ORIGINAL ARTICLE

An Investigation of Heart Rate and Oxygen Saturation Level (SpO_2) in Indicating Driving Fatigue

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ABSTRACT

Introduction: In Malaysia, the number of fatigue-related car accidents has increased in frequency with fatigued drivers at a higher risk as there is a decline in their driving performance. Thus, a reliable parameter to indicate driver fatigue is crucial. This research aimed to investigate the relationship between three factors: (i) types of roads, (ii) body mass index (BMI), and (iii) gender and their impact on (i) heart rate and (ii) oxygen saturation level (SpO_2) as indicators of driver fatigue. **Methods:** A total of 24 experimental runs developed by Design Expert software were conducted on real-road conditions. The investigation was administered during the first 15 minutes and the final 15 minutes of the driving session. **Results:** Overall, the final 15 minutes of the driving session exhibited a higher heart rate and a lower SpO_2 level in comparison to the first 15 minutes. This study discovered a consistent increase in heart rate and a drop in SpO_2 level as the driver's BMI transitioned from the healthy range of 18.5–24.9 kg/m^2 to 30 kg/m^2 and above, indicating obesity. Also, driving on a monotonous road generated critical driver fatigue compared to relatively demanding urban, uphill/downhill, and winding roads. In addition, female drivers showed higher heart rates and lower SpO_2 levels than male drivers during both periods of driving. **Conclusion:** The current study has established the relationship between types of roads, BMI, gender and their impact on heart rate and SpO_2 level. Thus, the outcomes might be useful to academicians and policymakers in the field of road safety in order to prevent traffic accidents due to driver fatigue.
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INTRODUCTION

Road traffic deaths and injuries have become a major public health concern, notably in low- and middle-income countries including Malaysia. According to statistics from the Malaysian Institute of Road Safety Research (MIROS), the number of traffic accidents in Malaysia had increased from 462,426 cases in 2012 to 567,516 cases in 2019. However, because of the execution of the movement control order (MCO) during the COVID-19 outbreak, the number experienced a decline, with a record of 418,245 cases in 2020 before rapidly increasing to 915,874 cases from 2021 to 2022 (1).

Slow reaction time, deteriorating decision-making skills, inability to operate vehicles and failure to recognize oncoming threats due to driving fatigue are the major causes of road crashes (2). Driving fatigue is defined as extreme tiredness caused by physical or mental strain while driving a vehicle. It is important to figure out parameters that can reliably indicate driver fatigue under different driving demands and conditions in order to reduce the number of road accidents.

A review of the available literature indicates that very limited research has looked into the ability of human physiological parameters to indicate driver fatigue, such as heart rate and oxygen saturation level (SpO_2). Research suggesting that heart rate is a valid indication of fatigue since it reflects both mental and physical condition. Driving fatigue occurs when the oxygen intake is lower than 95 per cent when driving due to the invigoration of the physiological activities where the supply is insufficient in comparison to the quantity needed. For example, a study revealed that an increase in driving duration decreases heart rate (2). This decrease in heart rate lowers blood pressure, causing chest pain due to insufficient oxygen-rich blood supply to the heart muscle. This sequence of events as a result of increased driving duration leads to fatigue (3). Moreover, in another study (4), the level of SpO_2 in the driver's body decreases as driving duration and fatigue rise. The drop in SpO_2 level with the onset of fatigue impairs crucial mental abilities such as decision-making (5). Hence, it is reasonable to consider heart rate and SpO_2 level as indicators of driver fatigue.

Therefore, the purpose of this study was to study the relationship between three variables: types of roads, body mass index (BMI), and gender and their impact on heart rate and SpO_2 level as indicators of driving fatigue. The comparative study was conducted between the first 15 minutes and the final 15 minutes of driving sessions.

MATERIALS AND METHODS

Independent variables selection and its level setting

Emerging evidence suggests that types of roads, body mass index (BMI) and gender affect the physiological system.

Types of Roads

Road geometry, such as uphill/downhill, urban, monotonous and winding has an effect on the driver's physiological performance.

Urban

The presence of street lighting, as well as the existence of curbs and channels adjacent to the roadside in most but not all cases as illustrated in Figure 1(a), defines urban streets. Due to the vast population size, minor and serious accidents are more likely in urban areas than in rural areas. When it comes to city centers, urban space gives a little amount of room for prospective traffic solutions like roundabouts and traffic lights. A high population combined with an abundance of traffic lights or roundabouts may result in significant traffic congestion on metropolitan routes, causing tension. In this study, the urban road driving tests were conducted out from Mydin MITC Ayer Keroh (2.271108717375982 ,102.29262414154466) to Universiti Teknikal Malaysia Melaka - Kampus Teknologi (2.279860517578614, 102.27356448764729).

