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Analysis of Driver Fatigue Caused By Highway Hypnosis in Monotonous Geometrics of Road: State of the Arth Review

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Abstract **-** Road performance continues to be improved to minimize the occurrence of road accidents. But on roads that have good performance, accidents still often occur. Based on the historical occurrence of accidents on toll roads, 45% of the incidents were caused by drivers suffering from fatigue and drowsiness on the road. Straight and monotonous roads are one of the main causes of highway hypnosis and decreased driver alertness. This is a requirement for the development of safe road design through real-time fatigue monitoring.
In general, the researcher developed a fatigue model based on motion (MOT), electroencephalogram (EEG), photoplethysmogram (PPG), electrocardiogram (ECG), galvanic skin response (GSR), electromyogram (EMG), skin temperature (Tsk), eye movement (Eye Movement Data), and respiration (RES) obtained through the device used. Supervised machine learning models, and more specifically binary classification models. These models are considered to have excellent performance in detecting fatigue, yet little effort has been made to ensure the use of high-quality data during model development.
However, driving performance and some physiological markers of alertness have not been observed in measured road geometric designs. The impact of monotony on road geometry has not been studied in detail. Also, no studies have been found that apply fatigue avoidance in road geometric design to improve driving alertness that can be used and guided by road designers, landscape architects, and traffic engineers to improve road safety. Together, the findings of this review reveal that methodological limitations have hampered the generalizability and road safety applicability of most of the proposed fatigue models.

Keywords**:** fatigue analysis, monotonous geometrics, highway hypnosis, physiological signals, machine learning.

1. Introduction

The characteristics of road geometry and roadside environment, among other factors that contribute to driving performance, can impact driving performance by affecting alertness and information processing. A monotonous and congested road environment with low traffic density may cause fluctuations in vigilance resulting in decreased alertness. Such performance degradation, caused by the task underload, may be as significant as what happens in congested urban highway situations, when arousal increases to the point where driving performance is negatively impacted. These task-induced factors can be referred to as "exogenous", as they stem from the individual's interaction with the road environment. Research data from naturalistic observation studies, and investigations through questionnaire completion, show a value of about 10-20% attributable to road accidents [1]. The number increases to 20-50% if only commercial vehicle accidents are taken into account [2]. 343 cases of accidents on the Trans Java Toll Road in the period December 2018-January 2019 [3]. 61% of the majority of accidents on the Trans-Java Toll Road due to passive driver fatigue ranging from decreased driver alertness, microsleep, and also highway hypnosis and also lack of anticipation in driving [4].

This paper presents an overview of fatigue analysis, in the domain of application to straight and flat road geometrics and fatigue mechanisms.

2. Fatigue Analysis Method on Monotonous Highway Geometrics

A literature search was conducted in the Scopus database covering the period from January 1, 2015 to October 7. 2023.

