

ORIGINAL ARTICLE

Factors Affecting Psychomotor Vigilance of Logistic Truck Drivers in Malaysia

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ABSTRACT

Introduction: Truck drivers play a crucial role in the logistics industry; however their occupation exposes them to high levels of fatigue due to long working hours, irregular shift schedules, inadequate rest, and monotonous driving conditions. Fatigue has been shown to impair both cognitive and motor functions, with psychomotor vigilance being one of the most affected domains. Reduced vigilance has been associated with slower reaction times, increased lapses, and a higher likelihood of errors, all of which can compromise road safety. This study aimed to identify the factors influencing psychomotor vigilance among logistics truck drivers. **Materials and Methods:** A cross-sectional study was conducted among 70 truck drivers in the Klang Valley. Data were collected using a structured questionnaire covering demographic characteristics, work-related information, sleepiness level, and psychomotor vigilance. Participants completed the Psychomotor Vigilance Test (PVT) and the Karolinska Sleepiness Scale (KSS) before and after work shift. Participants performed a 10-minute psychomotor vigilance test for two consecutive days. **Results:** The results indicated that truck drivers' mean reaction times ($p < 0.001$) and number of lapses ($p < 0.001$) increased at the end of the work shift. Age ($p < 0.001$), education level ($p < 0.005$), marital status ($p < 0.05$) and working experiences ($p < 0.05$) were found as the factors affecting truck drivers' psychomotor vigilance. **Conclusion:** In summary, truck drivers' psychomotor vigilance declines at the end of work shifts possibly due to accumulated physical and mental exhaustion. The PVT serves as a reliable tool for assessing cognitive performance under fatigue, offering valuable insights into alertness and attention across various occupational settings.

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INTRODUCTION

The e-commerce industry has risen globally due to the pandemic, especially in Malaysia, prompting many logistics service providers to expand their business to meet the delivery needs of online businesses at competitive costs. The government's implementation of the Movement Control Order (MCO) has significantly increased demand for courier services among Malaysians, prompting many companies to grant drivers exemptions to work extended hours to ensure an adequate supply of goods (1). Nevertheless, this action reduces supply shortage, but it also increases the risk of driving fatigue

(2). Fatigue, in the context of an occupational driver, is characterized by feelings of drowsiness, tiredness, and mental laziness resulting from extended driving periods, prolonged driving times, poor road conditions, changes in weather, or individual driver characteristics that contribute to road crashes and accidents (3,4). Research conducted globally indicates that fatigue-related accidents account for between 3% and 30% of vehicle collisions and are frequently associated with driver tiredness (5).

Truck drivers often work extended hours, which can lead to sleep deprivation and reduced alertness. The effect of driving fatigue is evident in reduced capacity to maintain vigilance, including speed, distance, and lane-keeping. These behaviours increase the risk of road accidents (6). A simulation study showed that long-term driving leads to driver fatigue and impairs

driver performance (4). A previous study conducted among truck drivers in Malaysia showed a significant correlation between work conditions before and after work ($p=0.009$). Similarly, a recent PVT study revealed a significant difference between pre- and post-shift working conditions, indicating high fatigue levels on the first and second days (7).

Research indicates that occupational fatigue is prevalent among truck drivers. For instance, a study in Malaysia found that 42.9% of logistic truck drivers experienced significant fatigue (8). In Australia, researchers found that nearly 20% of fatal accidents were caused by driving fatigue (9). In the UK, driver fatigue is now considered a major contributor to 15–30% of all crashes (10). Meanwhile in China, driving fatigue accounts for approximately 21% of total road accidents, with a notable increase in the rate of fatigue driving in 2020 (10).

Additionally, fatigue decreases physical and mental attentiveness, inhibiting the performance of cognitive and psychomotor tasks. Driving fatigue significantly impairs alertness through several cognitive and physical mechanisms, including slower reaction times (12), reduced vigilance and attention (13), impaired judgment (14) and decision-making as well as promote microsleep episodes (15). Psychomotor Vigilance Task (PVT) is one of the several cognitive assessments that has become a vital instrument for assessing prolonged mental effort, attention, and reaction speed. PVT promotes a standardised method to quantify the effect of fatigue and provide insight into strategies for individuals, as well as better policy recommendations (16,17).

