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Effects of Heat Exposure and Ice Slurry Ingestion on Risk-Taking Behavior in Healthcare Workers

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ABSTRACT

Purpose: Healthcare workers (HCWs) wearing personal protective equipment (PPE) experience physiological strain that can impair motor and psychological functions, potentially affecting patient care. We assessed the effects of heat exposure on maximal strength and risk-taking behavior amongst PPE-wearing HCWs and the efficacy of ice slurry to alleviate adverse effects. **Methods:** 17 HCWs completed two experimental trials in a crossover design, consuming 5g×kg^{-1} of body mass of ambient drink (AMB) or ice slurry (ICE) before donning PPE and undergoing 2-h of simulated decontamination exercise (wet-bulb globe temperature (WBGT): 25.9 ± 0.8ºC, PPE microenvironment WBGT: 29.1 ± 2.1ºC). Body core temperature (T_c), heart rate (HR), chest skin temperature (T_{sk}), ratings of perceived exertion (RPE), thermal sensation (RTS), maximal voluntary contraction (MVC), risk-taking behavior (Balloon Analogue Risk-Taking task; BART) and salivary cortisol were assessed. **Results:** Pre- to post-drinking ΔT_c was greater in ICE (-0.2 ± 0.1ºC) than AMB (-0.0 ± 0.1ºC, P=0.003). Post-drinking RTS was lower in ICE (2.7 ± 1.2) than AMB (4.1 ± 0.4, P<0.001). ICE and AMB had similar T_c and HR (both P>0.05), but T_{sk} was lower in ICE than AMB (P=0.049). A lower MVC (30.3 ± 6.7 kg vs 27.4 ± 4.9 kg, P=0.001) and higher BART adjusted total pump count (472 ± 170 pumps vs 615 ± 174 pumps, P=0.017) was observed pre- to post-trial in AMB but absent in ICE (both P>0.05). Salivary cortisol was similar between trials (P=0.42). **Conclusions:** Heat-exposed PPE-wearing HCWs had impaired maximal strength and elevated risk-taking behavior. This may increase the risk of avoidable workplace accidents that can jeopardize HCWs and patient care. Ice slurry ingestion alleviated these heat-related impairments, suggesting its potential as an ergogenic aid.

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Key Words: RISK-TAKING, PRE-COOLING, PHYSIOLOGICAL STRAIN, PERSONAL PROTECTIVE EQUIPMENT, HEALTHCARE

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INTRODUCTION

Individuals working in hot and humid environments while donning personal protective equipment (PPE) may be exposed to high levels of physiological strain. This is particularly concerning for healthcare workers (HCWs) deployed during chemical disasters or pandemic-response activities, where activities such as patient transfer from emergency services to the hospital or pre-hospital decontamination and/or triage are done in unregulated outdoor field environments whilst donning PPE (1, 2). The usage of PPE is necessary to protect HCWs from accidental secondary exposure. However, the highly insulative nature of PPE severely hampers heat dissipation mechanisms, exacerbating the level of physiological strain experienced (1, 3). This can lead to potential adverse effects such as impaired physical and cognitive functioning and increased occurrence of heat-related injuries and illnesses (4-6).

Epidemiological data has demonstrated a positive correlation between higher ambient temperatures and higher occurrences of work-related injuries (7, 8). Heat-related injuries and fatalities also accounted for 91.9% of exertion-based injuries and 87.6% of exertion-based fatalities in occupational settings in the United States (9), further demonstrating the impact of heat on the occupational injury and fatality burden. Increased physiological strain and physical and cognitive impairments have primarily been attributed to these increases (10, 11). In this regard, the physiological strain PPE-donning HCWs are exposed to is being increasingly studied, intensified by the increased PPE usage during the Ebola virus disease epidemic and the COVID-19 pandemic (2). Surveys conducted amongst HCWs in India and Singapore (n = 165) (12) and the United Kingdom (n = 224) (10) showed that HCWs had an increased perception of heat strain and experienced symptoms such as thirst, thermal discomfort, excessive sweating, headache, and

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fatigue when carrying out activities in PPE. However, studies utilizing physiological monitoring (e.g., body core temperature (T_c), heart rate (HR), sweat loss, etc.) yield inconclusive results. For example, elevated T_c above 38.0ºC was observed amongst HCWs donning PPE (13, 14), though studies observing minimal T_c rise and low thermal strain have also been reported (15, 16).

Most studies investigating the effects of heat exposure and its contribution to heat-related injuries have focused on physiological strain and physical and cognitive impairments (2, 7, 10). However, alternative mechanisms, such as potential impairments in psychological functioning, are less understood. Heat exposure can affect psychological functioning by contributing to increased levels of irritation, hostility and aggression (17) and impacting decision-making (2, 18). More specifically, heat exposure has been demonstrated to impair risk-based decision-making, resulting in lowered risk perceptions and increased risk-taking behavior (19, 20). This may explain how heat exposure can influence adherence to safety practices, potentially contributing to unsafe behaviors and the number of heat-related injuries, accidents and fatalities. These changes may also be modulated by elevations in cortisol due to heat exposure (21), where elevated salivary cortisol concentrations have been associated with increased risk-taking behavior and impaired decision-making (22). In healthcare settings, an increase in risky behaviors may lead to avoidable workplace accidents that can jeopardize the health and safety of HCWs and patients under their charge (2). Despite these potentially severe ramifications of heat exposure on risk-based decision-making, there is still limited research in this field. Thus, more research is necessary to expand the current understanding of the effects of heat exposure on risk-related mechanisms and its potential contribution to heat-related injuries, accidents and fatalities and to identify mitigation strategies against these adverse effects.

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Several mitigation strategies have been suggested in healthcare settings, including heat acclimation, work-rest cycles and cooling strategies (1, 3). However, strategies such as heat acclimation or work-rest cycles may not be feasible for HCWs, given their short time to deployment and inability to take breaks due to their busy schedules (12). In addition, per-cooling strategies (i.e., during work) such as water-perfused suits or cooling vests may not be readily available in austere environments and may pose an additional physical burden on HCWs should the cooling effect diminish during the shift (2). Given this, pre-cooling strategies (i.e., before work) may be advantageous. For example, ice slurry ingestion before work may effectively reduce initial T_c of HCWs, potentially improve thermal perception, and enhance heat tolerance time (23, 24). However, the efficacy of ice slurry ingestion to improve heat tolerance and performance during heat exposure has primarily been established in athletic (25, 26) and laboratory settings (23, 24). Thus, the ecological validity and effectiveness of ice slurry is field operations remains to be determined.. Furthermore, it also remains unclear how these strategies may affect risk-taking behavior and subsequently influence heat-related occupational injuries and accidents.

