

Moderate Thermal Strain in Healthcare Workers Wearing Personal Protective Equipment During Treatment and Care Activities in the Context of the 2014 Ebola Virus Disease Outbreak

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The extent of thermal strain while wearing personal protective equipment (PPE) during care activities for Ebola virus disease patients has not yet been characterized. From January to March 2015, 25 French healthcare workers (HCWs) in Conakry, Guinea, volunteered to be monitored while wearing PPE using an ingestible thermal sensor. The mean (standard deviation) working ambient temperature and relative humidity were 29.6°C (2.0°C) and 65.4% (10.3%), respectively; the mean time wearing PPE was 65.7 (13.5) minutes; and the mean core body temperature increased by 0.46°C (0.20°C). Four HCWs reached or exceeded a mean core body temperature of $\geq 38.5^{\circ}\text{C}$. HCWs wearing PPE for approximately 1 hour exhibited moderate but safe thermal strain.

Keywords. healthcare workers; treatment and care activities; personal protective equipment; Ebola virus disease outbreak; heat stress; core body temperature.

The treatment of patients with Ebola virus disease (EVD) requires that healthcare workers (HCWs) wear personal protective equipment (PPE). Although PPEs are designed to enhance personal safety, these garments impose a heat burden that may impair the performance of assigned tasks [1, 2]. Thus, quantifying the thermal strain experienced by HCWs performing treatment and care activities (TCAs) under harsh conditions is a prerequisite for accurately determining the appropriate PPE to ensure HCW safety. To date, such studies are scarce, and, to our

knowledge, none have been performed under field conditions [3]. To determine the heat stress induced by PPE in the field, we quantified the heat strain of French HCWs during deployment at an Ebola healthcare center in Conakry, Guinea, in 2015.

METHODS

This study was performed from January to March 2015 at an Ebola healthcare center in G'Bessia, Conakry, Guinea.

Subjects and PPE

Dormitories were the only air-conditioned premises. The HCWs performed all other nonworking activities, such as eating or exercising, outdoors to enable acclimatization to the conditions in Guinea.

The PPE was used in accordance with the World Health Organization regulations [4]. It comprised waterproof garments from head to toe (DuPont Tychem), European standard EN 143-approved class 2 respirators (3M Company), 2-layered gloves (nitrile long-sleeve gloves under the garment, nitrile short-sleeve gloves taped to the garment) with an extra latex glove worn over the 2-layered gloves during work, in accordance with the French Ministry of Health regulations [5], surgical hoods covering the head and neck, leg-covering waterproof boot covers, and waterproof aprons covering the torso to the level of the midcalf. The time of exposure to PPE (t-PPE) was defined as the time elapsed from respirator placement to respirator removal. Heat illness was defined as the onset of cramps, exhaustion, syncope or profound neuropsychiatric impairment during or after exercise [6].

Heart Rate and Core Body Temperature Measurements

We considered heart rate (HR) an indirect index of the intensity of working activities. It was continuously measured and recorded every 20 seconds using a wireless chest heart transmitter and recorder (Polar RS800CX; Polar Electror). Because artifacts in the PPE resulted in an excessive amount of invalid data for some subjects, HR analysis was restricted to the onset and the end of TCAs, using the averaged values collected during a period from 1 minute before to 1 minute after the beginning or the end of TCAs. Because TCA values were not standardized, HRs were compared with a theoretical maximal HR to determine the average intensity of physical activity during TCAs. The theoretical maximal HR was calculated according to Tanaka et al [7] was $208 - (0.7 \times \text{Age})$ for both female and male subjects.

Core body temperature (Tco) was assessed by continuously measuring the gastrointestinal temperature with an ingestible thermometer sensor (CorTemp sensor HT15002 and data recorder HT150016; HQ). The sensor was ingested at least 6 hours before donning of the PPE. The sensor transmitted the gastrointestinal temperature to a waterproof wearable receiver for data storage. The Tco was subsequently recorded while

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HCWs wore PPE during TCAs within the area that was contaminated with infected patients.

