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Mental Workload and Road Environment Complexity: Subjective Assessments

Nurainaa Kabilmiharbi[a,b] & Nor Kamaliana Khamis[a*]

[a]*Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bandar Baru Bangi, Selangor, Malaysia*

[b]*Department of Mechanical Engineering, College of Engineering, Universiti Tenaga Nasional, Bangi, Malaysia*

[*]*Corresponding author: kamaliana@ukm.edu.my*

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ABSTRACT

Since 2011, mental workload has been one of the top 10 causes of accidents in Malaysia, accounting for over a thousand fatalities yearly. Mental workload is defined as a comparable mediating variable to attention. The aim of this study is to identify the fundamental causes and influences that affect the difficulty of the road environment and vehicle task, as well as their impact on the driver's health. In this study, subjective measurement is used to assess the level of mental workload of drivers which includes NASA-TLX and KSS on two different road environment condition namely urban and rural road environment. The findings show that the complexity of the road environment has a significant effect towards the mental workload of a driver. The average NASA-TLX score for urban roads is higher than the average score for rural roads while, the results for KSS level indicates higher drowsiness level among the drivers when driving on a rural road as opposed to an urban road. These results may serve as a guide for future research into the mental workloads of drivers in various types of complex road environments, as well as a practical guide for car manufacturers, agencies responsible for road safety, and researchers to improve the safety design of cars and consider external factors related to road environment complexity when designing roads.

Keywords: Subjective evaluation; mental workload; drivers; NASA-TLX; KSS

INTRODUCTION

In 2019, traffic accidents are among the top 10 leading causes of death, accounting for 55 percent of the 55.4 million deaths worldwide. The World Health Organisation (WHO) ranks road accidents as the tenth largest cause of death worldwide since 2000. In recent years, automobile industry demand has increased dramatically. As the variety of vehicles increases, vehicle prices become more affordable, and vehicle ownership is becoming increasingly common today (Kareem 2020). According to a report by the Population Reference Bureau for the year 2020, as the number of vehicles on the road increases, consequently, increases the number of accidents (Population Reference Bureau 2020). The number of road accidents has increased awareness of the need to identify factors that could impact driving ability.

One of the main cause of accidents is identified as the driver is having workloads while driving. Workloads can be interpreted as being too tired and lack of focus when driving; underload or being too distracted and not being able to focus; overload. Drowsiness is a sign of a low mental workload or tiredness, while stress is a sign of a high mental workload or overload. Underload may cause a driver less aware and focused, while overload can distract and divert the driver's attention, which can make it harder for the driver to take in information before reacting (Brookhuis & de Waard 2010).

The major cause of increased mental effort among drivers is the distraction from driving that are caused by other activities which are unrelated to driving (Kabilmiharbi & Khamis 2020). These actions will influence the driver's performance and judgement, which will further decrease awareness and raise the risk of accidents or near-accidents that are comparable to those brought on by drug or alcohol

use (Almahasneh et al. 2014). Additionally, by evaluating the mental workload, one may ascertain the degree or quantity of cognitive demands made on the driver (Kong et al. 2017). Thus, in order to avoid or to decrease the incidence of road accidents, it is necessary to do more research into the elements that might lead to mental workload or mental weariness among drivers. Some accidents are a result of collisions between cars and some are mistakes that could've been prevented such as lack of focus when driving. Various research has been done all over the world to study the cause of road accidents.

Other than that, according to a survey conducted in Malaysia by the Malaysian Institute of Road Safety Research (MIROS), fatigue is one of the leading factors in car, truck, and bus accidents (Rasid 2012). Some accidents are a result of collisions between cars and some are mistakes that could've been prevented such as lack of focus when driving. Drivers are significantly impacted by mental workload, particularly during periods of high traffic. This type of behaviour frequently keeps drivers from concentrating on their primary job, which is driving. Driving while distracted can result in unfortunate mishaps or, in the worst-case scenario, fatalities.

Driving patterns and drivers are being studied using many methods including subjective evaluation in order to measure the driver's mental workload either before, during or after the driving sessions (Weinbeer et al. 2018; Ahlstrom et al. 2015). There were studies conducted on bus driver's mental workload where data was collected on the bus drivers after their day and night shifts to compare the different workload level and it is also found that the participants are more tired while driving at night compared to driving during the day (Flaa et al. 2019; Lee et al. 2017). Mental workload can also be seen in medical staffs (Ruiz-Rabelo et al. 2015, Miranda 2018, Zheng et al. 2012). Multiple level of focus during a long duration is needed to perform a surgery well. A subjective analysis was used to evaluate the mental workload of 70 surgeons were during a Bariatric Surgery and they were found to have high scores (Ruiz-Rebelo et al. 2015).