Therefore, this study aimed to determine the effect of heat exposure on maximal strength and risk-taking behavior amongst HCWs wearing full-body PPE during simulated decontamination exercise and assess the efficacy of pre-activity ice slurry ingestion to alleviate any adverse effects observed. We hypothesized that HCWs would experience increased physiological strain, impaired maximal strength and increased risk-taking behavior when exposed to heat and carrying out simulated decontamination while donning PPE and that ice slurry ingestion would alleviate the impairments observed.

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METHODS

Participants

17 healthcare workers (10 males and 7 females) comprising nurses and hospital administrative staff previously trained to conduct chemical decontamination were recruited (Table 1). All participants self-reported that they were healthy and did not have a prior history of gastrointestinal disease (necessary for ingestion of the telemetric capsule for T_c monitoring). Females self-reported that they were not pregnant and were tested at any point during their menstrual cycle to maintain ecological validity, where females work across their entire menstrual cycle. Ethical approval was obtained from the National University of Singapore Institutional Review Board (Reference code: NUS-IRB-2022-64) and Singhealth Centralised Institutional Review Board (Reference code: CIRB 2020/2718) per the Declaration of Helsinki. All participants were verbally briefed on the experimental procedures and possible risks before providing written informed consent prior to participation.

Experimental Design

In a full crossover design, participants completed two experimental trials, consuming either $5g \times kg^{-1}$ of ambient drink (AMB) or ice slurry (ICE) before full-donning PPE and undergoing 2-h of simulated decontamination activities in a randomized, counterbalanced order (Figure 1). All trials were conducted at a hospital decontamination station located in an accident and emergency (A&E) department of a local Singapore hospital (dry bulb temperature (T_{db}): 28.3 ± 1.2ºC, relative humidity (RH): 72 ± 7% and wet-bulb globe temperature (WBGT): 25.9 ± 0.8ºC), from November 2022 to February 2023. Trials were conducted at the same time of the

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day to account for diurnal cortisol variations. Participants could not be blinded to the experimental conditions but were unaware of the research hypotheses.

Participants were requested to replicate their diets and sleep schedules and refrain from strenuous physical activity and alcoholic beverages before each trial. Participants reported in a T-shirt, pants and athletic shoes. Upon arrival, participants completed a 24-h dietary and physical activity questionnaire to ensure compliance with trial requirements. Participants then voided their bladder and provided a mid-stream urine sample for the measurement of urine specific gravity (USG) using a handheld refractometer (PAL-10S, Atago, Japan). Participant hydration status, based on USG measurements, was classified as euhydrated (USG < 1.025) or dehydrated (USG ≥ 1.025) (27). Participants completed pre-trial measurements of maximum voluntary contraction (MVC) and balloon analogue risk-taking task (BART) and provided saliva samples for analysis of salivary cortisol concentrations ([salivary cortisol]).

Participants then commenced a 10-min pre-activity drinking phase, consuming $5g \times kg^{-1}$ of body mass of commercially available carbohydrate-electrolyte drink (Pocari Sweat, Otsuka Pharmaceutical, Japan; per 100ml, energy: 25kcal, carbohydrate: 6.2g, sodium chloride: 0.12g) in AMB (24.8 ± 0.8ºC) or ICE (-0.9 ± 0.3ºC), divided into two equal aliquots. The absolute drink amount was based on the participant's body mass, measured during their first experimental trial. Ice slurry was prepared using a commercially available ice slurry machine (IPRO, SPM Drink Systems, Italy). After completing the pre-activity drinking, participants fully donned their Level C PPE consisting of a one-piece chemical-resistant suit, gloves, boots and a full-face powered

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air-purifying respirator (CLD500©, Paul Boyé Technologies, France) and commenced 2-h of simulated chemical decontamination exercise.

Participants were allocated into one of four possible stations during the 2-h simulated decontamination exercise. They performed the same station in both experimental trials to ensure comparable levels of physical exertion. The four stations were: (1) Triage – Participants carried out triage, tagged casualties and administered injectable antidotes where needed; (2) Disrobing – Participants disrobed casualties and bagged and sealed collected valuables; (3) Showering – Participants showered casualties using liquid soap and water and (4) Screening and Re-clothing – Participants scanned casualties for residual contamination. Participants then dried and re-clothed casualties cleared of chemical contamination before the casualties were sent for further assessment and management at a clean area and subsequently in the Emergency department where necessary (28). During the 2-h simulated decontamination exercise, participants completed the full decontamination of 12 mannequins at an average rate of 10 minutes per mannequin. Participants then doffed their PPE before completing post-trial measurements of MVC and BART and providing post-trial saliva samples.

Measurements

Handgrip MVC measurements provide a measure of muscular strength (29, 30) and were assessed using a hand grip dynamometer (Commander Echo Grip, JTech Medical, Utah, USA). Participants held the dynamometer in their dominant hand, with their arm at a right angle and their elbow at the side of the body. The dynamometer was adjusted to ensure that the base rested at the heel of the participant's palm and the handle rested on the middle of the participant's four

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fingers. Participants were asked to squeeze the hand grip dynamometer twice at maximal strength and hold for five seconds, with 15-s rest in between. MVC force output was determined as the average of the two squeezes. The coefficient of variation (CV) was 6.0%.

