pittsburg and performed in accordance with the standards set by the latest revision of the Declaration of Helsinki. All testing was performed during the month of July, in the Northern Hemisphere (Pittsburgh, PA).

After screening, subjects performed a maximal exercise test on a treadmill using the Bruce protocol for determination of maximal oxygen uptake (5). Cardiorespiratory variables were collected continually during the test via telemetry (Polar) and indirect calorimetry (TrueOne, Parvo Medics). After screening, subjects reported to the county fire academy on three occasions. The first visit was to practice the firefighter skills test and receive orientation on the live fire protocols. The remaining two occasions were the experimental visits.

Instrumentation and measurements. Six to 8 h before arrival, subjects swallowed a telemetry pill (HQ Inc., Palmetto, FL) for measurement of core temperature. Heart rate was measured via telemetry (Polar Electrom, Kempele, Finland). Nude body weight was measured using a standard scale (Sartorius Corp., Bohemia, NY), which was used to quantify percentage changes in body weight pre– to post–fire suppression work. Urine specific gravity was measured in duplicate using a refractometer (Atago USA Inc., Bellevue, WA). Blood pressure was measured manually in duplicate by an experienced member of the research team. Mean arterial pressure was calculated as diastolic pressure plus 1/3 pulse pressure. Three site skinfold thickness was measured in triplicate at the chest, anterior abdomen, and anterior thigh for males and at the triceps, suprailliac, and anterior thigh in females (Lange Skinfold Caliper, Cambridge Scientific Industries, Cambridge, MD). Percent body fat was estimated from body density (24), which was calculated from the sum of three skinfolds for males (15) and females (16). Perceived exertion (0 = "extremely easy" to 10 = "extremely hard") and thermal sensation (0 = "comfortable" to 5 = "very hot") were measured on standard scales (11,12,26).

TABLE 1. Subject characteristics.

Sex (M/F)	22/4
Age (yr)	31 ± 8
Height (cm)	178 ± 9
Weight (kg)	87.2 ± 15.7
Body fat (%)	20 ± 5
$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	43.4 ± 6.7
Maximal heart rate (bpm)	189 ± 8

Data are presented as mean ± SD. $\dot{V}O_{2max}$, maximal oxygen uptake.

Firefighter skills test practice. During the second visit, the firefighters practiced the firefighter skills tests while wearing protective garments and breathing apparatus. The skills test included a series of physical tasks that required the firefighter 1) to carry a single section of a 4.4-cm-diameter fire hose over the shoulder while ascending four flights of stairs to the top of a tower; 2) to pull a single rolled section of a 10.1-cm fire hose up the outside of the tower using a rope and pulley and pull the section into the tower interior; 3) to return to ground level to pull a section of charged fire hose 15 m; and 4) to drag a 50-kg rescue manikin 15 m back to the starting line.

Live fire evolutions. During the second and third visits, subjects participated in live fire evolutions on back-to-back days, denoted as day 1 and day 2. Day 1 and day 2 for each subject were completed at the same time of day. Subjects reported to the fire academy in pairs. After a 20-min seated rest, baseline core temperature, heart rate, and blood pressure measurements were taken. Euhydration was verified by urine specific gravity of ≤1.020 (23). Subjects used the protective garments and breathing apparatus that had been issued to them by their fire department. All protective clothing and breathing apparatus were NFPA 1971 compliant and inspected by the fire academy staff before use. Subjects wore the same protective garments and breathing apparatus on day 1 and day 2. Subjects were instrumented and, after receiving a briefing, donned their protective gear and breathing apparatus and began the evolution. Subjects entered a concrete building and advanced a charged 4.4-cm fire hose to the second floor. Wood-fueled fires had been set in two rooms on the second floor. After extinguishing the first fire and ventilating the smoke from the room, the subjects advanced to the second fire to extinguish and ventilate. While the second room was being extinguished, an academy instructor relit the fire in the first room. Subjects continued this pattern of moving from room to room to extinguish the fires until one subject's low air alarm sounded or 20 min had elapsed. At that time, subjects retreated from the second floor and exited the building. During fire suppression, the teams of two alternated extinguishment and ventilation duties throughout the evolution. The same subjects were paired together on both days. Subjects were accompanied by an investigator who was an experienced firefighter. This investigator paced the fire suppression work and ensured that subjects switched positions after each extinguishment. Every subject had previously trained in that particular burn building so it is unlikely that there was a familiarization effect on day 1 compared with day 2. Heart rate, core temperature, and perceptual scales were recorded at the beginning and end of the evolution. Unfortunately, the fire academy burn building was not instrumented for the quantification of the thermal

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environment. However, the fire academy staff indicated that floor temperatures were 315°C–426°C. Importantly, in our experience, this difference is not likely discernable under protective garments and in such an uncompensable environment.