Uphill/downhill

A road is considered a hill road if it passes across terrain with a transverse slope of 25% or greater as illustrated in Figure 1(b). Driving on slopes downwards and upwards require more control, rising reaction time which is responsible for crashes. In this study, the uphill/downhill road driving tests were conducted out from Simpang Masjid Tanah Alor Gajah (2.409561830410841,102.15 719833139521) to Ayer Limau Alor Gajah (2.37382305 11734275,102.11318864589161).

Monotonous

Monotony driving is defined as long highway drives, with few turns, steady noise levels and boring scenery as illustrated in Figure 1(c). When the human central nervous system is subjected to monotony, the quantity of cerebral activation decreases, resulting in sensations of exhaustion, sleepiness, decreased concentration, disinterest in the work and a decline in attentiveness. Boredom in a driver can result in inattention, highway hypnosis (white line fever), fatigue, micro sleep and even deep sleep. In this study, monotonous road driving tests were conducted from Ayer Keroh Plaza Toll (2.3 01618847297943,102.31063058662528) to Simpang Ampat Plaza Toll (2.4469892722415527,102.1834889 2781675).

Winding

A winding road is defined as having three or more curves separated by a tangent distance as illustrated in Figure 1(d). It is well established that traffic collision on horizontal curves are a cause for concern in many nations due to the frequency and severity of accidents at curves than at road tangents. In this study, the winding road driving tests were conducted out from Kolej Al-Jazari UTeM (2.3217602455414634, 102.32709907855994) to Surau Kesang Tua (2.3219960861829816, 102.38321089048513).

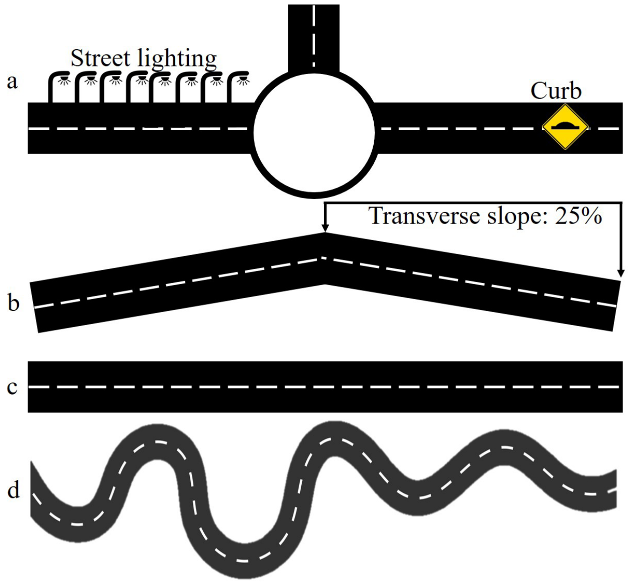

Figure 1: Driving route: (a) urban, (b) uphill/downhill, (c) monotonous, (d) winding

Body Mass Index (BMI)

Aside from chronic stress, depression and age, BMI is a risk factor for human physiological system failure. Due to greater bulk and baseline oxygen demand, high BMI individuals' blood volume and cardiac output rise. To compensate for increased ventilatory load, obese individuals may have increased neural respiratory drive. The failure of these compensatory mechanisms increases the risk of cardiovascular diseases such as hypertension (high blood pressure), coronary artery disease (CAD), stroke and heart failure.

Gender

Physiological system performance limits may vary by gender due to anatomical and physiological variances. Men have larger muscle mass, bone mass and lower body fat than women. These differences change many (if not all) organ systems in adult males and females, which might affect physiological function. Even when height is taken into account, men have bigger lungs, wider airways and better lung diffusion capacity than women. Hence, both genders were considered in this study (Table I).

Experimental Design Layout

The current study adopted an experimental design layout. The layout is a list of input parameter combinations, serving as independent variables, at their corresponding levels. Design Expert software was used to create the layout. Based on the three independent variables and their levels, a total of 24 experimental runs were generated. A sample of the experimental design layout is shown in Table II. A total of 12 participants (six females and six males), aged between 20 and 25, were selected to perform all 24 experimental runs. The age group was selected based on reports indicating that crash rates within this demographic are more than twice as high compared to individuals aged 30 to 34 (6).