Fluid Loss Assessment

Hydration status was assessed after monitoring the change in body mass (BM) from before to after TCAs while wearing PPE. Dry subjects in their underwear were weighed using a calibrated scale (Seca 910; SECA) before and after wearing PPE. The subjects towed off after removing the PPE and before being weighed. Dehydration was expressed as a percentage of BM using the following formula:

$$\text{Dehydration} = \frac{(\text{pre-TCA BM} - \text{post-TCA BM})}{(\text{pre-TCA BM}) \times 100}$$

Because the HCWs did not ingest water during their shifts of TCAs, BM loss (BML, in liters) and t-PPE (in hours) were used to calculate the sweating rate (SR, in liters per hour), according to the following equation:

$$\text{SR} = \text{BML} / \text{t} - \text{PPE}.$$

Statistical Analysis

The data were recorded using Excel 2010 software (Microsoft) and analyzed using PASW Statistics 18 (SPSS). Discrete variables were compared using χ^2 or Fisher exact tests when required. Continuous variables with a normal distribution were presented as the means (standard deviations [SDs]) and were compared using analysis of variance. Continuous variables with a nonnormal distribution were presented as medians with % interquartile ranges (25%–75%) and were compared using the Kruskal–Wallis test. Bilateral correlations between continuous variables were performed using the nonparametric Spearman rank correlation test. Differences were considered significant at $P < .05$.

Ethics Statement

This study was approved by the Human Research Ethics Committee of The Health Ministry of Guinea (No. 042). The participants were informed of the procedures, and all questions were answered before obtaining written consent for participation. The study conformed to the current Declaration of Helsinki guidelines.

RESULTS

Characteristics of the HCWs

Twenty-five French HCWs (11 female and 14 male; 9 nurses, 11 auxiliary nurses, and 5 physicians) volunteered for physiological monitoring during TCAs for patients with EVD. Their basic anthropometric characteristics are summarized in [Supplementary Table 1](#). Only 1 female HCW, with a BM index (BMI) of 34, was considered obese. Eight male HCWs had a BMI >25 , and 3 of the 8 had a mesomorph body type (ie, low body fat and large musculature).

Treatment and Care Activity Conditions

The mean (SD) ambient temperature and relative humidity during the Tco measurement periods were 29.6°C (2.0°C; ranging from 25°C at 03:10 to 33°C at 17:13) and 65% (10%; ranging from 42% at 03:10 to 83% at 17:15), respectively. Six shifts of TCAs were performed after sunset (approximately 19:00 local time).

Ambient Working Conditions

The HCWs underwent Tco measurements 17 days after arriving in Guinea before the initial recordings. For the entire HCW cohort, the mean (SD) t-PPE was 65.7 (13.5) minutes (range, 45–90 minutes). The mean time to remove the PPE was 15.5 (6.8) minutes (range, 7–34 minutes), accounting for 23.5% of the t-PPE.

Changes in HR

Mean (SD) HR shifted from 100/min (16/min; range, 67–137/min) at the onset of TCAs to 109/min (18/min; range, 64–132/min) at the end of TCAs, corresponding to 61% (7%; range, 40%–71%) of the theoretical maximal HR; no difference in HR was observed between male and female HCWs (see [Table 1](#)). HR and Tco at the onset of TCAs were correlated in the entire cohort ($r = 0.558$; $P < .01$; $n = 22$). However, among male HCWs, HR at the onset of TCAs was correlated with weight ($r = 0.63$; $P = .02$; $n = 13$) and Tco at the onset of TCAs ($r = 0.783$; $P < .01$; $n = 13$).

Changes in Tco

Among male and female HCWs, Tco increased by a mean of 0.15°C (0.30°C) while they were donning the PPE and reached 38.0°C (0.4°C) at the end of TCAs, immediately before removal

Table 1. Physiological Characteristics Before and After PPE Exposure

Characteristic	Mean (SD) Value		
	Baseline (Before Donning PPE)	Before TCAs	After TCAs
Heart rate/min			
Male HCWs	...	95 (15)	106 (18)
Female HCWs	...	107 (15)	114 (17)
P value	...	.08	.30
Tco, °C			
Male HCWs	37.3 (0.4)	37.5 (0.3)	37.9 (0.4)
Female HCWs	37.4 (0.4)	37.5 (0.4)	38.0 (0.5)
P value	.36	.77	.79
Sweating rate, L/h			
Male HCWs	...	...	0.8 (0.4)
Female HCWs	...	...	0.3 (0.2)
P value	...	...	.001
Dehydration, % of BM			
Male HCWs	...	...	1.03 (0.46)
Female HCWs	...	...	0.48 (.33)
P value	...	...	.003

Abbreviations: BM, body mass; HCWs, healthcare workers; PPE, personal protective equipment; SD, standard deviation; TCAs, treatment and care activities (time of PPE exposure); Tco, core body temperature.

of the PPE (see Table 1). The mean rate of Tco increase was 0.07°C (0.04°C)/10 min of TCAs. Four of the 25 HCWs reached or exceeded the working Tco limit of 38.5°C, and the maximal value was 38.7°C. The only predictive factor for reaching the working Tco limit was Tco before TCAs or before donning the PPE (see Supplementary Table 2).