BART is a widely used test to assess and predict risk-taking behaviors in real-world situations (31-33) with established test-retest reliability (32, 34). In this study, BART was utilized to assess the risk-taking behavior of participants. During the task, participants were shown a virtual balloon, two buttons to "*Pump up the balloon*" or to "*Collect $$$*" and four types of information (i.e., "Potential Earnings", "Balloon number", "Number of pumps" and "Total Winnings") on a computer screen. For each balloon, participants can incrementally inflate the balloon to accumulate earnings by clicking "*Pump up the balloon"*. Each pump would cause the balloon to increase in size incrementally, and participants would receive virtual earnings (5 cents per pump) added to their "Potential Earnings". Participants can stop inflating the balloon and transfer their "Potential Earnings" into permanent "Total Winnings" by clicking "*Collect $$$*". If the balloon explodes before the earnings are transferred, participants lose the potential money earned for that balloon, and a new virtual balloon will appear on the screen. This continued for 20 balloons per test, and participants were tasked to collect the highest "Total Winnings". The threshold by which the balloon would explode was unknown to participants, and they were told that the balloon might explode as early as the first pump or after it had filled the entire computer screen. The number of pumps before an explosion was between 1 and 128, and with each pump, the risk of the balloon exploding increased. Participants' risk-taking behavior was determined via the adjusted total number of pumps (i.e., total number of pumps on unexploded balloons) (33,

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35). The top three earners were given monetary incentives to provide a decision-based consequence to BART performance scores.

Saliva samples were collected by placing a swab in the participants' mouths to stimulate salivation. Swabs were removed after 5-min and placed into Salivette® Cortisol tubes (Sarstedt Inc., Germany). Tubes containing swabs were centrifuged at 1000g for 10-min before saliva was aliquoted into 2 ml tubes and stored at -80ºC for up to two months before being thawed for analyses. Enzyme-linked immunosorbent assay determined salivary cortisol concentrations ([salivary cortisol], µg×dL, Enzo Life Sciences, NY, USA). The CV was 2.6%.

T_c, heart rate (HR) and skin temperature (T_{sk}) were measured and recorded during the pre-activity drinking and simulated decontamination exercise. T_c was measured by a telemetric capsule (e-Celsius®, BodyCap, Hérouville-Saint-Clair, France) ingested eight to ten hours prior to the commencement of the trial (1 participant) or rectally self-inserted on the morning of the trial (16 participants). HR was monitored by a chest-based sensor (H10, Polar Electro Oy, Finland). Single-site chest T_{sk} was measured using a wireless iButton® (DS1923 Hygrochron iButton®, Maxim Integrated Products, Inc., USA) attached to the skin of the mid-belly of the chest on the right-hand side of the body using hypoallergenic polyacrylate adhesive tape (Fixomull®, Smith and Nephew Ltd., Auckland, New Zealand). Mean and peak T_c, HR and chest T_{sk} values were determined for each participant. Measurements of T_c, HR and chest T_{sk} were used to calculate adaptive PSI (aPSI) (36, 37). The mean and peak aPSI values were calculated for each participant. Perceptual responses of ratings of perceived exertion (RPE, Borg's scale) and thermal sensation (RTS) were assessed at three time points as follows: before pre-activity

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drinking (pre-drink), after pre-activity drinking (post-drink) and after the simulated decontamination exercise (post-trial).

Environmental conditions consisting of T_{db}, RH and WBGT were monitored using an environmental meter (QUESTemp 44, TSI Incorporated, Minneapolis, USA). An iButton® was placed inside the PPE donned by HCWs to assess the PPE microenvironment. Wet bulb temperature (T_{wb}) was calculated (38) and PPE microenvironment WBGT was subsequently estimated assuming no radiant heat load in the internal environment (39, 40).

Statistical analysis

A priori power calculation using G*Power (Heinrich-Heine-Universität Düsseldorf, Germany) was performed to determine the number of participants required (n=12) with an alpha level of 0.05 and desired power of 0.8 using data reported in previous literature (23). Statistical analysis was conducted using GraphPad Prism version 9 (GraphPad Software Inc., La Jolla, CA). Data were assessed for approximation to a normal distribution and sphericity. Greenhouse-Geisser corrections were applied to adjust for the lack of sphericity. Sex comparisons between anthropometric measures were analyzed via independent *t*-tests. Differences between trials for baseline USG, mean and peak data determined during the simulated decontamination exercise (i.e., PPE microenvironment WBGT, T_c, HR, chest T_{sk}, aPSI) were analyzed via paired *t*-tests. Data collected across time (i.e., T_c, HR, chest T_{sk}, aPSI, RPE, RTS, MVC force output, BART adjusted total pump count and [salivary cortisol]) were analyzed using two-way (trial x time) repeated measures ANOVA. When significant main or interaction effects were observed, *post hoc* Bonferroni-adjusted pairwise comparisons were made. An *a priori* alpha of $\alpha = 0.05$

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significance level was used for all statistical analyses. Data are presented as mean ± standard deviation (SD) unless stated otherwise.

RESULTS

Pre-trial hydration status

Mean pre-trial hydration status was similar between trials (AMB: 1.014 ± 0.009 [range: 1.009 – 1.027] vs ICE: 1.015 ± 0.009 [range: 1.003 – 1.030], P = 0.57). However, out of the 17 participants, 3 in AMB (prevalence: 18%) and 2 in ICE (prevalence: 12%) reported dehydrated (USG ≥ 1.025).

PPE microenvironment WBGT

Participants worked at a mean PPE microenvironment WBGT of 29.4 ± 2.2ºC in AMB and 28.8 ± 1.9ºC in ICE (Figure 2A). Mean PPE microenvironment WBGT was similar between trials (P_{trial} = 0.31) but increased over time (P_{time} < 0.001) to peak values of 30.7 ± 2.2ºC [range: 28.2 – 35.7] in AMB and 30.1 ± 2.0ºC [range: 27.4 – 34.7] in ICE during the simulated decontamination exercise. Peak PPE microenvironment WBGT was also similar between trials (P = 0.43; Figure 2F).

Physiological and perceptual responses

Mean pre-trial T_c was similar between trials (AMB: 37.3 ± 0.3ºC vs ICE: 37.3 ± 0.3ºC, P = 0.98). Pre-trial to post-drinking ΔT_c was greater in ICE (-0.2 ± 0.1ºC) than AMB (-0.0 ± 0.1ºC, P = 0.003). Participants worked at a mean T_c of 37.5 ± 0.3ºC in AMB and 37.5 ± 0.3ºC in ICE (P = 0.21; Figure 2B). No interaction effects were observed for mean T_c over time (P_{int} = 0.089),

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although main effects of time were observed (P_{time} < 0.001; Figure 3A). Peak T_c during the simulated decontamination exercise was also similar between trials (AMB: 37.8 ± 0.4ºC [range: 37.0 – 38.4] vs ICE: 37.7 ± 0.3ºC [range: 37.3 – 38.4], P = 0.38; Figure 2G).

