

RESEARCH PAPER

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## Exercise in personal protective equipment in a hot, humid environment does not affect risk propensity

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### ABSTRACT

We tested the hypothesis that heat stress created by light exertion in encapsulating personal protective equipment (PPE) in a hot, humid environment increases risk propensity. Ten healthy subjects ( $29 \pm 7$  y) completed 2 trials presented in a counter-balanced manner. Subjects donned encapsulating PPE, and in one trial they wore a tube-lined shirt underneath that was perfused with  $5^\circ\text{C}$  water. Subjects completed 2 15 min bouts of walking exercise on a treadmill at 50% maximal heart rate in a  $32^\circ\text{C}$ , 81% RH environment. Subjects completed the Balloon Analog Risk Task (BART), an objective measure of risk-taking, before, between the 2 exercise bouts, and following the final exercise bout. Personal cooling lowered ( $P < 0.01$ ) mean skin temperature by  $8.0 \pm 1.6^\circ\text{C}$ . Intestinal temperature rose ( $P < 0.01$ ) in both trials, but was lower ( $P < 0.01$ ) at the end of exercise in the cooling trial ( $38.0 \pm 0.3^\circ\text{C}$  vs.  $37.6 \pm 0.3^\circ\text{C}$ ). BART derived indices of risk propensity were not affected by trial or time (trial  $\times$  time interaction:  $P \geq 0.33$ ). These data indicate that 60 min of exposure to mild heat stress created by light exertion in encapsulating PPE does not affect risk-taking behavior.

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### Introduction

Healthcare workers treating patients stricken with or exposed to highly infectious diseases (e.g., Ebola) must wear encapsulating personal protective equipment (PPE). By increasing insulation and impeding evaporation, PPE represents a significant barrier to heat loss.<sup>1–3</sup> Thus, even in cool environments healthcare workers often experience increases in skin and core temperatures (i.e., heat stress),<sup>4–6</sup> which are exacerbated in hot and/or humid conditions,<sup>7</sup> such as those occurring in West African Ebola Treatment Units 8.

Heat stress elicits cardiovascular strain,<sup>9</sup> and sensations of warmth and thermal discomfort.<sup>9</sup> Heat stress is often, but not always,<sup>10–12</sup> associated with impaired cognitive functioning, particularly on complex tasks that involve aspects of memory and executive functioning.<sup>13–18</sup> Importantly, such cognitive changes can be brought about with relatively mild heat stress that involves only elevations in skin temperature.<sup>19</sup> As a result, heat stress is accompanied by an increased incidence of unsafe behaviors<sup>20</sup> and errors<sup>21,22</sup> in the workplace. Thus, healthcare workers wearing PPE, together with the subsequent development of heat

stress, may undertake behaviors that compromise the health and safety of both the worker and their patients.<sup>8</sup> One such behavior impacting workplace safety is the tendency to undertake risky behaviors.<sup>23</sup> However, interactions between PPE and heat stress on risk propensity is unknown.

The purpose of this study was to test the hypothesis that 60 min exposure to heat stress while wearing encapsulating PPE, similar to the conditions and practices in West African Ebola Treatment Units,<sup>8</sup> increases the propensity to take risks compared to a condition in which the magnitude of heat stress will be attenuated via personal cooling under the PPE.

### Methods

#### Subjects

Ten healthy subjects participated in this study (5 males). The subject characteristics are shown in Table 1. All subjects were physically active, non-smokers, not taking medications, and were free of any known cardiovascular, metabolic, neurological, or psychological diseases. Each subject was fully informed of

**Table 1.** Subject characteristics (mean  $\pm$  SD).

	Males	Females	All
Number of subjects	5	5	10
Age (y)	27 $\pm$ 7	32 $\pm$ 6	29 $\pm$ 7
Height (cm)	175 $\pm$ 4	163 $\pm$ 4	169 $\pm$ 8
Weight (kg)	80.9 $\pm$ 6.8	62.0 $\pm$ 4.2	71.5 $\pm$ 11.3

the experimental procedures and possible risks before giving informed, written consent. The study was approved by the Institutional Review Board at the University at Buffalo and conformed to the latest revision of the Declaration of Helsinki.

