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WORK ACTIVITIES USING ENCAPSULATED PERSONAL PROTECTIVE EQUIPMENT: DISCOMFORT AND PHYSIOLOGICAL RESPONSE AT DIFFERENT WORKING ENVIRONMENT TEMPERATURES

TOTONG TOTONG[1], HERMAN RAHADIAN SOETISNA[2] and HARDIANTO IRIDIASTADI[3]

[1]Ph.D. Candidate, Faculty of Industrial Technology, Institut Teknologi Bandung, Bandung, Indonesia.
Email: totongtaqy@gmail.com
[2]Faculty of Industrial Technology, Institut Teknologi Bandung, Bandung, Indonesia.
Email: hermanrs@ti.itb.ac.id
[3]Faculty of Industrial Technology, Institut Teknologi Bandung, Bandung, Indonesia. Email: hiridias@vt.edu

Abstract

Background: Activities using level III personal protective equipment (PPE) in a hot work environment have the potential to cause heat stress which results in discomfort and excessive physiological responses. This study aims to evaluate the occurrence of discomfort and the physiological response profile when doing activities using PPE level III in different working conditions. **Methods**: The experiment was carried out cross-sectionally and within subject design (repeated measures) in 3 tests (20 °C, 25 °C and 30 °C with relative humidity (50 ± 10) %). Twelve participants with age of (23.7±2.4) years and body mass index of (24.3±3.3) kg/m^2 were using PPE level III and carried out a simulation of 6 activities consisting of physical activity, activities requiring concentration and manual dexterity activities for one hour. Microclimate temperature and humidity between skin and clothing, perceived comfort of heat, perceived comfort of wetness, core body temperature, and skin temperature were measured at the end of each activity. The amount of sweat and weight loss were measured after all activities were completed. **Result**: Working environment temperature (20 °C, 25 °C, and 30 °C) affects microclimate temperature (29.29 °C, 31.70 °C, 33.22 °C, p=0.000), microclimate relative humidity (60.94 %, 92.30 %, 97.31 %, p=0.000), perception of heat discomfort (-0.56, -1.43, -2.04, p=0.000) and perception of wet discomfort (-1.14, -1.57, -2.14, p=0.000), core body temperature (37.45 °C, 37.62 °C, 37.97 °C; p=0.000), skin temperature (35.94 °C, 36.42 °C, 36.85 °C, p=0.000), sweat intensity (41.67 g, 63.67 g, 140.08 g, p=0.023), and weight loss (241.67 g, 291.67 g, 425.00 g, p=0.012). At a working environment temperature of 30 °C, the microclimate reaches a temperature of 33.22 °C and a relative humidity of 97.31 %. This results in high discomfort and a physiological response in the form of a core body temperature that exceeds 38 °C which is an indicator of an increased risk of heat-related diseases. **Conclusion**: Using PPE level III at a relatively high working environment temperature causes symptoms of discomfort and undue physiological strain. These findings form the basis for work arrangements and PPE redesign.

Keywords: Personal protective equipment, heat stress, discomfort, physiological response, working environment temperature

1. INTRODUCTION

Coronavirus disease (COVID)-19 was announced by the World Health Organization (WHO) as a pandemic since March 2020 and is still ongoing today. This virus spreads very quickly and continues to mutate, causing this pandemic to be very difficult to eradicate. As a result, the

The Seybold REPORT

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number of victims infected with COVID-19 continued to grow until it reached more than 627 million people and the death toll reached more than 6.5 million people (https://covid19.who.int/table, accessed on November 1, 2022).

Health workers are highly important in the efforts to treat COVID-19 patients, but this also means that they have a very high risk of being infected due to the contact intensity and the fact that some viruses are very easy and fast to transmit and spreads exponentially. The COVID-19 virus infection can occur through droplets, aerosols, human contact, contact with contaminated surfaces, and the fecal-oral routes of transmission (Meng et al., 2020, Donà, et al., 2020). One way to support the health workers in doing their job is by providing the best protection in every way possible, including PPE.

Appropriate personal protective equipment (PPE) is needed to prevent transmission of COVID-19 to health workers, but wearing PPE also cause heat stress which results in discomfort that consists of physical, psychological, and cognitive discomfort (Duan et al., 2021). The causes of discomfort at work are environmental factors (air temperature, radiation temperature, wind speed, and humidity) and individual factors (metabolic heat production and clothing worn (Song, 2011; Toomingas and Tornqvist, 2012). The causes mentioned above are certainly not static factors, so it is important to assess the risk of interference based on real exposure to working conditions, namely the length and intensity of workers exposed to heat, not just on measurements of the climate at work.

