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Cognitive Distraction in Novice Drivers: Analyzing Physiological and Workload Responses

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Abstract: Distracted driving poses a significant threat to road safety, with a notable impact on young drivers. This study explores the physiological responses and subjective workload experienced by young drivers aged 16-23 during distracted driving scenarios. Forty-two participants completed driving tasks in a simulator while their physiological data, including electrodermal activity (EDA), heart rate (HR), and temperature, were recorded. Additionally, participants completed a motion sickness susceptibility questionnaire and subjective workload assessment. Descriptive analysis revealed heightened physiological arousal during distracted driving, with increased EDA and HR compared to baseline. Factorial ANOVA showed significant effects of driving experience and motion sickness susceptibility on physiological responses, indicating a vulnerability among novice drivers and individuals with higher susceptibility to motion sickness. Correlation analyses further elucidated the relationships between driving experience, motion sickness susceptibility, and physiological responses. Moreover, subjective workload measures indicated a significant increase in perceived workload during distracted driving tasks. These findings underscore the importance of individual differences in understanding the impact of cognitive distractions on driving performance and safety. Tailored interventions based on driver characteristics may enhance driving safety amidst cognitive distractions. Further research is necessary to elucidate underlying mechanisms and develop targeted interventions to mitigate distraction-related impairments among drivers.

Keywords: Distracted driving, Young drivers, Physiological responses, Subjective workload, Motion sickness susceptibility

1. Introduction

According to the global status report on road safety by the World Health Organization (WHO), it was estimated that road traffic deaths amount to approximately 1.19 million annually on a global scale. This highlights the significant impact of road crashes on the development of technologies aimed at ensuring safer driving environments (WHO, 2023). The US National Highway Traffic Safety Administration (NHTSA) reports that in 2020, 8% of fatal crashes and 13% of all reported motor vehicle crashes were attributed to distraction. Specifically, 3,142 fatalities and an additional 324,652 injuries were associated with distracted driving. Notably, 7% of drivers aged 15-20 years were reported as distracted during fatal crashes, with this age group representing the highest proportion of distracted drivers involved in fatal crashes (Qi et al., 2020). As the automobile industry advances towards autonomous vehicles, addressing safe driving aspects becomes increasingly crucial (Koopman & Wagner, 2017; Young & Salmon, 2012). The mitigation of crashes or near-crash incidents is vital for the realization of these technological advancements. The issue of distracted driving is particularly pressing given its pervasive impact, especially among young drivers (Cunningham et al., 2020; Stavrinos et al., 2013). Distractions are commonly linked to the use of handheld devices such as mobile phones for texting and other activities, but they also encompass behaviors like eating, talking to co-passengers, or using in-vehicle information systems (IVIS) (Häuslschmid et al., 2017). Driver-assisted systems, including IVIS, can play a dual role: while they may contribute to distraction, they also have the potential to alert drivers to their distraction and inform them about their surroundings to prevent crashes.

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Extensive research has been conducted on distracted driving, focusing on vehicle kinematics, eye-glance monitoring, and facial monitoring (Alkinani et al., 2020; Edughele et al., 2022; Sun et al., 2021; Xu et al., 2024). However, when it comes to cognitive distraction, physiological factors like heart rate (HR), electrodermal activity (EDA), and body temperature are crucial yet understudied components (Ahmadi et al., 2022; Ba & Hu, 2023; Strle et al., 2023). While previous research has made significant strides in understanding the mechanics of distracted driving through vehicle and visual monitoring, there remains a substantial gap in literature regarding the physiological responses associated with distraction (Michelaraki et al., 2023). Most studies have not extensively explored how physiological factors are impacted during distracted driving, especially among young novice drivers (Cassarino & Murphy, 2018; Papantoniou et al., 2017). Addressing this gap is essential as physiological data can provide a deeper understanding of the cognitive and emotional states of drivers, thereby aiding in the development of more effective distraction mitigation systems. The aim of the study is to identify and discuss the effects on physiological factors such as HR, EDA, body temperature, and motion sickness during distracted driving among young drivers aged 16-23 years. The study seeks to understand how these physiological responses are influenced by driver distraction and to explore correlations with driving experience and motion sickness susceptibility. The insights gained from this study will be helpful in developing distraction mitigation systems and in-vehicle warning systems tailored to young drivers, thereby enhancing road safety and reducing the incidence of distraction-related crashes.

