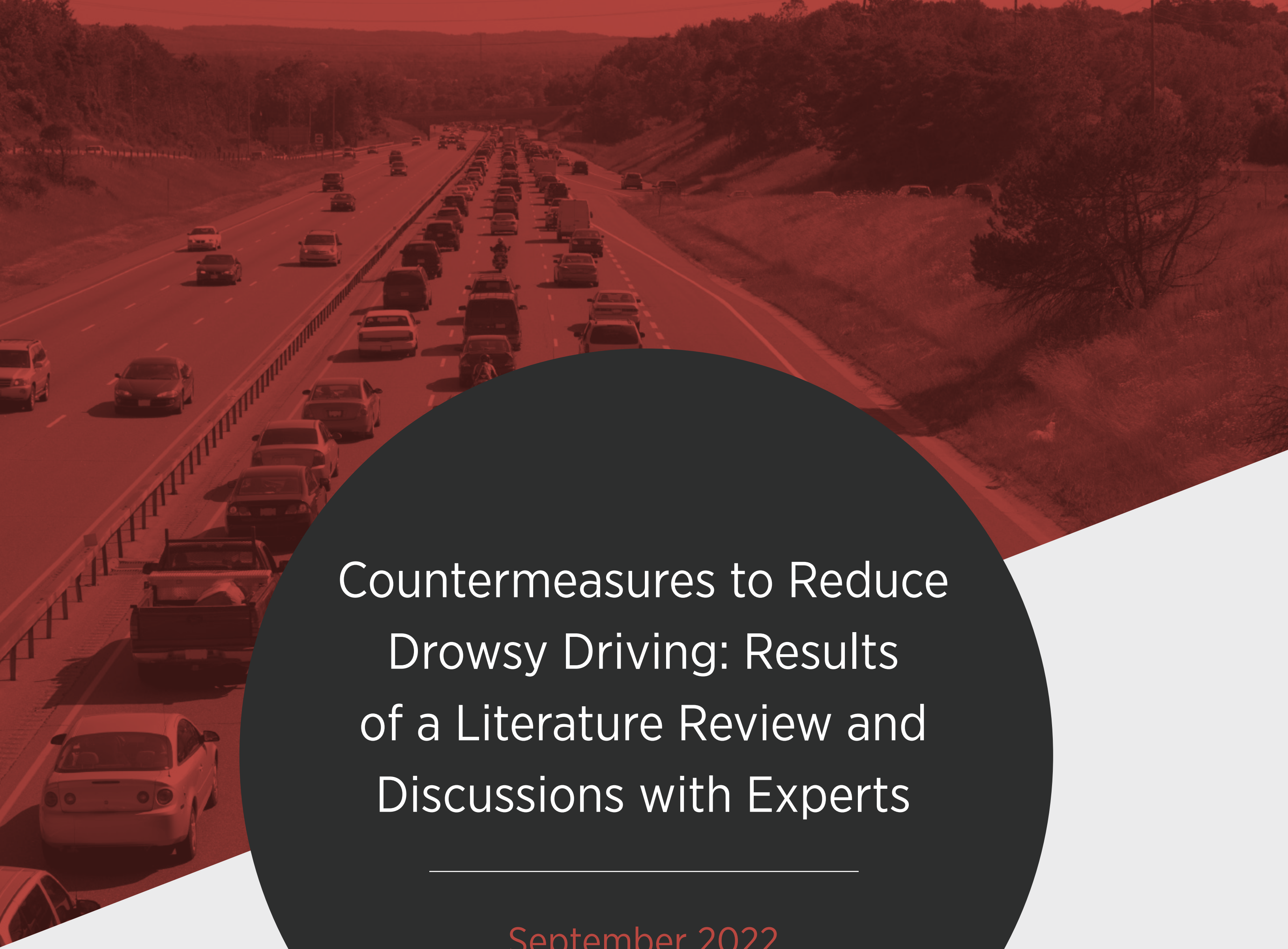

Countermeasures to Reduce Drowsy Driving: Results of a Literature Review and Discussions with Experts

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Title

Countermeasures to Reduce Drowsy Driving: Results of a Literature Review and Discussions with Experts

(September 2022)

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Foreword

In today's fast-paced society, many of us could be tempted to drive while drowsy. Indeed, our annual *Traffic Safety Culture Index* surveys find that although drivers acknowledge that drowsy driving is dangerous, it unfortunately is also all too common. Driving while drowsy presents substantial risks to our own safety as well as the safety of other people with whom we share the road. The AAA Foundation for Traffic Safety's previous research has found that drowsy driving may be a factor in as many as one in five crashes that result in a death—far higher than corresponding government statistics. In light of this, the AAA Foundation for Traffic Safety strives to find ways to reduce the prevalence and the impact of drowsy driving.

