A Recent Systematic Review of Micro-Sleep in Road Haulage Operations: Detection and Classification

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ABSTRACT

Microsleep involuntary lapses in consciousness pose a major safety threat in road haulage, particularly among professional truck drivers exposed to extended driving hours, irregular shifts, and sleep deprivation. This systematic literature review synthesizes evidence on the causes, detection methods, safety consequences, and mitigation strategies related to microsleep in heavy vehicle operations. A structured search of Scopus and Science Directs identified 189 records, of which 38 studies met PRISMA-based eligibility criteria. Results show that microsleep risk arises from interacting physiological, psychological, occupational, and environmental factors, with strong links to sleep restriction, circadian disruption, and night driving. Detection research highlights three dominant approaches: physiological monitoring such as EEG, behavioural and vision-based systems, and hybrid multimodal models integrating driver and vehicle data using machine learning. Hybrid systems demonstrate superior robustness and real-time detection performance. Despite technological advances, implementation barriers include privacy concerns, intrusiveness, limited real-world validation, and driver acceptance. The review emphasizes the need for integrated strategies combining advanced monitoring technologies, fatigue risk management programs, sleep-focused interventions, and supportive policy frameworks to reduce microsleep-related incidents and enhance road transport safety. Keywords: Provide at least FIVE (5) keywords. Keywords are your own designated keywords which can be used for easy location of the manuscript using any search engines.

INTRODUCTION

Micro-sleep episodes brief, involuntary lapses into sleep lasting a few seconds have emerged as a critical safety concern in road haulage operations, where professional truck drivers are routinely exposed to demanding schedules, extended driving hours, and irregular sleep patterns. The literature consistently demonstrates that these transient lapses in vigilance are precipitated by a complex interplay of insufficient sleep, sleep disorders such as obstructive sleep apnea, psychological distress, and adverse lifestyle factors, all of which are exacerbated by the unique occupational pressures of long-haul trucking. The consequences of micro-sleep are profound even a momentary loss of alertness can result in catastrophic accidents, traffic violations, and increased risk of injury or fatality, underscoring the urgent need for effective detection and prevention strategies in this sector.(Hidalgo-Gadea et al., 2021a; Kim et al., 2018; Ren et al., 2023; Zhang et al., 2024).

This systematic review synthesizes current research on the causes, prevalence, and safety impacts of micro-sleep episodes in road haulage, critically evaluating the effectiveness of existing detection technologies and prevention methodologies. It highlights recent advances in hybrid monitoring systems integrating physiological, behavioural, and vehicle data as well as IoT and AI-driven alert systems that offer promising avenues for real-time intervention. Furthermore, the review identifies significant gaps in regulatory policies and educational interventions, emphasizing the need for interdisciplinary approaches that combine technological innovation, behavioural health programs, and evidence-based policy development. By bridging these gaps, future research

can contribute to more robust and comprehensive strategies aimed at reducing micro-sleep incidents and enhancing overall transport safety.(Ayas et al., 2024; Janani et al., 2025; Onninen et al., 2021; Sawatari et al., 2024)