### Study overview

Subjects visited the laboratory on 4 occasions. Visit one was a screening session, while visit 2 was a PPE fitting and familiarization session. The remaining 2 visits involved the experimental trials, which are described in detail below. The experimental trials were separated by at least 48 h, but completed at the same time of day within a subject. For these trials, subjects arrived at the laboratory euhydrated, confirmed via urine specific gravity ( $1.008 \pm 0.006$ , no differences between trials:  $P = 0.08$ ) and having refrained from strenuous exercise and alcohol for a period of 24 h and caffeine for 12 h. In females, menstrual cycle phase was not controlled for. This was deemed acceptable given that female healthcare workers are required to work in encapsulating PPE throughout their menstrual cycle, ensuring external validity of the present findings. That said, the 2 experimental trials were conducted within the same menstrual cycle phase within a subject. Experimental testing was conducted during the winter months in Buffalo, NY, USA and as a result heat acclimatization was likely minimal.<sup>24</sup>

### Instrumentation and measurements

Six to 8 hours prior to experimental testing, each subject swallowed a telemetry pill (HQ Inc., Palmetto, FL, USA) for measurement of intestinal temperature. Mean skin temperature was measured as the weighted average of 4 thermocouples attached to right side of the body.<sup>25</sup> Heart rate was measured via a Polar heart rate monitor (Polar Electro, Kempele, Finland). Nude body weight was measured using a standard scale (Sartorius Corp. Bohemia, NY, USA) to quantify percentage changes in body weight pre- to post- exercise. Urine specific gravity was measured in duplicate using a refractometer

(Atago USA, Inc., Bellevue, WA, USA). Perceived exertion (0 = 'extremely easy' to 10 = 'extremely hard'), sweating (1 = 'not sweating' to 10 = 'drenching sweat'), thermal comfort (0 = 'comfortable' to 4 = 'very uncomfortable'), thermal sensation (0 = 'comfortable' to 5 = 'very hot'), and dyspnea (0 = 'nothing at all' to 10 = 'maximal') were measured on standard scales.<sup>26-28</sup>

Risk propensity was measured using the computerized Balloon Analog Risk Task [BART (Inquisit by Millisecond Software, Seattle, WA, USA)], a validated behavioral assessment of risk-taking.<sup>29</sup> During this task, subjects inflated simulated balloons on a computer screen. Subjects earned \$0.02 for each pump, which was achieved by clicking the mouse. After each pump, subjects could either 'bank' the money earned and move on to the next balloon or they could continue pumping the balloon and earning more money. However, if the balloon 'exploded', which happened on a random basis, the subjects would lose all money earned for that balloon. Subjects completed 30 balloons during each testing session and they received all money earned. Outcome variables were: money earned, the total number of balloons that exploded, total balloon pumps, and the average number of pumps on balloons that did not explode (i.e., adjusted average pump count). Subjects were not familiarized with this task prior to experimental testing.

Dexterity was quantified via a tool dexterity task.<sup>30</sup> During this task, right-handed subjects used their left hand to pass a bolt through one of 4 holes in an upright board mounted to a table. The test administrator handed a washer to the subject's right hand for them to place over the protruding bolt. Subjects then took a nut from the tabletop and thread it onto the bolt. Next, subjects picked up a closed-end wrench and a torque wrench and applied at least 54.4 kg of force to the assembly. This process was repeated until all 4 holes in the board were filled. The outcome variable was the length of time required to complete the task. Subjects practiced the entire task 3 times prior to their first experimental trial.

### Experimental protocol

Subjects completed 2 experimental trials, a Control Trial and a Cooling Trial. Both trials were identical except that in the Cooling trial, the subject wore a tube-lined long-sleeved shirt (weight: 1.3 kg, Med-Eng, Ottawa, ON, Canada) under the scrub top (which was

under the PPE ensemble) that was perfused with 5°C water throughout the duration of the 60 min work period. To eliminate the added thermal load, the tubelined shirt without cold water running through it was not worn during the Control Trial. The order of these trials was presented in a counter-balanced manner.