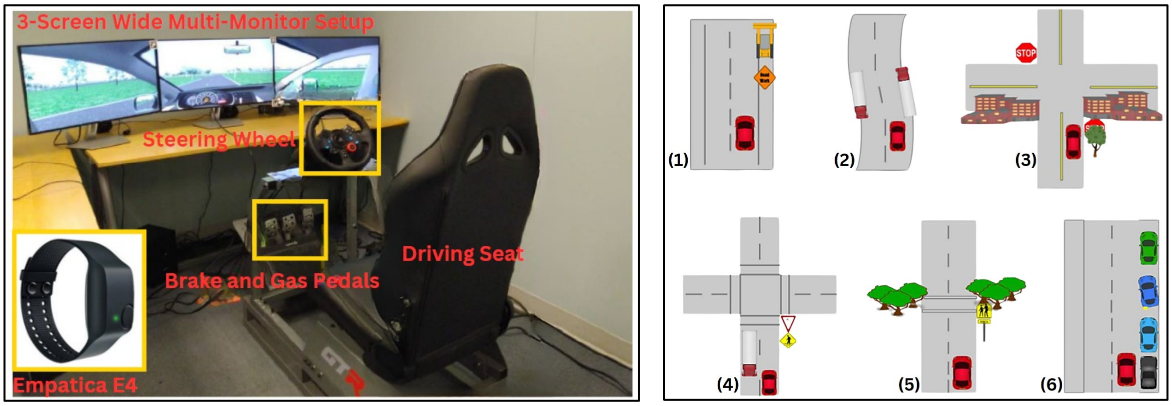
2. Methodology

2.1 Participants

The study comprised 42 participants, aged 16-23, with a mean age of 20.5 years (females: M = 20.78 years; males: M = 20.34 years). The sample included 14 females and 28 males. Participants were required to possess a full G Canadian driver's license and have less than 15,000 kilometers of driving experience. Individuals with known vertigo or motion sickness were excluded from the study. Ethics clearance was granted by the University of Waterloo Office of Research Ethics (ORE #40678), and the study was conducted in accordance with the approved protocols. Participants were required to possess adequate visual acuity, either naturally or corrected using contact lenses or spectacles. Each participant signed a consent form agreeing to participate in the study. Prior to the experiment, participants completed a Motion Sickness Susceptibility Questionnaire (MSSQ). The MSSQ assessed the participants' susceptibility to motion sickness, and those with high susceptibility scores were excluded to avoid simulator-induced sickness.