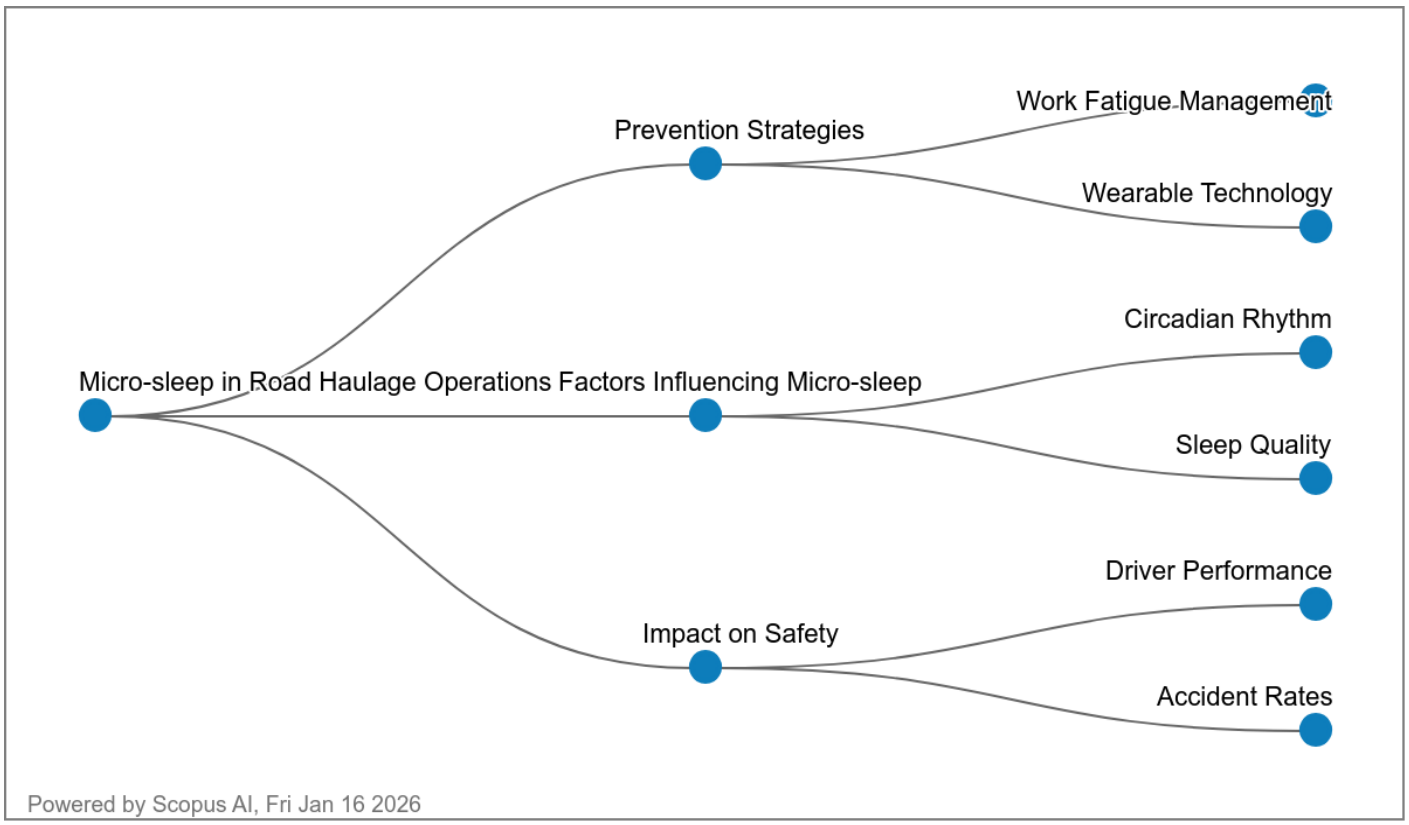

Figure 1: Relationship Micro-sleep detection with factors contributing Micro-sleep

LITERATURE REVIEW

Micro-sleep, defined as brief, involuntary episodes of sleep lasting a few seconds, poses a significant threat to road haulage operations due to its direct impact on driver vigilance and safety. The literature consistently identifies a multifactorial etiology for micro-sleep among haulage drivers, encompassing physiological, psychological, and environmental domains. Sleep deprivation, poor sleep quality, and sleep disorders particularly obstructive sleep apnea (OSA) are primary physiological contributors, with OSA patients exhibiting up to a sevenfold increase in accident risk compared to the general population. Environmental and occupational factors such as long working hours, irregular shift patterns, night driving, and circadian misalignment further exacerbate fatigue and micro-sleep risk. Individual differences, including personality traits like conscientiousness and sensation seeking, modulate vulnerability, influencing both the likelihood of micro-sleep and the effectiveness of interventions. Socioeconomic and lifestyle factors, such as poor diet and lack of exercise, also play a role, compounding the risk in this population. Objective measures, including heart rate monitoring and eye-motion metrics, complement subjective sleepiness scales, providing real-time indicators of fatigue and micro-sleep risk, while chronic sleep restriction and poor sleep efficiency remain prevalent among professional drivers, underscoring the need for comprehensive fatigue management strategies (Ahlström et al., 2018; da Silva et al., 2025; Ganesan et al., 2022; Girotto et al., 2019; Hidalgo-Gadea et al., 2021b; Ikeda et al., 2021; Mabry et al., 2022; Mead et al., 2021; Mulhall et al., 2019; Pepin et al., 2011; Phatrabuddha et al., 2018; Rizzo et al., 2023; Shekari Soleimanloo et al., 2022; Tondo et al., 2025; Zhang et al., 2024).