The psychomotor vigilance task (PVT), a validated and sensitive measure of reaction time and attention lapses, has emerged as a robust tool for quantifying fatigue-related performance decline. Yet, its application in logistic transportation research remains limited, and few studies have integrated PVT outcomes with demographic characteristics and sleep-related factors to better understand individual differences in fatigue vulnerability. Despite previous research on driver fatigue, there remains a significant gap in understanding the specific mechanisms through which fatigue impairs driving performance in the logistic industry, particularly due to the limited integration of objective vigilance measures, demographic factors, and sleep quality indicators (8,18,19).

In the Malaysian setting, driving fatigue has been studied extensively, involving several factors, including the psychomotor vigilance test (6), risk factors of driving fatigue (7) and psychological risk factors (20). According to Al-Mekhlafi and colleagues, applying the fatigue survey and questionnaire alone did not clearly explain the behaviour of fatigue; instead, a psychomotor vigilance test was employed to assess their

driving performance (7). Additionally, comprehensive risk factors involving demographic background, work-related factors, psychomotor vigilance, and job satisfaction were required to achieve valid and reliable results. Besides, Sabir and Isha explained that psychological risk factors, including personality traits, driving behaviours, and work stress, have an impact on driving fatigue (20). This study underscores the cognitive aspect of fatigue by examining its influence on drivers' attention and reaction capacities, as captured through psychomotor vigilance assessments. Moreover, this study offers a more thorough assessment of driving fatigue in the logistics industry by integrating PVT testing, demographic data, and sleep quality measures, addressing limitations in previous research. Therefore, this study aims to investigate how driving fatigue affects the driving performance among logistic truck drivers through the monitoring of the psychomotor vigilance task (PVT).

METHODOLOGY

Participants

Participants were selected from logistics companies in the Klang Valley and were employed as full-time drivers. A total of seventy male logistics truck drivers were eligible to participate in this study, with participants selected using a convenience sampling technique. This technique was employed due to its practicality since truck drivers often have variable schedules and limited availability, convenience sampling facilitates a smooth and timely data collection process. To be included in the study, workers must meet the following criteria: they must have been with the company for at least six months, be full-time truck drivers, possess a valid GDL license, and be willing to participate in the study. The exclusion criteria included any logistics truck drivers who were diagnosed with chronic diseases such as diabetes or cardiovascular disease, as they are more vulnerable to experiencing greater fatigue compared to those without such diagnoses. Furthermore, truck drivers with a medically confirmed diagnosis of a sleep disorder were excluded from participation in the study. An informed consent form was obtained from all participating truck drivers. Participation in the research was voluntary, and participants could refuse to provide information or withdraw from the research at any time. The interview session was conducted privately without interference from the management.

Procedures

A cross-sectional study was conducted at a logistics company in the Klang Valley, with the company's truck drivers serving as the sampling frame. A list of eligible drivers was obtained from the transportation department. Data collection was carried out in a small, quiet room to ensure privacy and minimize interruptions. All tests were administered at consistent times relative to each participant's work schedule to control for circadian

influences and enhance the comparability of results. Participants were assessed under their usual pre-shift conditions without requiring prior rest; therefore, the pre-shift PVT outcomes reflect their typical alertness levels, including any accumulated fatigue, rather than a fully rested baseline (21). After providing consent, respondents completed a structured questionnaire, followed by a 10-minute pre-shift PVT. They then resumed their routine work duties, and a corresponding post-shift PVT was administered at the end of their shift before they departed for home. The pre and post shift PVT measurements add a within-subject repeated-measures element, allowing the study to assess short term changes in alertness and cognitive performance due to work-related fatigue while still representing a snapshot of the population. Mean reaction time (RT) is scored by averaging all valid reaction times recorded during PVT test, excluding anticipatory responses typically defined as those faster than 100 milliseconds, meanwhile number of PVT lapses refers to the total count of reaction times that are 500 milliseconds or longer during test (22).