Upon arrival at the laboratory, urine specific gravity was assessed and nude weight was measured. While outside of the environmental chamber in a ~23°C environment subjects were fitted with a heart rate monitor and then donned a scrub top and pant, as well as the PPE ensemble, which was comprised of a properly sized hooded coverall (ChemMax 1, Lakeland Industries, Ronkonkoma, NY, USA), a double layer of nitrile gloves, an N95 particulate filter respirator (KC300, Kimberly-Clark, Roswell, GA USA), goggles, autopsy apron, and rubber boots (Hellfire, Thorogood Boots, Eau Claire, WI, USA). This ensemble is consistent with CDC recommendations for treating Ebola patients. Subjects then completed the BART and the dexterity task, in that order, in the seated position. They then entered the environmental chamber maintained at  $32 \pm 1^\circ\text{C}$ ,  $81 \pm 9\%$  RH, and walked on a treadmill for 15 minutes. Notably, these environmental conditions simulate the hot-humid conditions encountered in West African Ebola Treatment Units.<sup>8</sup> In the first experimental trial (independent of whether it was the Control or Cooling Trial), the treadmill speed was adjusted within the first 5 min of exercise to elicit  $50 \pm 4\%$  of age predicted maximum heart rate (e.g., 220-age). This treadmill speed ( $2.6 \pm 0.3$  km/h) was maintained constant throughout the remainder of the trial and kept the same during the subsequent trial. This intensity is equivalent to approximately 3 metabolic equivalents (METs), the average metabolic expenditure associated with health-care related activities.<sup>31</sup> After this period of exercise, subjects stepped off the treadmill, while remaining in the environmental chamber, and completed the BART and the dexterity task, in the standing position, the total duration of which was 15 min. After these assessments, the subjects walked on the treadmill for another 15 min, which was followed by the completion of the final BART and dexterity tasks. Thus, the entire experiment was 60 min in duration, approximating the work times observed in West African Ebola Treatment Units.<sup>8</sup> Heart rate, intestinal and mean skin temperatures, and perceptual measures were measured every 5 minutes during exercise, and

immediately following the final BART and dexterity tasks. Following these final assessments, subjects exited the environmental chamber and nude weight was measured.