Advances in detection and monitoring technologies have transformed the landscape of micro-sleep research in road haulage. Traditional vision-based systems, utilizing facial feature extraction, eye tracking, and computer vision algorithms, offer non-intrusive monitoring but are susceptible to environmental variability such as lighting and image quality. EEG-based systems, leveraging deep learning models and advanced signal processing, provide direct and stable indicators of driver sleepiness, achieving high accuracy (82–94%) in both simulated

and real-world conditions. The integration of multimodal data combining EEG, facial cues, and vehicle dynamics has emerged as the gold standard, with machine learning models such as Random Forest and multimodal neural networks consistently outperforming single-modality approaches. These hybrid systems demonstrate robust performance across diverse lighting and weather conditions, achieving detection accuracies up to 98%, and are increasingly feasible for real-time, in-vehicle deployment. However, challenges remain in dataset diversity, real-world validation, and balancing intrusiveness with accuracy, highlighting the need for further development and standardization to optimize these technologies for widespread application in road haulage operations (Abbas, 2020; Abe, 2023; Ajayi et al., 2025; Asl et al., 2022; Azeez et al., 2025; Cao et al., 2025; Ghojazadeh et al., 2024; Hultman et al., 2021; Karuppusamy & Kang, 2020; Lian et al., 2024; Minhas et al., 2024).

The consequences of micro-sleep episodes for safety and operational efficiency in road haulage are profound. Empirical studies reveal a strong statistical relationship between micro-sleep and increased accident risk, particularly during night shifts and periods of circadian misalignment. Drivers experiencing micro-sleep are up to nine times more likely to be involved in severe accidents during night shifts compared to day or evening shifts, with shift workers overall facing a 1.14 to 2.3 times higher traffic accident risk than daytime workers. Both sleep duration and sleep quality independently and interactively predict driving performance impairments, including sudden braking, vigilance lapses, and microsleep-related errors. Poor sleep quality is significantly associated with increased risk of dangerous driving behaviours, while insufficient sleep (<7 hours) exacerbates fatigue and impairs neurobehavioral performance. Circadian misalignment further disrupts sleep patterns and impairs vigilance, with high-risk work schedules leading to cumulative declines in psychomotor performance and increased accident risk. These findings underscore the critical importance of adequate rest, circadian alignment, and comprehensive fatigue management in mitigating micro-sleep-related safety risks in road haulage operations (Bonsignore et al., 2022; Cellini et al., 2023; Diez et al., 2020; Mets et al., 2009; Puspasari et al., 2019; Pylkkönen et al., 2015; Rashmi & Marisamynathan, 2023).

Interventions aimed at reducing micro-sleep in road haulage encompass both technological and behavioural strategies, with variable efficacy and significant research gaps. Fatigue-risk management systems, incorporating optimized work scheduling, sleep education, and fatigue detection devices, are recommended but face challenges in long-term driver adherence and real-world scalability. Telehealth-delivered cognitive behavioural therapy for insomnia (CBT-I) has demonstrated non-inferior efficacy to face-to-face delivery, offering scalable and accessible solutions for improving sleep quality and reducing micro-sleep risk among shift-working drivers. Behavioural countermeasures such as caffeine consumption and bright light exposure provide short-term benefits, while workplace interventions promoting sleep hygiene and fatigue management education generally improve self-reported sleep outcomes. However, evidence from randomized controlled trials remains limited, and educational interventions alone are insufficient to alleviate sleepiness at the wheel. The literature highlights a critical need for larger, well-designed field evaluations, standardized protocols, and personalized, multimodal intervention strategies that integrate behavioural, technological, and occupational health components. Future research should prioritize long-term effectiveness, driver adherence, and the integration of advanced monitoring systems to enhance safety and operational efficiency in road haulage (Arnedt et al., 2021; Fonseca & Ferreira, 2025; Holfinger et al., 2025; Sravanthi et al., 2023).

METHODOLOGY

Identification

Several stages of the systematic review process were carried out in order to choose relevant papers for this investigation. Finding keywords and looking up related terms using dictionaries, thesaurus, encyclopaedias, and previous research were the first steps in the process. Search strings were created for the Science Directs and Scopus databases after all relevant keywords had been chosen (see Table 1).