Subjects then doffed their gear and sat in a covered pavilion for a 20-min recovery period. Each subject received 500 mL of cool water to drink and immersed their forearms and hands into 19 L buckets of cool water (~10°C). At the end of the rest period, subjects donned their protective garments and breathing apparatus and completed the firefighter skills test. Total time to complete the test was recorded. Heart rate and core temperature were recorded at the beginning and end of the skills test.

Subjects consumed additional fluids after the skills test and were provided a water bottle and notebook and instructed to document all intake until arriving back at the fire academy at the same time the next day. Food intake was analyzed for calories and macronutrient content using Food Processor Nutrition Analysis Software (ESHA, Salem, OR). All the procedures on day 1 were repeated on day 2.

Data and statistical analyses. Baseline data collected upon arrival at the fire academy on day 1 and day 2 were compared via paired *t*-tests. Physiological and perceptual data pre– and post–fire suppression work, and the firefighter skills tests were analyzed using separate two-way (time–day) repeated-measures ANOVA. Where appropriate, *post hoc* Sidak adjusted pairwise comparisons were made. Absolute changes from pre– to post–fire suppression work were calculated. These data (and the firefighter skills test time) were analyzed via paired *t*-tests, providing a comparison of the magnitude of changes in physiological and perceptual strain between day 1 and day 2. Data were assessed for approximation to a normal distribution and sphericity, and no corrections were necessary. Data were analyzed using Prism software (Version 6; GraphPad Software Inc., La Jolla, CA). *A priori* statistical significance was set at $P \leq 0.05$ and actual P values are reported where possible. All data are reported as mean ± SD.

RESULTS

Baseline measures. Urine specific gravity ($P = 0.35$), body weight ($P = 0.43$), heart rate ($P = 0.71$), core temperature ($P = 0.39$), and mean arterial pressure ($P = 0.26$) was not different upon arrival at the fire academy on day 2 compared with day 1 (Table 2). During the overnight period, subjects consumed 12,545 ± 4509 kJ of energy (carbohydrate = 384 ± 165 g, protein = 123 ± 57 g, fat = 111 ± 44 g) and consumed 4.6 ± 2.6 L of fluid.

TABLE 2. Physiological variables upon arrival at the fire academy.

	Day 1	Day 2
Urine specific gravity	1.007 ± 0.006	1.005 ± 0.006
Body weight (kg)	87.7 ± 16.1	87.8 ± 16.0
Heart rate (bpm)	77 ± 14	76 ± 14
Core temperature (°C)	37.2 ± 0.4	37.1 ± 0.7
Mean arterial pressure (mm Hg)	93 ± 8	92 ± 7

Data are presented as mean ± SD.

Live fire evolution. Core temperature before the live fire evolutions was not different between day 1 and day 2 ($P = 0.13$). Core temperature increased on both days ($P < 0.01$), but the magnitude of the increase was greater on day 2 ($P < 0.01$, Fig. 1). Heart rate before fire suppression was not different between day 1 and day 2 ($P = 0.91$). Heart rate increased ($P < 0.01$) by a similar magnitude on both days ($P = 0.71$, Fig. 1) and elicited 92% ± 11% (day 1) and 90% ± 17% (day 2) of maximal heart rate. Subjects lost 0.6% ± 0.3% of their body weight on day 1 and 0.6% ± 0.4% on day 2, which were not different ($P = 0.91$).

Perceived exertion was not different between day 1 and day 2 before the live fire evolutions ($P = 0.62$) and was increased during fire suppression on both days ($P < 0.01$). However, the magnitude of the increase in perceived exertion was greater on day 2 ($P < 0.01$, Fig. 2). Thermal sensation before commencing fire suppression was not different between days ($P = 0.30$), but absolute thermal sensation was higher at the end of the live fire evolution on day 2 ($P < 0.01$, Fig. 2). However, the magnitude of the increased did not differ between day 1 and day 2 ($P = 0.17$, Fig. 2).

