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Cooling vests alleviate perceptual heat strain perceived by COVID-19 nurses

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ABSTRACT

Cooling vests alleviate heat strain. We quantified the perceptual and physiological heat strain and assessed the effects of wearing a 21°C phase change material cooling vest on these measures during work shifts of COVID-19 nurses wearing personal protective equipment (PPE). Seventeen nurses were monitored on two working days, consisting of a control (PPE only) and a cooling vest day (PPE + cooling vest). Sub-PPE air temperature, gastrointestinal temperature (T_{gi}), and heart rate (HR) were measured continuously. Thermal comfort (2 [1–4] $versus$ 1 [1–2], $p_{condtition}$ < 0.001) and thermal sensation (5 [4–7] $versus$ 4 [2–7], $p_{condition}$ < 0.001) improved in the cooling vest $versus$ control condition. Only 18% of nurses reported thermal discomfort and 36% a (slightly) warm thermal sensation in the cooling vest condition $versus$ 81% and 94% in the control condition (OR (95%CI) 0.05 (0.01–0.29) and 0.04 (<0.01–0.35), respectively). Accordingly, perceptual strain index was lower in the cooling vest $versus$ control condition (5.7 ± 1.5 $versus$ 4.3 ± 1.7, $p_{condition}$ < 0.001, respectively). No differences were observed for the physiological heat strain index T_{gi} and rating of perceived exertion across conditions. Average HR was slightly lower in the cooling vest $versus$ the control condition (85 ± 12 $versus$ 87 ± 11, $p_{condition}$ = 0.025). Although the physiological heat strain among nurses using PPE was limited, substantial perceptual heat strain was experienced. A 21°C phase change material cooling vest can successfully alleviate the perceptual heat strain encountered by nurses wearing PPE.

Introduction

Nurses use personal protective equipment (PPE) to safely perform their medical duties during the treatment and management of infectious disease outbreaks. The high evaporative resistance of PPE materials forms an insulated microclimate around the skin, leading to an impaired dry and evaporative heat loss capacity [1–3], and elevation of heat stress levels [2]. The PPE-induced heat strain is associated with increased exertion [4], thermal discomfort [5] and displacement beyond the thermoneutral zone [5] whereas sensory displeasure impairs effective decision-making [6], even in the absence of elevated core temperature.

Cooling interventions such as ice slurry ingestion, facial water sprays, and cooling vests can immediately alleviate heat strain in challenging environmental conditions [7]. In sports science,

cooling interventions are known to improve exercise performance, decrease heat strain, and enhance post-exercise recovery [7]. Similar results are found when cooling interventions are applied in conjunction with PPE in first-responders and military personnel, resulting in reduced heat strain and improved work times [8,9]. In highly stressful environmental conditions, cooling vests are demonstrated as the most appropriate cooling intervention, as they are effective and feasible in most occupational settings [10]. Since the magnitude of heat strain encountered by COVID-19 nurses wearing PPE is unknown [11,12], it remains unclear whether a cooling vest will effectively alleviate the perceptual and/or physiological heat strain in COVID-19 nurses using PPE.

Therefore, we quantified the perceptual and physiological heat strain encountered by COVID-

19 nurses wearing PPE during real-life work shifts. Moreover, we assessed the effects of wearing a 21°C phase change material cooling vest on perceptual and physiological outcomes. We hypothesized that the use of PPE results in significant heat strain and that cooling vests can decrease the physiological and perceptual responses encountered by COVID-19 nurses.

Methods

Participants

Nurses working at a COVID-19 ward were recruited via local hospital infrastructures (i.e. outbreak management team, managers COVID-19 departments, and the occupational physician). Exclusion criteria were based on the use of the ingestible temperature capsule: I) a history of obstructive/inflammatory bowel disease or surgery, II) an implanted electro-medical device, III), or a scheduled MRI scan within 5 days of the experiment. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Medical Ethical Committee of the Radboud university medical center (#2020-6379). All participants gave written informed consent prior to study participation.

Design

Participants were continuously measured on two separate working days (7:30 a.m. to 4 p.m.) between April 16 and 10 May 2020, while performing COVID-19 medical duties. Experimental days were divided into a control (PPE only; surgical mask (type IIR) or FFP2 respirator, goggles, face shield (in case of aerosol-generating procedures), a long-sleeved gown, and gloves) and cooling vest day (PPE + cooling vest), in a randomized order. Each day consisted of 3 work bouts of ±3 hours, separated by a morning and lunch break. Participants used one cooling vest per work bout and wore the vests underneath PPE but over their standard medical scrub (Figure 1).

