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ORIGINAL ARTICLE

Monitoring Driver's Heart Rate Response Using Heart Rate Detection Device (HDD)

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ABSTRACT

Introduction: Drowsiness driving is one factor contributing to road accidents resulting in fatalities of drivers and passengers. However, a warning system device to alert drivers about the drowsiness level has never been appropriately developed. This study aims to create a heart rate detection device that monitors drivers' heart rate and notify them about their drowsiness, which will, in the long term can help to reduce the number of road accidents due to drowsiness. **Methods:** In this experimental research, ten participants (Mean Age= 24 Years-Old, SD=0.4) were attached to the developed heart rate detection device on the steering wheel of a driving simulator. The participants underwent four 30-min sessions on the driving simulator sessions and heart rate reading throughout the driving period to obtain the heart rate mean value from the first three sessions. The obtained heart rate mean value was set as a threshold value so that the alarm will trigger if the value of heart rate falls below the threshold value in the fourth session. **Results:** The results showed that the respondents' average heart rate (bpm) decreased gradually the longer time they drove the car simulator. This study also revealed that the heart rate detection device successfully monitored the driver's heart rate and notified them when they were at drowsiness level. **Conclusion:** Overall, the device should be more user friendly by improving the sensitivity of sensors in all parts of the steering wheel for better data collection.
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Keywords: Drowsiness Driving; Heart Rate (HR); Karolinska Sleepiness Scale (KSS)

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INTRODUCTION

Malaysia hit 28.2 million vehicles on the roads based on Malaysian vehicle registration data up to June 2017 (1). Road accidents can be described as unintended incidents due to lost driving control until collision with other vehicles, property or other road users that cause injury to driver, passengers, and damage to public property (2). Drowsiness has been recognised as one of the most phenomena in contributing to road accidents (3). Motor vehicle crashes killed over 1.2 million people worldwide, and approximately 20% of vehicle crashes were related to drowsiness (4). Drowsiness can affect performance capabilities despite of practising, profession, education, motivation, IQ, individual skill or personality (5). In the United State, 37% of drivers that drive in the morning after night shift experienced a near-crash incident (6). However, a warning system device will still have a problem if it is not developed properly and the alarm did not represent the true state of drowsiness drivers (17). The study will contribute to a new finding to understand the driver's heart rate response and behaviour.

There were techniques or measures developed and used widely to monitor the driver's drowsiness by vehicle-based measures, behavioural and psychological measures. This study only implements behavioural and physiological measures to the respondents to detect the drowsiness symptoms.

Physiological measures the amount of times heartbeats per minute (bpm) or contractions of the heart which is known as heart rate. 60 to 100 beats per minute is a normal heartbeat range for adults (7). Many factors can influence heart rate, including age, activity, and fitness level. For emotions, heart rate can rise if someone was pressured, apprehensive or incredibly joyful or sad (8). If heart rate consistently approaching 100 bpm (tachycardia), or even less than 60 bpm and not a trained athlete (bradycardia) should consult a doctor if there were symptoms like shortness of breath, dizziness or fainting (9), (10). Heart rate is one of the standard primary vital signs for assessing general health. Knowing bpm helps one track their heart health and recognise growing health issues as one gets older (8).

Driver behaviour identification from observation of driver's behaviour while driving was known as behavioural measures. Behaviour measures such as chatting, yawning, eye closure and head position would determine the driver's driving state, such as alert, drowsy, fatigued, drunk or distracted (11). Karolinska Sleepiness Scale (KSS) has been frequently used in research relating to sleep deprivation (12). Data gathered from previous research associated with driving behaviour can be retrieved and used to categorise driver states or assess driver abilities (13). It is well known that driving habits vary between drivers respective to ages, genders, nationalities, driving experiences, emotions and so forth. KSS is a ten-point scale, starting with 1-(extremely alert) till 10-(extremely sleepy, cannot keep awake) (14). However, KSS is just a general scale level and no studies regarding mapping the KSS level with behavioural measures. In this study, we tried to map the KSS level with the behavioural measures such as the number of yawning, rubbing eyes, having conversation or singing and others.