### **Data and statistical analyses**

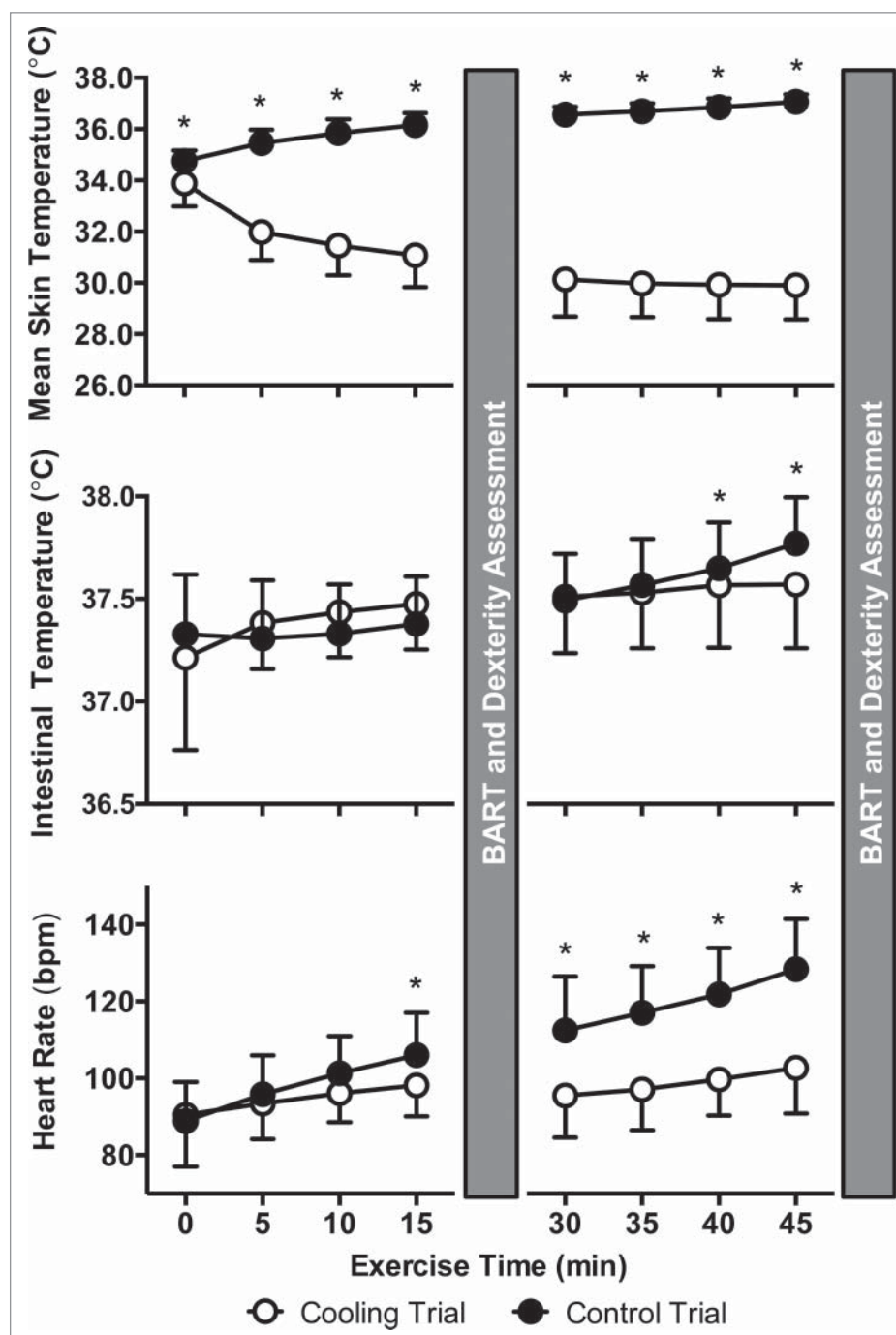
Data were analyzed using 2-way (main effects: trial  $\times$  time) repeated measures analysis of variance, and where appropriate, post hoc Sidak adjusted pair-wise comparisons were made. Data were analyzed using Prism software (Version 6, GraphPad Software Inc. La Jolla, CA, USA). A priori statistical significance was set at  $P \leq 0.05$  and actual p-values are reported where possible. All data are reported as mean  $\pm$  SD.

## **Results**

### **Physiological and perceptual responses**

Immediately upon arriving at the laboratory, intestinal temperatures and heart rates were not different ( $P \geq 0.55$ ) between the Control ( $37.2 \pm 0.4^\circ\text{C}$ ,  $66 \pm 6$  bpm) and Cooling ( $37.3 \pm 0.3^\circ\text{C}$ ,  $64 \pm 7$  bpm) Trials. Upon commencement of exercise, mean skin temperature was lower ( $P < 0.01$ ) during the Cooling Trial, which persisted throughout the duration of the trial (Fig. 1). Intestinal temperature did not differ ( $P \geq 0.24$ ) between trials through 35 min, but was higher ( $P < 0.01$ ) thereafter in the Control Trial compared to the Cooling Trial (Fig. 1). Heart rate was not different ( $P \geq 0.60$ ) between trials through 10 min of exercise, but was higher ( $P \leq 0.04$ ) during the Control Trial thereafter (Fig. 1). Notably, differences in heart rate (Control Trial:  $139 \pm 14$  bpm, Cooling Trial:  $100 \pm 12$  bpm,  $P < 0.01$ ), intestinal temperature (Control Trial:  $38.0 \pm 0.3^\circ\text{C}$ , Cooling Trial:  $37.6 \pm 0.3^\circ\text{C}$ ,  $P < 0.01$ ), and mean skin temperature (Control Trial:  $37.2 \pm 0.4^\circ\text{C}$ , Cooling Trial:  $29.2 \pm 1.3^\circ\text{C}$ ,  $P < 0.01$ ) persisted after the final BART and dexterity assessments. Body weight decreased to a greater extent ( $P < 0.01$ ) during the Control ( $-0.7 \pm 0.2\%$ ), compared to the Cooling ( $-0.2 \pm 0.1\%$ ) Trial.