This report describes the results of the current state of knowledge regarding countermeasures intended to combat drowsy driving. Information presented in this document offers insights into countermeasures already known to work, popular countermeasures known to be ineffective, as well as topics still in need of additional research. This report should be of interest to researchers, practitioners such as healthcare providers and risk managers, as well as other health and safety stakeholders.

C. Y. David Yang, Ph.D.

Executive Director
AAA Foundation for Traffic Safety

About the Sponsor

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Founded in 1947, the AAA Foundation for Traffic Safety in Washington, D.C., is a nonprofit, publicly supported charitable research and educational organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, individual members, AAA-affiliated insurance companies, and other organizations or sources.

Table of Contents

Executive Summary vi
Overview.. vi

Introduction 1

Methods 2
Literature Review and Environmental Scan.. 2
Technical Expert Panel.. 7
Key Informant Interviews 7

Results 8
Behavioral Countermeasures.. 8
Technological Countermeasures 15
Infrastructure Countermeasures 20
Educational Countermeasures.. 23
Medical Countermeasures.. 26
Policy Countermeasures 29

Conclusions 35

Acknowledgements 41

References 42

Appendix A: Drowsy Driving Countermeasure Summary Table..................... **online**

List of Abbreviations and Acronyms

AAP	American Academy of Pediatrics
ABE	Acoustic brain entrainment
ART-90	Act and React Test System
CDC	Centers for Disease Control and Prevention
CPAP	Continuous positive airway pressure
EEG	Electroencephalogram activities
EMS	Emergency medical services
FMCSA	Federal Motor Carrier Safety Administration
GDL	Graduated driver licensing laws
GHSA	Governors Highway Safety Association
HLDI	Highway Loss Data Institute
HOS	Hours of service regulations
HRV	Heart rate variability
IIHS	Insurance Institute for Highway Safety
KSS	Karolinska Sleepiness Scale
NADS	National Advanced Driving Simulator
NASEM	National Academies of Sciences, Engineering, and Medicine
NHTSA	National Highway Traffic Safety Administration
OSPAT	Occupational Safety Performance Assessment Test
PERCLOS	Percentage of eye closures
TOPS	Truck Operator Proficiency System
TRID	Transport Research International Documentation
V2I	Vehicle-to-infrastructure

Executive Summary

Overview

Drowsy driving is a serious public health issue in the United States. Drowsy driving occurs when an individual operates a motor vehicle while too fatigued or drowsy to remain alert. According to the National Highway Traffic Safety Administration (NHTSA), driving while drowsy contributes to motor vehicle crashes, injuries, and deaths (NHTSA, 2011). Whereas official statistics likely underestimate the scope of the problem, the AAA Foundation for Traffic Safety estimates that roughly 6 to 11 percent of all police-reported crashes and 16 to 20 percent of fatal crashes likely involved driver drowsiness (Owens, 2018; Tefft, 2012, 2014). Risk factors for drowsy driving include inadequate sleep or rest, untreated sleep disorders, using certain prescription medications with side effects, drinking alcohol, and working shift jobs, among others (Centers for Disease Control and Prevention [CDC], 2017).

Various strategies—or countermeasures—have been developed, tested, and implemented to reduce drowsy driving. Further research is needed to understand these countermeasures, their effectiveness, and their implementation. The purpose of this report is to describe the current landscape of drowsy driving countermeasures. This report documents drowsy driving countermeasures; describes the effectiveness and practical application, including their limitations; and explores which countermeasures can be implemented more widely.