For device part, the proposed system is established on the infrared (IR) working concept and employs pulse oximetry logic. A pulse oximeter determines a person's blood's heartbeat and oxygen saturation by sensing the luminosity absorbed by the blood in capillaries beneath the skin (15). An IR sensor is positioned on the person's fingertip and detects the heart rate before transmitting the data to the Arduino controller (16). The controller compares the sensed value to the threshold value, sends an alarm signal to the person via a buzzer, and displays the heart rate on the Blynk application. The major different of this study with Srinivasan et al. (2020) is the three lowest heart rate readings from the collected data for first three sessions will be calculate with threshold calculation to obtain the mean of the heart rate readings. The mean value of heart rate will be used to set up the threshold for the activation of buzzer. Meanwhile, Srinivasan divided the heart rate into three levels such as low heart rate level, normal heart rate level and high heart rate level.

In this monitoring system, buzzer will produce an alarm beep to notify the driver about their drowsiness according to their heart rate's level which avoid the system from producing false alarm. The output value is display through mobile phone which enable the driver to save their heart rate response for future reference and self-storage.

Existing methods to detect driver's drowsiness level has a problem in terms of accuracy and unsuitable for use while driving, as the device or components will be attached to the driver's body. Thus, the purpose of this research is to develop a comprehensive heart rate device equipped with a warning system and to improve the accuracy of detection. Therefore, once the driver exhibits signs of drowsiness, the alarm will be activated. Following that, the driver's behavior will be classified using the Karolinska Sleepiness Scale (KSS).

MATERIALS AND METHODS

Developing Heart Rate Detection Device (HDD)

Three main components that compulsory in this system consist of MAX30100 Heart-Rate Pulse & Oximeter Sensor as input, then ESP12E NodeMCU Wi-Fi ESP8266 for documentation purpose and Buzzer Piezo Alarm Driver Module to produce output. Figure 1 is the hardware block diagram for the Heart rate Detection Device. MAX30100 sensor is useful in retrieving heart rate data from the driver's fingertip in an analog signal, then sent to the NodeMCU to convert the analog signal into digital signal. The system will run and display the heart rate readings in real-time. Furthermore, the readings will be displayed in Blynk app, which means that the detection of heart rate and connection to handphone is successful. If the respondents are in drowsy condition where the heart rate (BPM) readings in the threshold range, then an alarm are produced by Buzzer to warn the driver is in a drowsy state. The alarm will stop buzzing once the driver's heart rate in normal range.

Figure 1: Driving Simulator

Arduino Software (IDE)

First, the system required Auth Token to connect the hardware with the smartphone before initialising the Pulse Oximeter. After the pin Mode and Blynk were successfully connected, the pulse oximeter will start collecting data for first three sessions of the experiment. The threshold value was decided by calculating the mean of the three lowest heart rate (BPM) readings from the previous sessions, and the value obtained was put in the margin of plus and minus five. While for the last session, if the BPM readings within the range of threshold that have been set up, the buzzer will produce an alarm beep to notify driver.

Driving Simulator

A driving simulator Is used to create an artificial environment believe in substituting the actual driving experience. The simulator was equipped with a monitor to display the virtual reality driving environment, a steering wheel, clutch/brake/oil pedal and real-size driver seat, as shown in Figure 1. BeamDrive.Ng is the software used to produce the driving environment for the respondent to roam freely on the highway throughout the experiment. The respondent's heart rate (BPM) readings were continuously recorded by the MAX30100 installed on the steering wheel.

Participants

A total of ten are volunteered as respondents for this experiment, where all of them have legal driving licenses with over five years of driving experience. The age of the participants is at a range between 24 to 25 years old, and the average age is 24.2 years old. All the respondents are non-smoker, free from critical disease and not taking any regular medications that could affect their performance while driving the simulator. Table I showed the respondent's characteristics taken before the experiment begin.