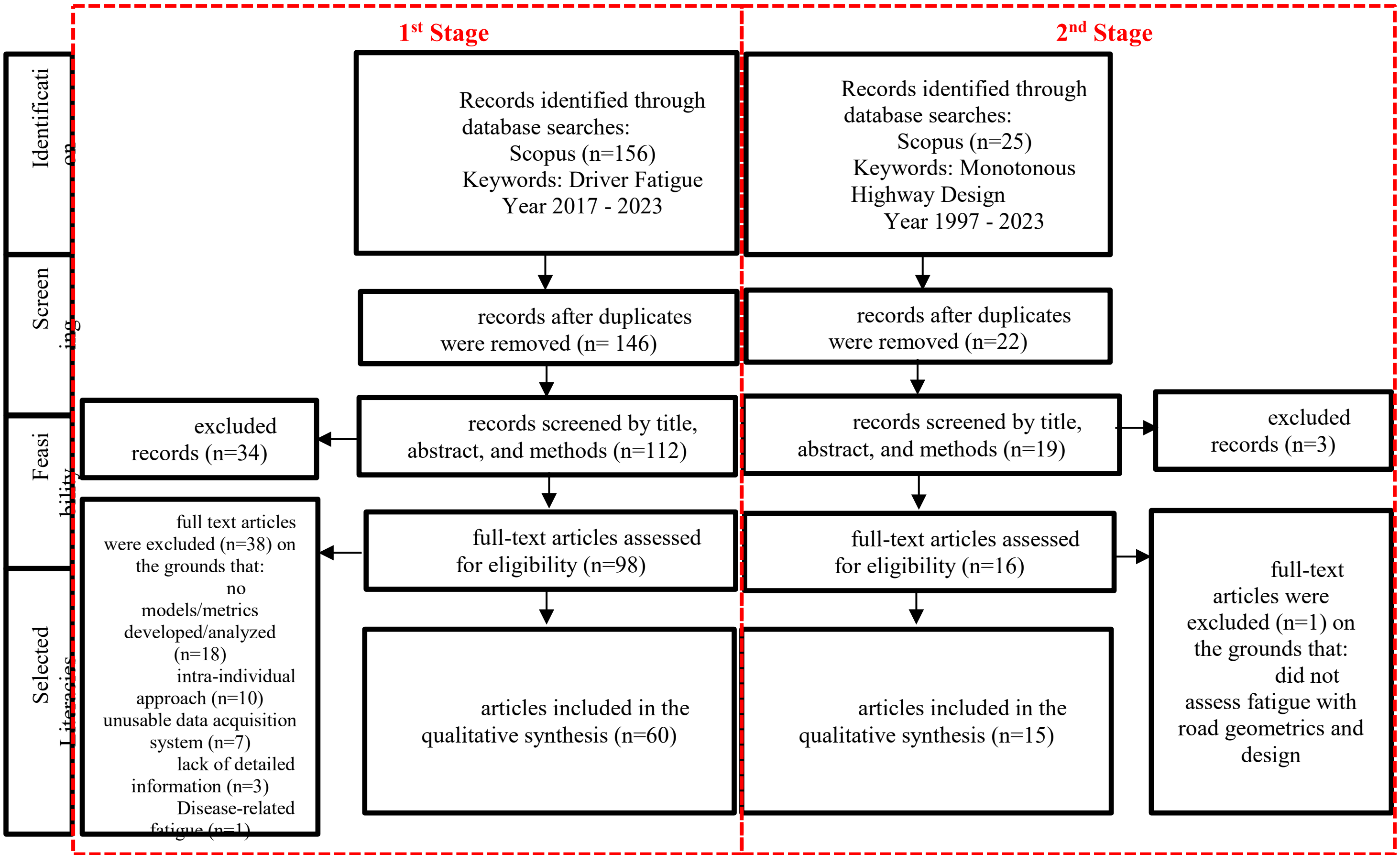


Fig.1: Information Flow Through the Various Stages of the Article Selection Process

Only articles with titles that had the terms "fatigue", "drowsiness", "alertness", "monotony", "geometry", and "road design" in the field of transportation were considered. The criteria used in this review were:

- research with a quantification approach of driver fatigue on monotonous roads
- describe the methodology for developing fatigue indices or models on monotonous roads
- assess the performance of the model/index from the outputs produced.

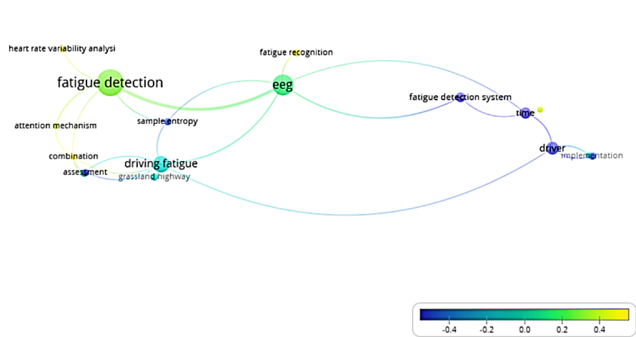
Given the scope of this review, the first stage of the research begins with a literacy search of systems that can be used for driver fatigue analysis in general. In the second stage, the most feasible systems for detecting driver fatigue due to saturation and monotonous road geometrics were filtered. A total of 25 articles were retrieved in the literature search. After removing duplicates, 22 remained. Of the identified articles, 3 articles were discarded at the filtering stage because they did not meet the criteria.

The full texts of the remaining 16 articles were assessed for eligibility. Of these, 1 article was excluded for not examining fatigue with road geometrics and design (n = 15), proposed a monotone geometry-type fatigue approach (n = 7), proposed a monotone road landscape-visual fatigue approach (n = 6), or did not use geometry approaches in fatigue (e.g., cognitive approaches to solving fatigue, etc., n = 2).

