Personal Protective Equipment for Health Workers from Virus Transmission: The Effect of Temperature of Working Environment on Physiological Responses

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Abstract

The use of personal protective equipment (PPE) can prevent the transmission of COVID-19. However, it also has the potential to cause excessive physiological responses. This study aims to investigate the effect of the physical work environment (temperature) on physiological responses related to activities using level III PPE for handling COVID-19 with laboratory experiments. Twelve participants (age 23.7 ± 2.4 years, BMI 24.3 ± 3.3 kg/m^2) wore level III PPE and carried out simulated activities in three different working temperatures (20 ^oC, 25 ^oC and 30 ^oC with relative humidity 50 ± 10 %). The experimental activities consisted of walking on a treadmill (speed of 2.9 km/hour), filling out logic-base puzzles, walking on a treadmill, filling out logic-base puzzles, walking on a treadmill, and bedding. Each activity was carried out for 9 minutes and the transfer time was 1 minute. At the end of each activity, physiological responses were measured including heart rate, oxygen consumption, and blood pressure. The results of this study show that working temperature had a significant effect on heart rate (p=0.002) and systolic blood pressure (p=0.043) but had no significant effect on oxygen consumption (p=0.411). A post-hoc analysis demonstrates that the working temperature of 30 ^oC had effects that were different from the other two conditions. It is concluded that wearing a PPE at a relatively high working temperature can result in undue physiological strains. Findings of this study can be used as a basis for work and PPE redesigns.

Keywords
Personal protective equipment, COVID-19, working environment temperature, laboratory experiments and physiological responses

1. Introduction
The Coronavirus Disease 19 (COVID-19) outbreak is one of the largest global health emergencies after the Second World War that impacted not only health but on devastating economies and social outcomes as well. This virus is contagious and often mutating and causing the pandemic difficult to handle properly. Pandemics was caused by viruses have occurred repeatedly such as the H1N1 virus (known as the Spanish flu) in 1918, the H2N2 influenza virus in 1957, the H3N2 influenza virus in 1968, and the swine flu virus (H1N1) in 2009 therefore there is a possibility of recurrence.

Health workers are people who directly handle COVID-19 patients therefore they have very high risks of being infected because this disease is contagious. The risks are higher as the intense contact between health workers and patients due to the increase the number of patients, but it has not been accompanied by an adequate number of health workers and care facilities. COVID-19 has been shown to spread through droplet infections, aerosols, human-to-human contact, contact with infected surfaces, and fecal transmission pathways (Donà et al. 2020).

Personal protective equipment (PPE) must be used by health workers to reduce the risk of transmission of COVID-19 but its use is causing side effects of thermal discomfort and the appearance of excessive physiological responses. Medical service activities using PPE are causing overheating which results in heat stress which has an impact on cognitive impairment, fatigue, productivity, and work accidents (Daanen et al. 2021; Messeri et al. 2021). The inconvenience of PPE for handling COVID-19 can be caused by several factors. Six fundamental factors that determine the human thermal environment are air temperature, radiant temperature, humidity, and air movement, as well as metabolic heat factors produced by human activities and the clothes worn (Song 2011). PPE textile materials are made of materials that do not absorb water, impermeable to water and air, so they cannot transfer heat and sweat from the body to the environment (Troynikov taken from Wang and Gao 2014). PPE suits form an encapsulation therefore they have about twice the evaporation resistance compared to standard medical scrubs (Foster et al. 2020). Discomfort is also influenced by activity and length of use as well as the work environment, especially in poorly conditioned rooms or outdoors with a tropical climate such as in Indonesia.

Investigations of thermal discomfort and physiological responses to the use of PPE have been carried out both by survey and experimental methods. A survey of health workers during activities using PPE for handling COVID-19 showed symptoms of increased body temperature, increased amount of sweat so that it causes wet clothes, difficulty of breathing, anxiety, headaches, weakness, fatigue, disruption of movement and difficulty of changing clothes (Davey et al. 2021; Duan et al. 2021; Messeri et al. 2021). Some of the symptoms above will trigger the onset of heat stress if it is not intervened. However, the survey method has the disadvantage of not being able to provide objective data so that researchers must ensure that the responses are bias-free.

Several studies have also been conducted to investigate the onset of side effects of using PPE with laboratory experiments. The research was conducted by Zwolinska and Bogdan (2012) who investigated the occurrence of heat stress in surgeons. Pyke et al. (2015) conducted research on the thermophysiological effects of mild nonmilitary personal body armor (PBA) in hot and humid environments. Yi et al. (2017) evaluated the effectiveness of new construction uniforms designed in the fight against heat stress. McQuerry et al. (2018) conducted experiments by modifying the structural design of firefighting clothing to reduce heat stress. Wilkinson et al. (2020) compared the physiological tension of the use of self-contained breathing apparatus confidence course (SCBACC) in the training of fire academy cadets. The studies above have investigated the occurrence of heat stress in the use of PPE in several work areas. However, as far as the researcher's knowledge is still very minimal, the data obtained about the physiological response profile on the use of PPE for handling COVID-19 in tropical working environment conditions such as in Indonesia is limited.