Table I: Respondent's Characteristics

Variable	Average	Standard Deviation
Age (years)	24.20	0.422
Height (cm)	162.30	6.395
Weight (kg)	60.85	7.326

Experimental Set-up

The experiment was carried out at the Ergonomic Laboratory of the School of Mechanical Engineering, Universiti Teknologi MARA (UiTM), Shah Alam. Before starting the experiment, the hardware was installed in the car simulator. At the same time, the respondents were asked to scan the QR code as a procedure before entering the laboratory and checked their body temperature and blood pressure. Then, the respondent was informed about the procedure and the total time required to complete four sessions of the experiment. Before the experiment begins, the respondent is required to fill up the background of the respondent form, and an informed consent form is also given to ensure that the respondent is agreeing to involve and completing the experiment. After the experiment ends, all respondent is asked to fill up the feedback of the device's performance and have a short interview for a verbal opinion from them regarding the experiment and device.

Experimental Procedure

Respondent was asked to sit comfortably on the car seat, then place their hand on the steering wheel as their usual while driving. The heart rate sensor was attached according to their index's fingertip with a tape to secure the heart rate sensor. The experiment is divided into four sessions, which each session required 30 minutes to be done. The first three sessions were for collecting respondent's heart rate readings in order to obtain the threshold value before the alarm system was attached for the fourth session. Throughout the experiment session conducted, the respondent will be observed in terms of the Driver's Behaviour Sleepiness Scale (DBSS). The participants were given 15 minutes to rest before continuing the next session.

Driver's Behaviour Sleepiness Scale with KSS Level

Driver's Behaviour Sleepiness Scale (DBSS) was inspired and mapped from Karolinska Sleepiness Scale (KSS) used to measure situational sleepiness and indicates the level of drowsiness of individuals. Therefore, DBSS in Table II showed the detailed description of each behaviour taken into observation to understand better and ease the data collection. The observer used to tick the frequency of each behaviour every five minutes for one complete session based on the observation done towards the respondent in the prepared form.

Table II: Driver's Behaviour Sleepiness Scale with KSS Level

LEVEL OF KSS		CRITERIA OF DROWSINESS	BEHAVIOR	EXPLAINATION
4		ALERT	Driving with one hand	The drivers suddenly change their driving style from both hands to one hand
6	6.00	Some Sign of Sleepiness	Having conversation or singing	The drivers start having conversation with people or singing while driving
	6.50		Yawning one time while driving	The driver yawning one time for more than 5 seconds
7	7.00	Sleepy, but no effort to keep awake	Yawning two times while driving	The driver yawning two times for more than 5 seconds
	7.50		Rubbing eyes	The driver rubbing their eyes more than 3 seconds
8	8.00	Sleepy, but some effort to keep awake	Yawning more than three time while driving	The driver uawning three times and above for more than 5 seconds
	8.50		Body incline to the front while driving	The driver moved the body towrds whe steering wheel

Statistical Analysis
The heart rate readings and DBSS data are recorded and analysed using the repeated measure ANOVA through IBM SPSS Statistics 26 software to determine the significance of the data. Multivariate analysis is suitable for complex data sets that can reduce the incorrect rejection of a true null hypothesis by finding the p-value, which needs to be below or equal to 0.05 ($p \leq 0.05$) for statistical significance.

