

Driver Drowsiness and Fatigue in the Safe Operation of Vehicles - Definition of Terms and Concepts

RATIONALE

The terms “drowsiness” and “fatigue” are used interchangeably as drowsy driver and driver fatigue; however, they are defined very differently. There is not an agreed upon operational definition of fatigue, and, even today, it remains unclear. However, generally speaking, fatigue is usually defined as a state of reduced physical or mental alertness that impairs performance and is often the result of physical or mental exertion (Williamson et al., 1996); whereas drowsiness is the inclination to sleep resulting from lack of sleep, monotony and boredom, hunger, or other outside factors (Stutts et al., 1999). Drowsiness and fatigue are difficult to objectively measure; therefore, it is challenging to assess and consequently regulate how to avoid driving while fatigued. As fatigue or hypovigilance are difficult to assess via post-crash reconstruction, estimates of the frequency and outcomes of fatigued driving are likely conservative. According to a consensus statement published by a group of experts in fatigue and transportation, fatigue contributes to 15 to 20% of transportation crashes (Akerstedt et al., 2000). Moreover, drivers may be hesitant to disclose their level of drowsiness while driving or unaware of the fluctuations of their alertness. The severity of a crash may also leave a driver too incapacitated to report this information. Nevertheless, it is clear that fatigued drivers are more likely to be involved in crashes and are more likely to be involved in higher severity crashes as their reaction times are often delayed (National Academies of Science, Engineering, and Medicine, 2016). Thus, there is a need for approaches that measure drowsiness and fatigue as it relates to the safe operation of a vehicle. This document provides a set of concepts and definitions of terms that can be used to measure drowsiness and fatigue.

1. SCOPE

This SAE Information Report provides definitions and discussions of key terms concerning driver drowsiness and fatigue, and basic information on measuring drowsiness and fatigue. It also includes information and concepts for driver drowsiness as they relate to the safe operation of a vehicle. The key driver drowsiness and fatigue causal factors include the following: (1) sleep quality and quantity, (2) time of day, (3) time awake, (4) time on task (modulated by characteristics of the driving task), (5) task-related fatigue (variations of arousal levels related to task underload and overload), and (6) combinations of these factors. Medical conditions, medication, alcohol, or drugs exacerbate drowsiness; however, the discussion in this report is limited to fatigue concepts.

This report has two primary outputs: (1) definitions and discussions of key terms concerning driver drowsiness and fatigue, and (2) basic information on measuring drowsiness and fatigue and its effects on the safe operation of a vehicle. These include the physiological and cognitive effects of driver drowsiness and fatigue on driving safety. Examples of effect of driver drowsiness and fatigue on driving safety include those related to vehicle control, operator vigilance (sustained attention), reaction times (object and event detection and response), situational awareness, physiological indicators, subjective assessments, and combinations thereof. For definitions of driving performance measures, refer to SAE J2944. This report applies to all worldwide motor vehicle passenger cars and light trucks, as well as heavy trucks, buses, motorcycles, and mopeds. The intended users of the document are practitioners and researchers in the automotive industry, academia, and other organizations with interest in driver drowsiness and fatigue, driving and driver performance assessment, and road safety.

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2. REFERENCES

See [Appendix A](#).

3. DEFINITIONS AND KEY CONCEPTS

Additional concepts not included in this document are in [Appendix B](#).

3.1 ACTIVE TASK

Tasks that require constant engagement (Cummings et al., 2016).

3.2 ACUTE FATIGUE

Results from short-term sleep loss or from short periods of heavy physical or mental work. The effects of acute fatigue are of short duration and can usually be reversed after a period of rest (Mizuno et al., 2011).

3.3 BOREDOM

Mental state resulting from a low challenge level as compared to individual skill level and the lack of intrinsic motivation (Csikszentmihalyi, 2014). Boredom is often linked with other physical and cognitive states such as fatigue, vigilance, and motivation (Desmond and Hancock, 2001; Eastwood et al., 2012).

3.4 CHRONIC FATIGUE

Caused by prolonged accumulation of acute fatigue. Typically, reversible via one or more days of adequate sleep.

3.5 DROWSINESS

The inclination to sleep resulting from lack of sleep, boredom, hunger, or other outside factors (Stutts et al., 1999).

3.6 DRIVER DISTRACTION

Mismatch between the driver's current resource allocation and that demanded by activities critical for safe driving, rather than in terms of attentional failures of the driver (Engstrom et al., 2013).

3.7 FATIGUE

A state of reduced physical or mental alertness that impairs performance and is often the result of physical or mental exertion (Williamson et al., 1996).