PPE used in handling COVID-19 is divided into 3 levels according to the level of danger faced (Liang, 2020). The leveling in PPE represents the protection level, so level III is the highest level used by officers when carrying out surgical procedures and other procedures and activities that generate aerosols on people under supervision and patients under surveillance or confirmation of COVID-19 and in taking respiratory samples. PPE level III covers almost the entire users' body consisting of head cap, medical masks (N95), eye protection, face shields, coveralls, disposable latex gloves, rubber boots and shoe protectors (Liang, 2020).

PPE suits for handling COVID-19 are made of materials that are impermeable to liquids, droplets, and viruses with a diameter of 65–125 nm. The best method for obtaining these characteristics is by coating the cloth to seal the pores that can be passed by liquids, droplets, or viruses (Troynikov taken from Wang and Gao, 2014). This makes the suit difficult to be penetrated by air and encapsulated which blocks heat transfer (Coca et al., 2017) so that it has about twice as much evaporation resistance as standard medical scrubs (Foster et al., 2020). The use of PPE causes the use of thresholds limit value (TLV) and wet bulb globe temperature (WBGT) tolerances to be unusable (ACGIH, 2021) so experiments are needed to obtain valid data.

Investigation of the discomfort of using PPE has been carried out using survey and experimental methods. Surveys of discomfort and physiological responses to the use of PPE for the treatment of COVID-19 generally use a cross-sectional study method and are carried out by distributing questionnaires online/web survey (Bonafede et al., 2022; Zhu et al., 2022). Health workers as respondents with certain demographic factors were asked to answer a

ISSN 1533-9211

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questionnaire with the parameters asked consisting of factors of physical discomfort, psychological, cognitive tasks, and risk factors. The survey method has the advantage of having a high ability to eliminate the subjectivity of researchers but has a weakness, namely the emergence of biased responses, so other, better methods are needed.

Experimental methods are also used to investigate the discomfort and physiological impact of using PPE for the treatment of COVID-19. This method is considered to have the advantage that the parameters for the variables studied can be tightly controlled so that it is possible to achieve the research objectives properly. Experiments to investigate heat stress and its impact on discomfort, physiological response and performance were carried out by comparing the use of KN95 masks (Arif et al., 2021), the use of aerosol PPE and standard surgical gowns (Chaudhari et al., 2022) and the use of PPE protection level I, II and III (Jin et al., 2022). The experimental protocol was prepared taking in to account the workload in real conditions when health workers were at work. The experimental results showed that there was an effect of using KN95 on EnCO2 and heart rate both at rest and exercise but there was no effect on respiratory rate, blood pressure and oxygen saturation (Arif et al., 2021). The use of aerosol PPE causes heat stress which has a negative impact on mood, motoric function, and task performance (Chaudhari et al., 2022). The higher the level of PPE protection shows the trend of increasing heart rate, oral temperature, task completion time, subjective fatigue, and fatigue level (Jin et al., 2022).

The research above has investigated the occurrence of heat stress in the use of PPE for the treatment of COVID-19 and its impact on discomfort and physiological response. The research covers the impact of using KN95 masks, a comparison of the use of aerosol PPE and standard medical uniforms and a comparison of the use of PPE with different levels of protection. The studies that have been conducted have not investigated the effect of working environmental conditions on the use of PPE for the treatment of COVID-19 while the treatment is carried out in places with different environmental conditions, including in the treatment room, emergency room, or outside the room. Therefore, the occurrence level of heat stress and its impact on discomfort, and physiological responses will be investigated in this study.

2. MATERIAL AND METHOD

2.1. Participants

Participants are physically and mentally healthy people aged 20-40 years (Zwolinska and Bogdan, 2012; Luze et al., 2020) and have a body mass index (BMI) between 18.5-29.9 kg/m^2. The number of participants was determined using a minimum sample determination technique based on the effect size d with a significance level of $\alpha = 0.05$ and statistical power (1-□) = 0.80. The minimum number of samples is seen in the Power Tables for Effect Size d (Cohen, 1988). The selection of participants was done randomly to avoid bias and to get a normal distribution. Before the experiment was carried out, the participants were confirmed not to have serious illnesses such as heart disease, hypertension, diabetes, cholesterol, and other disorders. Participants were asked to sleep for at least 5 hours at night and have a light breakfast the morning before the experiment. Participants were given a thorough explanation of the required

The Seybold Report
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forms of participation and were asked to fill out a consent form after agreeing to a series of experiments to be carried out.

2.2 Clothing suits

The clothing suits used during the experiment were medical uniforms and level III PPE which consist of head cap, N95 masks, latex gloves, eye protection, face shields, medical coveralls, rubber boots/shoes and shoe protectors (Task Force for the Acceleration of Handling COVID-19, 2020). Medical coveralls made from microporous nonwoven fabric as the largest part of PPE are produced by domestic companies and selected from the Indonesian Ministry of Health's LKPP web site.