Road environment could affect the driver's driving performance, where this may be observed by the driver's driving discomfort level, their driving performance, and their degree of awareness (Auberlet et al. 2012). Environmental distractions are linked to reduced driving efficiency whether it is inside or outside of the vehicle and can be indicated by higher levels of no hands on the steering wheel, eyes focused inside rather than outside the car, and road wanderings or intrusion of lanes (Stuttts et al. 2005). Furthermore, other external factors that may affect a driver's mental workload while driving include the type of road, the road layout, and the traffic flow (Paxion et al. 2014). In this case, by evaluating the mental workload of the drivers, one can offer a suggestion on the level or number of cognitive demands placed on the driver.

The aim of this study is to identify underlying factors and determinants related to road environment complexity and its impact on the driver's well-being. Two different type of road environment (urban and rural road) were selected in this study and are compared by using subjective (self-assessment subjective forms related to stress level rate) which are NASA-TLX and Karolinska Sleepiness Scale (KSS). The major factors related to road environment conditions and how it will further affect the drivers driving performance will be discussed. This information will make it easier for the research to contribute to the creation of safer driving habits among the drivers and safer road infrastructure construction by road makers. These results may be helpful as a guide for additional research into the limitation of a driver's mental workload while operating a vehicle in various types of road environments complexity.

METHODOLOGY

This section discusses the methodology utilized in the study, including participant selection, equipment, and experimental design.

PARTICIPANT SELECTION

Thirty-two participants between the age of 20-38 years old were selected through poster advertisement using social media with the following criteria:

1. Having regular sleeping schedule
2. Should abstain from caffeine intake at least 24 hours before experiment
3. Minimum of two years of driving experience

Previous studies have shown that consuming caffeine can affect the driver's driving performance significantly (Biggs et al. 2007). This activity is crucial since it could have an impact on the condition (e.g: motion or simulator sickness) and response of the driver during the real experiment (Horrey et al. 2009). This research protocol was approved by the Ethical Committee of Universiti Kebangsaan Malaysia with the reference number UKM PPI/111/8/JEP-2016-200. All participants were involved voluntarily and signed an informed consent form in compliance with institutional policies.

EQUIPMENT

According to prior research, a car simulator is appropriate to be used in this experiment in order to get reliable

observation of the driver's behaviour and to establish the necessary experimental control (Vincent et al. 2009). The simulator is as shown in Figure 1 that were being used for this research is located in the Ergonomics Laboratory, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM). The simulator is equipped with two different road environment scenes which are an urban and a rural road scene. The participants had to drive for about 15 mins per road scene at a speed of 65 km/h to 80 km/h as suggested by similar previous research (Brookhuis & de Waard 2010; Anund et al. 2017; Vincent et al. 2009). Driving at speeds between 65 km/h and 80 km/h is representative of urban and suburban driving conditions, ensuring that the study's findings are pertinent to real-world driving scenarios. Contributing to the ecological validity of the study, this speed range incorporates typical speed limits on many roads.

FIGURE 1. Car simulator

RESPONSE VARIABLES: NASA-TLX

NASA-TLX is a multidimensional evaluation tool that tests the perceived workload in order to determine the efficiency of a task, method or team or other aspects of performance. The NASA-TLX is found to be more reliable in terms of versatility as it is divided into six subjective subscales. The NASA-TLX is a subjective multidimensional assessment method that can evaluate workloads of a person in various aspects of performance. It is a questionnaire with six subjective subscales of workload aspects on a single page. The six subscales catered in mental demand, physical demand, temporal demand, performance, effort, and frustration. Basically, the six dimensions of this NASA TLX are as follows:

1. Mental demand is the amount of pondering, deciding, or calculating required to complete a task.
2. Physical demand is the quantity and intensity of physical activity necessary to execute a task.
3. Temporal demand is the quantity of time pressure involved in completing a task.
4. Effort is related to how challenging it is for the participant to maintain their level of performance.
5. Performance is the degree of accomplishment in completing the task.
6. Frustration level is the degree to which the participant felt insecure, discouraged, secure, or content during the task.