Mean pre-trial HR was similar between trials (AMB: 91 ± 11 bpm vs ICE: 93 ± 10 bpm, P = 0.30). Participants worked at a mean HR of 107 ± 14 bpm in AMB and 103 ± 12 bpm in ICE (P = 0.078; Figure 2C). No interaction effects were observed for mean HR over time (P_{int} = 0.95), although main effects of time were observed (P_{time} < 0.001; Figure 3B). Peak HR during the simulated decontamination exercise was also similar between trials (AMB: 121 ± 19 bpm [range: 97 – 158] vs ICE: 116 ± 16 bpm [range: 96 – 149], P = 0.065; Figure 2H).

Mean pre-trial chest T_{sk} was similar between trials (AMB: 34.2 ± 1.0ºC vs ICE: 34.3 ± 0.9ºC, P = 0.85). Participants worked at a higher mean chest T_{sk} of 35.3 ± 0.6ºC in AMB than in ICE (34.9 ± 0.5ºC in ICE, P = 0.006; Figure 2D). No interaction effects were observed for mean chest T_{sk} (P_{int} = 0.44), although main effects of trial (P_{trial} = 0.047) and time were observed (P_{time} < 0.001; Figure 3C). Peak chest T_{sk} during the simulated decontamination exercise was also higher in AMB than ICE (AMB: 36.0 ± 0.6ºC [range: 34.6 – 36.8] vs ICE: 35.5 ± 0.6ºC [range: 34.5 – 36.5], P = 0.001; Figure 2I).

Mean pre-trial aPSI was similar between trials (AMB: 2.1 ± 0.8 vs ICE: 2.2 ± 0.6, P = 0.49). Participants worked at a higher mean aPSI of 3.2 ± 0.9 in AMB than in ICE (2.8 ± 0.7, P = 0.026; Figure 2E). No interaction effects were observed for mean aPSI over time (P_{int} = 0.43), although main effects of time were observed (P_{time} < 0.001; Figure 3D). Peak aPSI during the

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simulated decontamination exercise was also similar between trials (AMB: 4.0 ± 1.3 [range: 2.1 – 6.6] vs ICE: 3.6 ± 0.9 [range: 2.6 – 5.7], P = 0.078; Figure 2J).

Mean pre-trial RPE (AMB: 7 ± 2 vs ICE: 7 ± 1, P = 0.70) and RTS (AMB: 4.6 ± 0.7 vs ICE: 4.3 ± 0.4, P = 0.81) were similar between trials. No interaction effects were observed for mean RPE over time (P_{int} = 0.99), although main effects of time were observed (P_{time} < 0.001; Figure 3E). Interaction (P_{int} = 0.003), trial (P_{trial} < 0.001) and time (P_{time} < 0.001) effects were observed for mean RTS over time (Figure 3F). *Post hoc* analysis revealed that mean RTS decreased from pre- to post-drinking in ICE (pre-drinking: 4.3 ± 0.3 vs post-drinking: 2.7 ± 1.2, P < 0.001), and post-drinking RTS was also lowered in ICE than AMB (ICE: 2.7 ± 1.2 vs AMB: 4.1 ± 0.4, P < 0.001).

MVC, BART and salivary cortisol concentrations

Mean pre-trial MVC output was similar between AMB and ICE (30.3 ± 6.7 kg vs 30.0 ± 5.5 kg, P = 0.73). No interaction effect was observed for mean MVC output over time (P_{int} = 0.21), although main effects of time were observed (P_{time} < 0.001). *Post hoc* analysis revealed that mean MVC output decreased from pre- to post-trial in AMB (pre-trial: 30.3 ± 6.7 kg vs post-trial: 27.4 ± 4.9 kg, P = 0.001), with no differences observed in ICE (pre-trial: 30.0 ± 5.5 kg vs post-trial: 28.5 ± 6.9 kg, P = 0.099; Figure 4A).

Mean pre-trial BART total adjusted pump count was similar between AMB and ICE (524 ± 170 pumps vs 472 ± 170 pumps, P = 0.21). An interaction effect was observed for mean BART total adjusted pump count over time (P_{int} = 0.030). *Post hoc* analysis revealed that mean BART

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total adjusted pump count increased from pre- to post-trial in AMB (472 ± 170 pumps vs 615 ± 174 pumps, P = 0.017), with no differences observed in ICE (524 ± 170 pumps vs 503 ± 141 pumps, P > 0.99). Mean BART total adjusted pump count was also higher post-trial in AMB than ICE (615 ± 174 pumps vs 503 ± 141 pumps, P = 0.039; Figure 4B).

Mean pre-trial [salivary cortisol] was similar between AMB and ICE (0.74 ± 0.60 μg×dL vs 0.78 ± 0.53 μg×dL, P = 0.75). No interaction (P_{int} = 0.42), trial (P_{trial} = 0.45) or time (P_{time} = 0.32) effect was observed for [salivary cortisol]. [Salivary cortisol] was similar from pre-to post-trial in both AMB (0.74 ± 0.60 vs 0.56 ± 0.42 μg×dL, P = 0.41) and ICE (0.78 ± 0.53 μg×dL vs 0.76 ± 0.58 μg×dL, P = 0.91).

DISCUSSION

We sought to determine the effect of heat stress on maximal strength and risk-taking behavior amongst HCWs wearing full-body PPE during simulated decontamination exercise and to assess the efficacy of pre-activity ice slurry ingestion to alleviate any adverse effects observed. Our findings demonstrate that this group of HCWs experienced relatively mild thermal strain and were exposed to higher environmental heat stress within the PPE as compared to ambient conditions. Despite the mild thermal strain, impairments in maximal strength and elevated risk-taking behavior were observed amongst HCWs which may have negative ramifications on HCW and patient safety and health. Ice slurry ingestion reduced pre-activity T_c and thermal sensation and successfully ameliorated decrements to maximal strength and risk-taking behavior, suggesting its potential as an ergogenic aid in similar settings.