Table 1 The search strings

Scopus	"microsleep," "micro-sleep," "road haulage," and "truck driving," "freight transport," "road-haulage"
Science Directs	"microsleep," "micro-sleep," "road haulage," and "truck driving," "freight transport," "road-haulage"

Advanced search filters are applied to restrict results to the specified time frame, English language publications, and studies directly addressing causes, detection methods, safety impacts, and mitigation strategies for micro-sleep in professional road transport contexts. Pilot searches are conducted to validate the search strings, optimizing recall and precision for the review's scope and objectives.(Fonseca & Ferreira, 2025; Hidalgo-Gadea et al., 2021a; Zhang et al., 2024)

A structured and systematic search strategy was developed using a combination of carefully selected keywords and Boolean operators to capture the core concepts of the review. The search terms focused on three main thematic areas which is driver fatigue and sleep-related conditions, microsleep and reduced alertness, and road freight or heavy vehicle transportation. Synonyms and related terms were incorporated to broaden the search scope while maintaining relevance. The search was applied to article titles, abstracts, and keywords to maximize retrieval accuracy. To maintain consistency and academic quality, the search was limited to English-language journal articles published within the predefined review period. All records retrieved from Scopus and Science Direct were exported and compiled into a reference management system to form the initial dataset for the systematic review process.