This evaluation is a 100-points range with 5-point steps and the ratings are then combined to make the task load index. The higher the value on the scale from each aspect in total, the higher the mental workload (Stutts et al. 2005). Participants were asked to fill up the NASA-TLX form at the end of each driving session.

KAROLINSKA SLEEPING SCALE (KSS)

KSS measures the level of sleepiness at a particular time during the day and it is situational sleepiness and is sensitive to fluctuations (Putilov 2015). It is known to be widely used in shift work, jetlag, driving, and clinical settings where it is useful to analyse changes in response to environmental factors, circadian rhythm, and drug effects (Kabilmiharbi et al. 2022). Furthermore, the KSS is a self-administered tool that takes an average of less than 5 minutes to complete. The KSS is also found to be very relatable to the EEG and behavioural variables. Moreover, KSS is a 9-point scale indicating the sleepiness level which starts from 1=extremely alert to 9=extremely sleepy, great difficulty to keep awake, fighting sleep. Participants were asked on their sleepiness level before, during and after each driving session.

DRIVING SIMULATOR EXPERIMENT DESIGN

All participant needs to undergo the experiment sequence flow as shown in Figure 2. The experiment duration takes about an hour. Participant was given a 10 minutes test drive in the simulator so that they can get comfortable and familiarize themselves with simulator driving. Then, they were given a 5 minutes break and they will start their driving sessions where they will drive in an urban road environment for 15 minutes. The urban road environment is full of buildings, car parking by the roadside and high

volume of overcoming cars. They will be asked on their KSS level mid-way through their driving session. Then, they were given another break for about 10 minutes while providing their feedback on workload level after the first scene using the NASA-TLX. Later, they will start their 15 minutes driving session on the second scene where they will drive in a rural road environment with less to no building at all on the roadside and lesser overcoming cars. They were again asked on their KSS level mid-way through their driving session and NASA-TLX workload level after they were done with the driving.

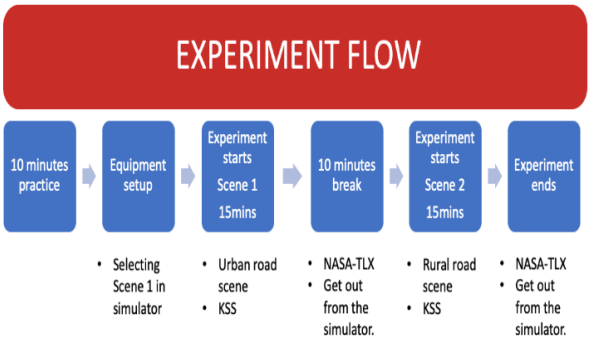

FIGURE 2. Experiment Flow

RESULTS AND DISCUSSION

NASA-TLX

Based on the current data obtained on the subjective evaluation using NASA-TLX, average workload for the participants to drive in urban road is slightly higher than the workload while driving in the rural environment. Mental demand results in Figure 3 are higher for urban road compare to rural road which indicates that the urban roads are more demanding and complex compared to rural roads. Next, physical demand in Figure 4 also shows higher value for urban road compared to rural road where driving on urban road are clearly more laborious compared to the restful driving of rural roads. Third, temporal demand shows in Figure 5 is higher value for urban road compare to the rural road where the time pressure is much higher for urban road. Then, the performance workload shows in Figure 6 is higher values for urban drive compared to rural drive which indicated that most participants are satisfied with their driving performance while driving in urban environment compared to the rural environment.