Phase change material cooling vest

In the cooling vest condition, participants were wearing an upper-body phase change material (PCM) cooling vest (21°C CoolOver, INUTEQ bv., Deventer, the Netherlands), that consisted of 36 PCM inserts (16 in front and 20 in back) and a thermoplastic polyurethane outer shell. The PCM cooling vest size was adjusted via two horizontal buckles to ensure an appropriate fit for all participants, but differences in contact surface area

Figure 1. Presentation of how the 21°C phase change material (PCM) cooling vest was worn over the standard medical scrub (a) and underneath the personal protective equipment (b).

may be present due to morphological differences. In preparation for the cooling vest day, the PCM cooling vests were activated in the refrigerator according to the manufacturer's instructions and were made available at the COVID-19 wards via a mobile cooler (70 Qt Xtreme Cooler, Coleman, US). The ready-to-use weight was 1.2 kg. After every single use, the PCM cooling vests were disinfected using alcohol and reactivated for subsequent use.

Measurements

Sub-PPE air temperature

The sub-PPE air temperature was continuously assessed at waist level. A monitor (Polar V800, Polar, Kempele, Finland) was attached to the participant's medical scrub belt loop. The sub-PPE air temperature was assessed at 1 s intervals, and minute averages were calculated using a customized MATLAB and Statistics Toolbox software package (2012b, The MathWorks, Inc., Natick, USA).

Perceptual measures

Thermal comfort, thermal sensation, and rating of perceived exertion (RPE) were ranked on a 4-point [13], 7-point [13], and a horizontal 10 cm visual analog scale, respectively. Thermal comfort ranged from 1 (comfortable) to 4 (very uncomfortable), thermal sensation from 1 (cold) to 7 (hot), and the rating of perceived exertion from 0 (very very light) to 10 (maximal exertion) and were determined by the distance (in cm) from the lower end of the visual analog scale to the mark placed by the participant. Perceptual measures were scored after each work bout and participants provided one value representing the entire work bout.

Perceptual strain index

The perceptual strain index was calculated according to the equation described by Tikuisis et al. [14]:

$$Perceptual strain index = 5 \cdot \frac{Thermal Sensation_t - 1}{6}$$
$$+ 5 \cdot \frac{Rating of perceived exerction_t}{10}$$

The values for thermal sensation and rating of perceived exertion were single scores and collected after each work bout.

Gastrointestinal temperature (T_{gi})

We used a validated ingestible electronic temperature capsule system (e-Celsius, BodyCap, Caen, France) [15] to continuously measure T_{gi} at predefined 1-min intervals. Participants ingested the temperature capsule 5–10 hours before the start of their workday, to avoid any interaction with fluid intake [16]. Upon the participant's arrival at the hospital, the electronic temperature capsule system was checked for functionality and settings. After the participants finished their workday, the recorded data were extracted using the e-viewer performance monitor.

Skin temperature

Due to the COVID-19 infection prevention measures in our hospital, we were not able to perform skin temperature measurements in any way.

Heart rate (HR)

HR was continuously measured at 1 s intervals using a V800 Polar system with a heart rate sensor worn around the chest (Polar, Kempele, Finland). HR measurements were started upon the participant's arrival at the hospital and ended after the participants finished their workday. Minute averages were calculated using a customized MATLAB and Statistics Toolbox software package (2012b, The MathWorks, Inc., Natick, USA).

Physiological strain index

The physiological strain index was calculated according to the equation described by Moran et al. [17]:

$$Physiological strain index = 5 \cdot \frac{T_{git} - T_{gi0}}{39.5 - T_{gi0}} + 5$$
$$\cdot \frac{HR_t - HR_0}{180 - HR_0}$$

The T_{git} and HR_t values represent minute averages over time per work bout. The T_{gi0} and HR_0 values represent baseline T_{gi} and HR values, defined as the lowest values reached during the first 15 minutes of each workday.

Air temperature

A centrally located iLog temperature logger (ESCORT Data Logging Systems, Auckland, New Zealand), placed at a 2-m height, was used to determine the ambient air temperature at the COVID-19 ward. The average air temperature was calculated for each experimental day.

Statistical analysis

Work bout averages and peak values of sub-PPE air temperature, T_{gi}, and HR were calculated for both experimental days. All parameters were visually inspected for normality. Continuous variables were presented as mean ± SD and categorical variables as proportions or as median [interquartile range]. Repeated measures ANOVA was used to assess changes over time within the control or cooling vest condition. Linear- and binary logistic generalized estimating equation analyses were used to compare differences across conditions over time. Odds ratios were calculated to compare the relative odds of the occurrence of thermal discomfort and (slightly) warm thermal sensations across conditions. Paired samples T-tests were used to compare differences across the control and cooling vest condition. Independent samples T-tests were used to compare differences across groups based on gender. Statistical analyses were performed with SPSS Statistics 25 (IBM Corp, Armonk, NY) and a p-value < 0.05 was considered significant.