Firefighter skills test. Firefighter skills test performance time was not different on day 1 (2.5 ± 0.5 min) and day 2 (2.5 ± 0.5 min, $P = 0.06$). Core temperature did not change from before (e.g., postrecovery) to after the firefighter skills test ($P = 0.52$) and did not differ at any time ($P = 0.95$) between day 1 (before = 37.5°C ± 0.4°C, after = 37.6°C ± 0.4°C) and day 2 (before = 37.5°C ± 0.7°C, after = 37.5°C ± 0.6°C). Heart rate increased during the firefighter skills test ($P < 0.01$), but heart rate did not differ at any time ($P = 0.36$) between day 1 (before = 114 ± 18 bpm, after = 172 ± 14 bpm) and day 2 (before = 115 ± 15 bpm, after = 175 ± 9 bpm).

DISCUSSION

In support of our hypothesis, physiological and perceptual heat strain was higher on the second of consecutive days of fire suppression work. This was highlighted by greater increases in core temperature during the live fire evolution (Fig. 1) and greater increases in perceived exertion and absolute thermal sensation at the end of fire suppression (Fig. 2) on day 2. Notably, this exacerbated heat strain did not affect performance on a high-intensity firefighter skills tests. Collectively, these data provide the first physiological basis for epidemiological data, indicating that the risk of exertional heat illness is elevated on the second of consecutive days of physical work in the heat (17,27,28).

Consecutive days of fire suppression exacerbates heat strain on the second day. Studies examining the physiological and perceptual effects of physical work in the heat on consecutive days are relatively sparse. We have identified three studies. Contrary to our study, none of these previous investigations found direct evidence of exacerbated physiological or perceptual heat strain on the

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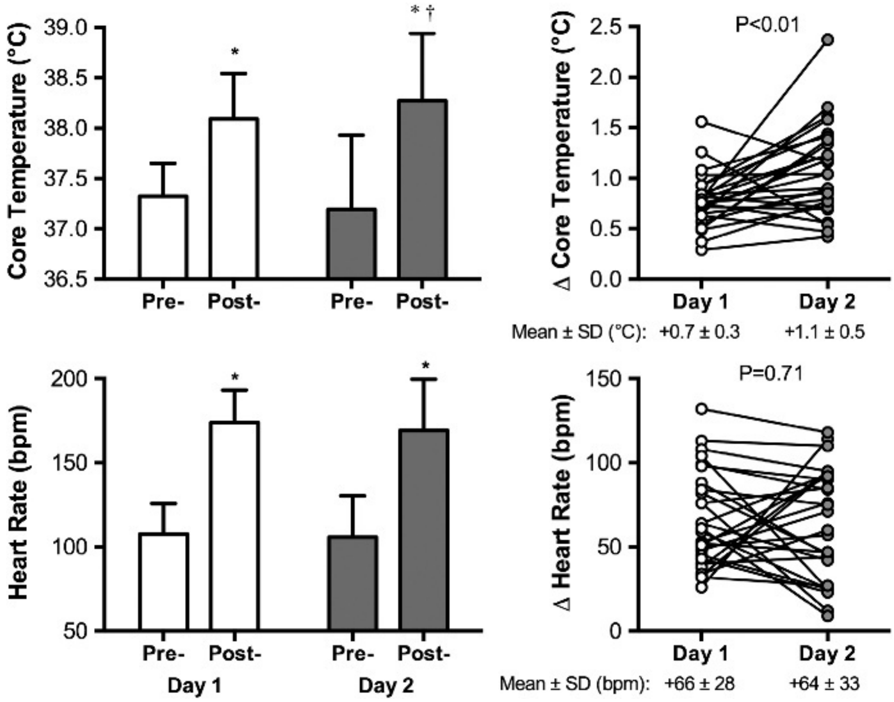

FIGURE 1—Absolute (on left) and the change from Pre- (on right, individual tracings and Mean ± SD) core temperature (top) and heart rate (bottom) responses to fire suppression on day 1 and day 2. Mean ± SD, *n* = 26. *Different from Pre- (*P* < 0.01). †Different from Post-, day 1 (*P* = 0.03).

second of two consecutive days of physical work or exercise in the heat (19–21). That said, in support of our observations of exacerbated physiological (Fig. 1) and perceptual (Fig. 2) heat strain on the second consecutive day of physical work in the heat, exercise tolerance has been found to be reduced by ~6% on the second of two consecutive days of exercise in the heat, with ~30% of subjects (5 of 18) ending exercise early during the 120-min protocol (three stopped because of