3.8 INSUFFICIENT ATTENTIONAL EFFORT

The driver's allocation of resources to activities critical for safe driving does not match the demand of these activities due to an inability of the driver to mobilize sufficient attentional effort. This may be due to fatigue (Engstrom et al., 2013; Hockey et al., 2008; Williamson et al., 2009).

3.9 MENTAL FATIGUE

Represents a failure to complete mental tasks that require self-motivation and internal cues in the absence of demonstrable cognitive failure or motor weakness (Chaudhuri and Behan, 2000).

3.10 MICROSLEEP

Brief, unintentional episodes of lapses in attention that usually occur when a person is fatigued or drowsy. Episodes are often associated with blank stares, periods of prolonged eye closure, and head snapping. Microsleeps can last between a fraction of a second to several minutes and often the person is unaware an event has occurred. Microsleeps often occur when a person's eyes are open, though the person fails to detect and respond to stimuli and events. Driving simulator testing has shown that microsleeps are associated with poor driving performance (Boyle et al., 2010; Paul et al., 2005).

3.11 MENTAL EXERTION

A psychophysiological state caused by sustained and prolonged cognitive activity.

3.12 MONOTONY

An objective task-related characteristic that is associated with an environment that is unchanging or that change in a repetitive or predictable way (Davies et al., 1983; McBain, 1970). Exposure to monotony can lead to reduced arousal and alertness, which may blunt the ability to react, resulting in impaired performance (refer to Thiffault and Bergeron, 2003 for a review; Straussberger et al., 2004).

3.13 PASSIVE FATIGUE (HYPOVIGILANCE)

Task underload, monotony, and automated systems are reasons for attention loss and performance decrements (Korber et al., 2015). Passive fatigue can reduce attention capacity, impair driving performance, and increase reaction times (Young and Stanton, 2002; Matthews and Desmond, 2002; Saxby et al., 2013; Thiffault and Bergeron, 2003).

3.14 PASSIVE TASKS

Tasks that require more oversight and monitoring and often lead to boredom, resulting in fatigue and lapses in attention which can impact job performance (Cummings et al., 2016).

3.15 PHYSICAL EXERTION

A symptom that decreases the ability of muscles to perform over time. It can be associated with a state of exhaustion, often following strenuous activity or work (Cordeiro et al., 2017).

3.16 PHYSICAL FATIGUE

Results from repeated muscle actions, also known as peripheral fatigue (Mizuno et al., 2011).

3.17 REACTION TIME

The amount of time it takes to respond to a stimulus. The control of a vehicle is directly determined by a driver's ability to react during driving performance. Longer reaction time and the ability to control the vehicle may affect safety under fatigued conditions (Guo et al., 2016).

3.18 SLEEP DEBT

Cumulative effect of a person not having enough sleep. Sleep debt can result in physical and/or mental fatigue (American Sleep Association, n.d.).

3.19 SLEEP DEPRIVATION

Occurs when an individual does not get enough sleep. The amount of sleep an individual requires varies person to person. On average, adults need 7 to 8 hours of sleep each night, teens require 9 hours/night, and children need 9 or more hours/night (depending on age; American Academy of Sleep Medicine, n.d.).

3.20 SLEEP-RELATED FATIGUE

Affected by sleep loss, poor quality sleep, and insufficient rest (Fan and Smith, 2017).

3.21 SLEEP-RELATED IMPAIRMENT

Allocation of resources to activities critical for safe driving does not match the demand of these activities due to factors related to sleep regulation (Engstrom et al., 2013).

3.22 TASK-RELATED FATIGUE

Related to task workload, can be active (i.e., high workload) or passive (i.e., low workload) fatigue (see terms).

3.23 VIGILANCE

Also known as *sustained attention*, vigilance is defined as the ability to detect signals in a task environment that is usually characterized by monotony and that unfolds over time (Mackie, 1987; Lanzetta et al., 1987; Warm, 1984). Operator vigilance is central to safe operations in all modes of transportation.

3.24 VISUAL FATIGUE

Occurs when eye muscles tighten during visually intense tasks. The tightening of the eye muscles can cause the eyes to become irritated and uncomfortable. Tedious visual tasks that require workers to focus with their eyes for extended, uninterrupted periods can cause visual fatigue (Sullivan, 2008).

3.25 WORKLOAD

In the context of occupational fatigue, high or low workload can contribute to the development of fatigue that can reduce performance. Workload involves three related components, including input load, operator effort, and performance (Jahns, 1973).