1.1 Objectives

This study aims to investigate the effect of the physical work environment (temperature) on physiological responses related to activities using level III PPE for handling COVID-19 with laboratory experiments. The results of this study have several benefits. First, the results of the evaluation of the physiological response profile on the use of PPE can be used as a reference in the design of textile materials and PPE suits. Secondly, the physiological response profile data becomes important information for determining preventive measures by regulating working time and workplace conditions. Third, the results of this study can also be used as a reference in decision making by the stakeholders such as the Ministry of Health, the Task Force for the Acceleration of COVID-19 Countermeasures, hospitals, and PPE manufacturers.

2. Literature Review

According to Liang (2020), the level of PPE protection for handling COVID-19 is divided into 3 levels. Protection level I is used by pre-torture triage officers and general outpatient sections. Protection level II is used by outpatients with fever symptoms, isolation ward areas (including isolated ICUs), examination of non-respiratory specimens in suspect/confirmed patients, imaging examinations of suspect/confirmed patients, and cleaning of surgical instruments used in suspect/confirmed patients. Level III protection is used by officers when performing procedures and surgical procedures on persons under supervision and patients under supervision or confirmed COVID-19. This level of protection is also used in activities that rise to aerosols (intubation, excavation, tracheotomy, cardiopulmonary resuscitation, bronchoscopy, NGT installation, gastrointestinal endoscopy) in persons under supervision and patients under supervision or covid-19 confirmation as well as in respiratory sampling (nasopharyngeal swabs and oropharynx).

Protection level I PPE consists of head coverings, surgical masks, workwear, disposable latex gloves and/or once isolation clothing. Protection level II PPE consists of a head covering, medical protective mask (N95), workwear, disposable medical protective uniform, disposable latex gloves, and goggles. Protection level III PPE (Figure 1) is the most complete PPE consisting of: head coverings, medical protective masks (N95), workwear, disposable medical protective uniforms (coveralls), disposable latex gloves, all-face respiratory protective devices, or powered air purifier respirators.

Figure 1. Level III PPE (Gugus Tugas Percepatan Penanganan COVID-19, 2020)

The use of PPE for the treatment of COVID-19 causes discomfort. The discomfort that occurs is divided into three parts, namely: physical, psychological, and cognitive discomfort. The results of an investigation show 54% of health workers reported that physical pressure and psychological pressure are both disturbing and 39% of health workers reported that psychological pressure is more pronounced than physical pressure during serving COVID-19 patients (Duan et al. 2021). The discomfort experienced by health workers when using PPE for handling COVID-19 is shown by the appearance of various symptoms. The diversity of these symptoms occurs due to differences in risk factors that trigger them so that the symptoms experienced is different in each study (Çağlar et al. 2021). Sometimes one complaint or more affects the complaints of the others (Thiagarajan et al. 2021).

Two factors cause discomfort when doing work, namely: environmental factors and individual factors. Climatic/environmental factors consist of air temperature, radiation temperature, wind speed, and air humidity and individual factors consist of heat production (which depends on workload) and thermal properties of clothing (Song 2011; Toomingas et al. 2012). The above causative factors are certainly not static factors, so it becomes important to assess the risk of disruption based on real exposure to working conditions, namely how long and with what intensity workers are exposed to heat or cold, not just on climate measurements in the workplace alone. To get comfort while working, the above factors must be adapted to the workplace situation, even in normal indoor conditions (for example the office) climate-related problems are still common.

The clothes worn (including PPE) are one of the causes of discomfort during activities. According to Troynikov et al. (taken from Wang and Gao 2014) there are several methods that can be done to achieve the function of PPE as a protector against viruses. These methods include the addition of polymer coatings, laminates, special polymer treatments, and high fabric density. The best method of obtaining liquid-resistant and pathogen-resistant characteristics is carried out by coating the fabric (nonbreathable). In addition to coating the fabric, the application of solid polymer membranes or films can also be done so that the fabric does not have pores that liquids or bacteria can pass through. PPE for handling COVID-19 has non-translucent and encapsulated properties that block heat transfer (Coca et al. 2017) so it has about twice the evaporation resistance compared to standard medical scrubs (Foster et al. 2020).

Risk factors causing discomfort in the use of PPE for handling COVID-19 are reported in the survey results. Risk factors are thus separated into 4 groups of risk factors, namely demographics, habits, ppe use and work environment. The risk factors reported as having very strong evidence of an influence on discomfort are the frequency of PPE use, the duration of PPE use, and the temperature of the work environment (Lee et al. 2020). The risk factors mentioned above need to be a concern for intervention so that they can support the safety, health, and comfort of health workers in carrying out their duties.