Methods

The research team used three research methods: a literature review and environmental scan, a technical expert panel, and key informant interviews. Through these methods, the research team identified different types of countermeasures and classified them into six types: (1) behavioral, (2) technological, (3) infrastructure, (4) educational, (5) medical, and (6) policy.

The literature review used the University of Chicago Library online system and the Transport Research International Documentation integrated database. The environmental scan used Google, Google Scholar, and organizational websites. The review identified peer-reviewed and grey literature focused on drowsy driving countermeasures and evaluations of their effectiveness. The researchers also reviewed references suggested by experts who participated in the technical expert panel and key informant interviews. Ultimately, the review included 152 articles in the literature review and environmental scan, which described a total of 207 drowsy driving countermeasures.

The technical expert panel and key informant interviews leveraged the expertise of 16 leading researchers and practitioners in traffic safety, sleep science, behavioral health, and policy. The expert panel was a two-day meeting held virtually with seven experts. Following the meeting, the researchers conducted key informant interviews virtually with nine additional experts who reviewed the countermeasures identified in the literature review and environmental scan. The experts also discussed implementation of these measures, including the evaluability and practicality of existing countermeasures, as well as gaps to be addressed in the future to reduce drowsy driving.

Key Findings

This report describes key findings from the literature and reflections from the experts. This study revealed that there are many different types of countermeasures to reduce drowsy driving. Findings for each type of countermeasure are summarized below.

Behavioral Countermeasures

Behavioral countermeasures refer to activities a driver may engage in before, during, or between drives to mitigate drowsiness; they include obtaining sufficient sleep, napping, and consuming caffeine. Experts note that getting sufficient sleep is the most effective countermeasure for reducing drowsy driving. While not a substitute for sufficient sleep, caffeine is an effective countermeasure for transient fatigue and provides a short-term benefit, though the optimal dose may differ from person to person. Evidence also supports the effectiveness of consuming caffeine prior to a short nap to increase driver alertness. Research is needed to understand how long the potential benefits of behavioral countermeasures last; the benefits for specific populations (e.g., general population of drivers, people who work shifts); and the benefits of combining behavioral countermeasure with other countermeasures.

Technology Countermeasures

Researchers continue developing innovative technologies to reduce drowsy driving or its consequences, including in-vehicle technology, driver monitoring, and advanced vehicle safety systems. Some technologies are designed to detect drowsiness at the point at which it impacts driving performance and therefore may prevent drowsy driving crashes; others can help to mitigate the consequences of drowsiness, for example by preventing the vehicle from departing the road or automatically applying the brakes in a crash-imminent situation. Research is needed to determine the best method for alerting drivers who show signs of drowsiness and impelling them to take appropriate action (e.g., stop driving and rest). Most research on technological countermeasures to detect drowsiness has been simulator-based. Real-world validation is necessary but can be difficult to implement for safety and feasibility reasons. Several real-world studies of data from crashes and insurance claims have shown clear safety benefits associated with certain vehicle-based crash avoidance technologies.

Infrastructure Countermeasures

Infrastructure countermeasures are modifications to the physical roadway environment to reduce the likelihood or severity of drowsy driving crashes. Infrastructure countermeasures can prevent drowsy driving crashes or mitigate the severity of crashes, but they are not specifically designed to keep drivers alert or to reverse drowsiness. Most research has focused on rumble strips, road markings, and road signs. Shoulder and centerline rumble strips are effective in reducing crash rates, though more research is needed on their effectiveness with respect to drowsy driving crashes. Additional research is also needed to evaluate the effects of providing rest areas in preventing drowsy driving crashes.

Educational Countermeasures

Educational countermeasures, including training programs, have been implemented to reduce drowsy driving. Educational countermeasures focus on increasing the understanding of the risks and signs of drowsiness to change behavior and promote better decision-making. Additionally, education on sufficient sleep can make individuals aware of the consequences of sleep deprivation and how it interferes with people's cognitive ability. Populations with an increased risk of drowsy driving crashes who can benefit from educational countermeasures include teen drivers and their parents, health care professionals, shift workers, and people with untreated sleep disorders, among others. Educational countermeasures are necessary but generally insufficient and must be used in conjunction with other countermeasures (e.g., technology, medical, policy).