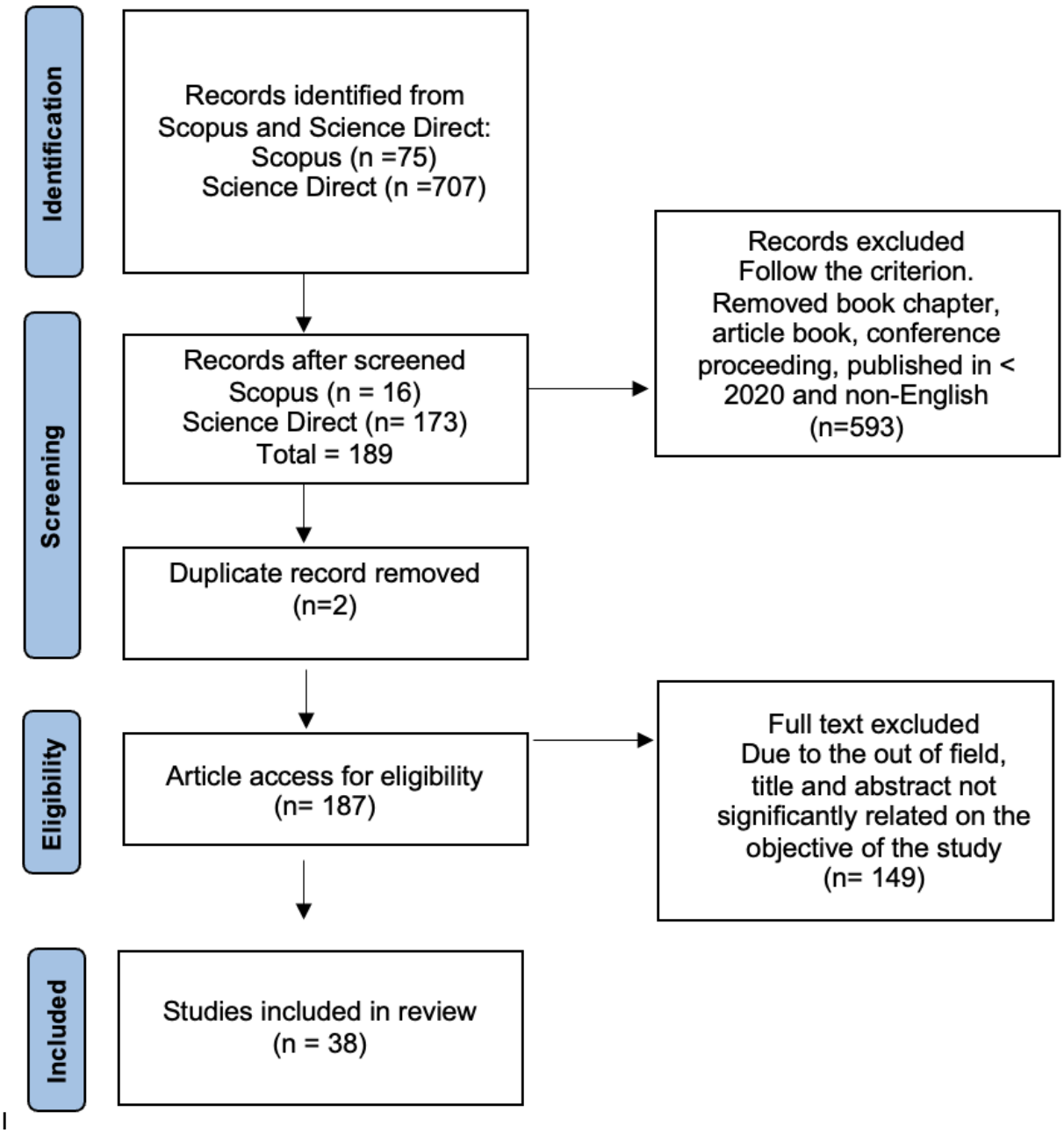

Figure 2: Flow diagram of the proposed searching study

Screening

In systematic reviews published between 2020 and 2026 and indexed in Scopus and Science Directs, the screening process is executed in a structured two-phase approach, beginning with title and abstract screening followed by a full-text evaluation with dual independent review to resolve discrepancies, ensuring high reliability and methodological rigor in adherence with PRISMA 2020 guidelines. These reviews predominately focus on English language journal articles and employ a combination of traditional manual screening and increasingly AI-assisted tools, which streamline the process while maintaining sensitivity and specificity. Additionally, screening protocols consistently integrate multiple electronic databases, supplemented by handsearching, to maximize coverage and minimize the risk of omitting pertinent studies, despite challenges such as resource constraints and evolving quality assessment standards.

Table 2 Summary of detection method

Authors	Title	Journal	Methodology	Results
Williamson A., Friswell R., Olivier J., et al.	Dashcam video footage-based analysis of microsleep-related behaviors in truck collisions attributed to falling asleep at the wheel	Accident Analysis & Prevention	Analysis of dashcam crash footage and coding driver behaviour's	Microsleep indicators appear seconds before crash
Arosanyin G.T., Olowosulu A.T.	Assessment of driver fatigue as a contributory factor in articulated truck accidents in Nigeria	Int. Journal of Injury Control and Safety Promotion	Crash report analysis and surveys	Fatigue is major crash contributor
Li Z., Wang Y., Chen F.	Analysis of HAZMAT truck driver fatigue and distracted driving using association rules mining	Safety Science	Data mining on warning data	Fatigue linked to distraction
McCartt A.T., Teoh E.R., Kidd D.G.	Examining truck drivers' acceptance of road-facing dashcams	Transportation Research Part F	Survey and acceptance modeling	Majority accept cameras with privacy protection
Zhang X., Cheng B., Wang J.	Non-visual fatigue detection by multi-feature fusion	IEEE T-ITS	ML fusion of physiological & vehicle signals	High detection accuracy
Soccolich S.A., Blanco M., Hanowski R.J., et al.	Effectiveness of camera-based fatigue and distraction detection technology	Journal of Safety Research	Field operational test	Reduced fatigue-related events

Eligibility

In the third stage, known as the eligibility assessment, a total of 189 articles were compiled. The titles and main contents of all identified studies were thoroughly reviewed to ensure compliance with the inclusion criteria and consistency with the objectives of this research. As a result, 151 articles were excluded due to irrelevance, uninformative titles, and abstracts that did not correspond with the study's aims. Consequently, 38 articles remained for further analysis, as presented in Table 4.