Perceived exertion, thermal sensation, thermal comfort, and the perception of sweating were all higher ( $P < 0.05$ ) during the initial stages of exercise in the Control, compared to the Cooling Trial, which persisted throughout the remainder of the trial (Fig. 2). Although dyspnea was not different ( $P \geq 0.16$ ) between trials through 35 min of exercise,



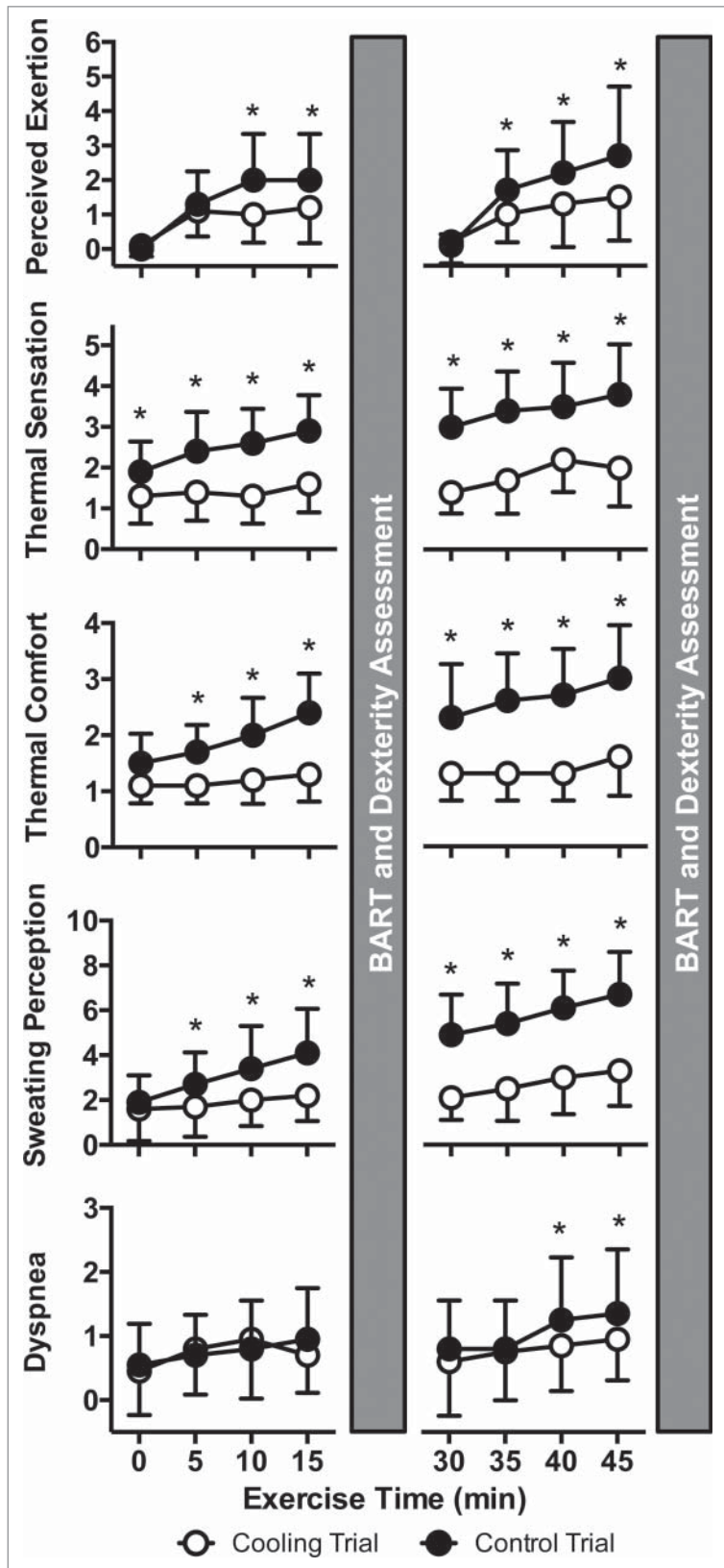
**Figure 1.** Mean skin temperature, intestinal temperature, and heart rate during exercise while wearing encapsulating personal protective equipment in a hot and humid environment during the Control Trial and during the Cooling Trial in which a long sleeved, tube-lined shirt was perfused with 5°C water ( $n = 10$ ). Data are mean  $\pm$  SD. \* Different from Cooling Trial ( $P \leq 0.04$ ).