Medical Countermeasures

Medical countermeasures include the treatment and management of sleep disorders that can cause drowsiness and affect driving. Drivers with sleep disorders, including insomnia, obstructive sleep apnea, and narcolepsy, have an increased risk of being in motor vehicle crashes. There are treatments for sleep disorders, though there are barriers to screening, referral, and treatment for the general population and for commercial vehicle drivers, specifically. More research is needed on the effectiveness of medical countermeasures, such as these treatments, on drowsy driving specifically. The literature suggests that health care professionals should incorporate sleep health into routine care and educate patients on improving their sleep, seeking treatment for sleep disorders, and preventing drowsy driving.

Policy Countermeasures

Drowsy driving countermeasures include both state legislation and policies and organizational/workplace policies. To date, two states—New Jersey and Arkansas—have laws that expressly address drowsy drivers who have injured or killed someone in a crash. All 50 states and the District of Columbia have Graduated Driver Licensing laws, which effectively reduce crashes among newly licensed young drivers, likely including those caused by drowsy driving. Employers commonly implement fatigue risk management systems or plans, though further research is needed to understand their effectiveness in preventing or mitigating drowsy driving or drowsy driving–related crashes. Accurate and reliable drowsy driving data, including data on drowsy driving crashes, are critical for creating and enforcing policy countermeasures and making a case for investing resources to address drowsy driving.

Conclusions

The results of this study highlight the complexity of reducing drowsy driving and suggest six conclusions:

1. Obtaining sufficient sleep, napping, and consuming caffeine reduce the risk of drowsy driving.
2. Advanced driver assistance systems are effective in preventing crashes in general, though more research is needed on their effectiveness in reducing drowsy driving–related crashes specifically.
3. Rumble strips are effective in preventing crashes, though more research is needed on their effectiveness in reducing drowsy driving–related crashes specifically.
4. Education is important for at-risk populations, but insufficient to reduce drowsy driving by itself, and must be combined with other countermeasures.
5. Treatments are available for sleep disorders, though more research is needed on the effects of treatments on drowsy driving.
6. Policy countermeasures require further research to understand their effectiveness in preventing or mitigating drowsy driving.

The experts identified three key cross-cutting areas for future research and action, which were supported by the literature:

1. Testing drowsy driving countermeasures in naturalistic settings or with real-world data to assess effectiveness is needed.
2. Reliable and informative driver drowsiness data is needed to understand and address drowsy driving.
3. Addressing drowsiness-related stigma in the workplace is needed.

Introduction

Drowsy driving is a serious public health issue in the United States. Drowsy driving occurs when an individual operates a motor vehicle while too drowsy to remain alert. The effects of drowsiness on driving performance are not limited to risk of falling asleep while driving; drowsiness can cause cognitive impairment, which slows reaction time and reduces vigilance (Anstey et al., 2005; Jackson & Van Dongen, 2011). In addition to risking one's own life, driving drowsy also poses a threat to others on the road. According to the National Highway Traffic Safety Administration (NHTSA), over 100,000 crashes and 1,500 deaths occur each year as a result of drowsy driving in the United States, based on contributory factors coded by police officers on crash reports (NHTSA, n.d.). However, it is generally accepted that these statistics underestimate the scope of the problem. Using data from multiple sources including in-depth crash investigations (Tefft, 2012, 2014) as well a large federally funded study of vehicles equipped with in-vehicle cameras (Owens et al., 2018), the AAA Foundation for Traffic Safety estimates that as many as 6 to 11 percent of all police-reported crashes and 16 to 21 percent of fatal crashes likely involved driver drowsiness.

Risk factors for drowsy driving include inadequate sleep or rest, untreated sleep disorders, using certain prescription medications with side effects, drinking alcohol, and working shift jobs, among others (CDC, 2017). NHTSA and the National Center for Sleep Disorders Research identified three populations that are over-involved in drowsy driving crashes: teenagers and young adults in their 20s, people who work irregular hours or shifts, and people with untreated sleep apnea or narcolepsy (Strohl et al., 1998). Reliable and informative data is lacking to understand the prevalence of drowsy driving crashes among these groups or the share of total drowsy driving crashes for which they are responsible.