2.3 Experiment Design

This study aims to determine the effect of the environmental conditions where health workers work when serving COVID-19 patients in Indonesia on discomfort, physiological responses and microclimatic conditions between skin and clothing. The working environment conditions that are the object of research consist of medical ward (20 ± 2) ^{o}C, emergency room at (25 ± 2) ^{o}C, and outdoors at (30 ± 2) ^{o}C with relative humidity (50 ± 10) %. The experimental protocol was designed for light (40 – 50) W and moderate (50 -100) W workloads (Toomingas and Tornqvist, 2012). The experiment was carried out using a cross sectional approach and within subject design (repeated measures) was used in this experiment with 3 tests under different environmental conditions. Participants were arranged according to a random crossover design (No et al., 2016) into 3 groups (4 participants per group). Each participant conducted the experiment at intervals of at least one week to avoid the effects of previous adaptation and training.

The experimental protocol includes preparation and physical effort (1 hour) representing the activities of health workers while working. COVID-19 patient service activities include patient care, drug delivery, bed making, and patient counseling, assisting patient needs, and monitoring vital signs (Choudhury et al., 2020). Luze et al. (2020) compiled physical effort consisting of six tasks representing the abilities needed in the care of COVID-19 patients, namely: tasks targeting mental capacity, manual dexterity, and strength, each of which lasts for 9 minutes with a rotation time between tasks for 1 minute.

Based on the experiments of Choudhury et al. (2020) and Luze et al. (2020), an experimental protocol was developed in the form of physical activity with several adjustments such as the type of activity and duration of work. Before carrying out data collection, participants took a break (in the laboratory area), a second break in the laboratory (20 minutes). Furthermore, the experimental protocol is explained in Figure 1. In the initial 30 minutes the participants wore complete PPE then carried out 6 activities each for 9 minutes and rotation time for 1 minute. Walking speed on a treadmill is a low speed (Bahannon, 1997). Parameter measurements were carried out during rotation between activities in the experimental protocol. The experiment was carried out at the Laboratory of Work System Engineering and Ergonomics, Faculty of Industrial Technology, Bandung Institute of Technology from 9.00 to 16.00.

ISSN 1533-9211
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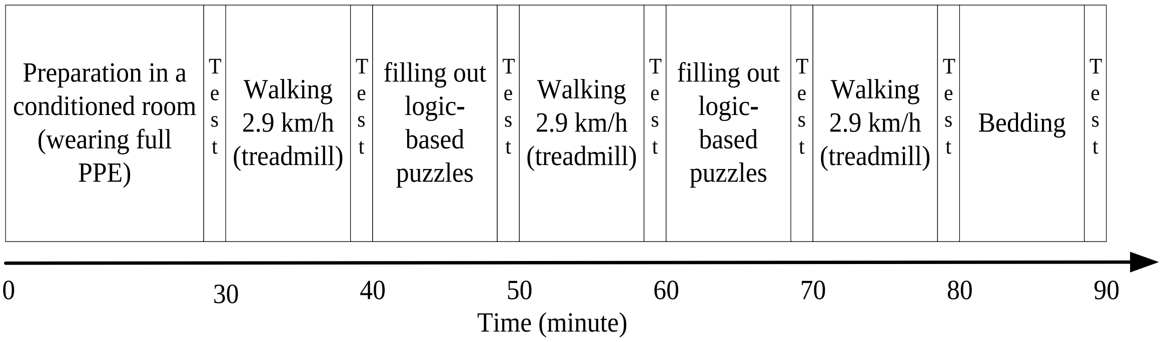

Figure 1: Experiment protocol

The discomfort parameter is indicated by a categorical scale with a seven-point thermal sensation rating point (3: very comfortable, 2: comfortable, 1: somewhat comfortable, 0: no, -1: slightly uncomfortable, -2: uncomfortable, and -3: very uncomfortable), and a seven-point wet sensation rating (3: very dry, 2: dry, 1: slightly dry, 0: no, -1: slightly wet, -2: wet, and -3: very wet) (Lee et al ., 2011). The physiological parameters measured consisted of core body temperature (temperature in the ear canal) and skin temperature (4 points, namely: neck, right scapula, left hand and right calf and were calculated by the formula T skin = 0.28 T neck + 0.28 T right scapula + 0.16 T left hand + 0.28 T right calf) were measured using a Beurer FT65 Digital thermometer (ISO 9886: 2004E). Microclimate temperature and humidity were measured using a Thermohygrometer brand: SATO model: SK-L200TH. Sweat intensity was determined based on measurements of body mass and clothing that were carried out before and after completing the experiment with Omron brand balances, Karada Scan Body Composition Monitor HBF-375.

2.4 Statistical analysis

Experimental data were processed using commercially available software, namely SPSS v. 26. Statistical analysis consisted of data normality test (Kolmogorov-Smirnov test), data uniformity test (Levene test), analysis of variance of one-way repeated measurements (one way ANOVA) on three working conditions and analysis of differences in mean between each treatment (Post-hoc Bonferroni test). If the normality of the data cannot be confirmed, then the analysis of variance uses the Kruskal Wallis test. The value of $p = 0.05$ is used as a statistical significance limit.