Instruments

A set of well-structured questionnaires was prepared for the respondents. The questionnaire was divided into three respective sections: Part A (demographic and working information), Part B (sleepiness level information), and Part C (PVT information). A pre-test was conducted prior to the actual data collection to ensure the clarity, reliability, and feasibility of the research instruments and procedures. About ten per cent ($n=7$) of the sample size was used to test whether questions were relevant and easy to understand by the subjects. The Cronbach's alpha obtained for reliability analysis was above 0.7, suggesting good internal consistency of the study. The Psychomotor Vigilance Task (PVT) is a valid instrument to assess the neurocognitive effects of sleep deprivation and fatigue-related changes in sustained alertness by repeated reactions to frequent stimuli. The reaction time (RT) is measured as an indirect assessment of fatigue. Reaction time, defined as the time between a stimulus onset and the response to such a stimulus, is highly compromised by fatigue. When reacting to a stimulus, the human body must perceive, process, and physically react to the stimulus (23). The PVT online application was used in this study to assess alertness and vigilance through a psychomotor vigilance task (PVT) test. In this study, a 10-minute PVT test was administered to assess participants' alertness and reaction time. During the test, visual stimuli appeared on the computer screen at random intervals, and participants were instructed to respond as quickly as possible by pressing the space-bar key. Reaction times were recorded for each stimulus, providing an objective measure of vigilance and fatigue. During the test, respondents will be asked to respond to a computer-generated stimulus that is randomly displayed (between 2 and 10) and briefly. For each presentation, respondents are supposed to respond as

quickly as they can by pressing the space-bar key on the computer. PVT tests were performed twice, before and after the work shift, to assess changes in alertness and cognitive performance due to work-related fatigue. For this study, PVT also performed two consecutive days to improve the reliability and validity of the results. All data were treated confidentially. Respondents were informed about the study and participated voluntarily. No personal identifiers were collected, and each participant was assigned a unique code to ensure their responses could not be linked to them. In addition, all digital data, including questionnaires and PVT results, were stored on password-protected, encrypted devices accessible only to the research team, and were not shared with employers or third parties.

Ethical Consideration

This research was approved by the Ethical Committee of Universiti Putra Malaysia (JKEUPM) JKEUPM-2020-346. Written informed consent was obtained from all participants before the study, and only the participants who gave consent were included.

Data Analysis

Data analyses were performed using Statistical Package for Social Sciences (SPSS) software version 25.0. A normality test was conducted, followed by a descriptive analysis of the respondents, which was presented using frequencies, percentages, mean values, and standard deviations. A paired t-test was used to compare respondents' PVT test results. To determine the risk factors of the PVT test, a multiple linear regression test was applied with a 95% confidence interval.

RESULTS

Table 1 shows the demographic information of the participants. The mean (SD) age of the participants was 35 (8.29); representing 100% male truck drivers. The results showed that most participants were married (69%), while the remaining 31% were single. Based on WHO classification, the mean BMI was 27.4 (SD = 6.49), with only 33% of participants classified as having a normal BMI (24). It also reported that more than half of the participants (58.6%) were smokers, and 31.4% did not engage in basic physical activity. The average working year for truck drivers was 6.9 (SD = 4.78). The mean KSS sleepiness score was 4.71 (SD = 1.69).

Psychomotor Vigilance Test Measurements of Truck Drivers

Table 2 presents the PVT test outcomes for two consecutive days. On day 1, there was a statistically significant difference between pre-shift and post-shift measurements for mean RT ($p<0.001$). Similar findings were observed for the number of lapses ($p<0.001$). However, the fastest 10% PVT reaction times showed no statistically significant difference between pre-shift and post-shift PVT measurements. On day 2, similar

Table I: Demographic, Working and Sleepiness Level Information of the Respondents

Demographic criteria		N (%)	Mean (SD)
Age	20 – 35	40 (57.1)	35 (8.29)
	36 and above	30 (42.9)	
Education level	Secondary	53 (75.7)	17 (24.3)
	Tertiary (diploma and above)	17 (24.3)	
Marital status	Single	22 (31.4)	48 (68.6)
	Married	48 (68.6)	
Smoking	Yes	41 (58.6)	29 (41.4)
	No	29 (41.4)	
BMI	<25	24 (34.2)	27.4 (6.49)
	≥25	46 (65.8)	
Physical activity	Yes	48 (68.6)	22 (31.4)
	No	22 (31.4)	
Duration of employment (years)	1-5	39 (55.7)	6.93 (4.780)
	6 and above	31 (44.3)	
KSS Sleepiness level	-	-	4.71 (1.687)