3. Literacy Results Fatigue Analysis Due To Monotony Through Road Geometrics

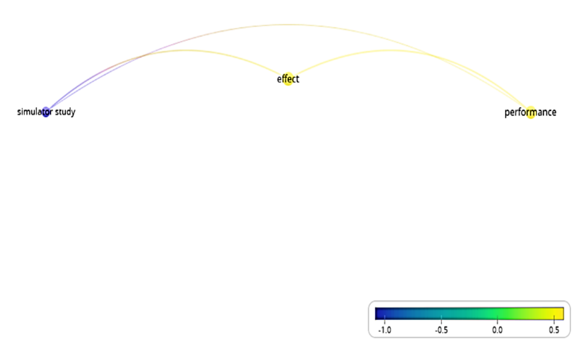
When moving from a monotonous road environment to a complex road environment, drivers feel greater complexity in in the road environment, making them more alert, although the increase in alertness is limited because they are already very very tired [5].

During a monotonous driving task, two dimensions of monotony, namely road design monotony and road edge variability, can cause a significant rapid decline in driver alertness [6]. In addition to the driver- and vehicle-based methods currently used to mitigate the effects of fatigue, the inclusion of such engineering measures can help reduce fatigue-related impairments in driving, especially if such treatments are applied in long straight stretches of monotonous road that are known to be associated with fatigue-related accidents [7]. The results obtained from the driver's steering wheel and road centerline data show that higher variations in road geometry can result in better performance and higher driver alertness. Adding variation to road design through horizontal bends can be considered as an effective method to increase the mental workload of drivers under monotonous and underload conditions.



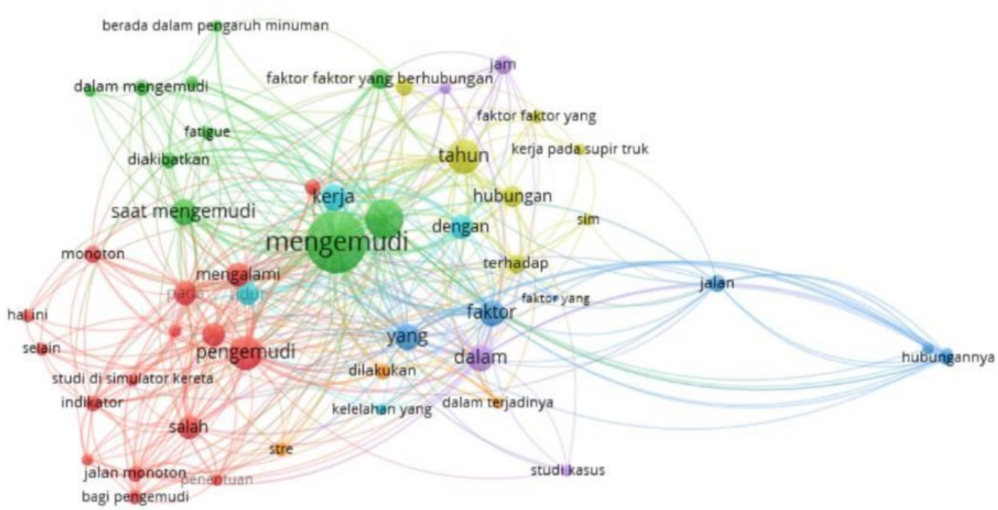
Source: Vos Viewer Reference Analysis Results, 2023

Fig.2: The reference "Driver Fatigue" Scopus Publications 2017 – 2023



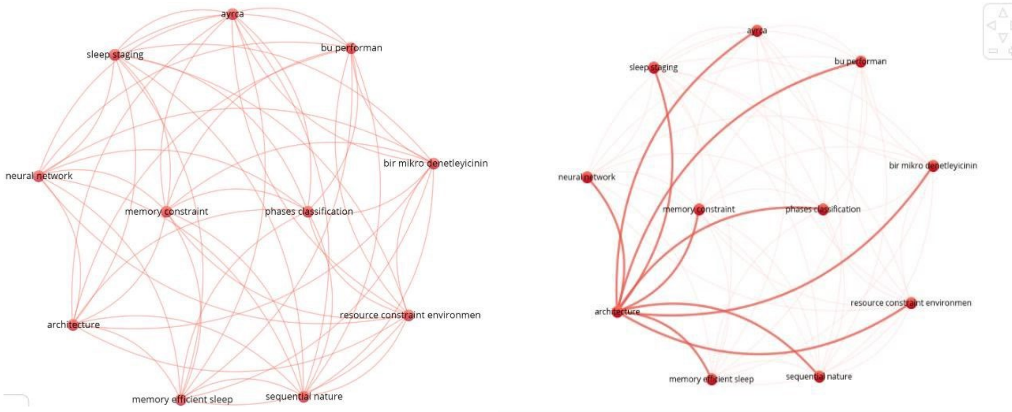
Source: Scopus 2017 - 2022, by VosViewer