ratings of dyspnea were higher ( $P < 0.01$ ) during the Control Trial thereafter (Fig. 2).

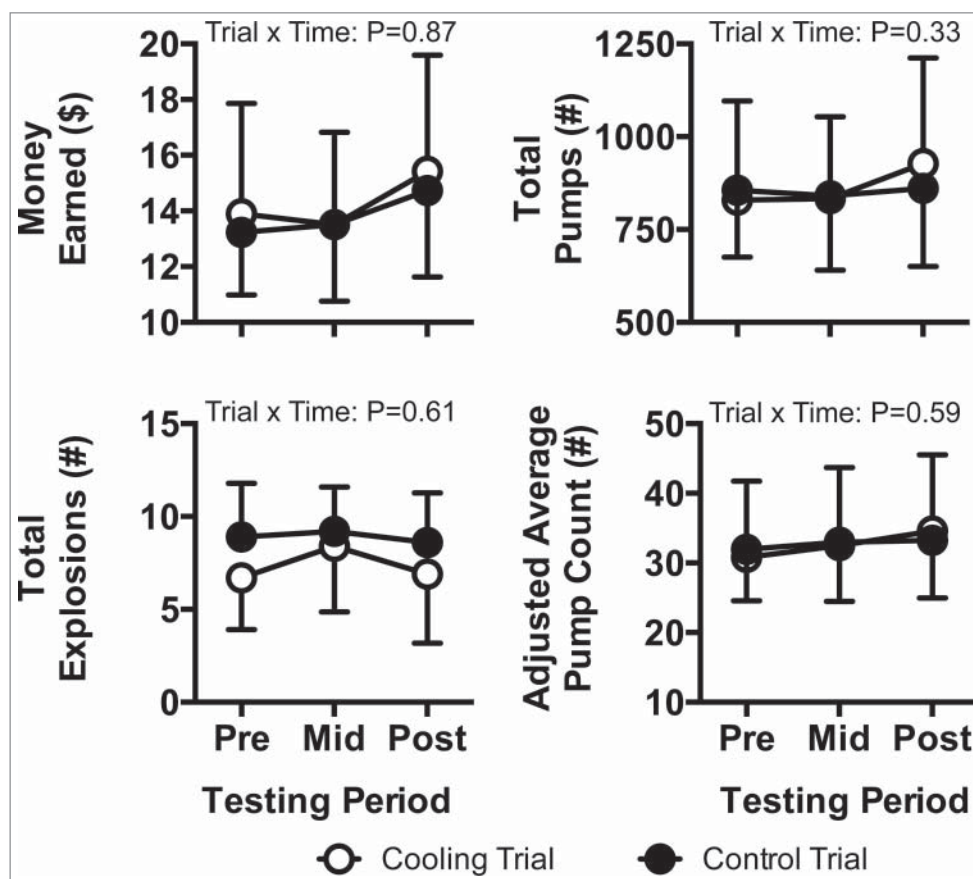
#### **Risk propensity and dexterity**

Money earned on the BART did not differ between the Control and Cooling Trials at any time point