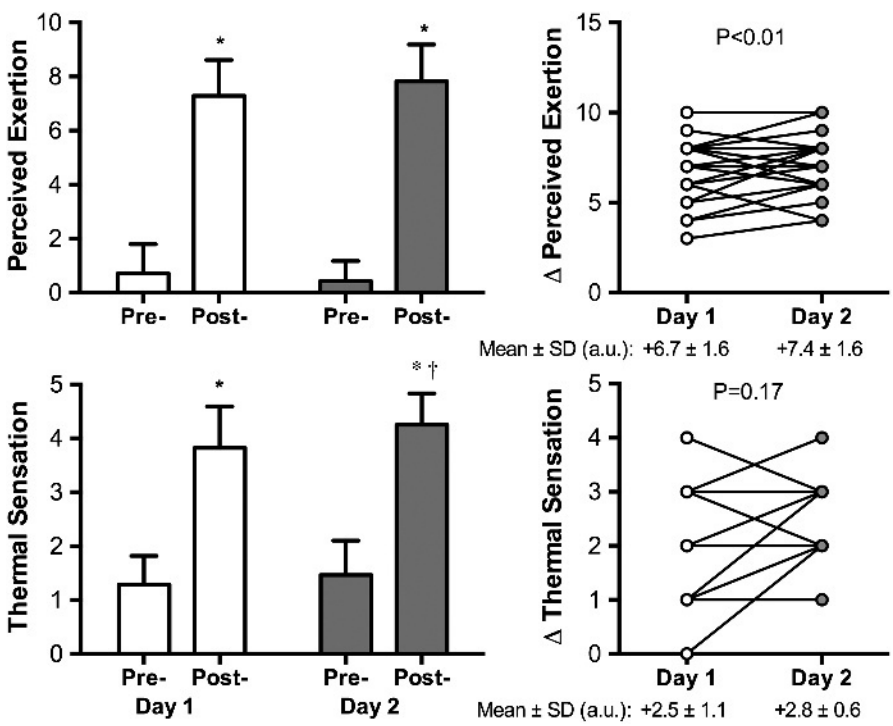

FIGURE 2—Absolute (on left) and the change from Pre- (on right, individual tracings and mean ± SD) perceived exertion (top) and thermal sensation (bottom) responses to fire suppression work on day 1 and day 2. Mean ± SD, *n* = 26. Note: The lack of 26 distinct lines on the individual tracings figures is due to the categorical nature of these perceptual data many of which were overlapping. *Different from Pre- (*P* < 0.01). †Different from Post-, day 1 (*P* < 0.01).

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excessive increases in core temperature and two stopped because of symptoms of exertional heat illness or excessive fatigue) (20). Furthermore, the magnitude of increases in core temperature, defined as the difference between baseline core temperature and the peak core temperature measured on the fireground, during wildland fire suppression work was more than 5 times higher on the second day (+0.2°C vs +1.3°C) (21). However, this was not an analysis formally conducted by these authors. Thus, until now, direct evidence regarding the physiological basis for the elevated risk of exertional heat illness on the second of back-to-back days of physical work in the heat (17,27,28) had been lacking.

The reason for the differences between our study and those conducted previously is currently unknown. However, it may be that work intensity and thermal compensability plays a role. The previous laboratory-based studies used low-intensity (19) or intermittent moderate-intensity (20) exercise. This is in contrast to our field study that evoked the thermal and metabolic demands of structural fire suppression work and elicited ~90% of maximal heart rate over an ~20-min period. Although heart rate was not measured during fire suppression in the present study, recent data published by our group have shown that the cardiovascular burden of fire suppression can result in a third of subjects exceeding maximal heart rate during this activity (2). Notably, this relative work intensity during fire suppression is higher than that observed during wildland fire suppression work in which heart rate was only higher than 70% maximal heart rate between ~8 and 22 min throughout a 12-h work day (21). Collectively, it is unlikely that the limits of thermal compensability were approached in the previous studies. In the present study, however, the relatively high work intensity of structural firefighting, together with protective clothing and very hot ambient conditions, likely elicited uncompensable heat stress. This is demonstrated by robust increases in core temperature on both day 1 (0.7°C ± 0.3°C) and day 2 (1.1°C ± 0.5°C, Fig. 1) that occurred over ~20 min. Therefore, it may be that for exacerbated heat strain to be observed on the second of consecutive days of work in the heat, the conditions on both days need to be uncompensable. In line with this hypothesis, we speculate that if the physical work was longer than ~20 min, which would elicit increases in core temperature in excess of that that observed in the current study (Fig. 1), the magnitude of the differences between day 1 and day 2 would be exacerbated. However, direct experimental evidence is required.