Fig.3: Scopus Publications 2000-2023 Research related to Monotonous Road Design



Source: Gscholar 2017 - 2022, by VosViewer

Fig.4: Review of Research Related to Monotonous Road Design G-Scholar Publications 2017-2022



Source: Gscholar 2017 s/d 2022, by VosViewer
Fig.5: Reference Research related to Microsleep G-Scholar Publications 2017-2022

The application of more complex horizontal geometry in underload conditions may inhibit the process of driver alertness decrease [8]. The pressure distribution of the driver's seat is less homogeneous on mountain and urban roads than on monotonous roads (highways and rural roads). Although there are pressure differences between seats, they lead to increased discomfort felt throughout the body throughout the driving session [9]. Objective and subjective sleepiness increases through monotonous driving scenarios. [10].

Behavior-based methods follow an observational approach to detecting fatigue and include external signs, such as yawning, sighing, closing the eyes, or nodding the head. As a result, technologies in this category often use metrics related to eye movements (EYE), head movements, and facial expressions as input features [11a],[11b], [11c]. While behavior-based methods can be real time and non-intrusive, they detect fatigue only when the first signs appear which may be too late to avoid exposure to fatigue-related risks [12].

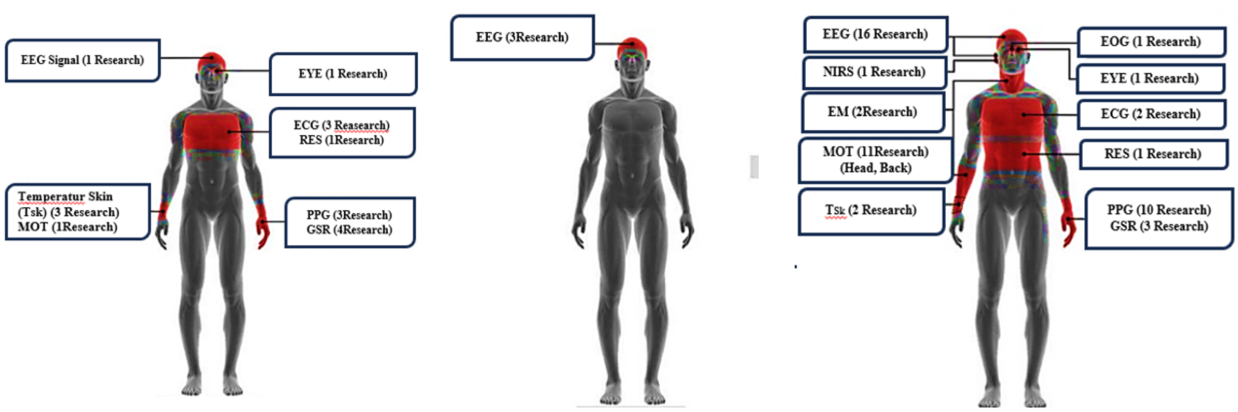
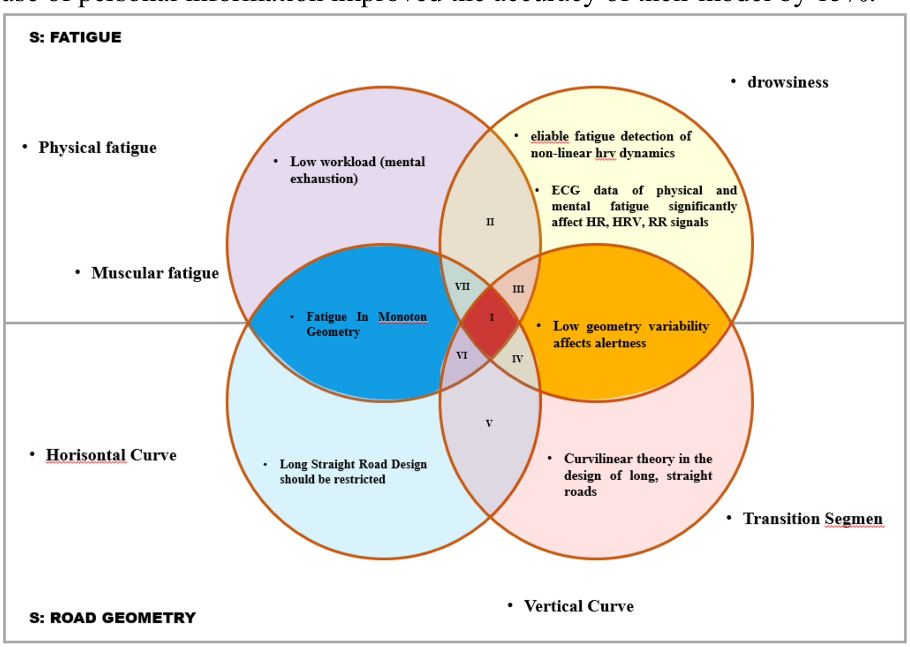