The scientific contribution of this study is the obtaining of a profile of physiological responses to the use of PPE for handling COVID-19 in Indonesia, which has a tropical climate. The PPE that is the object of this study is PPE for handling COVID-19 protection level III (the highest level of protection) which covers almost the entire body and has very low water repellent, waterproof, and breathable properties. The study was conducted with different environmental conditions that resembled conditions in the treatment room, conditions in the emergency department and outdoor conditions. Respondents to this study are Indonesians. The parameters of discomfort and physiological response tested are more complete.

3. Methods

3.1. Participants

Twelve physically and mentally healthy men between the ages of (23.7 ± 2.4) years and having a body mass index (BMI) of between (24.3 ± 3.3) kg/m2 participated in the study. The selection of participants was carried out randomly to avoid bias and get a normal distribution. Participants were selected from students of Institute Technology Bandung considering the ongoing pandemic situation. Before conducting the experiment, participants were interviewed about their medical history to make sure they did not have severe diseases such as heart disease, blood pressure, blood sugar, cholesterol, and other abnormalities. Participants were asked to prepare well, namely a minimum of 6 hours of sleep at night and a light breakfast. Participants are given a thorough explanation of the experiment to be carried out and the form of participation required. Participants are asked to fill out a form of willingness to participate in the experiment after agreeing to the series of experiments to be carried out.

3.2 Clothing Suit

Participants wore medical uniforms and PPE for handling COVID-19 level III protection that met the technical requirements (SNI 8913:2020). PPE for handling COVID-19 protection level III consists of head cap, N95 masks, latex gloves, googles, face shields, medical coveralls, rubber boots/shoes and shoe protection. Medical coveralls as the largest part of PPE are produced from domestic companies selected from the Lembaga Kebijakan Pengadaan Barang Jasa (LKPP) web site of the Ministry of Health of the Republic of Indonesia.

3.3 Experiment Design

The experimental approach was carried out cross-sectionally (Zwolinska and Bogdan 2012; Luze et al. 2020). The experiment was conducted at the Laboratory of Work Systems Engineering and Ergonomics, Faculty of Industrial Technology, Institut Teknologi Bandung. The condition of the experimental room is adjusted to the real conditions when health workers work to serve COVID-19 patients in Indonesia, namely the treatment room at (20 ± 2) ^{o}C, the emergency department room at a temperature of (25 ± 2) ^{o}C, and outdoors at a temperature (30 ± 2) ^{o}C with relative humidity (50 ± 10) %. Activities on experiments are designed on light (40-50) W and medium (50-100) W workloads (Toomingas 2012).

The experimental design used was within subject design (repeated measures) on three tests (three different environmental conditions). Participants were randomly divided into three groups. Each group consists of 4 people arranged according to a random crossover design (Table 1).

Table 1 Participant group settings (No et al., 2016)

Group (n=12)	Week 1	Week 2	Week 3
Group I (n=4)	A	B	C
Group II (n=4)	B	C	A
Group III (n=4)	C	A	B

Description A: temperature (20 ± 2) ^{o}C, B: temperature (25 ± 2) ^{o}C, and C temperature (30 ± 2) ^{o}C

PPE discomfort testing is carried out in 4 experimental stages. The first stage is participant preparation (in the laboratory area), the second stage is a rest in the laboratory (20 minutes), the third stage is a rest in a conditioned room (30 minutes) and the fourth stage is physical effort in a conditioned room (1 hour). The fourth stage is carrying out physical efforts that represent the activities of health workers at work which include: patient care, drug delivery, bed keeping, patient counseling, helping patient needs, and monitoring vital signs (Choudhury et al. 2020). On the research of Luze et al. (2020), the physical efforts carried out in the form of six tasks represent the abilities needed in the care of COVID-19 patients, namely: the task of targeting mental capacity, manual dexterity, and strength which each last for 9 minutes with a rotation time between tasks of 1 minute.

The experimental protocol was compiled based on the experiments of Choudhury et al. (2020) and Luze et al. (2020) with some adjustments such as activity and duration of work. The experimental protocol is as follows: Walking on a treadmill at a low speed of 2.9 km/h, tasks that target concentration (filling out logic-based puzzles), walking on a treadmill at a low speed of 2.9 km/h, tasks that target concentration (filling out logic-based puzzles), walking on a treadmill at a low speed of 2.9 km/h, and tasks that target hand dexterity (replacing and tidying up bed sheets and pillowcases). The time of performing activities is 9 minutes each and the rotation time from one activity to the next is 1 minute. The regulation of road speed is in accordance with the research of Bahannon (1997).

Data collection is carried out from 9.00 to 16.00. The physiological parameters measured consist of oxygen consumption and heart rate with VO2 Master Pro type 1.4.0 as well as blood pressure with omron digital hem 8712 brand sphygmo manometer. Measurements of physiological parameters are carried out every 9 minutes at the time of interchangeability of activities on the experimental protocol.

