ORIGINAL ARTICLE

A SURVEY ON ERGONOMICS OF INDUSTRIAL SAFETY HELMET: THERMAL PERCEPTION

Muhammad Muhsin HAIRUDIN[1]

[1] Institute of Medical Science Technology *(MESTECH), Universiti Kuala Lumpur, Malaysia.*

ABSTRACT

Commercial safety helmets offer head protection towards small falling items in working surroundings. In Malaysia, the construction industry is one of the major contributors for loss of life at the place of work. In spite of this fact, the study shows that seven out of ten safety helmets users avoided wearing helmets due to the advanced sense of hotness. This study aims to determine the type of industrial safety helmet use and the thermal perception of the industrial workers. An analytical experimental method was applied. Eighteen volunteers evaluated three different helmet designs. This study shows that active type safety helmet was the most preferred (Mean:4.1 SD:0.758) compare to other types of safety helmet tested and have significant different helmet temperature by ANOVA with a p-value less than 0.001. There is a significant correlation (p-value less than 0.001) of helmet temperature and comfort level of safety helmet with R^2 = 0.329. Every 1 unit decrease of helmet mean temperature, the comfort scale will increase as much as 0.276. This result is similar to previous research that supports that ventilation improves the comfort level. The finding of this study suggests that active type safety helmet is most preferred because it has the lowest in helmet temperature. The lower the helmet temperature, the greater the comfort level.

Keywords: *Construction, safety helmet, comfort level, thermal perception, ANOVA*

INTRODUCTION

Headgear is widely used in both occupation and leisure; it is used as a fashionable accessory or as an optional/mandatory means of protection. While headgear generally refers to everything one can wear on the head, most studies focused on headgear designed to have specific impact protective properties. Industrial safety helmets offer head protection against small falling objects striking the top of the shell in industrial surroundings (Hsu, Tai, & Chen, 2000). Wearing a proper safety helmet substantially decreases the chance of injury or maybe fatality (Naresh, Krishnudu, Hari Babu, & Hussain, 2015). Occasionally helmets without shielding function also are nevertheless used as an instance, symbolic or ceremonial helmet (Naresh et al., 2015). Substantial research attention went to optimizing its protective abilities (Aare, Kleiven, & Halldin, 2004) (Deck & Willinger, 2006) (Mills & Gilchrist, 2008). Industrial safety helmet also should be able to give protection from chemicals and weather conditions. Currently, there are two main types of safety helmet which are standard type and passive ventilation type. Most common is the standard type without any ventilation. Passive type is higher in cost and used by executive personnel in construction site and working area.

In Malaysia, Personal Protective Equipment (PPE) is one of the needs and requirements in the Factories and Machinery Act (FMA) 1967, Occupational Health and Safety Act (OSHA) 1994. Employers have the obligation to provide Personnel Protective Equipment (PPE) including safety helmet to all their employees without monetary charge as in guidelines on occupational safety and health in the service sector by Department of Occupational Safety and Health (DOSH) under Ministry of Human Resources Malaysia and also for logging activity as in guidelines on occupational safety and health in logging operations (OSHA, 1994). Occupational Safety and Health Act also stated it is mandatory for all laborers to wear safety gears while working. Employers who fail to provide all this and not comply with the laws can be compound not exceeding ten thousand ringgit or imprisoned not exceeding one year or both. For example, Perlis Department of Occupational Safety and Health director reported three compound notices amounting to RM7,500 had been issued to employers in the state in 2012 for failing to comply with the regulations (Zam, 2013, October 11). JKR also ordered all their workers to wear PPE including safety helmet as in the guideline publish by themselves to comply with the laws (Jabatan Kerja Raya Malaysia, 2013).

In spite of benefits of safety helmet and the enforcement, physiological aspects of protection helmets have turned out to be the most critical challenges confronted by the helmets design community. Employees aren't inclined to put on helmets at work for the reason that they are uncomfortable. Non-compliance with safety helmet has been a problem for a long time. A study in 1988 reveals that seven out of ten safety helmets users surveyed from 24 countries avoided wearing helmets because of advanced sense of hotness (Bogerd et al. 2015). A study among forest workers in the US shown that they are likely to take away head protection in hot and humid conditions as a result of thermal discomfort. (Davis, Edmisten, Thomas, Rummer, & Pascoe, 2001). In a survey done in 2009, almost 40% of construction workers were not sure whether they have to wear protective equipment on construction sites all the times. The same research also identified the major reasons for PPE lack of usage from workers. Uncomfortable or poor fit and temperature discomfort are the major reasons for this issue (Farooqui, Ahmed, Panthi, & Azhar, 2009). In addition, 98 percent of respondents who attended a seminar in Baltimore answered “yes” when asked if they had observed workers not wearing safety equipment when they are working. This was the finding from a survey conducted by Kimberly-Clark Profesional in 2010 (Smith, 2010, August 17).