2.2 Experimental Setup

The experimental setup used the Carnetsoft Driving Simulator (Misra et al., 2023) and the E4 Empatica Wristband (McCarthy et al., 2016) to collect data on participants' physiological responses during driving scenarios (Figure 1 (a)). The study implemented six distinct driving scenarios to investigate the effects of distraction on participants' physiological responses and driving performance as illustrated in Figure 2. Each scenario was meticulously crafted to replicate real-world driving conditions and included specific latent hazards to enhance the ecological validity of the experiment. In the *Work Zone Scenario*, participants navigated a two-lane highway at a speed of 110 km/h, encountering light traffic in the opposite lane. A concealed worker behind a bulldozer in the emergency lane served as the latent hazard, requiring participants to maintain heightened awareness while responding to cognitive tasks (Hajiseyedjavadi et al., 2018; Misra et al., 2023; Samuel et al., 2016). The *Curve Scenario* simulated a suburban road with trucks parked on either side of a curved segment, challenging participants to maintain control at 80 km/h while remaining vigilant for a hidden pedestrian concealed behind one of the trucks (Ebadi et al., 2018; Hajiseyedjavadi et al., 2018). At the *Stop-Controlled Intersection Scenario*, participants approached a four-way intersection in an urban area, where the stop sign was obscured by vegetation. This scenario tested participants' ability to detect hidden hazards and respond to verbal tasks while navigating through the intersection at a speed of 50 km/h (Samuel et al., 2016). In the *Pedestrian Crossing Scenario*, participants encountered a two-lane city road with a crosswalk and a truck parked on the left lane. A pedestrian hidden behind the truck posed a potential crossing hazard, requiring participants to remain attentive while engaging in distraction tasks (Vlakveld et al., 2011). The *School Zone Scenario* simulated a suburban road with prior signage warning of school children, where vegetation obstructed the view of a pedestrian attempting to cross at the crosswalk. Participants drove at 50 km/h through the school zone, remaining alert for unexpected crossings while responding to cognitive tasks (Hajiseyedjavadi et al., 2018; Vlakveld et al., 2011). Lastly, the *Parked Vehicles Scenario* presented participants with a two-lane road lined with parked cars, where a car with its turn signal on attempted to pull out into the participant's path. Participants managed distraction tasks while anticipating and reacting to potential hazards, demonstrating their ability to multitask under realistic driving conditions (Vlakveld et al., 2011). In three out of the six scenarios, participants engage in a cognitive distraction task. They listen to spoken grammatical reasoning statements and respond verbally with the subject, object, and plausibility (e.g., "The rat drove the car." Response: "Rat, Car, No"). The scenarios are presented in a pseudo-random order to control for learning effects and fatigue.



(a) **(b)**

Figure 1. Illustration of the (a) Experimental Setup and (b) Distraction Scenarios

2.3 Post-Drive Evaluation

After completing the driving scenarios, participants fill out the NASA TLX questionnaire to measure their subjective workload (Gawron, 2000). This multi-dimensional rating technique assesses mental demand, physical demand, temporal demand, perceived performance, effort, and frustration. Once the data were collected, we employed various statistical tests to analyze the physiological responses and driving performance data gathered during the experiment. These tests included descriptive analysis to summarize the dataset's characteristics, paired t-tests to compare mean values between baseline and distracted driving conditions, ANOVA to examine the effects of driving experience and MSSQ scores on physiological factors, Spearman's Rho calculation to assess relationships between parameters, Pearson's r test to determine linear relationships between variables, and ANOVA for evaluating workload parameters with and without distractions.

3. Results and Discussion

The mean driving experience was 1.45 years (SD = 1.383), with the most common experience level being 1 year, indicating a relatively homogeneous sample in terms of driving history. The mean MSSQ score was 5.143 (SD = 3.628), suggesting variability in participants' susceptibility to motion sickness. Descriptive analysis provided insights into the physiological responses of participants during both baseline and distracted driving conditions. Participants exhibited higher EDA and HR during distracted driving tasks compared to baseline, indicating increased physiological arousal in response to cognitive distraction. Specifically, the mean EDA during distraction was 2.22 µS (SD = 4.29) compared to 1.30 µS (SD = 2.07) during baseline. The mean HR during distraction was 79 beats per minute (SD = 9.07) compared to 78 beats per minute (SD = 9.22) during baseline. Conversely, the mean temperature was lower during distracted driving, with an average of 31.97°C (SD = 1.02) compared to 32.18°C (SD = 1.59) during baseline, potentially indicating stress-induced cooling. Overall, participants experienced increased physiological arousal and stress when engaged in distraction tasks. Factorial ANOVA revealed no significant differences between baseline and distracted values for EDA, HR, and temperature, suggesting that the cognitive distraction tasks did not produce marked changes in these physiological measures (Table 1).

Table 1. Factorial ANOVA for Baseline (B) vs Distracted (D) Values

Variables	F value	P value
B. EDA vs D. EDA	1.5535	0.2162
B. HR vs D. HR	0.3472	0.5573
B. Temp vs D. Temp	0.5001	0.4815

Driving experience significantly affected HR and temperature, but not EDA. Participants with less driving experience had higher EDA and HR values, indicating greater physiological reactivity to distraction (Table 2).