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HCWs in the present study experienced higher levels of environmental stress where PPE microenvironment WBGT (29.1 ± 2.1ºC) was higher than ambient environmental WBGT (25.9 ± 0.8ºC). This is likely contributed by endogenous heat production and impaired heat dissipation mechanisms resulting from the highly insulative nature of PPE (1, 3). Despite the exposure to higher levels of environmental heat stress when encapsulated by PPE, HCWs in the present study experienced relatively mild levels of physiological strain (mean peak T_c < 38.0ºC) and minimal T_c rise. Peak T_c in both trials averaged 37.7 ± 0.4ºC. However, 24% of individuals in AMB and 18% in ICE did exceed the 38.0ºC T_c threshold as suggested by the American Conference of Governmental and Industrial Hygiene (ACGIH) threshold limit values (TLV) to limit heat-related injuries (41). These findings agree with prior research reporting minimal T_c rise and low thermal strain amongst HCWs (15, 16) but contrast studies which observed T_c greater than 38.0ºC (14, 42). For example, a mean T_c of 38.9 ± 0.4ºC was observed amongst individuals donning PPE carrying out simulated clinical activities utilizing a 60-min continuous treadmill walking protocol at 2.5mph, 0% grade at 32°C and 92% RH (42). However, real-world clinical activities are rarely continuous and are typically carried out over a longer duration but at a lower intensity. In addition, while a separate study more closely profiled HCWs in a real-world setting (i.e., high-level isolation unit), albeit in less harsh environments at 20°C, 30-40% RH (14), the profiling was conducted over 4-h compared to the 2-h simulation in the present study. These differences in environmental conditions, duration and intensity of the activities profiled may have attributed to the discrepancies in T_c observed. Notwithstanding, individuals presenting with higher levels of thermal strain (above 38.0ºC) were still prevalent in this group of HCWs. This, coupled with their unique challenges (e.g., prolonged working hours of varying intensities, avoidance of taking breaks, limited ability to doff PPE, etc. (12)), may exacerbate physiological

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strain experienced by HCWs putting them at risk of occupational heat strain and its adverse effects.

These adverse effects include impairments in maximal strength and increased risk-taking behavior, as observed amongst HCWs despite the mild thermal strain attained in this study. Heat stress has been associated with neuromuscular fatigue and a reduction in motor activity, with neuromuscular impairments occurring progressively as T_c increases rather than only after attaining a specific T_c (43, 44). Thus, the deleterious effects on maximal strength despite the mild thermal strain may have resulted from a combination of environmental heat exposure, physiological and thermal strain, and prior activity (i.e., simulated decontamination exercise) exacerbating the onset of neuromuscular fatigue in the heat. While HCWs can experience increased muscular fatigue and physical exhaustion (3, 12), this study represents one of the first to objectively assess muscular strength amongst HCWs. Importantly, these impairments in maximal strength may lead to compromised patient care. For example, reduced maximal strength may result in an increased risk of musculoskeletal injuries and impact the ability of HCWs to perform physically demanding tasks effectively (e.g., lifting and moving patients) and life-saving tasks/procedures that require good manual dexterity and strength (e.g., intubation to secure airways or establishing intravenous cannulation), potentially compromising patient care (2, 3).

Heat stress can also impair psychological functioning, resulting in reduced psychomotor vigilance and impaired decision-making processes (2, 44). This in turn can affect risk-based decision-making and changes in risk perceptions and risk-taking behavior (19, 20). We had previously hypothesized that the cortisol stress response might modulate the increase in risk-

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taking behavior due to the association between elevated salivary cortisol and increased risk-taking behavior and impaired decision-making (22). However, although risk-taking behavior increased, [salivary cortisol] remained similar across time and between trials. This may be explained by the relatively mild increase in T_c and lighter exercise intensity during the simulated decontamination exercise (21, 45), in comparison to marked increments in plasma cortisol concentration observed when T_c is greater than 39.0ºC and exercise intensity higher than 60% (45, 46). Thus, our findings suggest that the cortisol stress response is unlikely to account for the increased risk-taking behavior observed. Instead, the elevations in T_{sk} accompanied by higher environmental heat exposure independent of significant T_c elevations (47), may have contributed to the increased risk-taking behavior observed amongst HCWs in this study. In healthcare settings, the ramifications of our findings can be potentially severe. Risk is generally understood to be intrinsic to healthcare, with clinical decisions undergoing risk evaluation processes that weigh potential harms against potential benefits (48). However, while some level of risk is "unavoidable" in healthcare (48), increased risk-taking behavior that affects adherence to safety procedures and an increase in "avoidable" workplace accidents (e.g., misjudgment, misdiagnosis and/or medication errors) may jeopardize HCWs and patients under their care (49).

Given the negative consequences of these impairments, strategies aimed at alleviating these adverse effects are necessary. Thus, ice slurry ingestion was utilized as a pre-activity cooling measure and was effective in reducing pre-activity T_c and thermal sensation amongst HCWs in this study. During the simulated decontamination exercise, ice slurry ingestion had minimal influence on T_c and HR. However, an apparent reduction in chest T_{sk} was observed, contributing to the lower mean aPSI in ICE than AMB. Ice slurry ingestion may induce potential

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compensatory reductions in heat dissipation mechanisms by reducing the perceived need for heat dissipation by stimulating abdominal thermoreceptors and affecting signals relayed to the preoptic area of the hypothalamus (50, 51). However, these reductions in chest T_{sk} may not represent an adverse effect of ice slurry ingestion, given that the highly insulative nature of PPE utilized would limit the impact that differences in vasomotor responses may have on heat dissipation (3). Instead, the lowered chest T_{sk} may have positively influenced the HCWs' perceptions of thermal comfort, which has been suggested to influence cognitive functioning (47, 52). Thus, it is plausible that the lowered chest T_{sk}, and subsequent lowering of mean aPSI following ice slurry ingestion may improve thermal comfort and lower physiological strain, attenuating the increase in risk-taking behavior. Furthermore, given the role of the central nervous system in neuromuscular fatigue and cognitive and psychological impairments, reductions in brain temperature following ice slurry ingestion (53, 54) may have contributed to the observed attenuations in the decrements in maximal strength and risk-taking behavior in the present study. Although several mechanisms have been speculated, this represents the first study to demonstrate the effectiveness of ice slurry ingestion in reducing impairments in maximal strength and risk-taking behavior following physical activity in the heat, with further studies required to fully elucidate the exact mechanisms underlying the effectiveness of ice slurry in this regard.