Results

A total of 17 nurses, of which 5 males and 12 females, participated in the present study (Table 1). Males were taller (p < 0.001) and had a higher body surface area (p < 0.009) compared to females. One participant was excluded for T_{gi} analysis because the connection with the electronic temperature capsule was lost in the cooling vest condition. The average ambient air temperature at the COVID-19 ward was 23.2 ± 0.4°C at measurement days (7:30 a.m. to 4 p.m.).

PPE-induced heat strain

In the control condition, the sub-PPE air temperature was on average 30.4 ± 1.3°C throughout the day and increased over time (p_{time} = 0.004) up to peak values of 32.2 ± 1.6°C. Thermal comfort and thermal sensation

Table 1. Participant characteristics for groups based on gender.

	Males (N = 5)	Females (N = 12)	Total group (N = 17)
Age (years)	30 ± 2	31 ± 10	31 ± 8
Height (cm)	187 ± 6	171 ± 4	175 ± 9
Weight (kg)	83 ± 3	74 ± 18	76 ± 15
BMI (kg/m2)	23.8 ± 1.1	25.3 ± 6.3	24.9 ± 5.3
BSA (m2)	2.1 ± 0.1	1.8 ± 0.2	1.9 ± 0.2

BMI, body mass index; BSA, body surface area. Data is presented as mean ± SD.

were 2 [1–4] and 5 [4–7], respectively. After work bout 1, 59% of nurses reported thermal discomfort and 82% a (slightly) warm thermal sensation, which increased to 81% and 94%, respectively, after work bout 3 (Figure 2). The average RPE score and perceptual strain index over the whole day were 4.1 ± 1.5 and 5.7 ± 1.5, respectively (Figure 4(b)).

Baseline T_{gi} in the control condition was 37.2 ± 0.3° C A modest time-dependent increase in T_{gi} (0.2°C) was observed throughout the day, from 37.3 ± 0.3°C at work bout 1 to 37.5 ± 0.2°C at work bout 3 (p_{time} = 0.004). Accordingly, peak T_{gi} values increased from 37.6 ± 0.3 at work bout 1 to 37.7 ± 0.2 at work bout 3 (p_{time} = 0.036). Average HR and peak HR did not differ across working bouts in the control condition (p_{time} = 0.68 and p_{time} = 0.20, respectively). The physiological heat strain index was 2.6 ± 0.8 (Figure 4(a)).

Cooling vest effect

Although the average sub-PPE air temperature (30.3 ± 1.1°C) and rating of perceived exertion (4.1 ± 1.8) did not differ between the cooling vest and control condition ($p_{condition}$ = 0.74 and $p_{condition}$ = 0.86, respectively), thermal comfort (1 [1–2]) and thermal sensation (4 [2–7]) were significantly improved in the cooling vest compared to the control condition (both $p_{condition}$ values < 0.001). Only 18% of nurses reported thermal discomfort and 35% a (slightly) warm thermal sensation after work bout 3 in the cooling vest condition, compared to 81% and 94%, in the control condition (OR (95%CI) 0.05 (0.01–0.29) and 0.04 (<0.01–0.35), respectively, Figure 2). Accordingly, the perceptual strain index (4.3 ± 1.7) was significantly lower in the cooling vest condition compared to the control condition ($p_{condition}$ < 0.001, Figure 4(b)).

Baseline T_{gi} of 37.2 ± 0.4°C in the cooling vest condition did not differ compared to the control