Table 2. ANOVA Test for Experience

Experience with	F value	P value	Effect size
EDA	1.226	0.272	0.014
HR	2997.651	3.54E-65	0.974
Temp	14207.6	1.14E-93	0.994

MSSQ score significantly affected EDA, HR, and temperature. Higher MSSQ scores were associated with increased EDA and lower temperature, suggesting that individuals more prone to motion sickness exhibit distinct physiological responses under cognitive load (Table 3).

Table 3. ANOVA for MSSQ and Physiological Factors

MSSQ with	F value	P value	Effect size
EDA	14.361	0.00028	0.149
HR	2055.22	8E-59	0.963
Temp	1219.03	5.47E-51	0.937

Spearman's correlation analysis showed a negative correlation between driving experience and HR, and between driving experience and EDA. MSSQ score had a negative correlation with temperature and a positive correlation with EDA. Pearson's correlation analysis revealed a significant negative correlation between driving experience and HR, and between MSSQ score and temperature. These correlations suggest that more experienced drivers have lower physiological responses (HR and EDA), while higher MSSQ scores are linked to increased EDA and lower temperature, reflecting greater cognitive and physiological stress during distraction (Table 4).

Table 4. Spearman's and Pearson's Correlation Analysis

MSSQ with	‘rs’ value	P value	‘r’ value	P value
Experience vs HR	-0.45398	0.00253	-0.4347	0.00458
Experience vs EDA	-0.13097	0.40839	0.2344	0.1351
MSSQ vs HR	-0.127	0.2878	-0.2019	0.1995
MSSQ vs EDA	0.16792	0.42286	0.0364	0.820
MSSQ vs Temperature	-0.19740	0.21112	-0.1099	0.4880

The ANOVA results for subjective workload measures showed that mental demand, physical demand, temporal demand, performance, effort, and frustration were significantly higher during distracted driving tasks compared to baseline. These findings indicate that cognitive distractions significantly increase perceived workload, consistent with physiological data trends (Table 5). These findings indicate that cognitive distractions significantly increase perceived workload, consistent with physiological data trends. A detailed version of the results can be found in the dissertation (Seenivasan, 2023).

Table 5. ANOVA for Workload with and without Distractions

Workload factors	‘rs’ value	P value
Mental demand	58.6383	3.32E-11
Physical demand	5.3698	0.02298
Temporal demand	72.6754	6.34E-13
Performance	26.2268	1.97E-6
Effort	44.0914	1.04E-9
Frustration	18.0361	6.51E-5

In summary, the study highlights the complex interplay between cognitive distractions, physiological responses, driving experience, and MSS among young drivers. Descriptive analysis showed heightened physiological arousal during distracted driving tasks. However, factorial ANOVA did not reveal significant differences in physiological measures between baseline and distracted conditions, suggesting the overall impact might not be substantial enough to show statistically significant differences in traditional arousal measures. Further analyses revealed significant effects of driving experience and MSS on physiological responses. Novice drivers and those with higher susceptibility to motion sickness displayed elevated physiological responses during distraction, indicating vulnerability to cognitive distractions. These findings underscore the importance of considering individual differences in susceptibility to distraction-induced stress when devising interventions to improve driving safety. Correlation analyses revealed relationships between driving experience, MSS, and physiological responses. Experienced drivers exhibited lower physiological responses during distraction, suggesting more efficient cognitive resource allocation. Conversely, higher motion sickness susceptibility was associated with increased physiological stress, highlighting the need for tailored interventions to mitigate distraction-related impairments among susceptible individuals. The analysis of subjective workload measures supported the physiological findings, indicating a significant increase in perceived workload during distracted driving tasks. This aligns with existing literature suggesting cognitive distractions impose additional cognitive and perceptual demands on drivers, requiring heightened mental and physical effort to maintain task performance. Overall, the study's hypotheses were largely confirmed. Results supported the hypothesis that driving experience influences physiological responses, with more experienced drivers exhibiting lower arousal levels during distraction. Similarly, the hypothesis regarding motion sickness susceptibility and physiological responses was upheld, as individuals with higher susceptibility displayed increased physiological stress during distraction tasks. These outcomes emphasize the importance of individual differences in understanding the impact of cognitive distractions on driving performance and safety.