Figure 6A. Physiology And Motion Signals For Mental Fatigue	Figure 6B. Physiology And Motion Signals For Alertness	Figure 6C. Physiology And Motion Signals For Sleepiness

Source: Reference Analysis, 2023
Fig.6: Physiological and motion signals for (A) mental fatigue, (B) alertness, (C) drowsiness, ECG, electroencephalogram; EEG, electroencephalogram; EMG, electromyogram; EOG, electrooculogram; EYE, eye movement; GSR, galvanic skin response; MOT, motion; NIRS, near infrared spectroscopy; PPG, photoplethysmogram; RES, respiration; Tsk, skin temperature

In addition, the computer vision technology used is sensitive to environmental factors (e.g. light). Physiological signal-based methods detect the onset of fatigue based on changes in the driver's physiological responses such as brain activity measured by electroencephalogram (EEG), heart rate (HR), or electromyogram (EMG). Electroencephalogram, for example, has been considered the standard for alertness [13a], [13b] and driver drowsiness detection [14a], [14b], [14c]. Whereas the designed deep network working with wavelet scalogram images of ECG signals significantly outperformed KNN and random forest classifiers trained on HRV-based features [15]. Several studies found that pulse interval, HR, and HRV derived from PPG signals collected by the devices used were relevant predictors of sleepiness (Figure 6C) and mental fatigue (Figure 6A).

In those studies, PPG data was obtained from the wrist or finger of drivers who mostly used commercial devices, although some used homemade systems [16a], [16b], [16c], [16d] designed a multi-sensor wristband with PPG and Tsk sensors, GSR electrodes, as well as motion sensors (acceleration and lap rate) to monitor driving stress, fatigue, and drowsiness. Research has also shown that wearable ECG sensors can be applied to detect fatigue. ECG signals are acquired by a chest strap HR monitor, except that in [17a], [17b] designed an epidermal electronic sensor. They fabricated filamentous serpentine mesh electrodes made of copper and graphite-based strain sensors for simultaneous monitoring of ECG, GSR and RES. These sensors were applied to the skin in the form of temporary tattoos. [17b] used a single-channel ECG patch to acquire physical and mental fatigue data found to significantly affect HR, HRV, RR intervals as well as their respective spectral power and dynamics.[18] investigated the use of different types of looping plots to detect drowsiness. The plots were created using pulse intervals from PPG or RR intervals. The results showed that recurrence patterns, which are known to capture the non-linear dynamics of HRV, are reliable predictors of sleepiness. The use of demographic attributes, such as age, height, weight (Sedighi Maman et al., 2020; Wang et al., 2018); contextual information, e.g. sleep quality, circular rhythm, and working conditions (Fu et al., 2016); and work duration and years of work experience (Aryal et al., 2017) combined with physiological and motion parameters, has been shown to improve the performance of fatigue models. Aryal et al., 2017 found that the use of personal information improved the accuracy of their model by 15%.



Source: Reference analysis, 2023

Fig.7: Linking the Truth, Science, and Research of Driver Fatigue in Monotonous Straight Road Geometrics

Description:

I. Mental fatigue (low workload) as a result of straight and monotonous road geometry There is no supporting research with measured geometric measurements.