Thermal Comfort
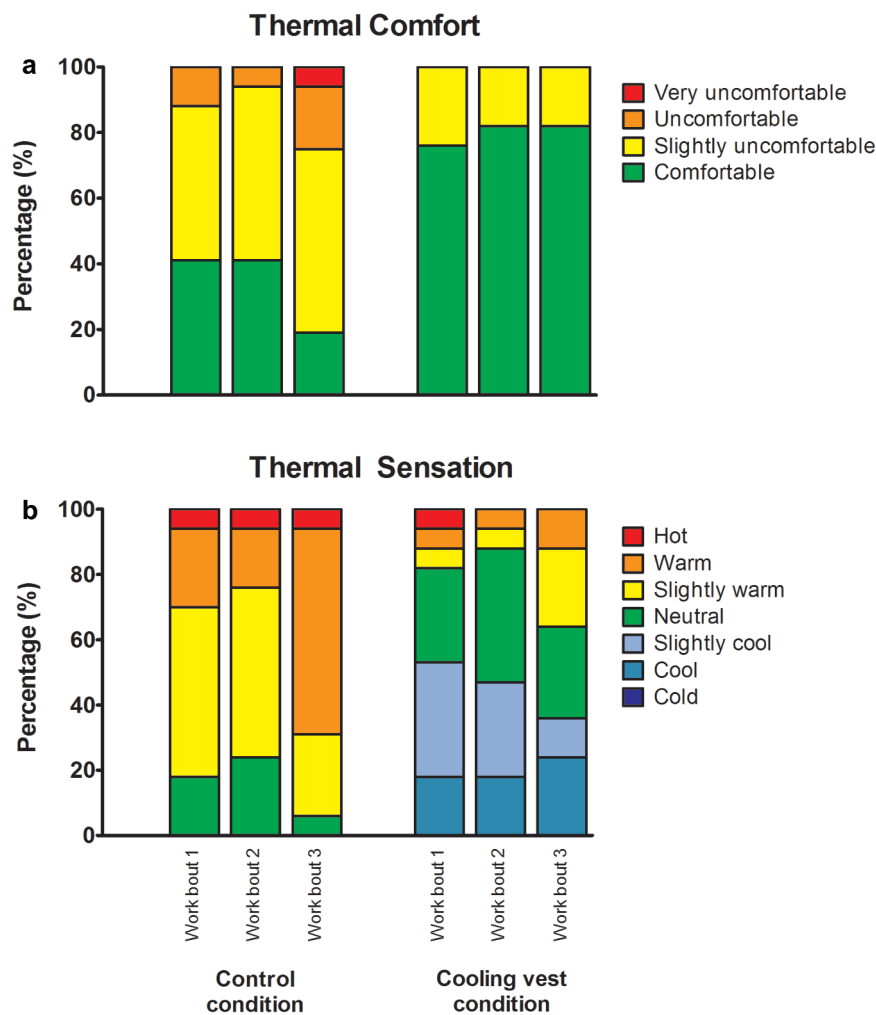

Thermal Sensation

Figure 2. Thermal comfort (panel A) and thermal sensation (panel B) across the three working bouts at the control and cooling vest condition. Significant improvements in thermal comfort ($p_{condition} < 0.001$) and thermal sensation ($p_{condition} < 0.001$) were observed during the cooling vest compared to control condition.

condition ($p_{condition} = 1.00$). Average T_{gi} and peak T_{gi} did not differ between the cooling vest and control condition ($p_{condition} = 0.90$ and $p_{condition} = 0.79$, respectively, Figure 3). However, average T_{gi} and peak T_{gi} did progressively increase in the control, but not in the cooling vest condition ($p_{interaction} < 0.001$ and $p_{interaction} = 0.015$, respectively, Figure 3). Although no differences were observed in the physiological heat strain in the cooling vest condition (2.5 ± 0.9) compared to the control condition ($p_{condition} = 0.40$, Figure 4(a)), an interaction effect across conditions was observed ($p_{interaction} = 0.003$, Figure 4(a)). No differences in peak HR were observed across conditions ($p_{condition} = 0.97$), whereas average HR was significantly lower in the cooling vest condition ($p_{condition} = 0.025$, Figure 3).