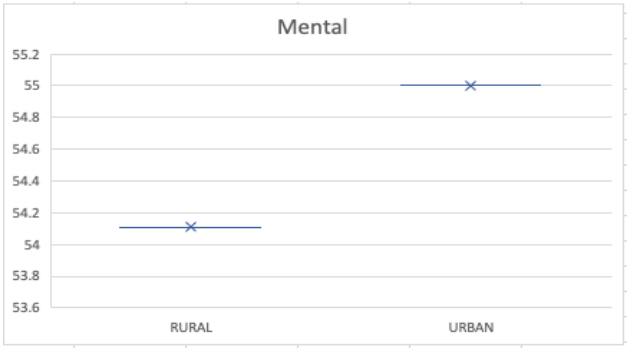

FIGURE 3. NASA-TLX (Mental) result

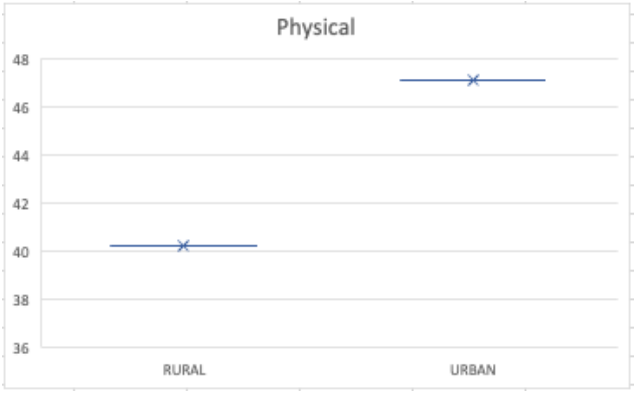

FIGURE 4. NASA-TLX (Pysical) result

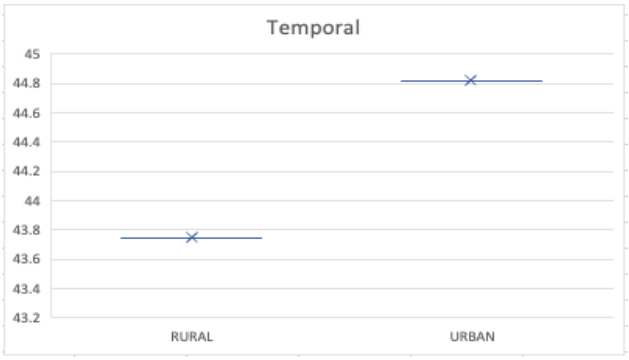

FIGURE 5. NASA-TLX (Temporal) result

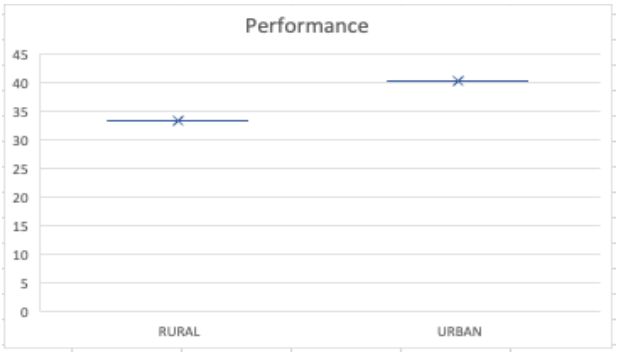

FIGURE 6. NASA-TLX (Performance) result

These findings related to mental, physical, temporal and performance are consistent with previous research that highlights the complexities and challenges faced by drivers in urban settings (Kabilmiharbi et al. 2022; Rudin-Brown et al. 2014). Urban roads often involve navigating through heavy traffic, negotiating intersections, and dealing with various distractions, making them mentally demanding for drivers. Physical effort required in urban driving, such as frequent braking, accelerating, and maneuvering in congested traffic. In contrast, rural roads generally offer smoother and less physically demanding driving experiences. In addition, rural roads may have more relaxed time constraints, leading to lower temporal demands for drivers.

On the other hand, the results from Figure 7, indicating that the effort value for rural driving is higher than urban driving, present interesting insights into the perceived difficulty of completing the driving task in different road environments. The higher effort value suggests that participants experienced rural driving as mentally and physically more demanding compared to urban driving. This finding may seem counterintuitive at first, as urban roads are commonly associated with higher traffic density and complex driving situations. However, several factors might explain this observation. In rural areas, the driving environment can be more monotonous and less stimulating, with fewer traffic signs, road markings, and other visual cues. As a result, drivers may need to exert additional mental effort to maintain focus and attention on the road, especially during long stretches of less challenging driving conditions. Research on cognitive load has shown that situations with low stimulation can lead to increased cognitive demand as individuals struggle to stay engaged and vigilant (Sugiono et al 2017; Farahmand & Boroujerdian 2018).