Researchers have tested many different countermeasures to prevent drowsy driving and its consequences (Gaspar et al., 2017; Grace et al., 1998; Zandi et al., 2019). These include behavioral, technological, infrastructure, education, medical, and policy countermeasures. Behavioral countermeasures are activities the driver engages in before, during, or between drives to prevent or mitigate drowsiness. Activities include obtaining sufficient sleep before a drive to prevent drowsiness, or consuming caffeine before or during a drive to counteract drowsiness when it occurs (Goodwin et al., 2013). Many behavioral countermeasures to prevent drowsy driving have been tested for effectiveness in laboratory and experimental settings (Lenné & Jacobs, 2016).

In addition to behavioral countermeasures, in-vehicle technology, such as driver monitoring systems, vehicle safety systems, and other technologies, can detect driver drowsiness or the associated decrements in driving performance and potentially mitigate it or its effects (Sparrow et al., 2019). The effectiveness of these technologies depends on their accuracy for detecting and countering task-related drowsiness experienced by the driver (May & Baldwin, 2009).

Infrastructure changes or modifications to the physical roadway environment, such as rumble strips, can reduce the likelihood and severity of drowsy driving–related crashes (Rahman & Kang, 2020). Additionally, road safety campaigns—educational efforts to increase knowledge—can increase understanding and awareness of drowsy driving and its consequences. Traffic safety organizations and government agencies have worked to increase public education about drowsy driving through roadside signage and campaigns. Communication campaigns that focus on at-risk driver subpopulations and behavioral factors may help reduce drowsy driving (Beck et al., 2018).

Medical countermeasures are used to treat sleep disorders that impact driving ability, including obstructive sleep apnea, narcolepsy, and insomnia. Lastly, policy initiatives, such as fatigue risk management systems or Graduated Driver Licensing programs may reduce drowsy driving among their target populations.

The purpose of this report is to describe the current landscape of drowsy driving countermeasures. The research described in this report aimed to document drowsy driving countermeasures and their effectiveness; describe the practical application of drowsy driving countermeasures, including their limitations; and explore which countermeasures can be implemented more widely.

Methods

Three key research questions guided the study. First, what types of countermeasures exist to reduce drowsy driving? Second, what are the limitations of the drowsy driving countermeasures identified? Third, which countermeasures may be considered for broader implementation?

The study methods comprised (1) a literature review and environmental scan to identify drowsy driving countermeasures, and (2) a virtual technical expert panel and key informant interviews with researchers and practitioners in traffic safety, sleep science, behavioral health, and policy to assess the limitations of the countermeasures and implementation considerations. The following sections describe the methods for the literature review and environmental scan, technical expert panel, and key informant interviews.

Literature Review and Environmental Scan

NORC conducted a literature review to identify peer-reviewed articles on drowsy driving countermeasures published in English in years 2010–2020. NORC also conducted an environmental scan to identify grey literature focused on drowsy driving countermeasures.

Data Sources

The literature review used two primary data sources: the University of Chicago online library system and the Transport Research International Documentation (TRID). The TRID integrated database combines the records from the Transportation Research Board's Transportation Research Information Services Database and the Organization for Economic Co-operation and Development's Joint Transport Research Centre's International Transport Research Documentation Database. The data sources for the environmental scan were Google, Google Scholar, and organizational websites to identify projects, white papers, toolkits, and unpublished papers focused on drowsy driving countermeasures.

Search Strategy

The search strings aligned with the research questions and were drawn from the search terms in Figure 1.

Drowsy Driving	Evaluation
Drowsy driving	Evidence
Fatigued driving	Effective
Driving while fatigued	Promising
Sleep deprived	Evaluation
Fall/fell asleep	Measurement
Countermeasures	Behavior change
Behavioral countermeasures	Prevention
Medical countermeasures	Intervention

About the Search Terms

Two categories of search terms were used to identify articles on drowsy driving countermeasures and evaluations of these countermeasures.

Figure 1. Search Terms.

To facilitate the search and identify as many countermeasures as possible, the research team used different combinations of the search terms and applied Boolean operators (i.e., "and, or"). The researchers assessed the initial results of the searches and determined whether to further refine the search strategy and terms. A similar approach was used for the environmental scan. Resources identified during the environmental scan referenced multiple countermeasures and studies on countermeasures. For these resources, a snowball method was used to identify evaluations that described the countermeasures.