Discussion

The current study provides new insights into the perceptual and physiological heat strain encountered by nurses wearing PPE during real-life work shifts, and the effectiveness of wearing a 21°C phase change material cooling vest to mitigate perceptual and physiological heat strain. Our data showed that the increased insulation by PPE results in high sub-PPE air temperatures. Although the physiological strain among nurses using PPE was relatively low, the elevated environmental heat stress levels provoked substantial perceptual heat strain, as the large majority of our study population reported thermal discomfort and a (slightly) warm thermal sensation. More importantly, we found that the use of cooling vests can
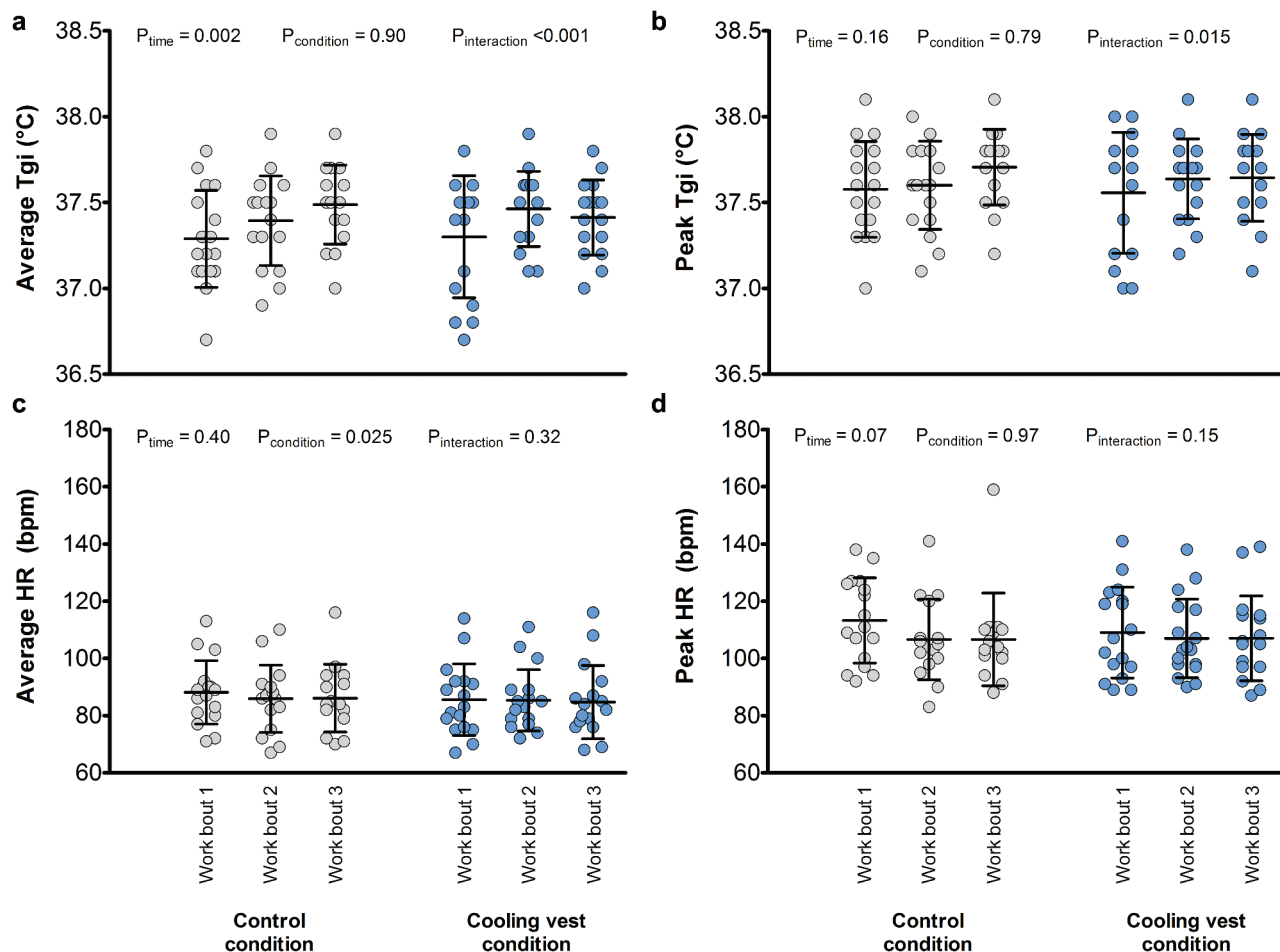
Figure 3. Average gastrointestinal temperature (T_{gi}) (panel A), peak T_{gi} (panel B), average heart rate (HR) (panel C), and peak HR (panel D) presented for the three working bouts at the control (gray circles) and cooling vest (blue circles) condition. A progressive increase in T_{gi} was observed in the control but not cooling vest condition ($p_{interaction} < 0.001$). Furthermore, average heart rate was lower ($p_{condition} = 0.025$) during the cooling vest compared to the control condition. Data is presented as individual data including a mean ± SD.

successfully alleviate thermal discomfort and warm thermal sensations in 63%, and 59% of nurses.

Environmental heat stress

Although the ambient air temperature at the COVID-19 ward was relatively low (23.2 ± 0.4°C), the increased insulation by PPE elevated the trapped sub-PPE air temperature up to peak values of 32.6 ± 1.6°C. It has been reported that trapped sub-PPE air temperature becomes higher and contains more water vapor relative to the surrounded air [18], leading to thermoregulatory challenges even in thermoneutral conditions close to 22°C [19]. The elevations in air temperature and humidity are caused by the combination of endogenous heat production [10] and the impaired dry and evaporative heat loss capacity induced by the insulative properties of PPE [1–3]. An increased sub-PPE air

temperature per se leads to a decrease in relative humidity when water vapor pressure remains constant because warmer air can contain more moisture. Evaporation of sweat further increases sub-PPE absolute humidity, leading to an additional attenuation of evaporative heat loss capacity. In COVID-19 practice, the encapsulation by PPE results in health-care personnel reporting high sweat rates and soaked clothing, making working conditions uncomfortable [20,21].