Heat stress can lead to additional fatigue and influences performance at workplace, awareness and competence of the workers. Labours working outdoors and in industries that involve heat source are vulnerable to heat strokes. For that reason, protection against heat strokes is a must. Head cooling shows effective effects in improving an individual’s state of wellbeing during periods of resting (Pretorius, Gagnon, & Giesbrecht, 2010) and exercising (Ansley et al., 2008). This is common in people in the seasonal country. In warm seasons, they preference to cool their heads to increase their overall thermal comfort as they fell cooler (Nakamura et al., 2008).

Therefore, this study intended to find the best type of helmet that can provide the most comfortable thermal comfort for helmet users in a hot and humid environment. To accomplish the objective, the preference of user toward a different type of safety helmet has to be determined via questionnaire. Experimental data on differences of helmet temperature of standard safety helmet, passive ventilation safety helmet and active ventilation safety helmet are required to determine the correlations of helmet temperature and comfort level of the safety helmet.

METHODS

Participants

The study population of this study was students from UniKL MESTECH. The inclusion criteria were male, fit and agreed with the consent of this research. 18 volunteers agreed to participate in this experiment. This was more than 8 volunteers as in to two previous study by (Guan, Dullah, & Zhou, 2007) and (Davis et al., 2001) because this user’s trail would be more simple as the temperature was not taken in real time while the volunteers was running on the treadmill rather the temperature was measured on head manikin.

Instrumentations

a) Questionnaire

For this study, a questionnaire was used as complimentary after the user trials. The questionnaire was prepared by referring to previous studies (Davis et al., 2001). The questionnaire was divided into 4 sections which are Section A for demographic data such as name, age, gender and weight. Section B consist of close-ended question on the description of the helmet, Section C asked on the user's perception on the safety helmet which will be in ranked scale and Section D consist of questions about the preference of the subject toward which type of safety helmet that was more preferred using paired comparisons.

For section B, the question was asked in opposite adjectives in a closed-ended way for the best description of the helmet used. For the helmet tested, the subject was asked to chose one of each pair of adjectives that best describes how it felt to them. These include 6 pairs of choice which are comfortable or uncomfortable, hot or not hot, not itchy or itchy, acceptable or not acceptable, sweating or not sweating and not heavy or heavy. This section aims to answer the first objective which was to determine the preference of user toward a different type of safety helmet.

For section C, the question was in ranked scale from 1 to 5 for 3 questions. This section focus on the user’s perception of the helmet. Question 1 was of comfort. The subject must choose from very uncomfortable to not at all uncomfortable in the scale 1 to 5. Question 2 was on hotness; subjects must choose from very hot to not hot at all in the scale of 1 to 5. The last question in this section which was question number 3 is about heaviness. The subject must choose from very heavy to not heavy at all in the scale of 1 to 5.

Section D was the last section for this questionnaire. This section was on the user's preference for the safety helmet by using paired comparisons. This section was asked after at least two helmets have been tested by the subject. Of the pair given, the subject must select the helmet they preferred for each of the criteria given which include comfort, less hot and less weight to determine the most preferred safety helmet used. This section aims to determine the correlations of thermal comfort and the type of safety helmet preferred.

b) Safety Helmets
Three safety helmets were tested namely standard type, passive ventilation type, and active ventilation type. Standard type has no ventilation hole at all. Passive ventilation type has 6 ventilation hole already installed Active ventilation type safety helmet is a helmet with a fan and one big ventilation in the front area. The fan is located in the front because the most sensitive part of the head toward thermal sensation is the front area of the head (Guan et al., 2007).

c) Head Manikin
This study used a head manikin (Fig. 1) to fix the helmet at a fix position mimicking the real position of a person wearing a safety helmet. The materials of this head manikin are a plastic mix with rubber due to cost efficiency. We measure the helmet temperature of the head manikin by putting a probe in front of the head and under the helmet. The head manikin then was elevated on a poll to a 1.65M height simulating a real person standing height (Fig. 1).