Table I: Variables and its levels

Variable	Level				Unit
Controlled Variable					
Driving Speed	80 - 90				km/h
Independent Variable					
Body Mass Index	18.5-24.9 (Healthy)	25.0-29.9 (Overweight)	30 and above (Obese)		kg/m
Types of Roads	Urban	Uphill/ Downhill	Monotonous	Winding	-
Gender	Female	Male			

Experimental Procedures

Anthropometric measurements, including weight and height, were taken first to confirm the participant's BMI. Regardless of BMI, all participants were free of both short- and long-term diseases and did not require daily medication. Considering that inadequate and excessive sleep can affect the ability to pay attention and deal with problems thus increasing the risk of falling asleep behind the wheel and inadequate nocturnal sleep may trigger high blood pressure or hypertension, which can harm vital organs like the heart, eyes, and lungs, the study participants were advised to get between seven and nine hours of sleep the night before the driving tests to ensure that their baseline fatigue levels were comparable. Before the driving test, the participant's blood pressure was monitored with an Omron Evolv to confirm they had a normal systolic blood pressure of less than 120 mmHg and diastolic blood pressure of less than 80 mmHg. The participants were also instructed not to consume anything containing caffeine or alcohol for seven to eight hours before the experiment.

The periods between 2.00 a.m. and 6.00 a.m., as well as between 2.00 p.m. and 4.00 p.m. are commonly associated with heightened occurrences of driver fatigue. These are the times when the biological clock naturally slows, resulting in fatigue and impaired concentration (7). To ensure that all respondents were fit to drive, the driving tests were conducted on the actual road between the hours of 9.00 a.m. and 10.30 a.m. All tests were

Table II: Sample of experimental design layout

Run	Factor 1 A: BMI kg/m	Factor 2 B: Gender	Factor 3 C: Types of Roads	Response 1 Heart Rate, bpm First 15 minutes	Response 2 Oxygen Saturation, % First 15 minutes	Response 3 Heart Rate, bpm Last 15 minutes	Response 4 Oxygen Saturation, % Last 15 minutes
1	27.13	Female	Uphill/Downhil	113.25	98	118.25	97
2	27.13	Female	Straight	105	97	113.66	96
3	27.13	Female	Winding	107.66	98	115.6	97
4	27.13	Female	Monotonous	105	97	111	96
5	27.13	Male	Uphill/Downhil	108.5	99	111.5	98
6	27.13	Male	Straight	96.5	98	103.5	97
7	27.13	Male	Winding	100.5	99	108.5	98
8	27.13	Male	Monotonous	95	98	102	97
9	18.50	Female	Uphill/Downhil	104.33	99	109	98
10	18.50	Female	Straight	100.33	98	105	97
…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…
21	30.00	Male	Uphill/Downhil	110	98	118	97
22	30.00	Male	Straight	102	97	110	96
23	30.00	Male	Winding	108	98	117	97
24	30.00	Male	Monotonous	101	97	107	96

carried out on sunny days. The use of mobile phones and radios was not allowed while driving. A Perodua Bezza 1.0 GA-T automatic transmission was used for the driving tests and the driving speed was maintained between 80 km/h to 90 km/h. Throughout the driving tests, an Oxitech wireless pulse oximeter was placed on the participant's fingertip to assess their heart rate and SpO_2 level (Figure 2).

Driving Duration

Many factors could explain the relationship between driving duration and the physiological system. First,