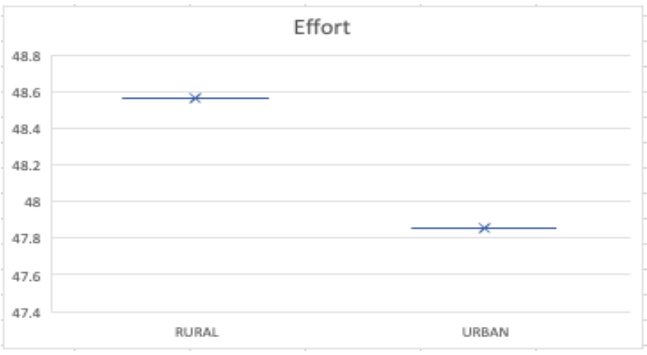

FIGURE 7. NASA-TLX (Effort) result

In addition, rural roads may present unique difficulties, such as winding and hilly terrains, which require greater physical exertion from drivers, particularly when travelling for extended periods of time. Narrow roads, uneven surfaces, and sharp turns can increase a driver's physical exertion (Sugiono et al 2017; Farahmand & Boroujerdian 2018). In contrast, despite having more traffic, urban roads may offer smoother driving conditions, with numerous stops and starts that allow for periodic rest breaks.

Figure 8 indicates that driving on low stimulating roads, such as rural roads, can lead to more frustration, discouragement, irritability, and stress compared to driving on high stimulating roads like urban roads. This finding aligns with studies on the psychological impact of road environments (Ahlström et al. 2018). The lack of stimulation in rural areas might contribute to feelings of monotony and unease, leading to higher levels of negative emotions among drivers.

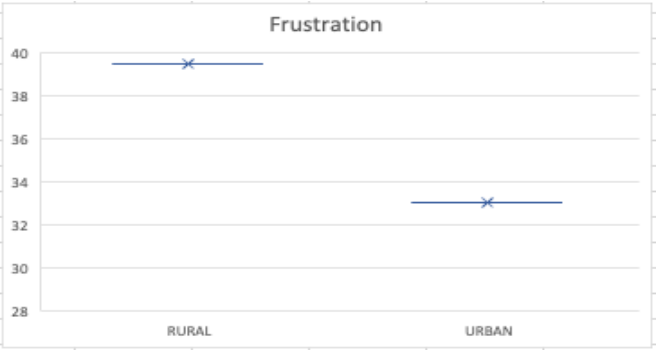

FIGURE 8. NASA-TLX (Frustration) result

KAROLINSKA SLEEPING SCALE (KSS)

The average KSS level of the participants before driving for both scenes are either 2 (which indicates 'very alert') or 3 (which indicates 'alert'). However, as the driving sessions progressed, the participants reported an increase in sleepiness levels for both road scenes. As displayed in Figure 9, notably, the sleepiness level was higher during the monotonous drive (referring to rural road) compared to the city drive (referring to urban road). After about 8 minutes of driving, the participants were asked to give their feedback on KSS level and it shows that the sleepiness level increased during both scenes with the monotonous drive being higher than the city drive. These levels indicate that the participants are in a condition between average of 3 (which indicates 'alert') for city drive and average of 7 (which indicates 'sleepy but no difficulty remaining awake') for monotonous drive. The higher sleepiness levels during the monotonous drive, as indicated by an average KSS level of around 7 ('sleepy but no difficulty remaining awake'), suggest that the participants experienced greater challenges in maintaining alertness during the monotonous road scene. On the other hand, the city drive's lower sleepiness levels, with an average KSS level around 3 ('alert'), indicate that the urban environment, with its

higher complexity and variability, helped in keeping participants more engaged and attentive during the driving task.

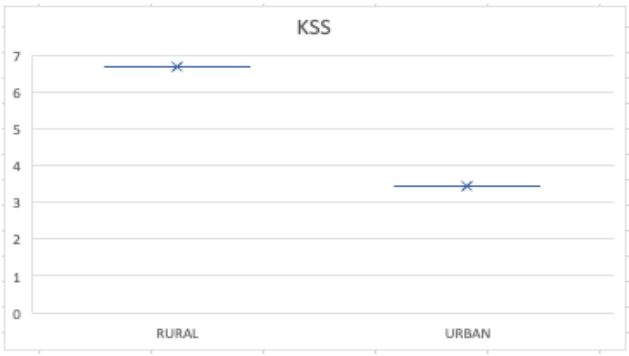

FIGURE 9. KSS result

Interestingly, after 14 minutes of driving in each scene, the participants' sleepiness levels began to reduce, with KSS levels ranging between 3 ('alert') and 4 ('rather alert'). This observation implies that the participants' initial increase in sleepiness was somewhat mitigated during the driving sessions, possibly due to adaptive mechanisms that kicked in as they continued to focus on the road and the driving task. This shows that initially before they started the experiment session for each road scene, participants are in a state of alert or rather alert. Afterwards, while driving, their level of sleepiness started to increase. Then, when the sessions are about to end, their sleepiness level started to reduce. This shows that different road environment complexity affects the driver sleepiness level differently.