Given the field-based nature of the present study, the mechanisms underlying the observed greater physiological and perceptual heat strain on day 2 are largely unknown. All other things being equal, our observations may be explained by a greater rate of metabolic heat production during fire suppression on day 2, making the conditions further uncompensable. However, that absolute (and changes in) heart rate were not different between day 1 and day 2 (Fig. 1) indirectly argues against any such differences. Heart rates were not tracked during fire suppression in the present report and may have been higher on day 2 while the subjects were performing fire suppression functions. Other factors that may have influenced thermal compensability and, thus, heat strain on day 2 are the ambient conditions during the live fire evolution and/or the duration of fire suppression work. Unfortunately, the fire building was not instrumented to capture ambient conditions. However, we cannot envision why either would have been systematically different on day 1 versus day 2. It is also possible that hydration status or energy balance contributes to the exacerbated physiological and perpetual heat strain on day 2. That said, this is unlikely given the volume of fluid and the quantity of energy consumed between day 1 and day 2, together with the physiological profile of our subjects upon arrival at the fire academy on both days (Table 2). Finally, it may be that the present observations are specific to the firefighters who completed the present study. These subjects were likely not heat acclimatized and are not considered to be of high aerobic fitness (Table 1), both of which are independent risk factors for exertional heat illness (4). Notably, if (and how) fitness and heat acclimatization status contribute to the observed exacerbated heat strain on the second of consecutive days of physical work in the heat is unknown. Collectively therefore, further research is required to understand the mechanisms and modulators of the exacerbated thermal strain incurred by completing high-intensity work on consecutive days in an uncompensably hot environment.

Considerations. There are a few additional methodological considerations that warrant mentioning. First, physiological and perceptual data were collected immediately pre– and post–fire suppression. This was largely a function of the field-based nature of the study design. That said, we do not know if the dynamics of changes in these variables differed between day 1 and day 2. Second, our measurements were constrained to only those that can be readily made in a field setting. Thus, we were limited to only core temperature and heart rate. Future investigations should consider including more in depth thermal, cardiovascular, metabolic, and fluid regulatory measures, which would provide insights regarding the mechanisms for our observations. Third, our study involved largely males and a few females (Table 1), and we did not control for the menstrual cycle. It is known that sex (9) and menstrual cycle phase (6) can modulate temperature regulation, particularly at high levels of heat stress, but it remains unknown if these factors modify the magnitude of heat strain incurred by physical work in the heat conducted on consecutive days.

Perspectives and significance. Although it is often not recommended, workers often must work in the heat on consecutive days. This situation has been found to increase the risk of heat illness on the second day (17,27,28). The present study at least partially provides an explanation for these epidemiological observations and demonstrates that physiological and perceptual heat strain are exacerbated on the second of consecutive days of physical work in the heat (Figs. 1 and 2). The magnitude of the increase in core temperature is particularly notable because, according to recent recommendations for unacclimated workers (3), average

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core temperature went from a level in which work would not be contraindicated on day 1 (less than a +1.0°C rise in core temperature, ~0.7°C) to a level in which work would be contraindicated on day 2 (greater than +1.0°C rise in core temperature, ~1.1°C). It should be noted, however, that there is some debate regarding the clinical merits of these core temperature guidelines (14). Our firefighter skills test performance data support such a reconsideration, such that the greater prior heat strain on day 2 did not affect firefighter performance. These findings question if the greater increase in core temperature with fire suppression on day 2 (by ~0.4°C) is sufficient to compromise worker performance and productivity later in the day.

That perceptual heat strain was elevated on day 2 is important because perceptual heat strain even in the absence of excessive physiological heat strain is associated with impairments in cognitive performance during heat stress (10). This is notable because alterations in cognitive performance may contribute to the increased frequency of unsafe behaviors in the workplace (22) and the elevated of risk of occupational accidents and injuries (1,8,25) during heat stress. To our knowledge, current occupational heat stress and strain recommendations do not address the potential for a day of physical work in the heat to carry over onto the next day (3,14). The present study shows that such an omission should be addressed and that conducting physical work in the heat on consecutive days may have important health, safety, and productivity implications for workers regularly exposed to heat (e.g., firefighters, miners, and agriculture workers).

CONCLUSIONS

We have demonstrated that the increases in core temperature, perceived exertion, and thermal sensation at the end of fire suppression is greater on the second of consecutive days of fire suppression work, despite evidence of being fully recovered before work on day 2. Importantly, however, this exacerbated heat strain did not affect firefighter skills test performance. These findings suggest that physiological and perceptual heat strain is exacerbated by consecutive days of physical work in the heat, providing some of the physiological basis for epidemiological data, indicating that the risk of exertional heat illness is elevated on the second of back-to-back days of physical work in the heat (17,27,28).

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