Table II: Description of PVT Test Outcome Measures for Two Consecutive Days

PVT Variables		Time of Measurement	Mean	Standard Deviation	T statistics	P value
Day 1	Mean	Pre-shift	486.07	74.03	-1.943	<0.001**
		Post-shift	525.66	91.86		
	No. of Lapses	Pre-shift	7.11	4.75	-10.318	<0.001**
		Post-shift	12.20	5.98		
	Fastest 10%	Pre-shift	393.24	57.40	1.131	0.262
		Post-shift	386.31	58.27		
Day 2	Mean	Pre-shift	503.79	81.85	-2.209	<0.001**
		Post-shift	545.20	112.10		
	No. of Lapses	Pre-shift	11.7	5.63	-7.637	<0.001**
		Post-shift	17.03	6.79		
	Fastest 10%	Pre-shift	403.30	62.50	-0.007	0.994
		Post-shift	403.38	69.53		

*Paired t-test

*P-value is significant at level 0.05

**P-value is significant at level 0.001

results were observed, with both mean RT and PVT lapses showing significant differences between pre-shift and post-shift measurements ($p < 0.01$). In contrast, the fastest 10% PVT reaction times showed no significant differences. The increase in mean reaction time post shift reflects reduced alertness due to mental and physical fatigue, which aligns with known effects of sustained wakefulness on attention networks in the brain (25).

Comparison Between PVT Parameters and Demographic, Working Condition and Sleep-Related Characteristics of the Participants

Table III shows the comparison of PVT parameters and respondents' characteristics. The results showed that there were significant differences between age factors and the mean reaction time. The mean RT of the truck drivers younger than 36 (491.90, SD=79) was significantly lower than the mean RT (570.67, SD=90) that of those older than 35 years old, indicating that reaction times increased with age ($p < 0.001$). The mean RT of the marital status reported that single truck drivers (490.47, SD=85) was significantly faster than the mean RT married truck drivers (541.78, SD=91.1), ($p < 0.05$). In addition, the analysis showed that single truck drivers had a lower mean RT (490.47, SD=85.0) compared to

married participants (541.78, SD=91.1). The difference was statistically significant, $t(69) = -2.291$, ($p < 0.05$). This finding suggests that marital status was associated with variations in vigilance performance, with married individuals demonstrating slower responses.

The results also revealed that truck drivers with less than 3 years of work experience had a lower mean RT, 505.9ms (SD=86.79), compared to those with more than 3 years of experience, 553.6ms (SD=93.04). This difference was statistically significant, $t(69) = -2.173$ ($p < 0.05$), indicating that longer work experience was associated with slower reaction times. Truck drivers with secondary school education reported a higher mean RT, 539.12ms (SD=98), compared to those with tertiary education, 483.70ms, (SD=53.31). The difference was statistically significant, $t(69) = 2.972$, ($p < 0.05$), indicating that respondents with higher educational attainment demonstrated faster psychomotor responses.

In the simple linear regression analysis, several factors including the demographic, working condition, and sleepiness level of the respondents were significantly associated with mean reaction time on the Psychomotor Vigilance Test (PVT) as shown in Table IV. The analysis

Table III: Association between PVT Parameters and Demographic, Working and Sleep-Related Information of the Participants

Characteristics	Mean (SD) Reaction Time (RT)	T statistics	P values†
Age (years)			
20 – 35 (40)	491.90 (79)	-3.827	<0.001**
36 and above (30)	570.67 (90)		
Marital status			
Single (22)	490.47 (85)	-2.291	0.027*
Married (48)	541.78 (91.1)		
Educational level			
Secondary (53)	539.12 (98)	2.972	0.005*
Tertiary (diploma and above) (17)	483.70 (53.31)		
Smoking			
Yes (41)	533.31 (77.61)	0.781	0.439
No (29)	514.83 (109.47)		
BMI			
<25 (24)	505.29 (88.53)	-1.368	0.178
≥25 (46)	536.29 (92.72)		
Physical activity			
Yes (48)	520.35 (85.17)	-0.656	0.517
No (22)	537.24 (106.24)		
Duration of employment (years)			
1 – 3 (41)	505.9 (86.79)	-2.173	0.034*
4 and above (29)	553.60 (93.04)		
Sleepiness level			
1-5 (42)	528.56 (90.41)	0.318	0.751
6-9 (28)	521.30 (95.5)		