TABLE 1. Summarized result

Road Type Assessment		Rural	Urban
NASA-TLX	Mental	54.11	55
	SD	26.07	24.42
	Physical	40.18	47.14
	SD	28.13	25.11
	Temporal	43.75	44.82
	SD	23.55	22.34
	Performance	33.39	40.36
	SD	22.32	25.12
	Effort	48.57	47.86
	SD	22.84	20.88
	Frustration	39.46	33.03
	SD	24.35	23.03
KSS		6.7	3.4
SD		0.897	1.071

SD=Standard Deviation

Overall, the summarized results of this study are as shown in Table 1 where this observation aligns with previous research on the impact of monotony on driving fatigue [24-25]. Monotonous driving conditions, such as long stretches of straight roads or repetitive landscapes, can lead to a decline in driver arousal and vigilance, contributing to increased sleepiness levels. The results collectively demonstrate that different road environment complexities indeed affect the drivers' sleepiness levels differently. Monotonous driving conditions appear to pose a greater risk of inducing sleepiness and reduced alertness compared to more stimulating city driving. These findings underscore the importance of designing roadways and implementing traffic management strategies that consider the potential impact of monotony on driver fatigue and safety.

The implications of these findings for future research and transportation safety design are substantial. Understanding the dynamic relationship between mental burden and road environment complexity can aid in the development of more precise models of driver behaviour and performance. This understanding is essential for the development of advanced driver assistance systems that can adapt to changing environments and assist drivers in effectively managing their mental workload.

This study is also in line with Government Road Safety plan. Recently, Ministry of Transport (MOT) has launched a Road Safety Plan 2022 - 2030 (PKJRM 2022-2030) in an effort to improve road safety in Malaysia at par with the developing countries (Road Safety Plan 2022). With the intention of increasing the awareness of road users, this plan also aims to make road safety a culture for authorities, vehicle manufacturers, road infrastructure builders, local communities, workplaces, and schools up to the family unit. The comprehensive scope of this ambitious plan demonstrates the Ministry's commitment to fostering a multi-dimensional approach to road safety, involving various stakeholders and sectors in the concerted effort to reduce accidents and fatalities on Malaysian roads. Through these collaborative and inclusive measures, the Ministry envisions a future where road safety is not just a priority, but an intrinsic value ingrained in the consciousness of every individual and institution across the nation, ultimately leading to safer roads, reduced incidents, and improved overall quality of life for the Malaysian people.

CONCLUSION

This study suggest that the complexity of the road environment has a significant impact on drivers' mental effort, and it is consistent with earlier studies that examined

drivers' mental workload in a similar manner. Driving in two different road environment conditions, namely rural and urban roads, demonstrates the various demands on the drivers' mental workload according to the NASA-TLX and KSS result obtained. According to NASA-TLX findings, urban roads have higher task demands than rural ones, mostly because they have more complicated road environment and are more likely to induce visual distractions in drivers. The KSS results indicate that travelling on a rural road consistently results in a higher drowsiness score than driving in the city. These findings may serve as a guide for future research on the effect of various levels of road environment complexity on the mental workload of drivers. This research will also contribute to the knowledge and understanding of how the complexity of the road environment impacts the drivers' mental workload. This information will facilitate the study's contribution to the development of safer driving practises and road infrastructure. In conclusion, the NASA-TLX and KSS subjective evaluations provide valuable evidence that driving in urban road conditions is associated with greater mental, physical, and temporal demands, resulting in a greater overall performance burden compared to driving on rural roads. Prior research on the challenges and complexities of urban transportation supports these findings. Understanding these distinctions can inform road design, traffic management strategies, and driver training programmes to improve the safety and efficiency of transportation in both urban and rural environments.

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DECLARATION OF COMPETING INTEREST

None.

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