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Limitations

Several methodological considerations limit interpretations of the results of this study. The study simulated chemical decontamination activities at a constant pace over a fixed duration of 2-h to ensure standardization between trials. However, real-world clinical work can be highly

variable depending on factors such as staffing, patient load and complexity of medical conditions. Furthermore, participants recruited had not been previously diagnosed with chronic medical conditions (e.g., cardiovascular disease or diabetes) and also not on long-term medications (e.g., beta-blockers, metformin) that can impair thermoregulation and compound the risk of developing heat-related illnesses (55) as part of ethical considerations. Taken together, physiological monitoring during a real-world chemical disaster or pandemic-response activity would be ideal to properly assess the physical, cognitive and mental stresses HCWs face in high-intensity emergency settings, including individuals at potentially greater risk due to their chronic medical conditions. The study was also not sufficiently powered to determine sex differences in physiological strain, performance measures, or ice slurry responses. Males and females may have differing responses to heat exposure (56, 57) and risk-taking behavior (58). Furthermore, females represent 67% of the health sector workforce (59), and future work to delineate potential sex differences is warranted. Lastly, real-life risk-taking decisions are influenced by factors, such as past experiences, personal values and ethical considerations that may not be fully encapsulated within the BART test. Although this study represents the first to demonstrate an increase in risk-taking behavior in HCWs following physical activity in the heat, more extensive confirmatory studies with multiple assessment methods are required for a more comprehensive understanding of the impacts heat exposure has on risk-taking behavior. Additionally, while the study demonstrates the benefits of pre-activity ice slurry ingestion, the feasibility of such a measure during real-world deployments would require further considerations before full implementation can be achieved.

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CONCLUSIONS

HCWs experienced mild levels of thermal strain and higher levels of environmental heat stress when donning full-body PPE and carrying out simulated decontamination activities. Despite the lower level of thermal strain, impairments in maximal strength and increased risk-taking behavior were observed. These deleterious effects were alleviated with pre-activity ice slurry ingestion, suggesting its potential as an ergogenic aid in similar settings. More broadly, this study highlights the potentially severe ramifications of heat exposure in healthcare settings, where reductions in strength and an increase in risky behaviors may jeopardize the health and safety of HCWs and patients under their charge. This underscores the importance of further research exploring the impact of heat exposure on risk-taking behavior and the need for appropriate mitigation strategies.

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FIGURE LEGENDS

Figure 1. Schematic representation of study design. Note: MVC, maximal voluntary contractions; BART, balloon analogue risk-taking task; [salivary cortisol], salivary cortisol concentrations; USG, urine specific gravity; T_c, core temperature; HR, heart rate; T_{sk}, chest skin temperature; RPE, ratings of perceived exertion; RTS, ratings of thermal sensation.

Figure 2. Mean (A-E) and Peak (F-J) measures of PPE microenvironment WBGT (A, F), core temperature (B, G), heart rate (C, H), chest skin temperature (D, I) and adaptive physiological strain index (E, J) calculated during the simulated decontamination exercise. Absolute data are presented as mean and SD (error bars). Individual data are presented as small symbols. * ($P < 0.05$) and ** ($P < 0.01$) denotes significant difference between AMB and ICE trials. Note: PPE, personal protective equipment; WBGT, wet bulb globe temperature; SD, standard deviation; AMB, ambient drink; ICE, ice slurry.

Figure 3. Mean (A) core temperature, (B) heart rate, (C) chest skin temperature and (D) adaptive physiological strain index at 5-min intervals during the pre-activity drinking and simulated decontamination exercise. Horizontal axis shading depicts pre-activity drinking (blue) and simulated decontamination exercise (grey). Mean (E) ratings of perceived exertion and (F) ratings of thermal sensation at pre-drinking, post-drinking, and post-trial. Absolute data are presented as mean and SD (error bars). Individual data (E, F) are presented as small symbols. * ($P < 0.05$), ** ($P < 0.01$) and *** ($P < 0.001$) denotes significant difference between AMB and ICE trials. Note: SD, standard deviation; AMB, ambient drink; ICE, ice slurry.

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Figure 4. Mean (A) MVC output and (B) BART adjusted total pump count during pre- and post-trial measurements. Absolute data are presented as mean and SD (error bars). Individual data are presented as small symbols. * ($P < 0.05$) and ** ($P < 0.01$) denotes significant difference between trials. Note: MVC, maximal voluntary contractions; BART, balloon analogue risk-taking task; SD, standard deviation.