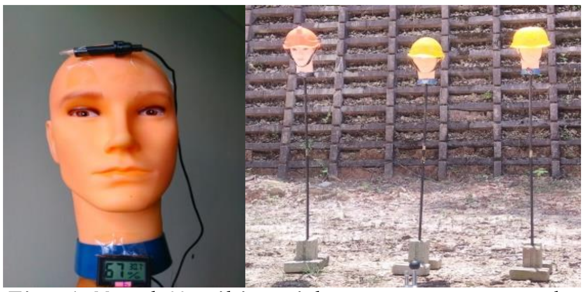

Fig. 1 Head Manikin with temperature probe and display (Left); Experimental set up (Right)

d) Treadmill
This study uses RT Aero (BHF-T1005) treadmill that UniKL MESTECH Gymnasium has. The speed will be set to 5km/h referring to (Guan et al., 2007) and (Davis et al., 2001). This speed aims to simulate a real working workforce of 360kcal/h with the same for self-pace manual task for workers. This was started by (Davis et al., 2001) with set the speed to 5.6km/h then followed by (Guan et al., 2007) by setting the speed to 5km/h. All this was to maintain the condition as same as working as a real construction worker while wearing the experimental helmets.

e) Temperature Measurements
This study used TM-188 Heat Stress WBGT Meter for measuring temperature with an accuracy of ±0.8 °C. For temperature probe, this study use three sets of Digital Hygro-Thermometer with an accuracy of ±1.0 °C. This probe measures the helmet temperature of the experimental head manikin.

Procedure
Figure 2 represents the graphical overview of methodology. For the experimental method, three types of helmet which are non ventilated safety helmet, passively ventilated safety helmet and actively ventilated safety helmet will be tested on the helmet temperature against time in a hot environment exposed to the sun in Kajang area which represents Kuala Lumpur and Malaysia temperature.

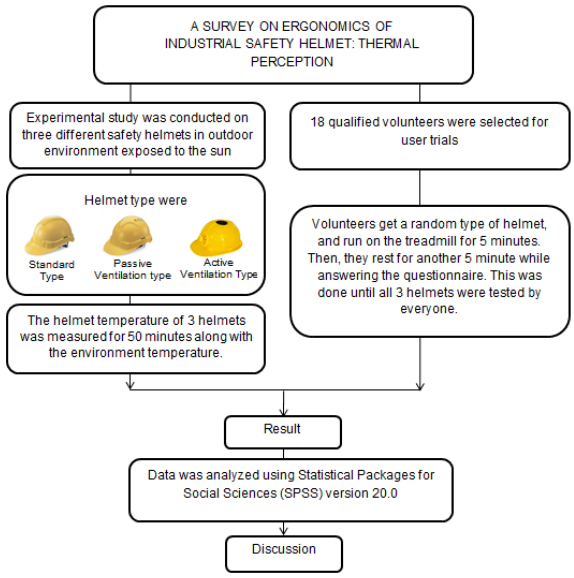

Fig. 2 Graphical overview of methodology

For the user trials, subjects were taken from Unikl MESTECH student as a respondent with some payment. 18 respondents have agreed to participate in this study. Each respondent session is 30 minutes. They will run while wearing the tested helmet for 5 minutes and then rest for 5 minutes. This will repeat 3 times within 30 minutes. The sequence of helmet type was random. After 5 minute run, they will rest 5 minutes. Within this 5 minutes, they will answer the simple questionnaire. This repeat until all three helmets was tested. This user trial was conducted in UniKL MESTECH Gymnasium with a controlled temperature suitable to the Malaysian climate which is 30°C and 70% relative humidity. All these methods were referring to (Davis et al., 2001) and (Guan et al., 2007) that also use a similar method in user trials. The difference was the duration which was 45 minutes and 50 minutes respectively. This experiment was conducted in March 2018.

RESULTS

The demographic background of respondents

The total number of respondents was 18. The mean age of the participants is 22 with an SD of 2.007, ranging from 20 years old to 26 years old. All respondent is male. The mean BMI is 24.8 with a minimum of 18.37 to a maximum of 32.37. Majority of the respondents were Malay with 17 people (94.4 %) follow by Indian 1 person (5.6 %).

Table 1 Summary of demographic data of respondents

Variable	Mean	SD	Min	Max
Age	22.44	2.007	20	26
BMI	24.82	4.23	18.37	32.37

Preference of user toward a different type of safety helmet

From Table 2, active type safety helmet ranked the highest among other types of safety helmet in comfort scale followed by the passive type and standard type as the lowest mean score. The comfort scale uses 1 to 5 scale as (1) very uncomfortable and (5) very comfortable. This result indicates that active type helmet is most preferred by users.

Table 2 Mean score of standard, passive and active type of safety helmet on comfort

Type of helmet	Mean	SD
Standard	2.7	0.878
Passive	3.1	0.676
Active	4.1	0.758

The temperature of standard safety helmet, passive ventilation safety helmet and active ventilation safety helmet

There is a significant difference in temperature of all different type of safety helmet tested against environmental temperature. From Table 3, by using one-way ANOVA, the p-value is less than 0.001 which is less than alpha (0.05). This show very significant difference between temperature helmet for all three different types of helmet tested which are standard, passive and active type safety helmet.