3. RESULT

Twelve physically and mentally healthy men with ages between (23.7±2.4) years and with a body mass index (BMI) between (24.3±3.3) kg/m^2 participated in this study. All participants completely carried out 3 experiments according to the experimental design that was made. The experimental results of the effect of temperature on microclimatic conditions, perception of discomfort and physiological responses are presented below.

The Seybold REPORT
ISSN 1533-9211
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3.1 Microclimate temperature

Microclimate temperature data at 20 °C (p=0.101), 25 °C (p=0.213) and 30 °C (p=0.554) were normally distributed (Kolmogorov-Smirnov test, p>0.05) and the variance of the three data was homogeneous (levene test, p = 0.170). The results of the analysis of variance (ANOVA) showed that there was an effect of the work environment on microclimate temperature (p=0.000). There is an increasing trend in the average microclimate temperature of 29.9 °C (at a working environment temperature of 20 °C), 31.07 °C (at a working environment temperature of 25 °C) and 33.22 °C (at a working environment temperature of 30 °C), and this is in line with the increase in working environment temperature (figure 2). Trends have been seen from the beginning of the activity to the end of the activity. This difference was confirmed from the Post Hoc test which showed statistically significant differences in microclimate temperature at the working environment temperature of 20 °C to 25 °C, temperature of 20 °C to 30 °C and temperature of 25 °C to 30 °C.

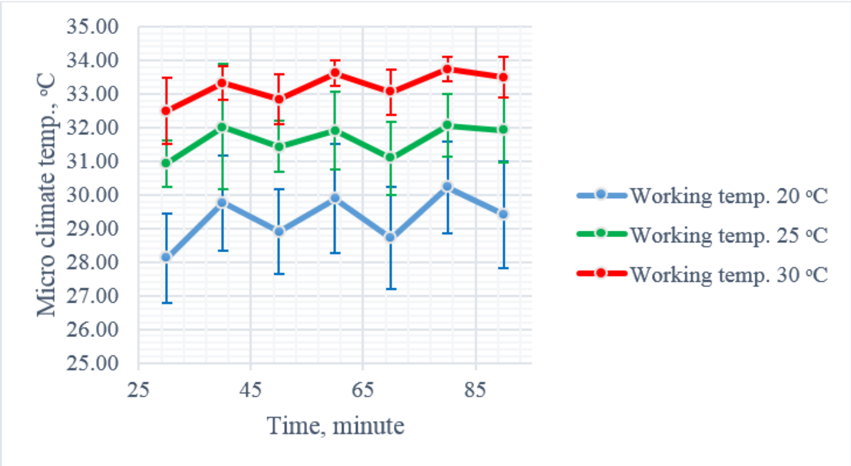

Figure 2: Microclimate temperature

3.2 Microclimate relative humidity

Microclimate air humidity data at 20 °C (p=0.842), 25 °C (p=0.233) and 30 °C (p=0.739) were normally distributed (Kolmogorov-Smirnov test, p>0.05) and the variance of the three data was not homogeneous (levene test, p=0.000). The results of the Kruskal Wallis test showed that there was an effect of the work environment on microclimate air humidity (p=0.000). There is an increasing trend in the average microclimate air humidity of 60.94% (at a working environment temperature of 20 °C), 92.30% (at a working environment temperature of 25 °C) and 97.31% (at a working environment temperature of 30 °C) as the working environment temperature increases (figure 3). Trends have been seen from the beginning of the activity to the end of the activity. This difference was confirmed from the Post Hoc test which showed statistically significant differences in microclimate air humidity at work environment temperatures of 20 °C and 25 °C, 20 °C and 30 °C, and at work environment temperatures of 25 °C and 30 °C, there was no significant difference. This is because at a working environment

DOI 10.5281/zenodo.7409322

temperature of 30 °C the air humidity reaches a maximum of 100% and after that condensation occurs (the maximum humidity read on the test equipment is 100%).

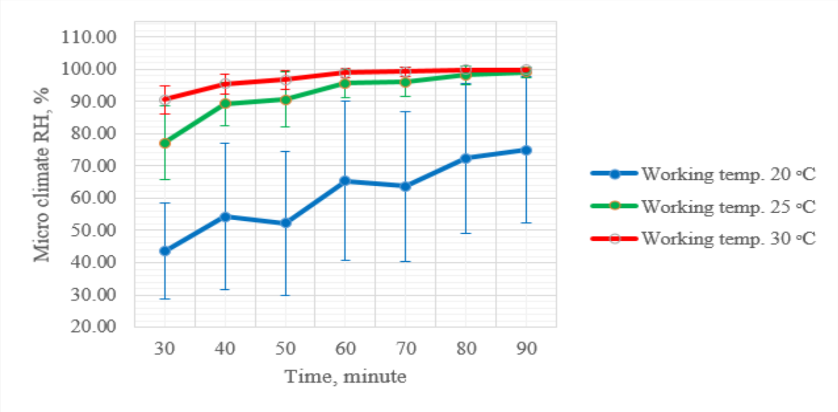

Figure 3: Microclimate Relative Humidity (RH)