3.4 Statistical Analysis

The analysis was carried out to prove the hypothesis based on experimental data on the evaluation of inequality and physiological responses during activities using PPE for handling COVID-19 in different environments. Statistical analysis was carried out using commercially available software, namely SPSS v. 26. Statistical analysis consists of normality test, homogeneity test, independency test, measurement variance analysis (ANOVA) and analysis of the average difference between each treatment. The value of $p=0.05$ is used as a statistical significance limit. Normality is confirmed using the Kolmogorov-Smirnov test. One-way ANOVA analysis of the measurement variance was performed on three working environment conditions. The Bonferroni Post-hoc test is used to investigate the difference in the average test results between each condition (Wilkinson et al. 2020).

4. Data Collection

A series of studies was carried out from literature studies, direct observational and laboratory experiments. Laboratory experiments objectively measured the physiological response of the respondents who conducted experimental protocols on three conditions that represented the working environment of health workers (temperatures 20 ^{o}C, 25 ^{o}C and 30 ^{o}C with RH (50±10) %. The physiological response was measured when one activity was completed as presented in Table 2. The results of physiological response measurements are presented in Figure 1, Figure 2, Figure 3 and Figure 4.

Table 2. Experiment activities and times

No	Activity	Time, minutes
1	Base line	0
2	Preparation in a conditioned room (wearing full PPE)	30
3	Walking on a treadmill at a speed of 2.9 km/hour	40
4	filling out logic-based puzzles	50
5	Walking on a treadmill at a speed of 2.9 km/hour	60
6	filling out logic-based puzzles	70
7	Walking on a treadmill at a speed of 2.9 km/hour	80
8	Bedding	90

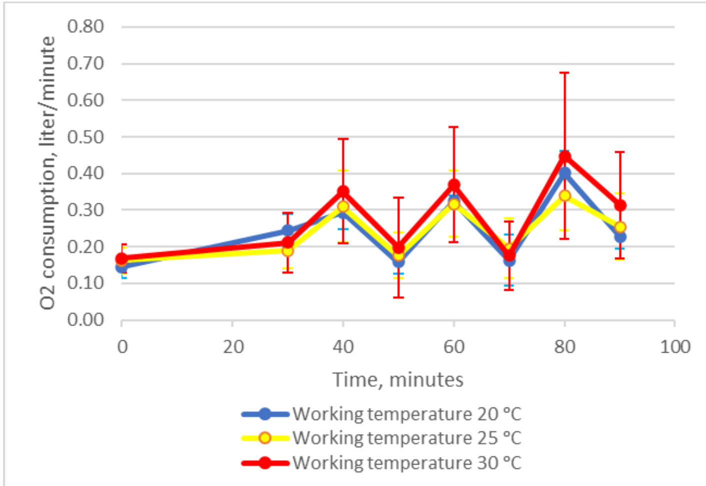

Figure 2. Oxygen consumption

Figure 2 shows the relationship between the time of doing activities that are simulated at a working environment temperature of 20 °C, 25 °C and 30 °C with oxygen consumption. Broadly speaking there is no visible difference in oxygen consumption when carrying out simulated activities at a working environment temperature of 20 °C, 25 °C and 30 °C. At the time of 40 minutes, 60 minutes, and 80 minutes there was an increase in oxygen consumption compared to the 50 minutes, 70 minutes, and 80 minutes. This is because at the time of 40 minutes, 60 minutes, and 80 minutes the respondents had finished doing physical activity, namely walking on a treadmill, while at the time of 50 minutes, 70 minutes, and 80 minutes the respondents were sitting while filling out logic-based puzzles. Physical activity requires energy which is supplied through the body's metabolism. The body's metabolism requires oxygen so that oxygen consumption increases when physical activity increases.

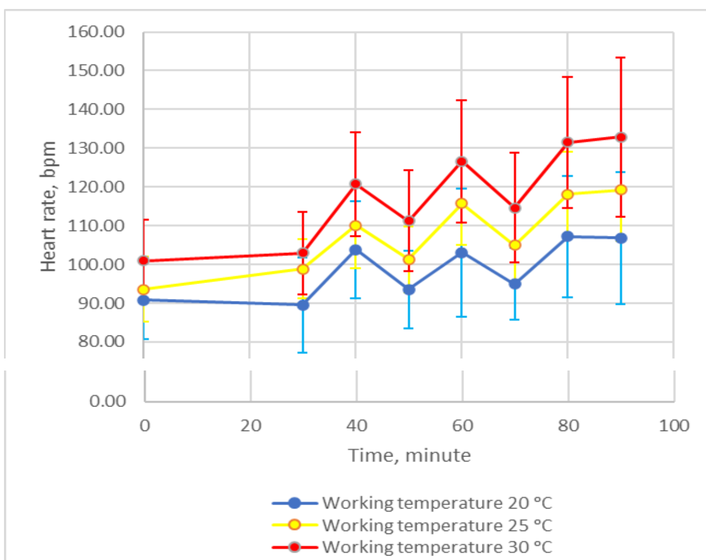

Figure 3. Heart rate

Figure 3 shows the relationship between the time of doing activities that are simulated at a work environment temperature of 20 °C, 25 °C and 30 °C with heart rate. Broadly speaking there are differences in heart rate when doing activities that are simulated at a working environment temperature of 20 °C, 25 °C and 30 °C. At the time of 40 minutes, 60 minutes, and 80 minutes, there was an increase in heart rate compared to the 50 minutes, 70 minutes, and 80 minutes. This is because at the time of 40 minutes, 60 minutes, and 80 minutes the respondents had finished doing physical activity, namely walking on a treadmill, while at the time of 50 minutes, 70 minutes, and 80 minutes the respondents were sitting while filling out logic-based puzzles. Physical activity requires energy which is supplied through the body's metabolism. The body's metabolism requires oxygen which is supplied through the bloodstream so that if oxygen consumption increases, the heart rate also increases.