†Independent t-test

*P-value <0.05

**P-value<0.001

showed that age was a significant predictor of mean RT, with an estimated increase of 4.76ms (95% CI: 2.34, 7.18) for each additional year of age ($p<0.001$). Truck drivers with tertiary-level education demonstrated significantly faster reaction times compared to those with secondary education, with an average reduction of 55.42ms in mean RT ($\beta = -55.419$, 95% CI: -105.11 to -5.728, $p<0.05$). Similarly, marital status was associated

Table IV: Associated Factors of Psychomotor Vigilance Among Logistic Truck Drivers

Variables	Mean RT PVT	
	B (95% CI)	P-value
Age	4.756 (2.337, 7.176)	<0.001**
Level of education (tertiary)	-55.419 (-105.11, -5.728)	0.029*
Smoking (yes)	18.486 (-26.094, 63.066)	0.411
Marital status (single)	-51.307 (-97.198, -5.415)	0.029*
BMI	1.672 (-1.729, 5.073)	0.330
Duration of employment	4.576 (0.060, 9.093)	0.047*
KSS Sleepiness level	-5.479 (-18.592, 7.634)	0.407
Duration of working hour	2.575 (-2.9, 8.05)	0.351

*Simple Linear Regression

*P-value <0.05

**P-value<0.001

with performance, as single participants showed a mean RT reduction of 51.31ms relative to married participants ($\beta=-51.307$, 95% CI: -97.198 to -5.415, $p<0.05$). Finally for demographic characteristics, duration of employment was also a significant predictor, where each additional year of employment was associated with a 4.58ms increase in mean RT ($\beta = 4.576$, 95% CI: 0.060–9.093, $p<0.05$). Overall, the findings suggest that older age and longer employment duration were associated with slower reaction times, whereas higher educational attainment and being single were associated with faster reaction times.

A multiple linear regression (MLR) analyses were performed to examine the predictive effects of age, education level, marital status, and duration of employment on participants' mean reaction times (Table V). Age emerged as a significant predictor of mean RT. The MLR model examining factors associated with Mean RT was statistically significant $p<0.001$ and explained 13.2% of the variance in mean RT ($R = 0.132$). Specifically, each additional year of age was associated with an increase of 4.76ms in mean RT (Adjusted $\beta = 4.756$, 95% CI: 2.337–7.176, $SE=1.212$, $t=3.923$, $p<0.001$). This finding indicates that older drivers demonstrated slower psychomotor vigilance compared to their younger counterparts. Overall, the model fit suggests that psychomotor vigilance among truck drivers is multifactorial, with age being a key determinant, while the modest R^2 underscores the need for future research incorporating additional physiological, sleep-related, or workload-related variables to enhance predictive accuracy.

Table V: Model of Factors Affecting Psychomotor Vigilance Among Logistic Truck Drivers

Factors	MLR			
	Adjusted β (95% CI)	T statistics	P value	Standard error
Age	4.756 (2.337, 7.176)	3.923	<0.001**	1.212

Model, $R^2= 0.132$ $p<0.001$ **

DISCUSSION

Fatigue decreased the ability to drive safely and impaired alertness and vigilance. The degradation of vigilance levels among truck drivers while driving poses a risk to their health and safety. The increase in reaction time and lapses reflects a diminished capacity to maintain psychomotor vigilance, which poses substantial safety concerns in the context of long-haul driving. Drivers experiencing reduced vigilance are more likely to overlook critical signals or react too slowly to sudden hazards, heightening the risk of accidents (26). The present study aims to identify the factors that affect the psychomotor vigilance of truck drivers working in a logistics company. For this purpose, the psychomotor vigilance of truck drivers was assessed in terms of mean reaction time, number of lapses, and the 10% fastest

responses, measured both before and after the work shift.

In line with previous research, increasing age was found to be significantly associated with slower reaction times, suggesting an age-related decline in neurocognitive function that may impact driving safety. This supports earlier studies indicating that older drivers are more prone to lapses in sustained attention and psychomotor performance (27). Given that long-haul truck driving requires continuous alertness, this finding underscores the need for tailored fatigue management strategies for ageing drivers, such as incorporating PVT data into driver fatigue management systems to enable real-time monitoring and proactive risk prediction of alertness levels.