3.3 Heat sensation rating

The heat sensation rating data at 20 °C ($p=0.799$), 25 °C ($p=0.166$) and 30 °C ($p=0.330$) were normally distributed (Kolmogorov-Smirnov test, $p>0.05$) and the variance of the three data was homogeneous (levene test, $p=0.067$). The results of the analysis of variance (ANOVA) showed that there was an influence of the work environment on the heat sensation rating ($p=0.000$). There is a decreasing trend in the average heat sensation rating from -0.60 (at a working environment temperature of 20 °C), -1.43 (at a working environment temperature of 25 °C) and -2.04 (at a working environment temperature of 30 °C) as the working environment temperature increases (figure 4). Trends have been seen from the beginning of the activity to the end of the activity. This difference was confirmed from the Post Hoc test which showed statistically significant differences in heat sensation rating at working environment temperatures of 20 °C and 25 °C, temperatures of 20 °C and 30 °C and temperatures of 25 °C and 30 °C.

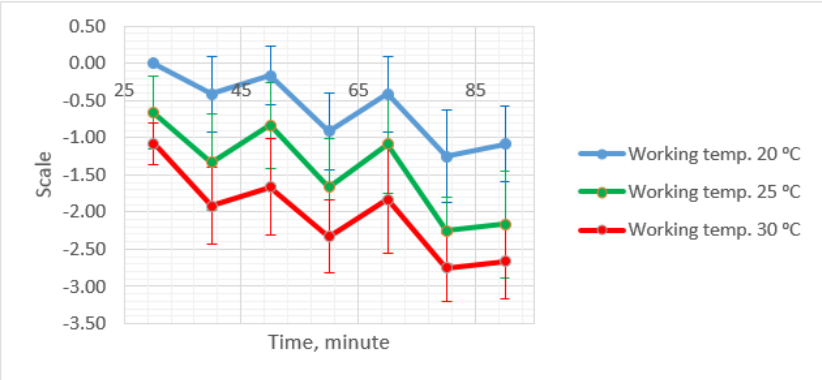

Figure 4: Heat sensation rating

ISSN 1533-9211
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3.4 Wet sensation rating

Wet sensation rating data at 20 °C (p=0.282), 25 °C (p=0.183) and 30 °C (p=0.233) were normally distributed (Kolmogorov-Smirnov test, p>0.05) and the variance of the three data was homogeneous (levene test, p=0.156). The results of the analysis of variance (ANOVA) showed that there was an influence of the work environment on the wet sensation rating (p=0.000). There is a decreasing trend in the average wet sensation rating from -0.56 (at a working environment temperature of 20 °C), -1.58 (at a working environment temperature of 25 °C) and -2.15 (at a working environment temperature of 30 °C) as the working environment temperature increases (figure 5). Trends have been seen from the beginning of the activity to the end of the activity. This difference was confirmed from the Post Hoc test which showed statistically significant differences in wet sensation rating at working environment temperatures of 20 °C and 25 °C, temperatures of 20 °C and 30 °C and temperatures of 25 °C and 30 °C.

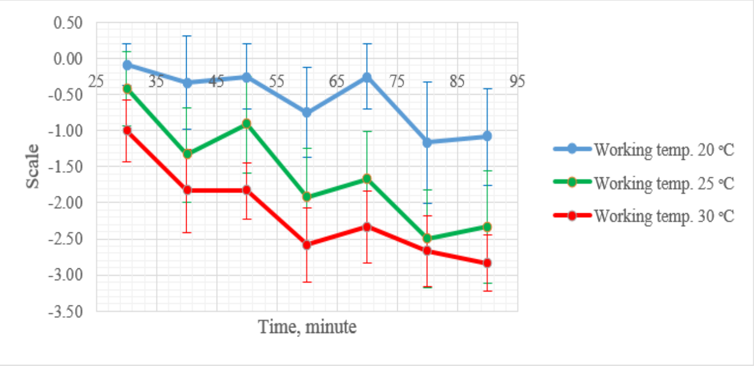

Figure 5: Wet sensation rating

3.5 Core temperature

Core body temperature data at 20 °C (p=0.455), 30 °C (p=0.465) were normally distributed (Kolmogorov-Smirnov test, p>0.05) and 25 °C (p=0.002) were not normally distributed (Kolmogorov-Smirnov test, p< 0.05) and the variance of the three data is homogeneous (Levene test, p=0.159). The results of the Kruskal Wallis test showed that there was an effect of the working environment on core temperature (p=0.000). There is an increasing trend of the average core temperature of 37.45 °C (at a working environment temperature of 20 °C), 37.62 °C (at a working environment temperature of 25 °C) and 37.97 °C (at a working environment temperature of 30 °C) as the working environment temperature increases (figure 6). There was a significant upward trend from working environment temperature of 20 °C to 30 °C and 25 °C to 30 °C but less significant from working environment temperature of 20 °C to 25 °C (Post Hoc test).