Table 3 One way ANOVA

Type of helmet	Mean	SD	F	P Value
Standard	40.18	1.270		
Passive	37.87	1.061	60.129	<0.001**
Active	35.30	0.721		

**very significant

The highest mean temperature is standard type safety helmet which is 40.18 °C followed by passive type safety helmet 37.87 °C and the lowest mean temperature is active safety helmet 35.30 °C. The pattern of all the temperature of different type of safety helmet and the external environment temperatures is the same as it rises as the environment temperature rise and decreases as the external environment temperature decrease. At one point (20 minutes), the helmet temperature of the active safety helmet is a bit lower compared to the environmental temperature. All this refer to Figure 3.

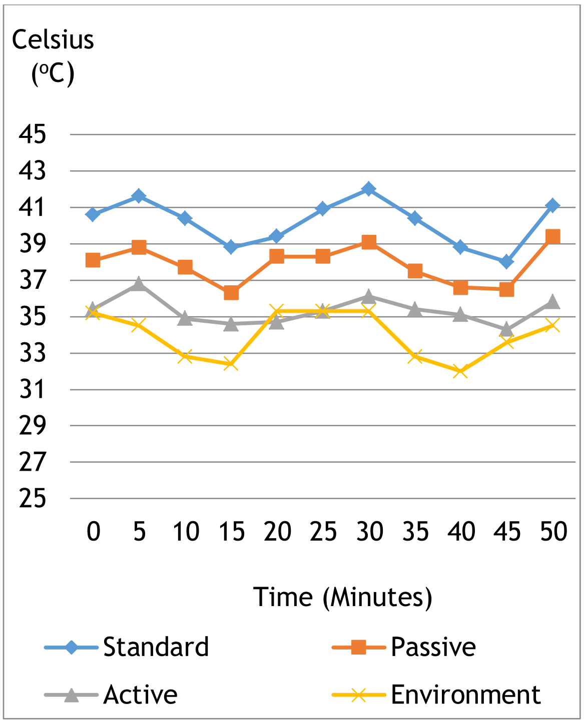

Fig. 3 Temperature against time for a different type of safety helmet and the environmental temperature

From Table 4, we can see the mean temperature helmet varies greatly compare to the outside environment by 37.78 °C and 33.97 °C respectively. The maximum temperature for helmet temperature is 42.0 °C and for the outside environment is 35.30 °C. The lowest minimum temperature for helmet temperature is 34.3 °C and for the outside environment is 32.0 °C.

Table 4 Summary of temperature in experiment

Temperature	Mean (°C)	Max (°C)	Min (°C)
In helmet	37.78	42.00	34.30
Outside environment	33.97	35.30	32.00

Correlations of helmet temperature and comfort level of safety helmet

There is a significant correlation of helmet temperature and comfort level as the mean helmet temperature increases, the mean score for comfort scale decreases as shown in Table 5. By using linear regression of these data, the result shows significant correlation (p-value less than 0.001) of helmet temperature and comfort level of safety helmet (Table 6). The adjusted R2 is 0.329. This show that the mean mark score depends 33% on helmet temperature. In conclusion, it shows that every 1 unit decrease of helmet mean temperature, the comfort scale will increase as much as 0.276.

Table 5 Mean helmet temperature and mean score for comfort scale

Type of helmet	Mean helmet temperature (°C)	Mean score for comfort scale
Active	35.3	4.1
Passive	37.87	3.1
Standard	40.18	2.7

Table 6 Association analysis between mean helmet temperature and mean comfort score

Variable	B	t	p-value
Comfort	17.75	2.010	<0.001**
Helmet temperature	-0.276	0.053	<0.001**

Linear regression test using the Enter method
**very significant

CONCLUSION

This study shows that active type safety helmet was the most preferred compared to other types of helmet tested. Experimental results show a clear difference in internal helmet temperature which is statistically significant. These results suggest that as the mean internal temperature of the helmet decrease, the preference of that specific helmet increase. Every 1 unit decrease of helmet mean temperature, the comfort scale will increase as much as 0.289. However, this research has a few limitations to take into account. For example, the experiment only uses head manikin and the volunteers were not the real working construction workers. Therefore, a number of recommendations are also suggested for future work. Firstly, future research needs to do real-time temperature and user trials test. This would allow the researcher the find clearer connection thus can make causal effect relationship by regression test. Secondly, future research should include real working industrial and construction workers as the volunteers so that the feedback given will be more quality and more accurate because they are the real end user of the safety helmet.

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COMPETING INTERESTS

There is no conflict of interest.

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