ETHICAL CLEARANCE

This study was approved by Research Ethics Committee (REC), Universiti Teknologi MARA Ref. No. REC/05/2021 (MR/331)

RESULTS

The respondents drove the car driving simulator for four sessions which each session required 30 minutes to complete. However, only the first three-session data was collected as the fourth session, the alarm system was activated, interrupting the heart rate readings. The graph in Figure 2 showed the mean heart rate in BPM

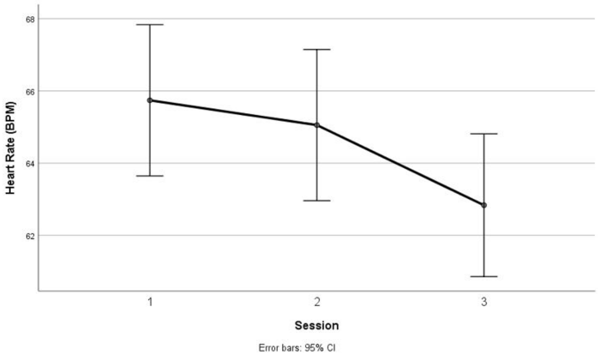

Figure 2: Mean of Heart Rate for Overall Session

for ten respondents in the first three sessions. There was no statistically difference in heart rate (bpm) based on respondent's prior sessions, $F(2,297) = 2.28$, $p>0.05$; Wilks' Lambda = 0.985, partial $\eta^2 = .015$.

Figure 3 showed the average value of heart rate for five male and five female respondents for three experiment

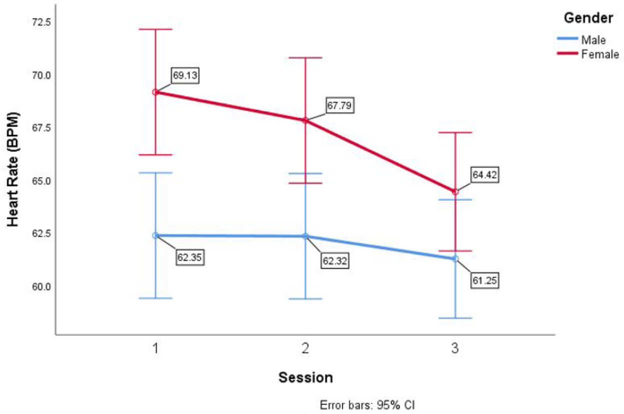

Figure 3: Mean of Heart Rate by Gender

sessions. Thus, this study identified the normal and drowsy heart rate mean value of drivers while driving the car simulator using a heart rate detection device. However, the statistical analysis results of this experiment showed that there is no significant difference between sessions, gender and respondents.

Karolinska Sleepiness Scale (KSS)
The observer rated drowsiness subjectively with the KSS in range of 4 (alert) to 8 (sleepy, but some effort to keep awake). For this study, drowsiness in driving is defined if the respondents showed the specific sign according to the driver's behaviour sleepiness scale with KSS level on Table II. Based on Figure 4, the average value of KSS for ten respondents in the three sessions showed no significant difference in KSS based on the respondent's prior sessions, $F(2,57) = 4.09$, $p>0.05$; Wilks' Lambda = 0.875, partial $\eta^2 = .125$.

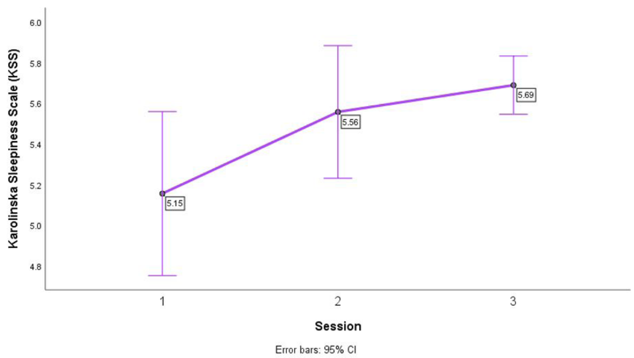

Figure 4: Mean of KSS by Overall Session

Heart Rate Detection Device
Figure 5 showed the mean of KSS for ten respondents in the third and fourth session presented in a line graph. There was no statistically difference in heart rate (bpm) based on respondent's prior sessions, $F(1,59) = 2.9$, $p>0.05$; Wilks' Lambda = 0.953, partial $\eta^2 = .047$. During the fourth session, besides monitored the heart rate, the heart rate detection device also activated the alarm system to notify the respondents based on the calculated threshold.