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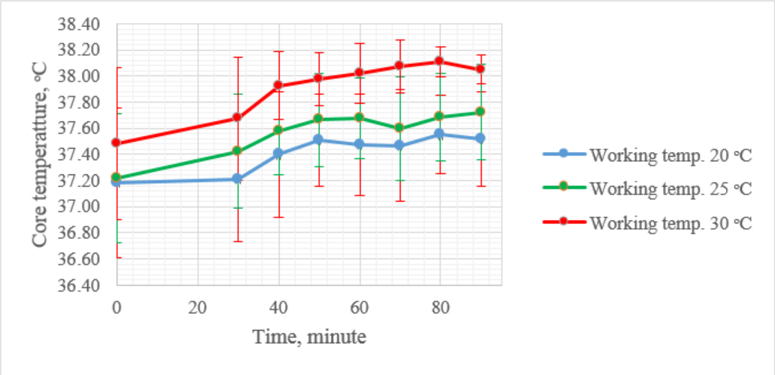

Figure 6: Core body temperature

3.6 Skin temperature

Skin temperature data at 20 °C (p=0.946), 25 °C (p=0.773) and 30 °C (p=0.925) were normally distributed (Kolmogorov-Smirnov test, p>0.05) and the variance of the three data was homogeneous (levene test, p = 0.102). The results of the analysis of variance (ANOVA) showed that there was an effect of the work environment on skin temperature (p=0.000). There is an increasing trend in the average skin temperature of 35.94 °C (at a working environment temperature of 20 °C), 36.42 °C (at a working environment temperature of 25 °C) and 36.85 °C (at a working environment temperature of 30 °C) as the working environment temperature increases (figure 7). Trends have been seen from the beginning of the activity to the end of the activity. This difference was confirmed from the Post Hoc test which showed statistically significant differences in skin temperature at work environment temperatures of 20 °C and 25 °C, temperatures of 20 °C and 30 °C and temperatures of 25 °C and 30 °C.

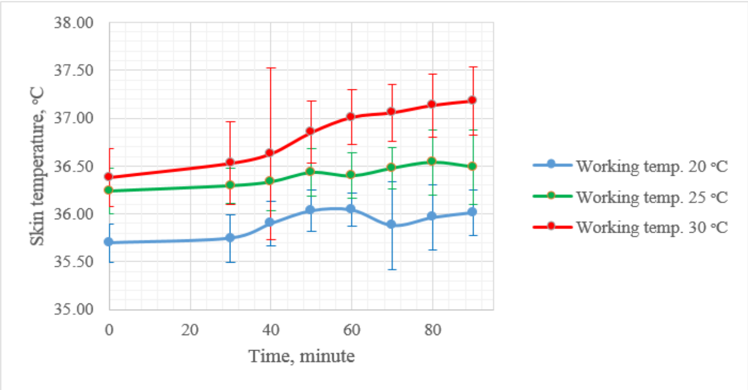

Figure 7: Skin temperature

3.7 Weight loss

Weight loss data at 20 °C (p=0.063), 25 °C (p=0.172) and 30 °C (p=0.284) were normally distributed (Kolmogorov-Smirnov test, p>0.05) and the variance of the three data was homogeneous (levene test, p = 0.197). The results of the analysis of variance (ANOVA)

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showed that there was an effect of the work environment on weight loss (p=0.012). There is a trend of increasing average weight loss of 241.67 g (at a working environment temperature of 20 °C), 291.67 g (at a working environment temperature of 25 °C) and 425.00 g (at a working environment temperature of 30 °C) as the working environment temperature increases (figure 8). The trend of increasing average weight loss occurred significantly from working environment temperature of 20 °C to 30 °C and 25 °C to 30 °C but less significant from working environment temperature of 20 °C to 25 °C (Post Hoc test).

3.8 Sweat on cloth

Sweat on cloth data at 20 °C (p=0.066), 25 °C (p=0.884) and 30 °C (p=0.911) were normally distributed (Kolmogorov-Smirnov test, p>0.05) and the variance of the three data was homogeneous (levene test, p=0.453). The results of the analysis of variance (ANOVA) showed that there was an effect of the work environment on sweat on cloth (p=0.023). There is an increasing trend in the average sweat on cloth from 41.67 g (at a work environment temperature of 20 °C), 63.67 g (at a work environment temperature of 25 °C) and 140.68 g (at a work environment temperature of 30 °C) as the working environment temperature increases (figure 8). The trend of increasing the average sweat on cloth occurred significantly from the working environment temperature of 20 °C to 30 °C and 25 °C to 30 °C but less significant from the working environment temperature of 20 °C to 25 °C (Post Hoc test).