Perceptual heat strain

As much as 81% of nurses using PPE reported thermal discomfort and 94% a (slightly) warm thermal sensation at the end of their workday. These findings perfectly align with a recent study describing the experiences of health-care personnel during the COVID-19 outbreak in Hubei, China [20]. Health-
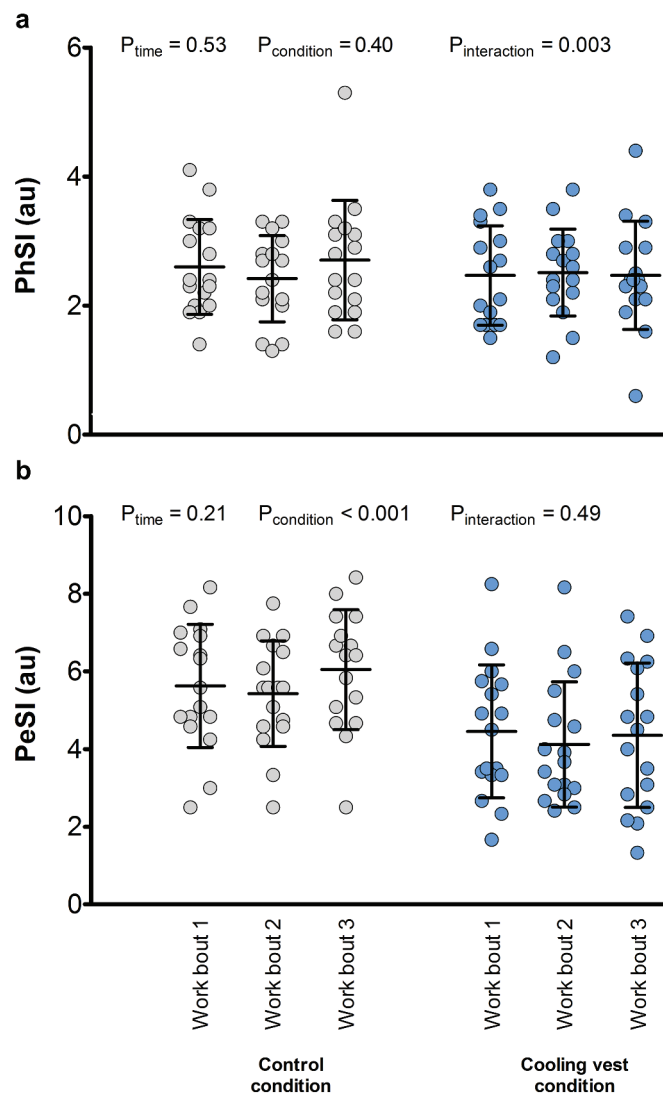
Figure 4. Physiological strain index (PhSI) (panel A) and perceptual strain index (PeSI) (panel B) presented for the three working bouts at the control (gray circles) and cooling vest (blue circles) condition. An interaction effect for physiological heat strain was observed across conditions ($p_{interaction}$ = 0.003). The perceptual heat strain was lower in the cooling vest condition compared to the control condition ($p_{condition}$ < 0.001). Data is presented as individual data including a mean ± SD.

care personnel in Hubei repeatedly reported that wearing the complete PPE ensemble is a major physical challenge, as PPE insulation is very uncomfortable and makes you feel very hot [20]. Similar results were reported in Hunan, China, illustrating that PPE use in COVID-19 health-care personnel resulted in fatigue and discomfort [22]. It is important to place the results of these qualitative studies into perspective. Both studies obtained their data during the early stages of the COVID-19 outbreak in China, during which the Chinese health care was overwhelmed and personnel were exhausted due to the shortage of personnel and the intensive, stressful, and long working hours [20,22]. On the other hand, a recent online survey describing the level of perceptual heat strain experienced by

COVID-19 health-care personnel wearing PPE in the United Kingdom (UK) demonstrates that 100% of personnel perceived (slightly) hot thermal sensations and ~99% experienced some level of thermal discomfort [21]. The discrepancy between our perceptual heat strain results and those of the online survey in the UK may be due to differences in PPE wear time, as ~73% of health-care personnel in the UK have work bouts longer than 4 h compared to ~2.5 h in our study population. Besides, the environmental conditions in health-care settings in the UK, especially in old buildings, are demonstrated to be more severe with higher ambient air temperatures (24–29°C) [23] compared to our study (~23°C). Conclusively, our data show that COVID-19 nurses wearing PPE experience significant

perceptual thermal strain, resulting in uncomfortable working conditions in thermoneutral conditions even with work bouts of <3 h, 2 breaks a day, and a high but still well-regulated workload.