(Trial  $\times$  time Interaction:  $P = 0.87$ , Fig. 3). Other measures of risk propensity also did not differ between trials at any time point (Trial  $\times$  time Interactions: total explosions -  $P = 0.61$ , total pumps -  $P = 0.33$ , adjusted average pump count -  $P = 0.59$ , Fig. 3). Time to complete the dexterity tool task also was not different (Trial  $\times$  time



**Figure 2.** Perceived exertion, thermal sensation, thermal comfort, sweating perception, and dyspnea during exercise while wearing encapsulating personal protective equipment in a hot and humid environment during the Control Trial and during the Cooling Trial in which a long sleeved, tube-lined shirt was perfused with 5°C water (n = 10). Data are mean ± SD. \* Different from Cooling Trial (P ≤ 0.05).



**Figure 3.** Money earned, total explosions, total pumps, and adjusted average pump count on the Balloon Analog Risk Task during assessments conducted before exercise (Pre), following 15 min of exercise (Mid), and after the final 15 min of exercise (Post) while wearing encapsulating personal protective equipment in a hot and humid environment during the Control Trial and during the Cooling Trial in which a long sleeved, tube-lined shirt was perfused with 5°C water ( $n = 10$ ). There were no significant Trial  $\times$  time interactions for any comparisons ( $P$ -values for these interactions are reported). Data are mean  $\pm$  SD.

Interaction:  $P = 0.88$ ) between the Control (mean:  $59 \pm 3$  s) and Cooling (mean:  $61 \pm 2$  s) Trials at any time point.

## Discussion

This study tested the hypothesis that 60 min of heat stress while wearing encapsulating PPE during exercise in a hot, humid environment increases risk propensity. In contrast to our hypothesis, 60 min exposure to a 32°C and 81% RH environment interspersed with light intensity intermittent exercise had no effect on objective measures of risk propensity in the Control Trial (Fig. 3). Personal cooling clearly attenuated physiological (Fig. 1) and perceptual (Fig. 2) heat stress responses, but did not affect risk-taking behavior (Fig. 3). Collectively, the findings of the current study suggest that 60 min of mild heat stress associated with exercise at an intensity approximating the metabolic

demands of healthcare work while wearing encapsulating PPE does not affect risk propensity.

### Risk-taking and heat stress

To our knowledge, this is the first study to objectively quantify changes in risk propensity during heat stress. Increases in core and skin temperatures,<sup>13-18</sup> and even increases in skin temperature alone,<sup>19</sup> are associated with reductions in many aspects of cognitive performance, although this is not always observed.<sup>10-12</sup> Furthermore, work during heat stress is accompanied by an increased incidence of unsafe behaviors<sup>20</sup> and errors<sup>21,22</sup> in the workplace. Thus, working in PPE together with development of heat stress likely alters behavior, which can compromise the health and safety of both the healthcare workers and their patients. One such behavior that is important for safety in the workplace is the willingness to undertake risky behaviors.<sup>23</sup>

Therefore, it is surprising that the assessed measure of risk-taking was largely unaffected by the magnitude of heat strain imposed by experimental conditions and that the alleviation of heat strain by personal cooling provided no benefit (Fig. 3).