4. FATIGUE, DROWSINESS, AND DISTRACTION

Distraction, fatigue, and drowsiness all contribute to driver inattention. It is difficult to differentiate between these concepts given the conceptual complexity, measurement difficulties, and overlap in performance impairment. However, it is important to make this differentiation, as these are different problems that require distinct interventions.

Fatigue- and drowsiness-related inattention (i.e., hypovigilance) are associated with sustained attention caused by lowered alertness; distraction-based inattention is associated with divided attention and originates from a dual task paradigm (Thiffault, 2011). Per Thiffault (2011), "...hypovigilance (i.e., lowering of the ability to monitor the environment and to continuously adapt to the changes in the driving task) is the most robust effect of fatigue and has a significant detrimental impact on driving performance. Hypovigilance-related driving errors, by definition, are therefore synonymous to inattention errors." (p.40). Furthermore, to mitigate hypovigilance and drowsiness, drivers naturally tend to engage in secondary tasks while driving in order to generate stimulation, creating opportunities for distraction-related inattention errors. Overall, these driver inattention concepts are likely to result in comparable deteriorations in driving performance; however, they call for different interventions. Refer to SAE J3151 for driver distraction metrics and definitions.

5. CONCEPTS FOR RELATING METRICS OF DRIVER DROWSINESS AND FATIGUE TO DRIVING PERFORMANCE

5.1 Causal Factors

5.1.1 Sleep Quality and Quantity

Although there are individual differences with respect to sleep needs, most people require 7 to 9 hours of nightly sleep (National Sleep Foundation, n.d.). Prolonged periods of wakefulness can lead to performance decrements and impairments in judgment (Lim and Dinges, 2010; Williamson and Feyer, 2000). These deficits increase crash risk. However, there is no "fatigue" or "drowsy" test (Governors Highway Safety Association, n.d.). States have begun to understand this is a public safety issue by proposing drowsy driving laws. However, only two states (New Jersey and Arkansas) have passed laws addressing drowsy driving (both outlaw driving without sleep for 24 consecutive hours). Commercial motor vehicle drivers are regulated by the Federal Motor Carrier Safety Administration (FMCSA, 2017), which limits the amount of working and driving time.

5.1.2 Time of Day (Circadian Rhythm)

Regardless of sleep quantity and/or quality, the body has a natural tendency to feel drowsy from 2:00 to 4:00 a.m. and 1:00 to 3:00 p.m., even with adequate sleep quantity and quality. This is termed "sleep pressure." This is the body's circadian rhythm, with the effect being the strongest from 2:00 to 4:00 a.m. (National Sleep Foundation, 2018).

5.1.3 Time on Task

The amount of time performing a task can lead to fatigue, and time dependent, monotonous tasks that require attention, such as driving, result in decrements in performance. Thus, the longer the amount of time spent driving, the greater the likelihood of driver fatigue and associated performance decrements that may increase crash risk. However, breaks from driving were found to counteract this trend (Jovanis et al., 2011). Breaks after driving 6 to 8 consecutive hours are likely to reduce driver fatigue (Blanco et al., 2011; Jovanis et al., 2011).

5.1.4 Time Awake

A lot of work has been done on the effect of time awake or time-on-task on crash rate. It is generally understood that time awake, or hours of continuous wakefulness, is a more significant issue than time-on-task per se. In general, scientific data show that being awake for more than 16 hours is associated with significant performance decrements (Rosekind, 2005).

5.1.5 Vigilance/Task-Related Fatigue (Task Underload and Overload)

Sustained attention (vigilance) is central to safe driving. The vigilance decrement (hypovigilance) is associated with performance impairment, which can be measured using monotonous vigilance tasks. Driving in monotonous conditions is comparable to a vigilance task and the effects of hypovigilance on driving include poor task control, decrease in environment monitoring, increase in reaction time, decrease in tracking efficiency, increase in speed variability, reduction in defensive driving strategies, etc.

Hypovigilance is associated with mild fluctuations of arousal that can be phasic, transitory, and task related. Tasks that are low-demanding, with few or repetitive non-relevant stimulation, tend to produce phasic decreases in alertness and generate hypovigilance. On the opposite end of the spectrum, overstimulating tasks can also impact operator performance, but by means of a mechanism comparable to a stress response. Optimal performance is achieved with intermediate levels of stimulation and task workload, as defined in the classical inverted U-shaped function between arousal and performance (Yerkes and Dodson, 1908). Llaneras et al., 2018, illustrated this relationship by showing that physical and cognitive workload-based countermeasures can effectively re-engage drowsy drivers. Steering demands and gaming interactions, and, less effectively, listening to music, restored drivers to an alert state, at least from a vigilance perspective.