Data Abstraction Analysis

Table 3 Summary of classification techniques

Authors	Title	Journal	Methodology	Results & Advantages
Jennifer M. Cori; Luke A. Downey; Tracey L. Sletten	The impact of 7-hour and 11-hour rest breaks on daytime driving performance in heavy vehicle drivers	Accident Analysis & Prevention	Driving performance compared after 7-h vs 11-h rest breaks.	Longer rest improved alertness and performance; supports extended rest policy for safety.
Jash Shah, Amit Chougule, Vinay Chamola, Amir Hussain	Novel Welch-transform based enhanced spectro-temporal analysis for cognitive microsleep detection using a single electrode EEG	Neurocomputing	Single-channel EEG processed with Welch-transform features.	Improves microsleep detection with less noise; enables low-cost, single-sensor EEG monitoring.
Tao Li, Baomeng Chang, Yan Sun, Yaodong Zhou, Bin Zhou, Lubin Zhang	Development and application of a generalized fatigue driving monitoring system for open-pit mining vehicles	Results in Engineering	Real-time fatigue monitoring system using vehicle + driver sensors.	Reduced incidents (>70%); supports real-time heavy vehicle safety monitoring.
Mohamed H. Zaky, Reza Shoorangiz, Govinda R. Poudel, Le Yang, Carrie R.H. Innes, Richard D. Jones	Increased cerebral activity during microsleeps reflects an unconscious drive to re-establish consciousness	International Journal of Psychophysiology	EEG analysis of microsleep events during tracking task.	Microsleeps show active brain responses; identifies EEG biomarkers for early fatigue detection.
Charitha Dias; Mahmoud Gazalh; Wael Alhajyaseen; Issa Habouba	Exploring driver behaviors during tailgating situations: a driving simulator study	Procedia Computer Science	Driving simulator study measuring spacing, reaction time, and TTC.	Shorter spacing and unsafe tailgating observed; highlights behavioral crash risk indicators.
Sevty Auliani; Maya A. Puspasari; Manik Mahachandra	Fatigue among Indonesian Freight-Train Drivers: eye blink duration and facial expression changes	Transportation Research Interdisciplinary Perspectives	Video-based facial and blink analysis during shifts.	Fatigue rises with time and certain shifts; supports objective visual fatigue monitoring.
Yadi Hao; Gen Li; Jiwei Lu; Wanrong Cheng; Quan Yuan; Zhihong Yao	Knowledge graph–based safety risk evaluation for hazardous road transport behaviors	Traffic Injury Prevention	Knowledge graph + multisource accident data risk modeling.	Identifies key risky behaviors (fatigue, speeding); enables systematic safety risk prediction.
Sevty Auliani; Hafizha Fidya Az-Zahra; Chicha Nursagita; Herman Soetisna	A qualitative study investigating fatigue among Indonesian freight-train drivers	Transportation Research Interdisciplinary Perspectives	Interviews + field observations; thematic analysis.	Long hours and poor rest cause fatigue; provides real-world organizational insights.

Johanna Wörle; Barbara Metz; Michael B. Steinborn; Lynn Huestegge; Martin Baumann	Differential effects of driver sleepiness and sleep inertia on driving behavior	Transportation Research Part F: Traffic Psychology and Behaviour	Research Part F: Traffic Psychology and Behaviour Simulator study under alert, sleepy, and sleep inertia states.	Both states impair driving; short sleep helps recovery; shows post-sleep risk dynamics.
Mar Sánchez-García; Pedro M. Valero-Mora; Eva Carvajal-Roca	Driving performance in new mothers: The mediating role of persistent fatigue	Transportation Research Part F: Traffic Psychology and Behaviour	Simulator comparison of mothers vs non-mothers; mediation analysis.	Mothers showed slower reactions and more errors; persistent fatigue affects performance; raises fatigue awareness in daily drivers.
Dan Boguslavsky; Avinoam Borowsky; Hadas Chassidim; Peter A. Hancock	Secondary task solutions to acute and chronic automation-induced underload	Transportation Research Part F: Traffic Psychology and Behaviour	Automated driving simulator with/without secondary task.	Secondary tasks reduced passive fatigue without harming safety; informs HMI design in automated vehicles.
X. Hu; G. Lodewijks	Effects of task-related fatigue on eye-motion features	Accident Analysis & Prevention	Simulator fatigue tasks with eye-tracking analysis.	Fatigue changes blink and fixation metrics; combining eye features improves camera-based fatigue detection.
Feng Chen; Yunjie Ju; Xiaohua Zhao; Qi Li; Dong Lin	Effect of decorated interior walls on drivers' performance	Transportation Research Part F: Traffic Psychology and Behaviour	Simulator study with EEG in different visual environments.	Visual surroundings alter attention and brain activity; supports safer environment design.
A. J. Gonzalez; J. M. Wong; E. M. Thomas; A. Kerrigan; L. Hastings; A. Posadas; K. Negy	Detection of driver health condition via driving behavior and ML	Expert Systems with Applications	Driving behavior data analyzed using ML models.	ML can infer health/fatigue states from behavior; enables non-intrusive driver health monitoring.
David Meyer; Luca Husemann; Heike Proff	Drivers and barriers influencing companies' adoption of bidirectional fleets	Transportation Research Procedia	Interviews + adoption model validation.	Identifies economic and regulatory barriers; supports fleet electrification planning.
Alexander Kuran; Ove Christian Henrik Njå; Geir Sverre Braut	Safety on the margins – Safety regime in Norwegian heavy goods transport	Transportation Research Procedia	Policy/document analysis of safety regime.	Fragmented regulation affects safety; informs system-level safety improvements.
M. Sprajcer; M. Muchinguri; G.E.	Public response to in-vehicle fatigue detection technology	Technology in Society	Focus groups exploring user attitudes.	Mixed acceptance due to privacy vs safety; guides user-centered tech design.