In this study, it was found that the mean reaction time of individuals with higher educational levels was faster compared to those with only completed secondary school education. These findings suggest that educational background may play a meaningful role in sustaining attention and psychomotor performance in safety-critical occupations such as truck driving. A previous study found that workers with limited or incomplete education were more likely to experience work-related fatigue. It is recommended to implement targeted fatigue-management strategies, particularly skills-based training for truck drivers with lower education levels that emphasizes fatigue-recognition cues, sleep hygiene, and alertness techniques (28). Furthermore, higher education is often linked with better awareness of fatigue management strategies, which could indirectly support psychomotor performance during prolonged tasks. Likewise, participants with higher education attainment exhibit better performance on the personal computer (PC-PVT) test (29,30).

Similarly, in this study, marital status is one of the factors positively affecting psychomotor vigilance. The findings of the present study are compatible with the literature, which states that married workers reported higher fatigue scores than single people. This may be attributed to greater psychosocial and familial responsibilities, which can compromise sleep duration and quality, ultimately leading to impaired vigilance (31). A structure fatigue management system which integrates education, scheduling adjustments and real-time monitoring can mitigate the vigilance deficits observed among married drivers (28). Neither smoking nor BMI influenced the level of reaction times of PVT. Consistent with these findings, smoking was not found to be associated with any measurable decline in alertness. In another study conducted among industry workers in Indonesia, a very weak relationship was found between smoking habits and work fatigue, as well as a weak correlation between BMI category and work fatigue (32,33). Studies with a wide distribution of participants across different types of job categories should be conducted better to assess

the association between these factors and psychomotor vigilance.

The present study demonstrated that duration of employment was significantly associated with degradation of psychomotor vigilance performance, as reflected by longer reaction times with increasing years of employment. Consistent with the findings of Charlton and Baas, their study reported that PVT performance was significantly associated with shift length and the number of driving days per week. Similarly, drivers who undertook longer shifts and had insufficient rest before their shifts were more likely to experience crashes. These observations suggest that experienced drivers may accumulate fatigue from prolonged work exposure, including extended or frequent driving shifts, which can impair vigilance and slow reaction times (34,35).

Multiple linear regression showed that age was a significant predictor of mean reaction time in the PVT among logistic truck drivers. It is consistent with previous studies reporting that a decline in cognitive processing speed, attention, and vigilance accompanies advancing age. Increasing the age gradually decreased the attention and reaction time which leads to fatigue driving and poor driver performance (36). To mitigate these effects and improve mean reaction time on the PVT, several strategies may be recommended. It includes optimizing sleep quality and quantity through consistent sleep schedules, creating a conducive sleep environment, and incorporating short restorative naps can enhance alertness (37). In addition, regular physical activity and brief movement breaks during long drives have been shown to improve cerebral perfusion and attentional capacity (38).

CONCLUSION

The findings of this study demonstrate significant degradation of psychomotor vigilance among truck drivers, as indicated by prolonged mean RT and an increased number of lapses following work shifts. According to the results, psychomotor vigilance among truck drivers was influenced by factors such as age, level of education, marital status, and years of employment, with alertness levels further declining towards the end of the shift. Several strategies can be used to increase truck drivers' psychomotor vigilance, including ensuring adequate rest periods and proper shift scheduling. Additionally, regular health promotion programs, such as sleep hygiene education and lifestyle interventions, may also help sustain alertness. In addition, the use of fatigue monitoring devices and periodic vigilance assessments may facilitate early detection of impairment. Moreover, workplace policies that foster work-life balance and reduce psychosocial stressors are essential for preserving drivers' performance and safety.

At the policy level, the findings highlight the need for

stronger fatigue management regulations, including strict adherence to rest-time and working hours rules. Policies should also promote routine health and vigilance screenings particularly for older drivers and consider incorporating psychomotor vigilance testing into occupational assessments to identify early declines in alertness that may increase crash risk. This study has several limitations that should be acknowledged. The cross-sectional design precludes any inference of causality between the variables studied. Additionally, the sample was restricted to a single geographical area (Klang Valley), which may limit the generalizability of the findings. Finally, as only male participants were included, the results may not be representative of all drivers, and caution should be exercised when extrapolating these findings to female drivers or broader populations. Future research should employ longitudinal fatigue monitoring and intervention-based studies to evaluate the effectiveness of fatigue management strategies and their impact on driver vigilance across diverse populations.

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