3. Conclusion

In conclusion, this study provides comprehensive insights into the physiological and subjective workload responses of young drivers during cognitive distractions. While the overall impact of distractions on traditional physiological measures may be subtle, individual differences in driving experience and motion sickness susceptibility significantly influence physiological responses to distraction. These findings underscore the importance of personalized interventions tailored to individual driver characteristics to enhance driving safety in the face of cognitive distractions. Further research is necessary to elucidate the underlying mechanisms driving these effects and develop targeted interventions to mitigate distraction-related impairments among drivers.

4. References

Ahmadi, N., Sasangohar, F., Nisar, T., Danesh, V., Larsen, E., Sultana, I., & Bosetti, R. (2022). Quantifying Occupational Stress in Intensive Care Unit Nurses: An Applied Naturalistic Study of Correlations Among Stress, Heart Rate, Electrodermal Activity, and Skin Temperature. Human Factors, 64(1), 159–172. https://doi.org/10.1177/00187208211040889

Alkinani, M. H., Khan, W. Z., & Arshad, Q. (2020). Detecting Human Driver Inattentive and Aggressive Driving Behavior Using Deep Learning: Recent Advances, Requirements and Open Challenges. IEEE Access, 8, 105008–105030. https://doi.org/10.1109/ACCESS.2020.2999829

Ba, S., & Hu, X. (2023). Measuring emotions in education using wearable devices: A systematic review. Computers & Education, 200, 104797. https://doi.org/10.1016/j.compedu.2023.104797

Cassarino, M., & Murphy, G. (2018). Reducing young drivers' crash risk: Are we there yet? An ecological systems-based review of the last decade of research. Transportation Research Part F: Traffic Psychology and Behaviour, 56, 54–73. https://doi.org/10.1016/j.trf.2018.04.003

Cunningham, M. L., Regan, M. A., & Imberger, K. (2020). Understanding driver distraction associated with specific behavioural interactions with in-vehicle and portable technologies. Journal of the Australasian College of Road Safety, 28(1), 27–40. https://doi.org/10.3316/informit.695045538098973

Ebadi, Y., Mangalore, G. P., & Samuel, S. (2018). Impact of Cognitive Distractions on Drivers' Anticipation Behavior in Vehicle-bicycle Conflict Situations. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 62(1), 1898–1902. https://doi.org/10.1177/1541931218621431

Edughele, H. O., Zhang, Y., Muhammad-Sukki, F., Vien, Q.-T., Morris-Cafiero, H., & Opoku Agyeman, M. (2022). Eye-Tracking Assistive Technologies for Individuals With Amyotrophic Lateral Sclerosis. IEEE Access, 10, 41952–41972. https://doi.org/10.1109/ACCESS.2022.3164075