5.1.6 Combinations of Factors

The endogenous (time-of-day, time-awake, sleep deficit) and exogenous (task-related) causal factors that lead to driver drowsiness and fatigue are not mutually exclusive, but are rather involved in a systemic relationship that generates, at any given point in time, a specific level of alertness and associated level of vigilance (Thiffault and Bergeron, 2003). Considering vigilance as the main output variable, the endogenous state of the operator represents the base level and strongest influence; however, it can always be modified by what the person is doing and under what conditions. A monotonous driving situation might not bring an alert driver into drowsiness and sleep, but it can generate hypovigilance and present a significant risk for safety. In the case of an operator that is already fatigued, from an endogenous perspective, monotony can act as a fatigue facilitator and exacerbate the decrease of alertness, increasing the potential for microsleep episodes and falling asleep per se (Kecklund and Åkerstedt, 2004). Figure 1 illustrates how endogenous and exogenous factors impact driver alertness and, subsequently, driver vigilance and performance.

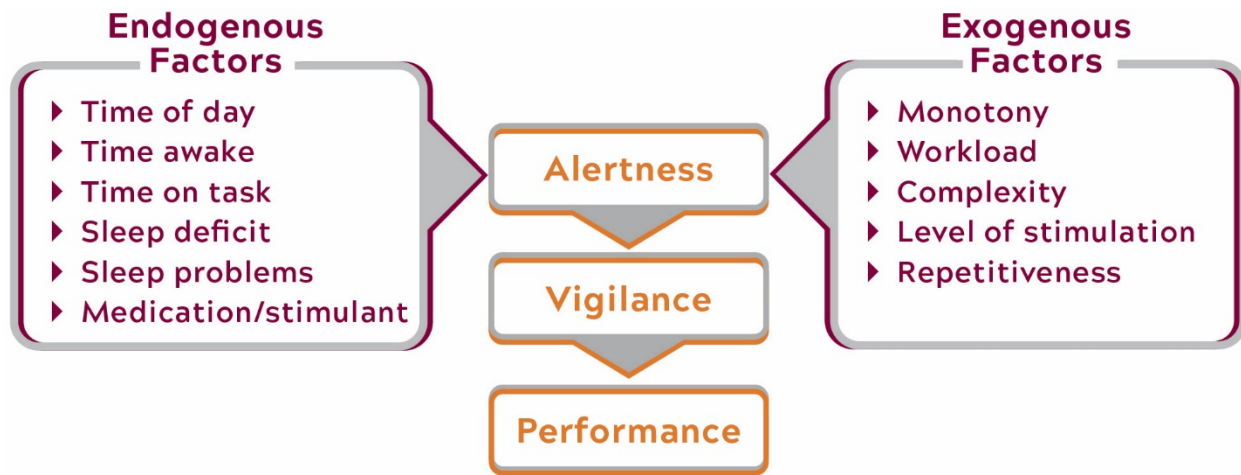


Figure 1 - Endogenous and exogenous factors that impact driver alertness
(adapted from Thiffault, 2011)

5.1.7 Other Factors

Many other factors may induce driver drowsiness, such as over-the-counter medications (e.g., antihistamines), prescription medications (e.g., benzodiazepines), alcohol, illicit drugs, air quality, vibration, food, exercise, and automated driving systems/automated driver assistance systems. Certain medical conditions may also interfere with sleep (e.g., obstructive sleep apnea), which induces driver drowsiness, or directly induce driver drowsiness (e.g., narcolepsy). These factors were not considered in the [5.2](#) driver drowsiness metrics.

5.2 Drowsiness and Fatigue Metrics

5.2.1 Subjective Assessments

Subjective ratings of drowsiness and fatigue are usually underestimated by people (Banks et al., 2010; Van Dongen et al., 2003). Moreover, self-assessment of drowsiness and fatigue are increasingly impaired as the level of drowsiness and fatigue increases; however, self-confidence in the ability to self-assess fatigue remains constant (Banks et al., 2010; Van Dongen et al., 2003). Drivers' subjective ratings of fatigue and drowsiness can be made while driving via a verbal response or inputting a response on a touchscreen.

5.2.1.1 Karolinska Sleepiness Scale (KSS)

Fatigue impairs operator's ability to assess their own level of alertness. As a result, people tend to underestimate fatigue and drowsiness (Banks et al., 2010; Van Dongen et al., 2003). Furthermore, this impairment increases as fatigue and drowsiness increase, but self-confidence in the ability to self-assess fatigue remains constant (Banks et al., 2010; Van Dongen et al., 2003). Drivers' subjective ratings of fatigue and drowsiness can be made while driving via a verbal response or inputting a response on a touchscreen.