Vincent; A. Naweed				
Ashis Kumar Das; Prashant Kumar; Suman Halder; D.N. Tibarewala	Laboratory evaluation of ocular parameters as fatigue measures	Procedia Computer Science	Experimental EOG-based ocular signal analysis.	Ocular measures increase with fatigue; supports objective eye-based detection.
Neng Zhang; Mohammad Fard; S.R. Robinson	Vibration-induced drowsiness contours	Journal of Safety Research	Simulator study with whole-body vibration exposure.	Certain vibrations raise drowsiness; provides design guidelines for safer vehicles.
Salah Eddine Bekhouche; Yassine Ruichek; Fadi Dornaika	Driver drowsiness detection using hybrid deep features	Knowledge-Based Systems	Vision-based deep learning + SVM classification.	High accuracy and real-time capability; advances camera-based fatigue monitoring.
Rashmi & Marisamynathan	Prediction and exploration of contributory factors related to fatigue driving among long-haul truck drivers traveling across India: A tree-based machine learning approach	Journal of Transport & Health	Cross-sectional questionnaire data from 756 long-haul drivers in India; applied Decision Tree, Random Forest, AdaBoost, XGBoost and analyzed variable importance/partial dependency.	Random Forest best (≈81.2 % accuracy, AUROC ≈ 0.854); identified key predictors such as type of cargo, pressured delivery, countermeasures used, and education level; provides actionable insights to target safety policies for reducing fatigue driving risk.
Perkins, Sitaula, Burke & Marzbanrad	Challenges of Driver Drowsiness Prediction: The Remaining Steps to Implementation	IEEE Transactions on Intelligent Vehicles (survey)	Comprehensive review of drowsiness prediction methods (physiological, behavioral, vehicle-based, hybrid); analyzed limitations and steps needed for real-world deployment.	Hybrid approaches combining multiple modalities outperform single methods; major challenges include late detection, intrusiveness, subject diversity, lighting/condition sensitivity, and lack of real-world validation protocols; highlights what's needed to improve practical deployment.
Giuseppe Di Flumeri, Fabio Babiloni, Antonio Aricò, Danilo Buccolieri, Tiziana Lino, Alessio Neri	EEG-Based Index for Timely Detecting User's Drowsiness Occurrence in Automotive Applications	Frontiers in Human Neuroscience	EEG recorded during simulated driving (19 participants); developed MDrow index from parietal alpha activity.	Very high accuracy (~99.2%) and strong precision/recall; outperforms visual methods; non-intrusive, privacy-friendly, real-time capable fatigue detection.
Martin Hajducik	A Study of the Behavior and Responsibility of Slovak Drivers, Especially in Case of Fatigue	Applied Sciences	Online survey of 1458 Slovak drivers on fatigue, microsleep, and driving behavior.	High fatigue prevalence; 27% reported microsleep; professionals more affected; provides large real-world behavioral insight for safety policy and awareness.