Gawron, V. J. (2000). Human performance measures handbook (pp. xiii, 188). Lawrence Erlbaum Associates Publishers.
Hajiseyedjavadi, F., Zhang, T., Agrawal, R., Knodler, M., Fisher, D., & Samuel, S. (2018). Effectiveness of visual warnings on young drivers hazard anticipation and hazard mitigation abilities. Accident Analysis & Prevention, 116, 41–52. https://doi.org/10.1016/j.aap.2017.11.037
Häuslschmid, R., Pfleging, B., & Butz, A. (2017). The Influence of Non-driving-Related Activities on the Driver's Resources and Performance. In G. Meixner & C. Müller (Eds.), Automotive User Interfaces: Creating Interactive Experiences in the Car (pp. 215–247). Springer International Publishing. https://doi.org/10.1007/978-3-319-49448-7_8
Koopman, P., & Wagner, M. (2017). Autonomous Vehicle Safety: An Interdisciplinary Challenge. IEEE Intelligent Transportation Systems Magazine, 9(1), 90–96. https://doi.org/10.1109/MITS.2016.2583491
McCarthy, C., Pradhan, N., Redpath, C., & Adler, A. (2016). Validation of the Empatica E4 wristband. 2016 IEEE EMBS International Student Conference (ISC), 1–4. https://doi.org/10.1109/EMBSISC.2016.7508621
Michelaraki, E., Katrakazas, C., Kaiser, S., Brijs, T., & Yannis, G. (2023). Real-time monitoring of driver distraction: State-of-the-art and future insights. Accident Analysis & Prevention, 192, 107241. https://doi.org/10.1016/j.aap.2023.107241
Misra, A., Samuel, S., Cao, S., & Shariatmadari, K. (2023). Detection of Driver Cognitive Distraction Using Machine Learning Methods. IEEE Access, 11, 18000–18012. https://doi.org/10.1109/ACCESS.2023.3245122
Papantoniou, P., Papadimitriou, E., & Yannis, G. (2017). Review of driving performance parameters critical for distracted driving research. Transportation Research Procedia, 25, 1796–1805. https://doi.org/10.1016/j.trpro.2017.05.148
Qi, Y., Vennu, R., & Pokhrel, R. (2020). Distracted Driving: A Literature Review. FHWA-ICT-20-004. https://doi.org/10.36501/0197-9191/20-005
Samuel, S., Borowsky, A., Zilberstein, S., & Fisher, D. L. (2016). Minimum Time to Situation Awareness in Scenarios Involving Transfer of Control from an Automated Driving Suite. Transportation Research Record, 2602(1), 115–120. https://doi.org/10.3141/2602-14
Seenivasan, R. D. (2023). Trends in Electrodermal Activity, Heart Rate and Temperature during Distracted Driving among Young Novice Drivers. [Master Thesis, University of Waterloo]. https://uwspace.uwaterloo.ca/handle/10012/19029
Stavrinos, D., Jones, J. L., Garner, A. A., Griffin, R., Franklin, C. A., Ball, D., Welburn, S. C., Ball, K. K., Sisiopiku, V. P., & Fine, P. R. (2013). Impact of distracted driving on safety and traffic flow. Accident Analysis & Prevention, 61, 63–70. https://doi.org/10.1016/j.aap.2013.02.003
Strle, G., Košir, A., Sodnik, J., & Pečečnik, K. S. (2023). Physiological Signals as Predictors of Cognitive Load Induced by the Type of Automotive Head-Up Display. IEEE Access, 11, 87835–87848. https://doi.org/10.1109/ACCESS.2023.3305383
Sun, W., Aguirre, M., Jin, J. (Judy), Feng, F., Rajab, S., Saigusa, S., Dsa, J., & Bao, S. (2021). Online distraction detection for naturalistic driving dataset using kinematic motion models and a multiple model algorithm. Transportation Research Part C: Emerging Technologies, 130, 103317. https://doi.org/10.1016/j.trc.2021.103317
Vlakveld, W., Romoser, M. R. E., Mehranian, H., Diete, F., Pollatsek, A., & Fisher, D. L. (2011). Do Crashes and near Crashes in Simulator-Based Training Enhance Novice Drivers' Visual Search for Latent Hazards? Transportation Research Record, 2265(1), 153–160. https://doi.org/10.3141/2265-17
WHO. (2023). Global status report on road safety 2023. https://www.who.int/teams/social-determinants-of-health/safety-and-mobility/global-status-report-on-road-safety-2023
Xu, J., Qian, C., Han, S., & Guo, F. (2024). Detecting Critical Mismatched Driver Visual Attention During Lane Change: An Embedding Kernel Algorithm. IEEE Transactions on Intelligent Transportation Systems, 1–11. https://doi.org/10.1109/TITS.2023.3346684
Young, K. L., & Salmon, P. M. (2012). Examining the relationship between driver distraction and driving errors: A discussion of theory, studies and methods. Safety Science, 50(2), 165–174. https://doi.org/10.1016/j.ssci.2011.07.008