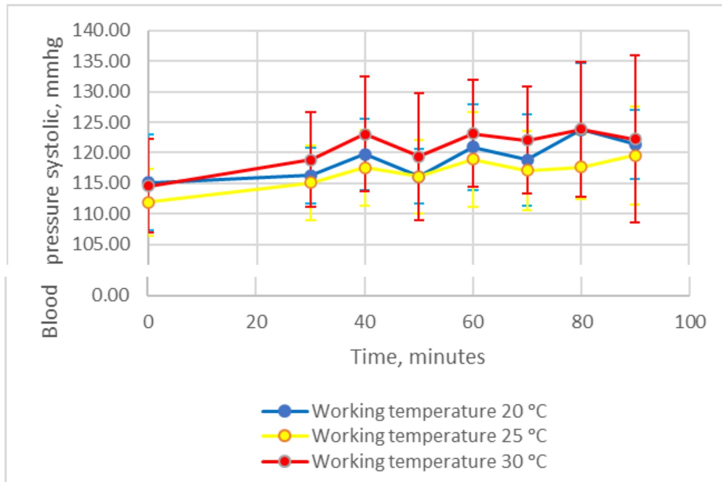

Figure 4. Blood pressure systolic

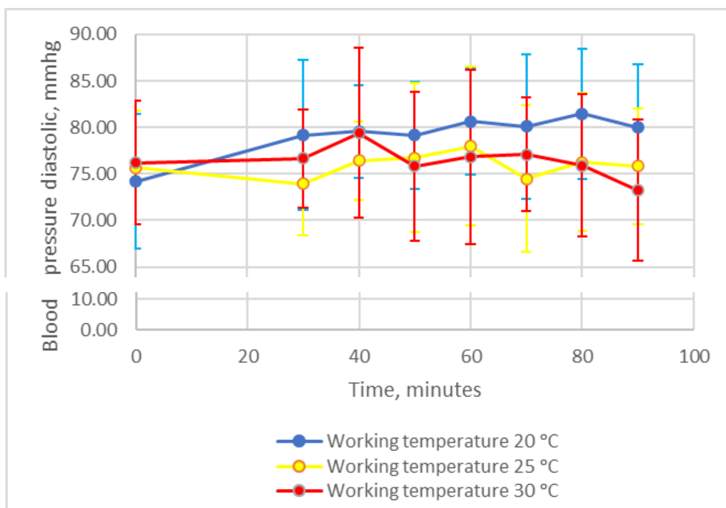

Figure 5. Blood pressure diastolic

Figure 4 and Figure 5 show the relationship between the time of doing activities that are simulated at a working environment temperature of 20 ºC, 25 ºC and 30 ºC with blood pressure. Broadly speaking there is a difference in systolic blood pressure when doing activities that are simulated at a working environment temperature of 20 ºC, 25 ºC and 30 ºC and there is no difference in diastolic blood pressure when doing simulated activities at a working environment temperature of 20 ºC, 25 ºC and 30 ºC. At the time of 40 minutes, 60 minutes, and 80 minutes there was an increase in blood pressure compared to the 50 minutes, 70 minutes, and 80 minutes. This is because at the time of 40 minutes, 60 minutes, and 80 minutes the respondents had finished doing physical activity, namely walking on a treadmill, while at the time of 50 minutes, 70 minutes, and 80 minutes the respondents were sitting while filling out logic-based puzzles. Physical activity requires energy which is supplied through the body's metabolism. The body's metabolism requires oxygen which is supplied through the bloodstream so that if oxygen consumption increases, blood pressure also increases.

5. Results and Discussion

Some of the factors affecting human thermal environment are environmental and individual factors. Absent-minded factors are air temperature, radiation temperature, wind speed, and air humidity, as well as individual factors namely: heat production that depends on the workload and thermal properties of clothing (Song 2011; Toomingas et al. 2012). Level III PPE is made from textile materials that be able to prevent insviral infection to health workers while working to serve covid-19 patients. According to Troynikov (taken from Wang and Gao 2014) PPE material is made of materials that are not translucent, do not absorb water, do not penetrate air, so they cannot transfer heat and sweat from the body to the environment. The above causative factors are certainly not static factors because they are influenced by the length and intensity of heat exposure.