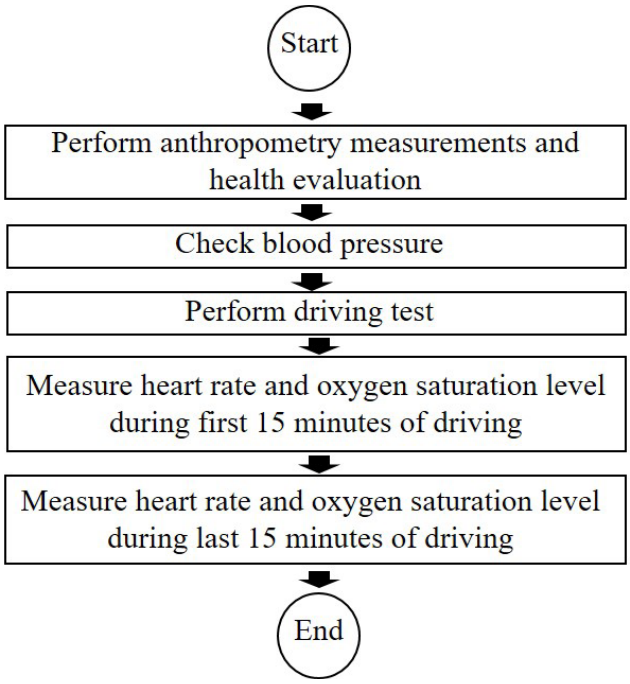

Figure 2: Experimental set up

stressful occurrences while driving such as keeping a constant speed, braking and pulling away at traffic lights or simply sitting in traffic may cause an acute stress response, affecting vital physiological systems. Second, driving necessitates prolonged sitting, which may compromise cardiometabolic health. As a result, each experimental run in this study was completed in 30 minutes. The initial reading was taken within the first 15 minutes, followed by another 15 minutes of driving session. The comparison between these two timeframes was then made.

Ethical Clearance

This study was approved by the Research and Ethical Committee, Faculty of Manufacturing Engineering, Universiti Teknikal of Malaysia Melaka (FRGS/1/2020/TK02/UTEM/02/5).

RESULTS

The trend of heart rate and oxygen saturation (SpO_2) level during the first 15 minutes and last 15 minutes of the driving session. Figure 3a,3b and Figure 4a,4b demonstrate the trend of heart rate and SpO_2 level during the first 15 minutes and last 15 minutes of the driving session for male and female, respectively. Overall, the results demonstrate an increased heart rate and a decreased SpO_2 level for both genders while driving on all four types of roads during the both driving sessions. In comparison, the results demonstrate a higher heart rate and a lower SpO_2 level during the last 15 minutes of driving than the first 15 minutes.

The effect of types of roads on heart rate and oxygen saturation (SpO_2) level

Figure 3a,3b and Figure 4a,4b reveal that driving on a

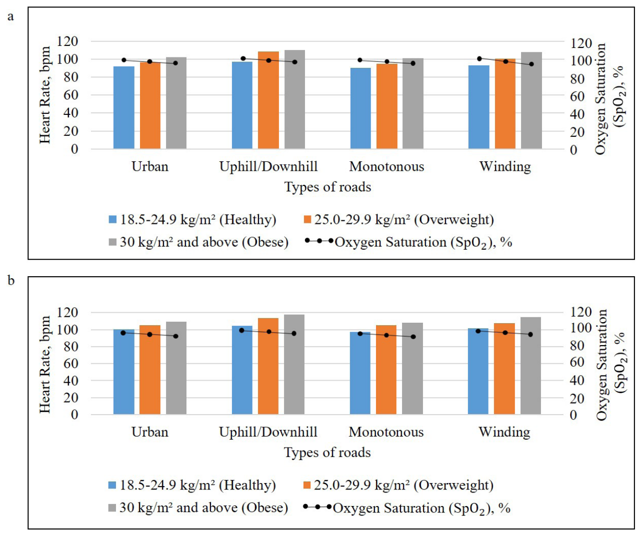

Figure 3: Heart rate and SpO^2 level during the first 15 minutes of driving session: (a) male (b) female

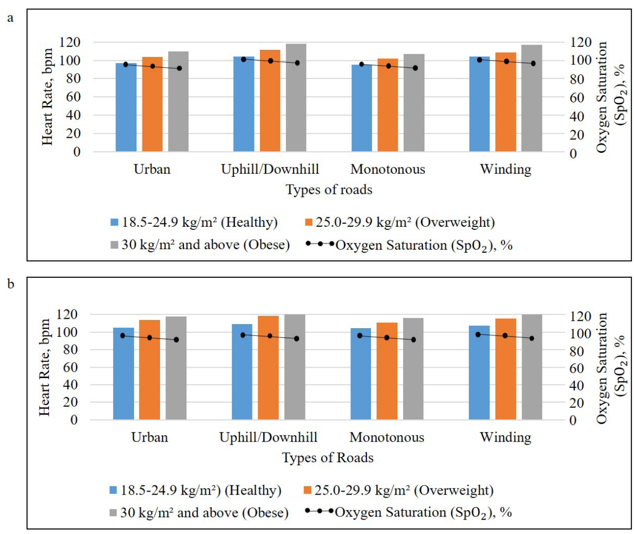

Figure 4: Heart rate and SpO_2 level during the last 15 minutes of driving session: (a) male (b) female

low-difficulty, monotonous road geometry results in the lowest heart rate and SpO_2 level compared to driving on a reasonably demanding urban, uphill/downhill and winding roads during the first 15 minutes and the last 15 minutes of driving session.