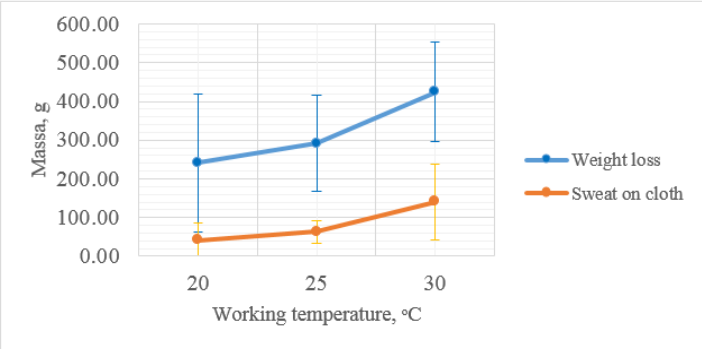

Figure 8: Weight loss and sweat on cloth

4. DISCUSSION

The COVID-19 pandemic hasn't ended, so health workers still need PPE to treat COVID-19 patients. PPE is used to prevent transmission of the COVID-19 virus, which is very small in size, namely 65–125 nm in diameter (Shereen et al., 2020). Therefore, PPE for handling COVID-19 is made from materials that have low water absorption, dan are impermeable to water and air (Troynikov, taken from Wang and Gao, 2014) so that they have high heat and water vapor resistance (Foster et al., 2020).

Hot working conditions, strenuous activities and clothing that inhibits heat transfer from the body can cause heat stress. Heat stress that causes discomfort triggers heat strain (McLellan et al., 2013). Heat stress has an impact on increasing workload which is characterized by the

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perception of discomfort and the emergence of excessive physiological responses (Bindu et al., 2022; Yuan et al., 2021; Yunus et al., 2021; Zhu et al., 2022). Discomfort can negatively affect productivity, judgment, and emotions, thereby reducing work capacity and increasing errors (Chinnadurai et al., 2016).

WBGT is one of the indicators of the work environment which is used as a reference for setting working hours based on work activities (ACGIH, 2021). The WBGT threshold value and its adjustment as the basis for setting employee working hours related to the working environment temperature cannot be used for encapsulated clothing that is impermeable or has high resistance to moisture or airflow on the fabric (ACGIH, 2021). To find out the actual conditions of heat stress and its impact on heat strain, experiments are needed. Experiments evaluating the occurrence of heat stress on the use of PPE level III were carried out with protocols and environmental conditions in the workplace of health workers. Experiments were carried out in the laboratory so that the related variables can be controlled properly.

The experimental results (figure 2 – figure 7) show an increase in microclimate temperature and humidity, sensation of thermal discomfort and wetness, core temperature, and skin temperature at 40 minutes, 60 minutes, and 80 minutes compared to 50 minutes. 70 minutes, and 90 minutes. This is because at the firsttime interval, the respondents had undergone some physical activities, namely walking on a treadmill. On the other hand, in the second time interval, the respondents were sitting while filling out logic-based puzzles. Physical activity requires energy which is supplied through the body's metabolism and produces heat. Increased heat triggers another metabolism to take over. The human body is homeothermic which will try to maintain heat balance by pumping more blood to the skin and sweating (Toomingas and Tornqvist, 2012). More blood is pumped by the heart, causing heart rate and blood pressure to increase as well (Smith and Havenith, 2012 taken from Parson, 2014).

The temperature and relative humidity of the microclimate between the body and clothing increase in accordance with increasing working environment temperature (figure 2 and figure 3). The microclimate conditions during the experiment were at a working environment temperature of 25 ^{o}C starting from the 50th minute until the end of the experiment, reaching 30 ^{o}C-32 ^{o}C (figure 2) with a relative humidity of 90% - 100% (figure 3) and at a working environment temperature of 30 ^{o}C from the 30th minute until the end of the experiment, reaching 32.5 ^{o}C - 34 ^{o}C with a relative humidity of 90% to 100% (figure 2 and figure 3). Extremely high temperatures and humidity in microclimates lead to increased thermal and wet discomfort (figures 4 and figure 5). Very high microclimate temperature and humidity can inhibit sweating so that the body's core temperature and skin temperature also increase (figure 6 and figure 7). The very high temperature and humidity of the microclimate, besides being influenced by the temperature of the working environment, also occurs because PPE level III is made of a material that is difficult for air and moisture to penetrate (Troynikov taken from Wang and Gao, 2014) and is encapsulated so that it inhibits heat transfer and evaporation of sweat vapor to outside the body (McLellan et al., 2013).