Health workers treat COVID-19 patients in several different working environment conditions with different activities showed a vary physiological response profile. The workplace of health workers can be in the treatment room (inpatient), ICU room, ER room, laboratory room, or outdoors such as at the drive thru sample collection place, patient pick-up place, and funeral. Hot working environment conditions, strenuous activity and PPE that hinders heat transfer have an impact on increased body temperature which leads to increasing workload characterized by the appearance of excessive physiological responses.

5.1 Numerical Results

Measurement of physiological responses to respondents was carried out objectively and the research variables were strictly controlled. The measurement results are presented in Table 3, Table 4, Table 5 and Table 6. Tables below shows the average values and standard deviations, as well as the results of tests of normality, homogeneity, a nova and post hoc. Statistical analysis is carried out to assist in drawing conclusions from the results of the experiment.

Table 3. Oxygen consumption

Environment Temperature	(Mean ± s) liter/minute	Normality	Homogenity	Anova
20 °C	0.254 ± 0.054	p=0.955 normal	p=0.16 homogeneous	p=0.411 not significantly different
25 °C	0.277 ± 0.073	p=0.087 normal		
30 °C	0.296 ± 0.089	p=0.398 normal		

Table 3 presents the results of statistical analysis of respondents' oxygen consumption data when carrying out activities (experimental protocols) at working environment temperatures of 20 °C, 25 °C and 30 °C. Each data is normally distributed ($p > 0.05$) and the three data are homogeneous ($p > 0.05$). The results of the analysis of variance (anova) obtained the value of $p = 0.411$ ($p \geq 0.05$). This shows that there is no influence of working environment conditions (temperatures of 20 °C, 25 °C and 30 °C) on oxygen consumption.

Table 4. Heart rate

Environment Temperature	(Mean ± s) bpm	Normality	Homogenity	Anova	Post Hoc Test
20 °C	100.45 ± 13.32	p=0.076 normal	p=0.150 homogeneous	p=0.002 significantly different	T20=T25 T25≠T30 T20≠T30
25 °C	109.61 ± 9.29	p=0.292 normal			
30 °C	120.25 ± 13.93	p=0.925 normal			

The results of statistical analysis of respondents' heart rate data when carrying out activities (experimental protocols) at working environment temperatures of 20 °C, 25 °C and 30 °C are presented in Table 4. Each data is normally distributed ($p > 0.05$) and all three data are homogeneous ($p > 0.05$). The analysis of variance (anova) resulted in a value of $p = 0.002$ ($p \leq 0.05$) so that it can be concluded that there is an effect of working environment conditions (temperatures of 20 °C, 25 °C and 30 °C) on the respondent's heart rate. The post hoc test showed no significant difference in the working environment temperatures of 20 °C with 25 °C and there was a significant difference in the heart rate of respondents at working environment temperatures of 20 °C with 30 °C and 25 °C with 30 °C.

Table 5. Blood pressure systolic

Environment Temperature	(Mean ± s) mmhg	Normality	Homogenity	Anova	Post Hoc Test
20 ºC	119.60 ± 5.02	p=0.343 normal	p=0.716 homogeneous	p=0,043 significantly different	T20=T25, T25≠T30, T20=T30
25 ºC	117.44 ± 4.62	p=0.980 normal			
30 ºC	123.34 ± 6.46	p=0.646 normal			

Data on the results of statistical analysis of systolic blood pressure are presented in Table 5. Each data is normally distributed ($p > 0.05$), and the three data are homogeneous ($p > 0.05$). Analysis of variance (a nova) of systolic blood pressure data resulted a value of $p = 0.002$ ($p \leq 0.05$) so that it can be concluded that there is an influence of working environment conditions (temperatures of 20 ºC, 25 ºC and 30 ºC) on the respondents' systolic blood pressure. The post hoc test showed that there was no significant difference in respondents' systolic blood pressure at working environment temperatures of 20 ºC with 25 ºC and 20 ºC with 30 ºC and there was a significant difference in respondents' systolic blood pressure at a working environment temperature of 25 ºC with 30 ºC.

Table 6. Blood pressure diastolic

Environment Temperature	(Mean ± s) mmhg	Normality	Homogenity	Anova
20 ºC	80.02 ± 4.98	p=0.320 normal	p=0.310 homogeneous	p=0,188 not significantly different
25 ºC	75.95 ± 5.90	p=0.209 normal		
30 ºC	77.12 ± 6.21	p=0.453 normal		

A statistical analysis of diastolic blood pressure is presented in Table 6. Each data is normally distributed ($p > 0.05$), and the three data are homogeneous ($p > 0.05$). Analysis of variance (anova) resulted in a value of $p = 0.188$ ($p \geq 0.05$) showing that there was no significant difference in the results of the respondent's diastolic blood pressure measurement.

5.2 Graphical Results

Oxygen consumption data obtained from respondents who carried out activities according to the experimental protocol on 3 working environment conditions (temperatures of 20 ºC, 25 ºC and 30 ºC) are presented in Figure 6.