The effect of body mass index (BMI) on heart rate and oxygen saturation (SpO_2) level

Generally, for each type of road, male and female drivers demonstrate a consistent increase in heart rate and a decrease in SpO_2 level when the driver's BMI increases from 18.5-24.9 kg/m (healthy) to 30 kg/m and above (obese) during the both driving sessions as shown in Figure 3a,3b and Figure 4a,4b respectively.

The effect of gender on heart rate and oxygen saturation (SpO_2) level

Figure 3a,3b and Figure 4a,4b demonstrate that female drivers have greater heart rate and lower SpO_2 levels than male drivers for each BMI category while driving on all four types of roads during the first 15 minutes and the last 15 minutes of driving session.

Analysis of Variance (ANOVA)

Table III demonstrates the ANOVA during the first 15 minutes and the last 15 minutes of driving session for heart rate and SpO_2 level. The null hypothesis is rejected if the Prob > F is less than the significance level of 0.05. Table III shows that Prob>F values for heart rate and SpO_2 level models during both driving sessions are < 0.0001, which is less than the significance level of 0.05. This indicates that the null hypothesis should be rejected and the independent variables (types of roads, BMI and gender) are likely to influence the heart rate and SpO_2 level.

DISCUSSION

The study revealed that there was a higher heart rate and a lower SpO_2 level observed in the final 15 minutes of driving compared to the first 15 minutes. The increase in the heart rate pattern could be attributed to the stressful driving scenarios which triggered adrenaline. Driving is a stressful activity that involves a number of risky and unpredictable events. For example, according to (8), exceptionally lengthy travel distances and irregular working hours are the reasons for stress among long-distance truck drivers. Therefore, the extended duration of driving amplifies the probability of encountering stressful events, which in turn increases the heart rate. This is because, the human body temporarily releases adrenaline in response to stress, a hormone that causes the heart rate to increase in order to increase the force of the heart's contraction (9).

In short, the stress generated by long periods of driving elevated the heart rate. On the other hand, the current study found that the stress caused by extended hours of

Table III: ANOVA

ANOVA: Heart Rate (First 15 minutes)					
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**
Model	1220.40	13	93.88	56.64	< 0.0001
BMI	551.16	1	551.16	332.51	< 0.0001
Gender	343.00	1	343.00	206.93	< 0.0001
Types of Roads	289.62	3	96.54	58.24	< 0.0001
ANOVA: Heart Rate (Last 15 minutes)					
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**
Model	1183.36	13	91.03	66.49	< 0.0001
BMI	620.31	1	620.31	453.12	< 0.0001
Gender	279.07	1	279.07	203.86	< 0.0001
Types of Roads	232.36	3	77.45	56.58	< 0.0001
ANOVA: Oxygen Saturation Level (First 15 minutes)					
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**
Model	28.00	13	2.15	6.366E+007	< 0.0001
BMI	14.77	1	14.77	6.366E+007	< 0.0001
Gender	6.00	1	6.00	6.366E+007	< 0.0001
Types of Roads	6.00	3	2.00	6.366E+007	< 0.0001
ANOVA: Oxygen Saturation Level (Last 15 minutes)					
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**
Model	28.00	13	2.15	6.366E+007	< 0.0001
BMI	14.77	1	14.77	6.366E+007	< 0.0001
Gender	6.00	1	6.00	6.366E+007	< 0.0001
Types of Roads	6.00	3	2.00	6.366E+007	< 0.0001

driving lowered SpO_2 levels in the final 15 minutes of driving because of the abnormal rise in heart rate. The inability of the human heart to pump enough blood to the rest of the body accelerates heartbeats. As a result, the decline in SpO_2 level hastens fatigue.

Driving on a low-difficulty, monotonous road geometry resulted in a low heart rate and SpO_2 level compared to driving on demanding urban, uphill/downhill, and winding roads across different BMI categories for both genders. This result could be due to the sensory stimulation generated by the road geometry.

Monotonous roads, such as motorways, are typically planned with little geometric change to allow for high-speed driving. The combination of monotonous road conditions with repetitive and stimulus-free settings produces a tedious driving experience that can result in mind wandering and task disengagement, affecting heart rate and SpO_2 level. As a result, driving in a less demanding environment and route design reduced a driver's attention markedly (10).