Thermal and wet discomfort ratings decrease as the working environment temperature increases. The discomfort that occurs is exacerbated by using PPE which is made from unbreathable and encapsulated materials which causes metabolic body heat and sweat to be trapped in the microclimate between the body and the PPE suit. The decrease in comfort was marked by a decrease in the heat sensation rating scale and the wet sensation rating scale from the beginning of the activity to the end of the activity (figure 4 and figure 5). The heat sensation rating scale and the wet sensation rating scale were low, especially at a working environment temperature of 25 °C and very low at a working environment temperature of 30 °C (reaching -3)

Increased core body temperature and skin temperature are physiological responses to increased working environment temperatures (figure 6 and figure 7). The core body temperature climbed over 38 °C from 50 minutes in the experiment with a working environment temperature of 30 °C. A core body temperature of more than 38 °C indicates a moderate to high category of heat strain has occurred (Moran et al., 1998). Heat stress standards/guidelines that determine the upper limit of safe heat exposure have been prepared by international bodies that control health risks due to work-related heat stress in workers. These standards/guidelines are generally based on preventing a core temperature exceeding 38 °C as the risk of heat-related illness will increase above this threshold (National Institute for Occupational Safety and Health (NIOSH), 2013). Setting the working time is required when the oral temperature is > 37.6 °C, then the working time is reduced by 1/3 (OSHA).

The temperature of the working environment affects the amount of sweat that can be observed from weight loss and the amount of sweat absorbed on clothes (figure 8). The physiological response due to continuous heat storage is vasodilation to increase skin temperature and causes a lot of sweat to be distributed throughout the body (Smith and Havenith, 2012 taken from Parson, 2014). The body will protect itself from overheating by transferring most of the blood flow from the middle of the body to the skin, mucous membranes, and peripheral parts of the body which are regulated by stimulation of the autonomic nervous system (Gavhed taken from Toomingas and Tornqvist, 2012).

Energy metabolism is, in certain cases, higher during working in hot conditions. Hot working conditions further limit the workload and work length before putting risk into a person’s health. During physical activity, most of the blood flows to the working muscles. If the heating continues, the body will sweat to release more heat. The ability to sweat is the most important human attribute for tolerating heat. The body has between 2 - 5 million sweat glands. The body usually sweats 0.5 - 1.5 l/hour in hot weather, but in extreme conditions, sweat can reach 3 l/hour (Gavhed taken from Toomingas and Tornqvist, 2012).

The combination of environmental factors and physiological responses increases the risk of discomfort and heat illness (Toomingas and Tornqvist, 2012, Davey et al., 2021; Lee et al., 2020). Humidity and high air temperature cause the least amount of sweat to evaporate from the skin so that the body's heating rate increases. The high demand for blood supply to the muscles and skin at the same time can lead to overload, fatigue and collapse. Sweating intensively and drinking too little can lead to dehydration and salt deficiency. Dehydration causes plasma volume, as well as strength and heart rate to decrease. Fainting can occur

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because the circulation of fluid to the brain decreases, muscle cramps occur due to massive loss of salts and minerals, and muscle fatigue (Gavhed taken from Toomingas and Tornqvist, 2012).

5. CONCLUSION

The purpose of this study was to investigate the effect of working environment temperature on the discomfort and physiological responses experienced by health workers when treating COVID-19 patients using level III PPE. The working environment conditions that were used as the study were temperatures that represented the working environment temperature of health workers, namely at 20 °C, 25 °C and 30 °C with RH (50±10) %. The chosen method is a laboratory experiment to strictly control the research variables. Twelve respondents with an age range (23.7±2.4) years and BMI (24.3±3.3) kg/m2 participated in this study. The experimental protocol is a simulation that represents activities that are usually carried out by health workers in the workplace, namely physical activity, activities that require concentration and hand dexterity.

Analysis of variance on experimental data showed that there was a statistically significant effect of working environment temperature (20 °C, 25 °C and 30 °C) on temperature and humidity, microclimate between skin and clothing, rating of thermal and wet sensation, core body temperature, temperature skin as well as weight loss and sweat on clothing. Post hoc tests showed statistically significant differences in the parameters of core body temperature, weight loss and sweat on clothing at working environment temperatures of 20 °C vs 30 °C and 25 °C vs 30 °C as well as microclimate temperature and humidity, ratings of thermal and wet comfort sensation, and skin temperature at working environment temperature 20 °C vs 25 °C, 20 °C vs 30 °C and 25 °C vs 30 °C. There is no statistically significant difference in microclimate humidity at the working environment temperature of 25 °C vs 30 °C.

The body's core temperature reaches more than 38 °C at a working environment temperature of 30 °C which indicates moderate to high heat strain. Based on the analysis above, it can be concluded that the use of PPE at relatively high working temperatures can result in unnecessary physiological strain. The findings of this study can be used as a basis for PPE work and redesign.

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