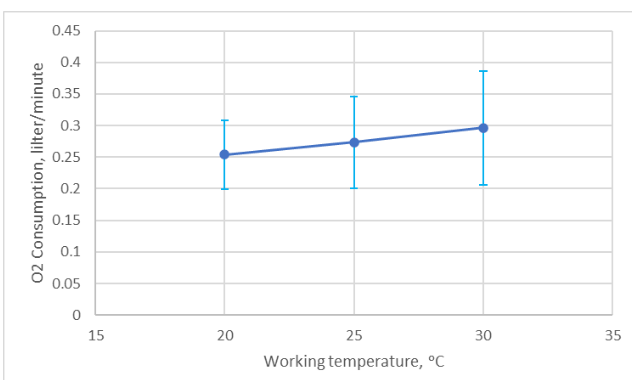

Figure 6. Oxygen consumption

Figure 6 shows the trend of increasing oxygen consumption (0.254 l/min; 277 l/min; and 0.296 l/min) caused by an increase in the temperature of the working environment (temperature 20 °C, 25 °C and 30 °C). However, the analysis of variance (a nova) shows that there is no influence of the working environment (temperature 20 ºC, 25 ºC and 30

°C) on oxygen consumption (p value = 0.411). This might be due to an experimental protocol that only provides light to moderate workloads. The working environment conditions in the experiment were not too extreme for respondents to get used to activities in tropical environments. The existence of acclimation before the experiment made respondents adapt physiologically to the environment. The effect of using masks that can inhibit oxygen consumption during activities is in accordance with research conducted by Yuan et al (2020) and choudhury et al. (2020) which states that breathing difficulty occurs when using Level III PPE. The use of N95 masks limits the amount of oxygen consumed during activities so that oxygen consumption becomes less than oxygen consumption at the same workload. N95 mask is a mask that functions to filter 95 % of particles floating in the air according to the N95 standard from the National Institute for Occupational Safety and Health (NIOSH) air filtration rating of the United States.

Oxygen consumption is influenced by several factors, namely: internal factors such as intake, storage, nutrient utilization, and heart condition; somatic factors such as age and gender; health factors such as health conditions, skills, fitness; psychological factors such as motivation, training, attitude; and environment (Kroemer et al. 1997). In addition, there are other factors that influence, namely: differences in the use of protocols, experimental conditions, and the use of research tools.

Heart rate data obtained from respondents who carried out activities according to the experimental protocol on 3 working environment conditions (temperatures of 20 °C, 25 °C and 30 °C) are presented in Figure 7.

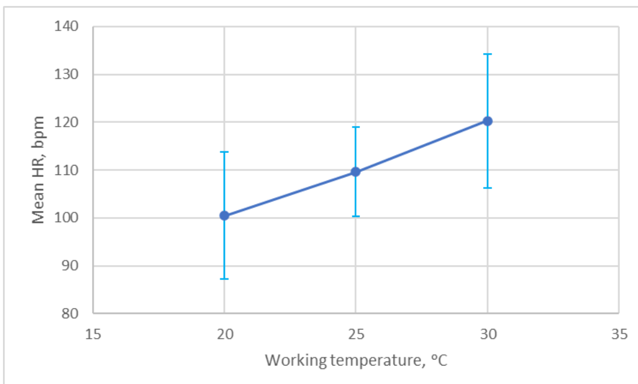

Figure 7. Heart rate

The classification of workloads by heart rate at the time of the experiments carried out can be categorized into light to heavy workloads (Astrand I., 1990 taken from Toomingas, 2012). At a working environment temperature of 20 °C a heart rate (100.45 ± 13.32) bpm was obtained which was included into light to moderate workloads, at an ambient temperature of 25 °C a heart rate (109.61 ± 9.29) bpm was obtained that can be classified as a moderate workload and at a working environment temperature of 30 °C a heart rate (120.25 ± 13.93) was obtained and was included to moderate to heavy workloads.

In Figure 7, there is an upward trend in heart rate in respondents when conducting experimental protocols at environmental temperatures of 20 °C, 25 °C and 30 °C. The human body strives to achieve a balance (homeostasis) between heat production and heat transfer to maintain optimal conditions for biochemical activity in the body. The physiological response to heat conditions is the body's effort to maintain workability and health. The body will protect itself from overheating by draining most of the blood flow from the middle of the body to the skin, mucous membranes, and peripheral parts of the body that are regulated by the stimulation of the autonomic nervous system. Hot conditions lead to dilation of blood vessels in the skin and the opening of arteriovenous anastomoses. An increase in heart rate through an increase in the strength and speed of contraction of the heart to compensate for the greater volume of vessels. Thus, the heart rate is a relatively simple measure of the circulatory load and the heat load, which can be used in assessing physiological tension in hot conditions (Gavhed in Toomingas 2012).

Data on systolic and diastolic blood pressure obtained from respondents who carried out activities according to the experimental protocol on 3 working environment conditions (temperatures of 20 °C, 25 °C and 30 °C) are presented in Figures 8 and 9.