The precise rationale underlying these observations is not entirely clear. As the present findings suggest, it may be that exercise and heat stress does not affect risk propensity. However, recent findings indicate that acute, competitive exercise increases risk-taking in young males.<sup>32</sup> Therefore, there are 3 possible reasons either independently or in combination that may explain why risk-taking was unaffected in the current paradigm. 1) The intensity of the exercise was light (50% heart rate max) and relatively short (30 min total duration). Thus, risk propensity may have been affected had the exercise been of higher intensity and/or a longer duration. 2) The level of heat stress was mild, i.e., the increase in intestinal temperature during the Control Trial was only 0.6°C. This mild heat stress was a product of both the light exercise intensity and relatively short trial duration. Nevertheless, it may be that if the increase in body temperature was higher (in the 1.0 – 1.5°C range) the evaluated risk-taking indices may have been affected. However, it should be noted that the level of heat stress incurred in the present study was similar to that observed in healthcare workers practicing in West Africa Ebola Treatment Units.<sup>8</sup> 3) This study utilized both male and female subjects ( $n = 5$  in each group). It is known that males typically undertake more risky behavior than females.<sup>33</sup> Notably however, post hoc analysis of our data indicates that the risk propensity responses observed for the group on the whole were similar to that which occurred in males and females independently (data not shown). Furthermore, this analysis also found that there were no differences ( $P \geq 0.21$ ) in risk propensity between sexes. However, these findings are not conclusive given the low number of subjects in each group and that this study was not designed to discern differences between sexes. Thus, further research is required in order to fully understand the impact of heat stress on risk propensity.

### **Personal cooling mitigates physiological and perceptual strain**

According to media reports, work times are reduced by more than 75% than that expected (40 vs. 180 min) in

the hot and humid West Africa Ebola Treatment Units. This is undoubtedly due to the profound physiological and perceptual heat strain associated with working in encapsulating PPE.<sup>34,35</sup> Personal cooling is a proven strategy to minimize heat strain while wearing PPE, which can improve work tolerance.<sup>36</sup> Unfortunately, a lack of formal evidence has limited its use in healthcare settings. To date, only 2 studies, with limited subject numbers (range: 1–6 subjects), have examined the efficacy of personal cooling in settings typically encountered by healthcare workers.<sup>6,37</sup> These studies have identified that personal cooling while wearing non-encapsulating surgical PPE during exposure to environments approximating modern medical environments (e.g., surgical theaters, 23–27°C) lowered skin temperatures, improved thermal comfort, and decreased sensations of warmth.<sup>6,37</sup> The current study, which featured a larger cohort of subjects, extends these findings to more austere thermal conditions and demonstrates that personal cooling alleviates all measured aspects of physiological (Fig. 1) and perceptual (Fig. 2) strain during work in encapsulating PPE at a metabolic demand that is typical of healthcare related activities. Such findings suggest that personal cooling may be effective at extending work tolerance while wearing encapsulating PPE in hot, humid conditions.

### **Strengths and limitations**

This study has several strengths. First, we quantified risk-taking using an objective measure, as opposed to relying on subjective self-reports. Second, we used both male and female participants. It is critical to utilize females in such studies, as the overwhelming majority of healthcare workers are female. Third, we used a strong, repeated measures design. This study also has limitations. First, this was a pilot study that recruited a relatively small number of subjects, which prevented us from formally evaluating differences in risk propensity between sexes. Second, the magnitude and duration of heat stress was relatively mild. Thus, the impact of greater levels of heat stress on risk propensity remains unknown. Third, all of our subjects were young and healthy, which may have reduced our likelihood of observing an impact of heat stress on risk-taking. It is likely, therefore, that healthcare workers treating patients with highly infectious diseases will be older and perhaps less healthy. Finally, healthcare workers are often sleep deprived and/or fatigued,<sup>38</sup>

both of which can impact risk propensity.<sup>39,40</sup> However, interactions between sleep deprivation or fatigue, PPE, and heat stress on risk propensity remains unknown. Clearly, future studies need to focus on a broader range of age and fitness levels, and mimic more 'real life' circumstances in order for these data to be translated to the healthcare workplace.

## Conclusions

The present study demonstrates that 60 min exposure to heat stress associated with wearing encapsulating PPE during exercise simulating the metabolic demands of healthcare related activities in a hot, humid environment does not affect risk-taking behavior. Personal cooling was effective at mitigating physiological and perceptual heat stress responses under the imposed conditions, but had no effect upon risk propensity.

## Abbreviations

BART Balloon Analog Risk Task

PPE Personal Protective Equipment

## Disclosure of potential conflicts of interest

No potential conflicts of interest were disclosed.

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