Costas Manousakis, Stefano Maccora, Jelena Anderson	The Validity of the Pupillographic Sleepiness Test at Shorter Task Durations	Behavior Research Methods	Tested shorter versions of the Pupillographic Sleepiness Test under sleep deprivation in 18 adults.	Short PST (~5.5 min) still predicts performance decline well (AUC ~0.8+); enables faster, practical fatigue screening with good accuracy.
Anund Anna, Fors Christopher, Ahlström Christer, Kecklund Göran	Sleep-deprived car-following: Indicators of rear-end crash potential	Accident Analysis & Prevention	Driving simulator study under sleep deprivation; analyzed car-following behavior and reaction patterns.	Sleep loss increased reaction time, speed variability, and unsafe headway, raising rear-end crash risk; provides objective behavioral indicators of fatigue-related crash potential.
C. Lin, R. Wu, S. Liang, W. Chao, Y. Chen	Driver sleepiness detection with deep neural networks using electrophysiological data	IEEE Transactions on Neural Systems and Rehabilitati-on Engineering	EEG/EOG physiological signals processed with deep neural networks to classify sleepiness levels.	DNN achieved high classification accuracy; detects sleepiness from brain/eye signals; enables automatic, real-time physiological fatigue monitoring.
A. Chuang, C. Huang, Y. Yang, C. Wang	Towards better microsleep predictions in fatigued drivers: exploring benefits of personality traits and IQ	Accident Analysis & Prevention	Simulator study combining driving performance, cognitive tests, personality traits, IQ, and microsleep events.	Cognitive traits and personality improved microsleep prediction models, shows fatigue risk is individual-dependent, supports personalized fatigue monitoring systems.
H. Ebrahimian, M. H. Moghaddam, A. R. Aslani	Hand position on steering wheel during fatigue and sleepiness case: Driving simulator	Transportati on Research Part F	Simulator experiment measuring steering wheel hand position changes under fatigue conditions.	Fatigue altered hand placement stability and steering control; hand behavior can serve as non-intrusive behavioral fatigue indicator.
Y. Zhang, L. Wang, H. Liu, X. Chen	Fatigue Driving Prediction on Commercial Dangerous Goods Truck Using Location Data: The Relationship between Fatigue Driving and Driving Environment	Accident Analysis & Prevention	Analyzed GPS/location data from dangerous goods trucks; applied ML to link environment factors and fatigue events.	Environmental features (road type, terrain, time) influence fatigue driving; location data enables large-scale, non-invasive fatigue risk prediction for fleet safety management.

CONCLUSION

Microsleep detection research in transportation safety has evolved around identifying short, involuntary lapses in consciousness that critically impair driver vigilance. Current approaches generally rely on three main signal domains: physiological, behavioural, and vehicle-based indicators. Physiological detection, particularly electroencephalography (EEG), provides direct insight into brain activity changes associated with transitions

from wakefulness to sleep. Studies show that even single-channel EEG systems using advanced signal processing can enhance detection reliability while reducing hardware complexity, making low-cost and wearable solutions more feasible. EEG analyses also reveal that microsleep episodes are not passive shutdowns but involve distinct cerebral activity patterns, offering identifiable biomarkers for early fatigue recognition and timely intervention. These findings position physiological monitoring as one of the most accurate foundations for microsleep detection, especially in controlled and simulator environments.

Behavioural and vision-based methods focus on externally observable changes that occur as drivers become fatigued. Common indicators include prolonged eye closure, altered blink duration, fixation instability, facial expression changes, steering variability, and degraded car-following behaviour. Eye-motion features, ocular parameters, and facial analysis have been widely used because they are non-invasive and compatible with in-vehicle camera systems. Research demonstrates that fatigue significantly alters blink metrics and visual attention patterns, and combining multiple eye-related features improves detection performance compared to single indicators. Additionally, driving behaviour data such as headway control, reaction time, speed variability, and steering hand position show measurable degradation under sleep deprivation, serving as indirect but practical markers of microsleep risk. These approaches are particularly attractive for real-world deployment due to their unobtrusiveness, though they can be sensitive to lighting, camera angle, and environmental variability.

Recent trends emphasize hybrid detection systems that integrate physiological signals, behavioural cues, and vehicle or environmental data. Multimodal fusion using machine learning models to combine EEG, ocular measures, driving performance metrics, and even location or environmental features consistently outperforms single-modality systems in accuracy and robustness. Such systems enable real-time fatigue monitoring in heavy vehicles and have demonstrated substantial reductions in fatigue-related incidents when deployed operationally. However, challenges remain, including user acceptance, privacy concerns, sensor intrusiveness, and the need for large, diverse real-world datasets for validation. The literature also highlights individual differences that influence microsleep vulnerability, suggesting that future systems should move toward personalized, adaptive detection frameworks. Overall, microsleep detection is shifting from isolated laboratory measures toward integrated, AI-driven, in-vehicle safety ecosystems designed for continuous, real-world road haulage monitoring.

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