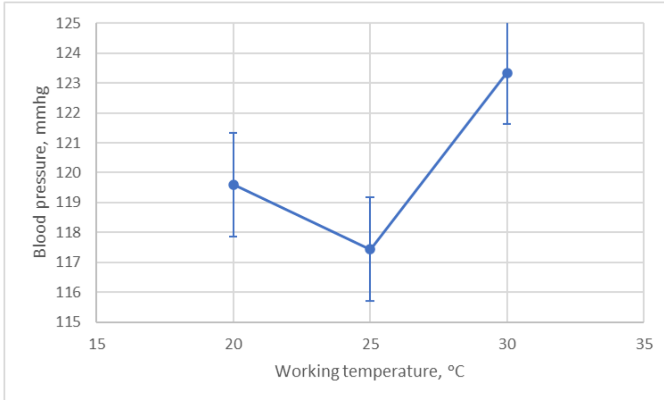

Figure 8. Blood pressure systolic

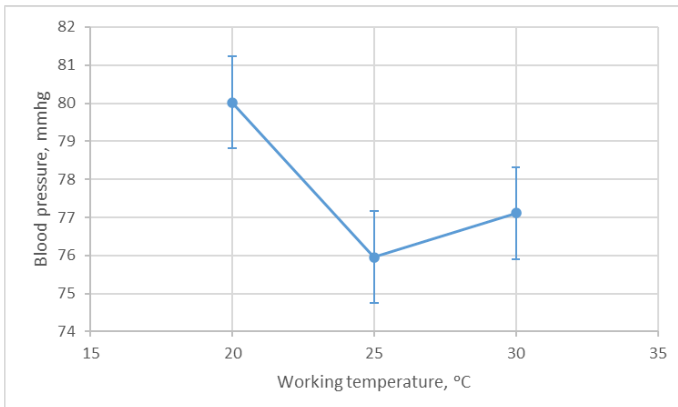

Figure 9. Blood pressure diastolic

Figure 8 shows the effect of working environment temperature (20 °C, 25 °C and 30 °C) on systolic blood pressure. The results of post hoc analysis showed that there was a significant difference between blood pressure at a work environment temperature of 25 °C and 30 °C and there was no significant difference between the work environment temperature of 20 °C and 25° C and 25 °C with 30 °C. Working in a hot environment coupled with the effect of using unbreathable level III PPE makes the body adjust itself by flowing more blood to the skin to cool the body and coupled with flowing blood to the muscles to carry food substances and oxygen for metabolic purposes. Blood needs to be pumped by the heart to flow so that there is a connection between heart rate and blood pressure. The combination of behavioral and physiological responses is used by human to maintain a constant core body temperature at (37 ± 1) °C, and generally efficient thermoregulation in this body temperature range of 35 °C - 40 °C (Parsons, 2014). Blood pressure is getting higher due to the higher body temperature which the result of the blocked evaporation processes by PPE.

The trend from the chart shows that blood pressure drops from 20 °C to 25 °C degrees although statistically it does not differ significantly and rises again from 25 °C to 30 °C. This phenomenon occurs because working at a temperature of 20 °C requires higher blood pressure for metabolism and maintaining an ideal body temperature. At a working environment temperature of 25 °C the blood pressure tends to drop because the temperature of 23-27 °C is the most comfortable temperature in the tropical region for people to work in which results in a normal heart rate. If the temperature and humidity of the work environment are too high in a sufficiently strenuous job (for example, at an air temperature exceeding 25 °C), human body cannot react sufficiently so that the body temperature rises. At a temperature of 30 °C there is a rise in body temperature and the body responds by flowing a lot of blood from the middle of the body to the skin to discharge heat into the environment so that the body temperature is stable.

Figure 9 shows the relationship of activity at the temperature of the working environment with diastolic blood pressure. The result of statistical analysis shows that there is no influence of the work environment (20 °C, 25 °C and 30 °C) on diatolic blood pressure. This happens because the change in diastolic blood pressure is relatively smaller than that of systolic blood pressure. (Toomingas 2012).

6. Conclusion

This study was conducted to evaluate the physiological response experienced by health workers when doing work dealing with COVID-19 patients using level III PPE in places with different working environment conditions, namely at temperatures of 20 °C, 25 °C and 30 °C with RH (50 ± 10) %. Experiments were carried out in the laboratory to obtain controlled research variables. Respondents were taken from S1 and S2 ITB students with age range of (23.7 ± 2.4) years and BMI of (24.3 ± 3.3) kg/m^2. The experimental protocol is designed to describe the activities that health workers usually do at work, namely physical activity, activities that require concentration and dexterity of the hands. Analysis of variance on experimental results showed that there was an influence of simulated working environment temperature (20 °C, 25 °C and 30 °C) on heart rate and systolic blood pressure and there was no effect on oxygen consumption and diastolic blood pressure. Post hoc analysis of the physiological response at a working environment temperature of 30 °C is different from other working environments (temperatures of 20 °C and 25 °C). Based on the analysis of the experimental results, it can be concluded that wearing PPE at a relatively high working temperature can result in undue physiological tension. The findings of this study can be used as the basis for the work and redesign of PPE.

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