Physiological heat strain

The link between PPE use and physiological heat strain in occupational work is well established [24]. The high evaporative resistance of PPE materials markedly limits the heat exchange with the environment through convection and evaporation of sweat [1–3], causing T_{gi} to increase in proportion to working intensity. In our study, however, we only observed relatively low physiological strain throughout the day (2.6 ± 0.8) with limited increases in T_{gi}. Peak T_{gi} temperature values were 37.7 ± 0.2°C with an individual maximal value of 38.2°C. Our findings are somewhat lower compared to values reported in young individuals exposed to laboratory simulated Ebola outbreak conditions in West Africa (38.9 ± 0.4°C) [25] or health-care personnel at an Ebola health-care center in Conakry, Guinea (38.0 ± 0.4°C) [26]. The discrepant findings are most likely due to differences in used PPE type, environmental conditions, and working/exercise intensity. For example, the ambient temperatures of the Ebola studies (32°C [25] and 30°C [26]) were substantially higher compared to the ambient temperature in our study, limiting the heat tolerance as dry heat loss is the primary avenue for heat exchange when individuals are capsuled in PPE [4]. Moreover, the laboratory-based Ebola study used 60 min of continuous treadmill walking at 4 km/h to mimic health care working activities [25], whereas real-life medical duties are typically intermittent, at a lower intensity but longer duration [20,22]. Taken together, it seems that the physiological heat strain is not the primary problem for nurses working at the relatively low intermittent intensity in thermoneutral environments wearing PPE even if sub-PPE air temperatures increase up to 32.6 ± 1.6°C.

Benefits of a cooling vest

The most important finding of our study is that the use of cooling vests can successfully alleviate thermal discomfort and (slightly) hot thermal sensations in 63%, and 59% of nurses. Accordingly, the perceptual strain was significantly lower in the cooling vest condition. Since sensory displeasure impairs effective decision-making [6], even in the absence of elevated core temperature, improving comfort might be helpful to nurses. During an already intensive and stressful crisis like the current COVID-19 pandemic, comfortable working conditions are of utmost importance. Outcomes from the present study, therefore, support the use of a cooling vest for nurses wearing PPE.

While the current study is a field study with a strong emphasis on practical implications, several implications of the cooling vest on thermal afferents and their relation to thermal effectors can be discussed. Concerning the thermal afferents, the cooling vest is placed on the torso, which is covered by non-glabrous skin (hairy skin). Non-glabrous skin is typically well insulated by clothing (not in direct contact with the environment) and is reported to provide strong auxiliary feedback signals for both autonomic and behavioral responses as it reflects the temperature of the superficial shell of the body[27]. Although no apparent changes in whole-body heat balance were detectable due to an insignificant change in core temperature, it is reasonable to assume that skin temperature of the torso was higher in the control condition compared to the cooling vest condition, which is supported in pilot measures that we conducted (Figure S1). However, in this study, we were only able to detect significantly lower thermal discomfort in the cooling vest condition compared to the control condition, which suggests a strong drive for a thermal behavior effector has been alleviated. Hence, performance degradation due to distraction by thermal discomfort may have been prevented.

Strength and limitations

To the best of our knowledge, we are the first to examine the effectiveness of wearing a cooling vest to mitigate perceptual and physiological heat strain encountered by COVID-19 nurses wearing PPE during real-life work shifts. Despite the applied and ecologically valid approach of our study, we were not able to measure the skin temperature responses of participating nurses due to the local COVID-19 infection prevention measures. As perceptual heat strain has been demonstrated to be strongly related to skin temperature [28–30], it is recommended that future (lab-based) studies take this into account. Another possible limitation may be the difference in the energy cost of locomotion between conditions due to the additional weight of the cooling vest. To account

for this, we considered the usage of non-activated cooling vests during the control trial. However, the use of non-activated cooling vests results in an inaccurate reflection of the thermal strain encountered by nurses during real-life work shifts with PPE. Therefore, we decided not to include non-activated cooling vests in the control condition, which might have resulted in an underestimation of the beneficial cooling effects. Lastly, the inability to blind participants to the aim of the study and the use of the cooling vests may have influenced our results. To reduce such bias as much as possible, we 1) randomized the condition order, and 2) provided neutral information toward study participants (i.e. the cooling vest can lower your temperature, but also adds weight to your medical scrub).