Donning PPE induced a weak thermal strain because the associated rate of increase in Tco was limited. Tco during TCAs did not correlate with subject characteristics, such as BMI, age, or sex, or with environmental variables, such as relative humidity or ambient temperature. The correlation between t-PPE and the increase in Tco during TCAs was not statistically significant ($P = .59$). Figure 1 illustrates the changes in HR and Tco in a male HCW wearing PPE for a 65-minute shift of TCAs. Supplementary Figure 1 depicts representative cases of Tco at the onset of and during TCAs.

Loss of Body Mass

During the mean t-PPE, BML in the entire HCW cohort averaged 0.6 (SD, 0.41) kg, with a maximum of 1.5 kg. The BML in female HCWs (range, 0–0.7 kg; $n = 11$) was significantly less than that in male HCWs (mean [SD], 0.31 [0.23] kg vs 0.82 [0.38] kg; $P < .001$). BML was positively correlated with BMI ($r = 0.528$; $P < .01$) and age ($r = 0.482$; $P = .015$); however, multivariate analysis showed an association of BML only with sex. BML did not correlate with ambient temperature, relative humidity, or t-PPE regardless of sex.

The mean (SD) amount of dehydration was 0.79% (0.49%; range, 0%–1.68%) of BM. Dehydration was significantly less extensive in female than in male HCWs (see Table 1), and it did not correlate with ambient temperature, relative humidity or t-PPE. The mean (SD) SR in the entire cohort was 0.57 (0.41) L/h, corresponding to 9.5 mL/min, although the SR was significantly lower among female HCWs (see Table 1). The SR did not correlate with ambient temperature, relative humidity, or t-PPE, but it correlated with BMI ($r = 0.521$; $P < .01$), BML ($r = 0.938$; $P = .001$), and age ($r = 0.481$; $P = .02$).

DISCUSSION

The main finding of this field study was that HCWs wearing PPE while treating patients with EVD for a mean duration of 65.7 minutes exhibited only limited heat strain. The putative thermal burden was of major concern because high Tco is typically associated with fatigue and decreases in both motor and cognitive performance, thus increasing the risk of stress-related errors that could lead to hazardous self-contamination by HCWs.

Physiological responses to hot laboratory conditions or in the field under similar conditions have been well documented, such as in firefighters, miners or soldiers [8]. According to Sprecher et al [3], “standard testing procedures employed by the protective garment industry do not well simulate filovirus exposure.” Our study was the first to measure the level of heat strain