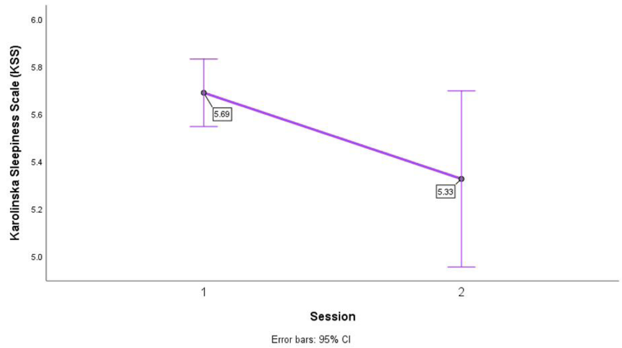

Figure 5: Performance of KSS with Heart Rate Detection Device

The results of the repeated measure ANOVA from the five answered questionnaires indicated a significant difference in performance based on the respondent's initial questionnaire, F (3,7) = 7.03, $p<0.05$; Wilks' Lambda = 0.249, partial η^2= .751. Therefore, the null hypothesis was rejected for this section.

DISCUSSION

While this study did not confirm the normal and drowsy mean heart rate, it partially substantiated that the driver will be drowsier as the time of driving increases just as stated in the hypothesis. Figure 2 showed that the heart rate decreased from the first session to the third session, even though there is no significant differences between the session, we can see the trend of heart rate decreased gradually. When doing further analysis by comparing between the gender, we can see apperantly female mean heart rate was gradually decreased as compared to male heart rate as in Figure 3.

As mention in the introduction, this study is tried to map KSS level with behavioural measures through observation. Based on result in Figure 4, mean of KSS by overall session, the result shows that the level of KSS gradually increase from level 1 to level 3.However, there was no significant difference between the session. There was no signifiance difference between the grah of heart rate for overall session between the session is due to two factors. Number one is the sample size collected is small which was only 10 persons participated in the experiment. Number two is the total time of experiment conducted per session was short compared to an experiment conducted by a previous study that required 2 hours non-stop. This study was conducted for 30 minutes per session, and the total number of sessions was four. In addition, before each session started, there was a 15-minute break for the respondents to get ready for the following sessions. Besides that, possible interuptions may occur during the experiment that affected the quality of results obtained, such as the failed connection of the heart rate detection device.

CONCLUSION

In this study, a heart rate detection device was attached to the steering wheel of a driving simulator. The experiment involved ten respondents for four 30-minutes sessions. The first three sessions heart rate data collected were used to obtain the heart rate mean value to set the threshold for activation of the alarm system in the fourth session. The findings showed no significant difference for heart rate (bpm) and KSS between sessions, gender and respondents. In contrast, the performance of the heart rate detection device showed a significant difference where the value of P for the questionnaire was less than 0.05 ($p<0.05$). However, these findings indicate that the hypotheses of this study were accepted in certain circumstances. A few recommendations might help the future research; recruit more respondents with longer experimental duration, increase the variation of age group and health status, change to device with the printed circuit board (PCB), an advanced system of vehicle-based metrics on car driving simulator. Therefore, it can be concluded that the heart rate detection device was successfully operated.

Despite those limitations, this study has identified that both KSS and DBSS with KSS levels had similar performance in detecting drowsiness conditions. Furthermore, the data can be retrieved for categorised the driver state (18) in the future with an enhanced experiment set-up. Furthermore, although other respondents were scored inconsistently in KSS level, the behaviour measure used (16) on Table 2 was a reliable predictor of drowsiness conditions in determining the driver's driving state. Lastly, the longer time spent driving will increase the frequency of driver's behaviour sleepiness scale with KSS level as shown in Figure 4.

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