II. The occurrence of mental fatigue (low workload), causing heart rate variability to increase according to study #6 measuring CFQ via ECG (Heart Rate variability) ACC = 75.5%, AUC = 0.74. And study #8 measured HRV metrics (ECG) and ACC = 94.3%.

Huang et al. (#6) using single channel ECG patches to acquire physical and mental fatigue data was found to significantly affect HR intervals, HRV, RR as well as spectral power and dynamics respectively. The results suggest that the recurrence pattern, which is known to capture the non-linear dynamics of HRV, is a reliable predictor of sleepiness.

III. *The occurrence of mental fatigue (low workload), leads to increased heart rate variability, the impact of low geometric variation. This is consistent with studies #61, 66, #67, #69, #70, #74. Showed that HRV was lower after the 2nd driving session (after 100 minutes) than during the same period during the monitoring session (from p=0.01 to p=0.006).*

IV. *The occurrence of increased heart rate, due to monotonous roads, and low geometric variation. This condition is consistent with studies #6, #8*

V. *The maximum length of straight roads is regulated in the PUPR Guidelines SE.No.20/SE/Db/2021 related to visual needs and the impact of speed on visual perception. Bend Radius 3000 to 30,000 meters, deflection angle 30˚, Maximum Length not more than 2.5 minutes according to design speed (VR)*

VI. *The occurrence of fatigue (light mental load) due to monotonous and long roads, and low variation in road geometrics. This condition is consistent with studies #62, #74. Drivers reported drowsiness starting around 20 minutes into the drive on straight, monotonous roads.*

VII. *The occurrence of fatigue (low mental load), leading to heart rate variability, as a result of the monotonous road. In accordance with studies #61, #73. Where heart rate variability (SDNN) increased from 0.07 to 0.16 when microsleep occurred due to straight, low variability walking. Low alertness from 0.12 to 0.39.*

4. Discussion of the Causes of Driver Fatigue Due to Straight Road Geometric Monotony

Overall, fatigue studies are mostly short-term studies, conducted in the laboratory. Moreover, in the real world the acquisition of fatigue reference values is further compounded, when using scales and questionnaires. Obtaining reference values in 2-hour intervals or three times a day, as applied in studies [19a], [19b], may not be appropriate when aiming to develop fatigue monitoring systems for safety-related applications, e.g. at the same time, there is a lack of valid reference measurements that can provide continuous and unobtrusive estimates of a person's fatigue level.

Simulation tasks have been commonly used, particularly in research investigating driver drowsiness. Although they resemble the real situation, simulated environments cannot reproduce its complexity and dynamism [20]. In addition, drivers' effort and perception of risk are reduced in simulated environments [21]. The effectiveness of the task used to induce fatigue is key to fatigue research in the laboratory and to some extent depends on the participants' engagement in the task.

Reference measures of fatigue also differ between studies. Some researchers discount the use of fatigue measures by relying on the assumption that participants will rest before performing a fatigue-inducing task and become fatigued afterwards. [22] questioned this assumption with respect to sleepiness. As noted by [23], sleepiness does not develop linearly in time, it can be expressed by general fatigue. Indeed, there is an effect of time on task on fatigue [24]. However, for reasons unrelated to the research protocol, drivers may feel tired before performing a task that causes fatigue or they may not become tired if it is performed on a high-performing individual or if the selected task is not effective in causing fatigue.

5. Conclusion

This review found that a generalization of the widely published research on fatigue analysis in monotonous road geometrics has not been found. There has been no standardization in methods for the design of long, straight road geometrics and establishing fatigue limits in straight geometric designs. A concerted effort should be made to find consensus and establish adequate standards in this area of research.

Research in fatigue monitoring in monotonous road geometrics has focused on the performance of fatigue factor measurements through developed tools and models, but ignored the road geometric design as the underlying driver. More studies have focused on the effect of fatigue on parameters derived from physiological/movement signals measured non-invasively.

Further research is needed to develop measures that consider the temporal dynamics of fatigue. Long-term research is lacking, which suggests that geometric designs that can awaken or wake up drivers are of maximum value in the field of fatigue research. Deployable devices allow continuous and long-term monitoring in a non-intrusive and real time manner. The analysis of critical limits of driver fatigue in monotonous straight road geometrics and its implementation in road geometric design creates an opportunity to better understand fatigue and its impact on road safety. There is a need for empirical measurements in design decisions. The lack of literacy of geometry design improvements and even those that do not go deep into the geometry require further studies that are more measurable and in-depth.

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