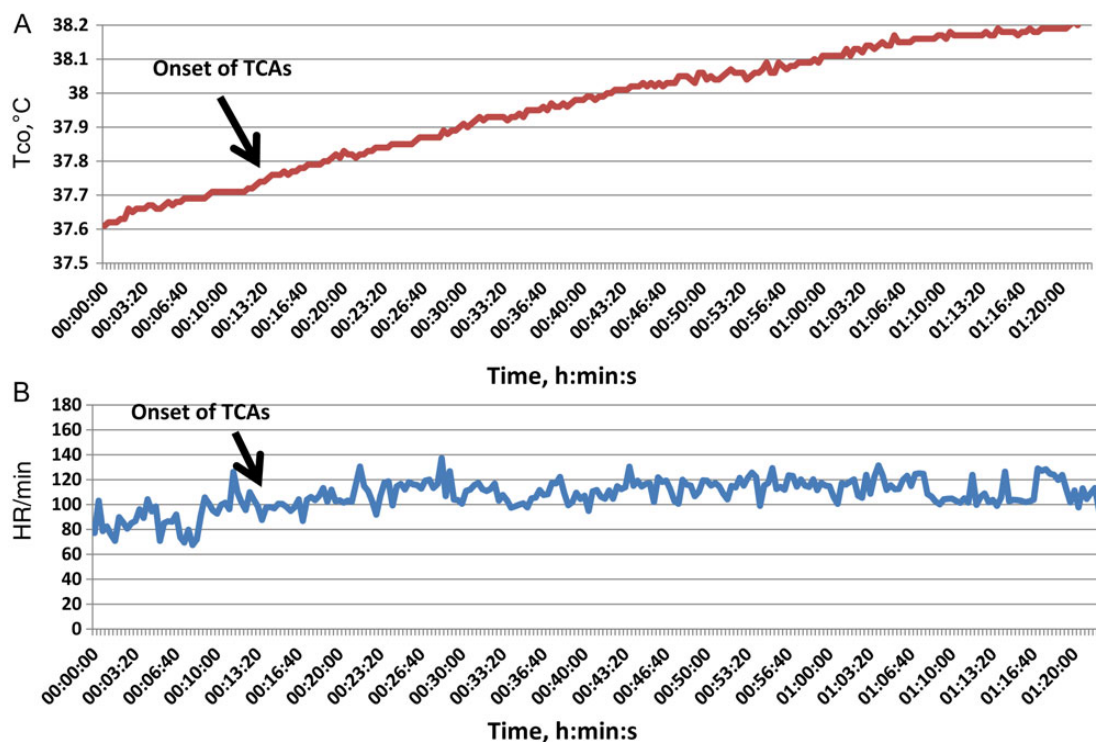


Figure 1. Changes in core body temperature (Tco; A) and heart rate (HR; B) during a 65-minute period of treatment and care activities (TCAs; onset at 17:15) exhibited by a 49-year-old male physician. Note the typical increase in Tco (rate of increase, 0.072°C/10 min) and the very stable HR (mean [standard deviation], 108/min [13/min]) throughout the period of TCAs. The ambient temperature and relative humidity were 31°C and 42%, respectively.

experienced by HCWs wearing PPE under field conditions. The limitations of this study include the absence of controlled environmental factors. However, ambient temperature and relative humidity varied within a small range, with mean (SD) values of 29.6°C (2.0°C) and 65% (10%), respectively, throughout the experiment.

The rate of increase in Tco during TCAs was 2-fold less than that measured by Brearley and coworkers [9] during a 35-minute simulated period of TCAs. This finding revealed that actual TCAs for patients with EVD required low energy expenditure, consistent with the moderate average HR observed during TCAs, corresponding to moderately intense activity according to the American Heart Association [10].

The observation of a low SR demonstrated that evaporative cooling via sweat production was mildly activated in HCWs during TCAs, leading to limited dehydration (ie, mean [SD] of 0.48% [0.33%] of BM among female HCWs and 1.03% [0.46%] among male HCWs) after the completion of TCAs. This rate was lower than the 2% decrease in BM typically associated with physical performance [11].

Despite their harsh ambient working conditions, no HCWs presented signs of or complained of heat illnesses, probably because of the short duration of each shift of TCAs (65.7 minutes). Several predisposing factors were present during this study, such as high ambient temperature, intense solar radiation, and dehydration [6]. Body fat is recognized as a strong risk factor for heat illness in the military, particularly among women [12]. Because 9 of the 25 HCWs (36%) had a BMI >25, excess body fat is probably not a deleterious factor in this cohort. However, other factors related to heat illness, such as the levels of physical fitness and sleep deprivation, were not recorded. A lack of acclimatization could be ruled out because the initial recordings were performed 17 days after arrival, beyond the 14 days of heat exposure considered to be required for acclimatization [13]. Fortunately, no HCWs complained of heat illness.

Thus, the data obtained from this field study were consistent with the results of Brearley et al [14], who showed that heat-acclimatized HCWs undertaking a standardized 70-minute simulated period of TCAs while wearing PPE in a hot environment (ambient temperature, 38.3°C; wet-bulb globe temperature, 32.3°C) exhibited a limited thermal burden. However, half of those individuals attained or exceeded the 38.5°C working Tco limit, and the maximal value was 38.8°C [14].

In conclusion, HCWs treating patients with EVD under the hot conditions of West Africa for a mean duration of 65.7 minutes did not experience a dangerous thermal burden. However, because approximately 4 of the 25 caregivers exhibited a Tco above the 38.5°C recommended upper limit for working [15], a simple device should be used to continuously monitor Tco

when the ambient working conditions become harsher, and thus hazardous, or when the duration of TCAs is expected to exceed 60 minutes.

Supplementary Data

Supplementary materials are available at <http://jid.oxfordjournals.org>. Consisting of data provided by the author to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the author, so questions or comments should be addressed to the author.

Notes

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