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Figure 1

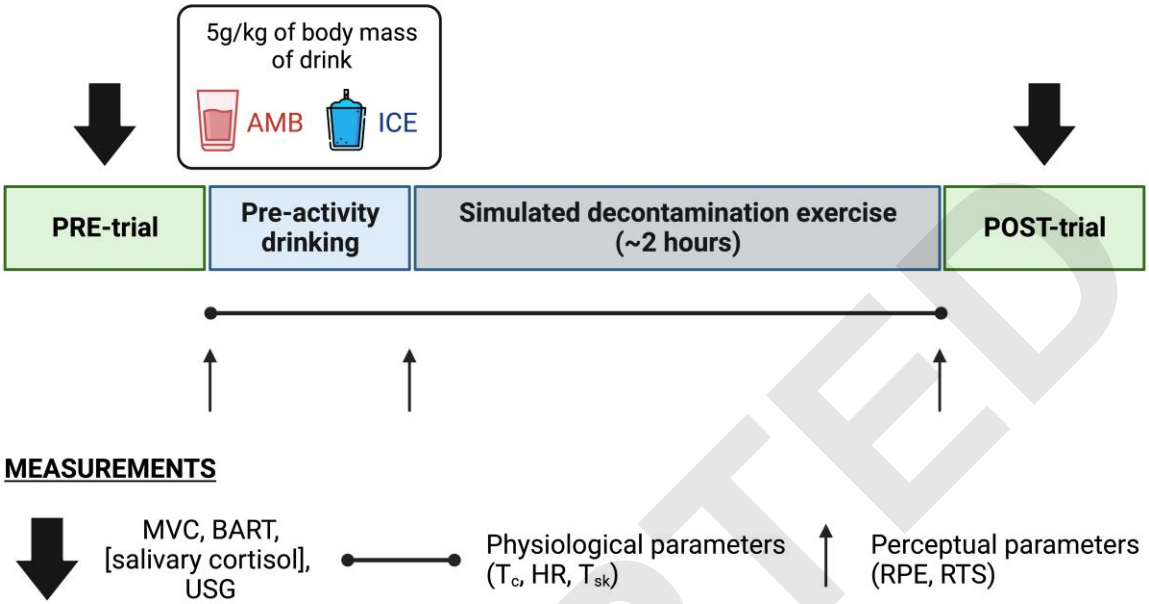

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Figure 2

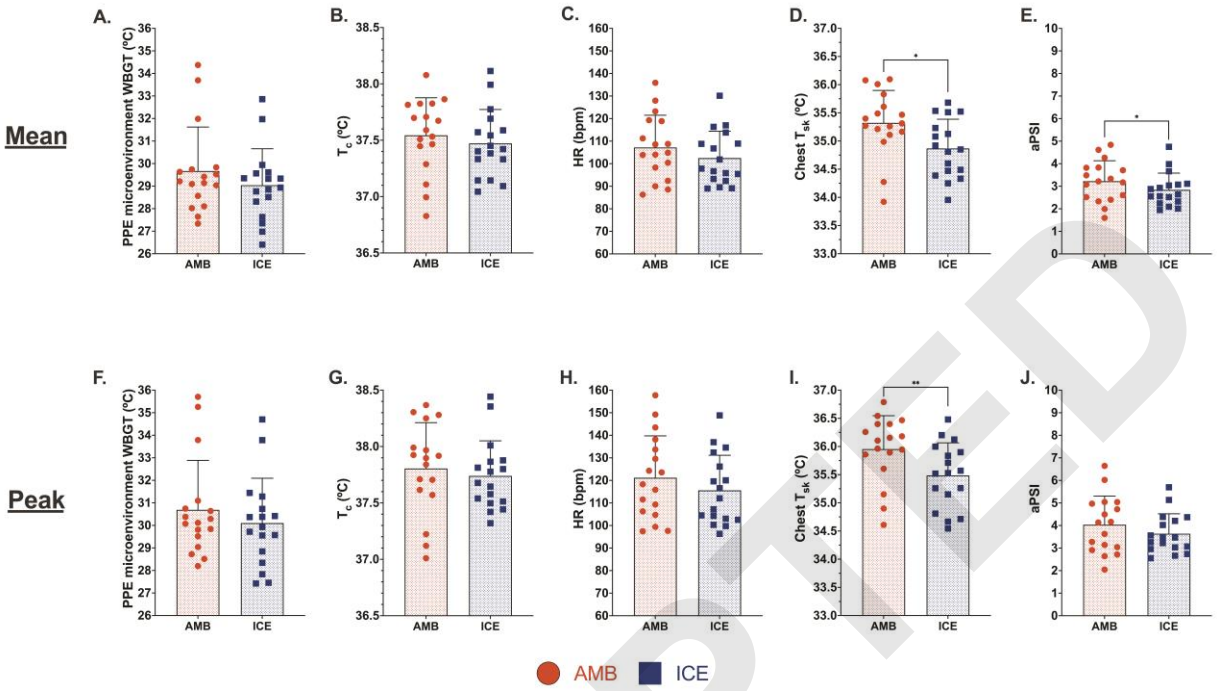

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Figure 3

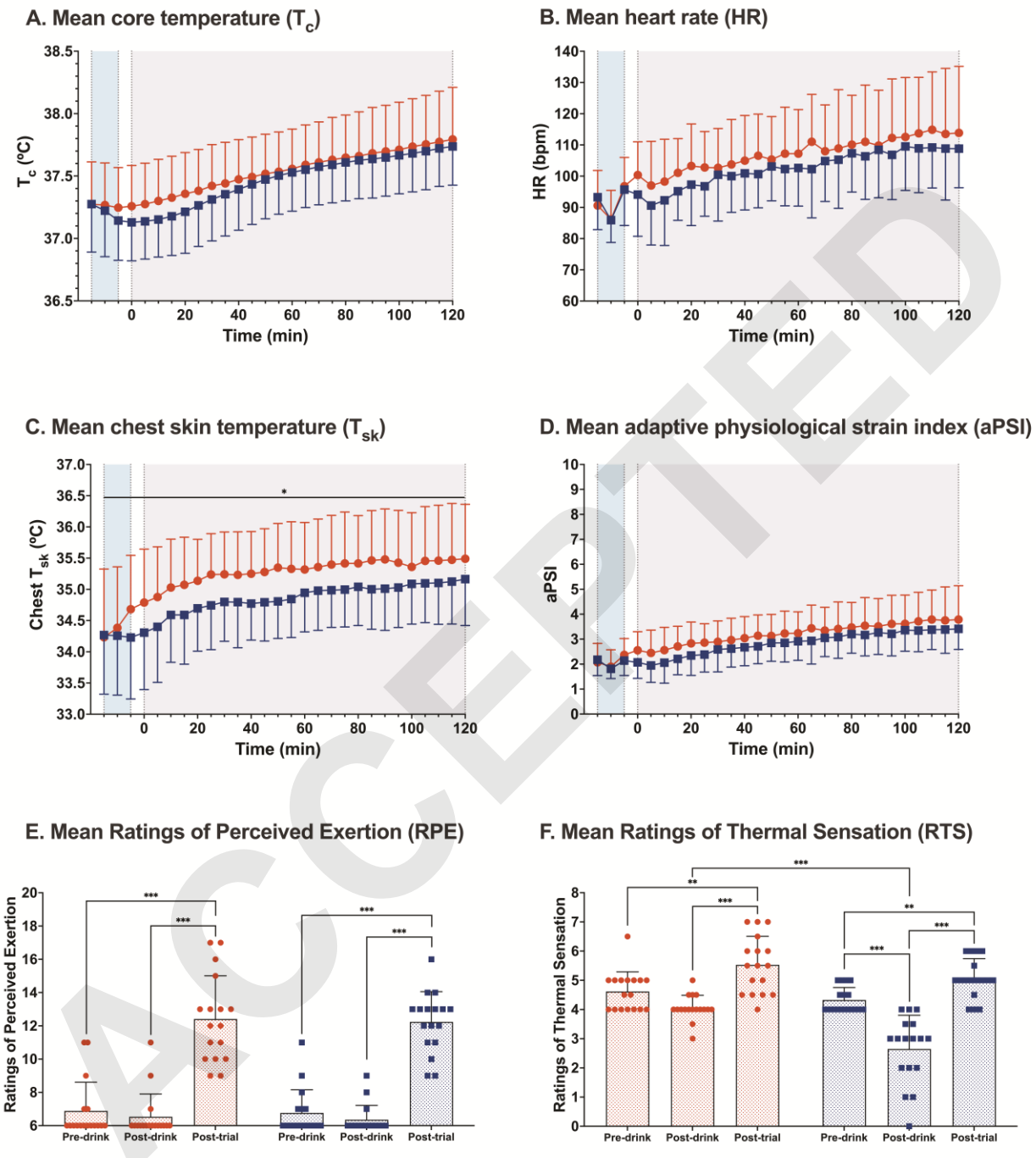

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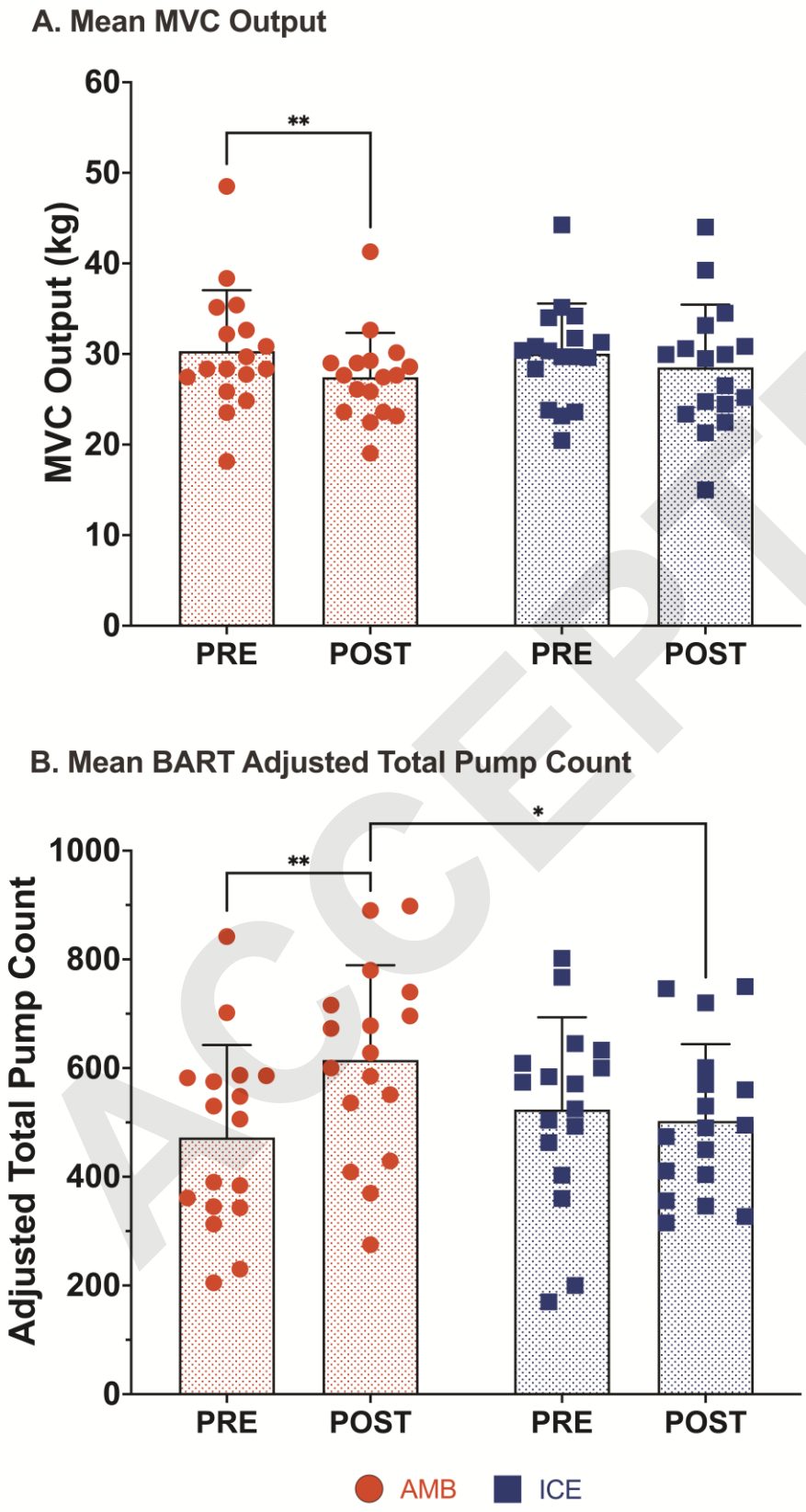
Figure 4



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Tables

Table 1. Participant characteristics. Data are presented as mean ± SD [range].

Characteristic	**Total (n=17)**	**Male (n=10)**	**Female (n=7)**	**p-value[a]**
Age (years)	31 ± 9 [24 – 53]	33 ± 9 [24 – 53]	29 ± 7 [24 – 45]	0.38
Height (m)	1.65 ± 0.07 [1.50 – 1.74]	1.68 ± 0.05 [1.57 – 1.74]	1.62 ± 0.08 [1.50 – 1.70]	0.11
Body mass (kg)[b]	66.6 ± 12.2 [49.3 – 91.0]	71.5 ± 10.4 [57.0 – 91.0]	59.8 ± 11.5 [49.3 – 81.9]	0.048
Body Mass Index (kg/m^2)	24 ± 3 [19 – 31]	25 ± 3 [22 – 31]	23 ± 3 [19 – 28]	0.076

[a]p-value are for sex comparisons for various anthropometric measures derived using independent *t*-tests.

[b]body mass includes participants' personal clothing.

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