Conclusion and practical recommendations

Physiological heat strain among nurses wearing PPE is limited, but environmental heat stress induces substantial perceptual heat strain. We demonstrated that the use of a 21°C phase change material cooling vest can successfully alleviate perceptual heat. Hence, a cooling vest is now part of the standard medical scrub in nurses from our hospital that are involved in COVID-19 care. Based on our experience and feedback from end-users (i.e. nurses), we recommend to: 1) activate the phase change material cooling vest in a refrigerator, 2) wear the activated cooling vest over the standard medical scrub but underneath the personal protective equipment, 3) perform regular medical duties with cooling up to 3 hours, 4) remove and disinfect the cooling vest, 5) reactivate the cooling vest in the refrigerator (Figure 5). Finally, we want to emphasize that medical cooling vests
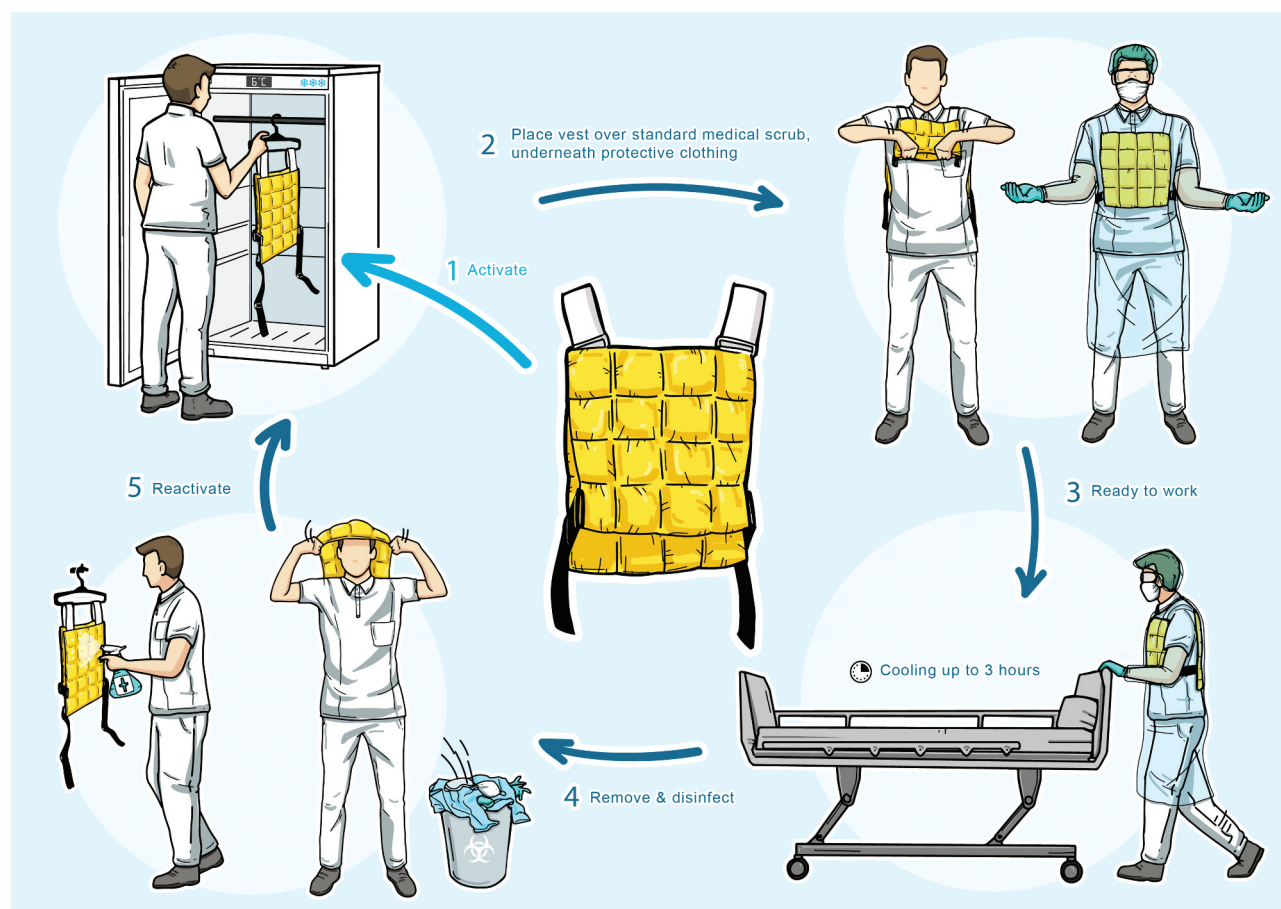

Figure 5. Schematic overview of practical recommendations to implement, activate, and use a 21°C phase change material-cooling vest to attenuate perceptual heat strain encountered by nurses during infectious disease outbreaks like the COVID-19 pandemic. (a) Activate the cooling in the refrigerator. Make sure the front and backside of the cooling vest are hanging straight down with some air in between. (b) Wear the activated cooling vest over the standard medical scrub and adjust the fit using the horizontal buckles to ensure the entire cooling vest is contact with the skin surface. Put the personal protective equipment over the cooling vest. (c) Perform regular medical duties with cooling power up to 3 hours. (d) Remove the personal protective equipment and cooling vest and disinfect accordingly. (e) Reactivate the cooling vest by placing it back into the refrigerator (see step 1) after which it can be re-used again.

can be used beyond the ongoing COVID-19 pandemic, as infectious disease outbreaks occur more frequently (i.e. SARS/MERS/Ebola), and occupational heat strain could be attenuated under these conditions as well.

Abbreviations

PPE	Personal protective equipment
Tgi	Gastrointestinal temperature
HR	Heart rate
PCM	Phase change material
COVID-19	Coronavirus Disease 2019

Data availability statement

Data that support the findings of this study are available from the corresponding author upon reasonable request. https://www.radboudumc.nl/coolvid

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