In addition, a separate study reported a higher level of driver fatigue while driving on the expressway than while driving on a road with varying geometry for the same period of time (11). This indicates that drivers suffer greater passive fatigue symptoms on monotonous roads as the experience lowers their heart rate and SpO_2 level, leading to sleepy driving. According to (12) which analysed the heart rate fluctuations of normal and sleepy driving, the heart rate drops dramatically during drowsy driving, from 85±5.6 bpm to 81.5±bpm.

Meanwhile, the uphill or downhill road offered a wider range of geometry and required maximal effort to navigate several steep slopes and turns. Compared to a monotonous road, an uphill or downhill road necessitates increased alertness and vigilance to avoid collisions. Adrenaline, a hormone that briefly boosts heart rate and blood flow to the brain and muscles, is neutrally released by the human body in reaction to such exciting conditions.

The current study found a consistent relationship between an increase in heart rate, a decrease in SpO_2 level, and the driver's BMI. This could be linked to obesity-related health problems. A person with a BMI equal to or exceeding 30 kg/m , classified as obese, is 40 per cent more likely to suffer from atrial fibrillation, a fast and irregular heartbeat caused by an accumulation of fatty substances in the arteries, compared to healthy adults (13). The findings are consistent with previous studies, which discovered that obese people have a higher heart rate than adults with a normal BMI (14). Obese people's arteries become clogged with excess fatty substances, causing their hearts to work harder to carry blood throughout the body, resulting in their hearts beating faster. When the heart beats too quickly, it may not be able to pump enough blood to the rest of the body. As a result, the decrease in SpO_2 level increases the rate of muscular exhaustion.

Female drivers recorded a higher heart rate than male drivers across BMI categories when driving on all four types of roads during both driving periods. The variation in heart rate could be explained by the difference in sex hormones. Men and women handle stressful tasks differently, including when driving a car. Driving requires a high level of cognitive skills such as working memory, decision-making, and cognitive flexibility. These cognitive demands can trigger stress. Studies have indicated that stressful living conditions cause a fast heart rate (15). Women are twice as likely as males to experience severe anxiety and stress (16). . This finding is comparable to a study that found that women are more vulnerable to stress when driving than men (17). Women have been observed to react more emotionally compared to men because of their hormonal system. These gender differences manifest during the reproductive years and gradually decrease after menopause (18).

The hormone system has a direct effect on women's emotional state affecting their heart rate. In general, the human body reacts to stressful events by generating adrenaline, a hormone that causes the heart rate to increase. The current study found that female drivers' high heart rates had a direct impact on SpO_2 levels. In addition, female drivers, across BMI categories, recorded lower SpO_2 levels than male drivers when driving on all four road types. In short, the increase in heartbeats presents difficulties for the body system to pump blood throughout the entire body, resulting in a decline of SpO_2 level drops and an increase in the rate of muscular exhaustion.

CONCLUSION

The goal of this study is to investigate the interaction of three factors, (i) types of roads, (ii) BMI and (iii) gender on heart rate and SpO_2 levels in indicating driving fatigue. The comparison is conducted between the first 15 minutes and the last 15 minutes of the driving session. The driving experiments were conducted on real-road conditions. Twenty-four experimental runs were developed by Design Expert software based on to the three factors and its levels. Overall, (i) types of roads, (ii) BMI and (iii) gender have a considerable influence on the heart rate and SpO_2 level to indicate driving fatigue. The results demonstrate that the last 15 minutes of driving had a higher heart rate and a lower SpO_2 level than the first 15 minutes. This study concluded that driving on a monotonous road could cause drivers to become fatigued because it produced the lowest heart rate and SpO_2 level compared to a reasonably difficult urban, uphill/downhill and winding roads for each BMI category for both genders. This study also found a similar tendency for both periods of driving, with both genders demonstrating a continuous increase in heart rate and a fall in SpO_2 level when the driver's BMI increased from 18.5-24.9 kg/m (healthy) to 30 kg/m and above (obese) for each kind of road. This study also discovered that female drivers have higher heart rates and lower SpO_2 levels than male drivers in each BMI category while driving on all four types of roads throughout the first and last 15 minutes of the driving session. The findings of this study will assist researchers and policymakers in the field of road safety in taking appropriate measures to prevent fatigue-related road accidents by analyzing heart rate and SpO_2 as a valid indicator.

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