Eligibility Criteria and Screening Process

Articles were selected in two rounds. In the first round, three researchers screened each article title and abstract to determine inclusion and ensure articles met the following criteria:

- Published between 2010 and 2020
- English language
- Focused on different transportation modes
- Related to drowsy driving

In the second round, one researcher reviewed the full text of each article to assess the article's relevance to drowsy driving countermeasures.

When conducting the environmental scan, studies published before 2010 that were listed as references in key papers were also included. To answer the research questions of interest, the research team reviewed each paper to ensure that it focused on countermeasures for drowsy driving, documented evidence of countermeasure effectiveness, and described outcome measures. Papers that were not specific to these topics were excluded. All discrepancies were resolved by consensus. The researchers recorded the number of articles that resulted from each search and the number of articles excluded during the review process.

The initial searches yielded 376 articles deemed potentially relevant based on the screening by title and abstract. After reviewing the full text of each article, the number of relevant articles was reduced to 106. Two hundred and seventy articles were excluded because they were not about drowsy driving countermeasures or did not document evidence of the effectiveness of countermeasures. The 106 articles included in this study evaluated a total of 239 countermeasures. Experts provided feedback on the countermeasures and suggested additional articles to review (described in the next section). After expert review, 84 articles were included in the literature review. Thirty-four articles were excluded as a result of expert feedback. This resulted in a total of 152 articles included in the final report, with a total of 207 countermeasures examined. (Note that these are not necessarily unique countermeasures, as countermeasures examined in multiple studies are counted multiple times.) Figure 2 depicts the procedure for article inclusion for the literature review and environmental scan, as well as the additional articles suggested by experts.

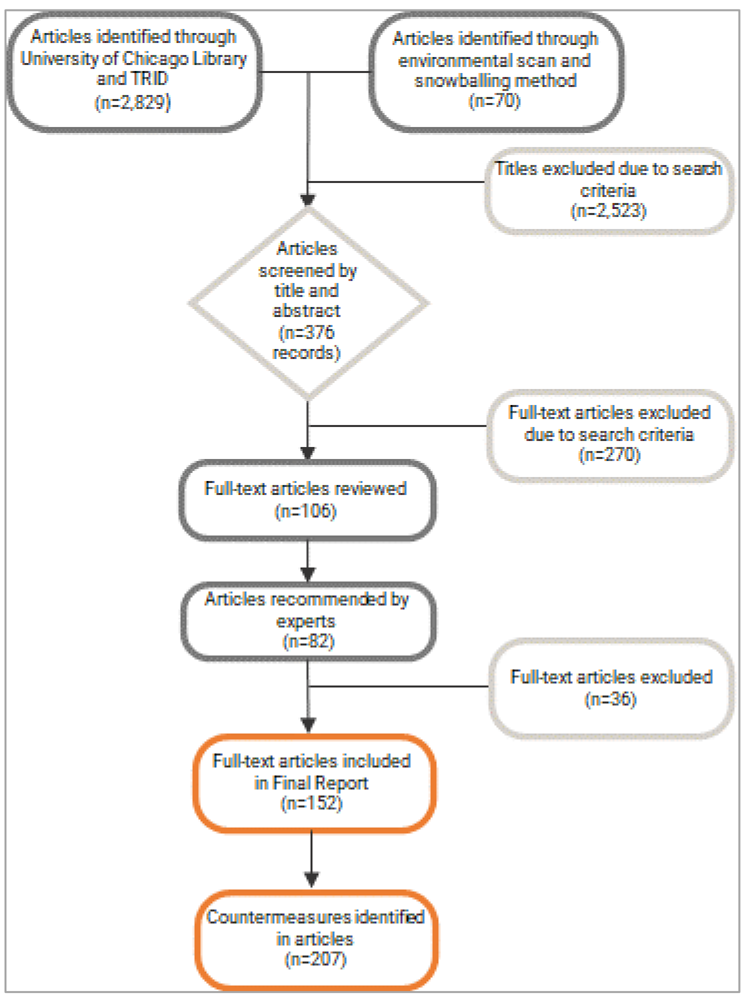


Figure 2. Procedure for Article Inclusion.

Data Extraction Process

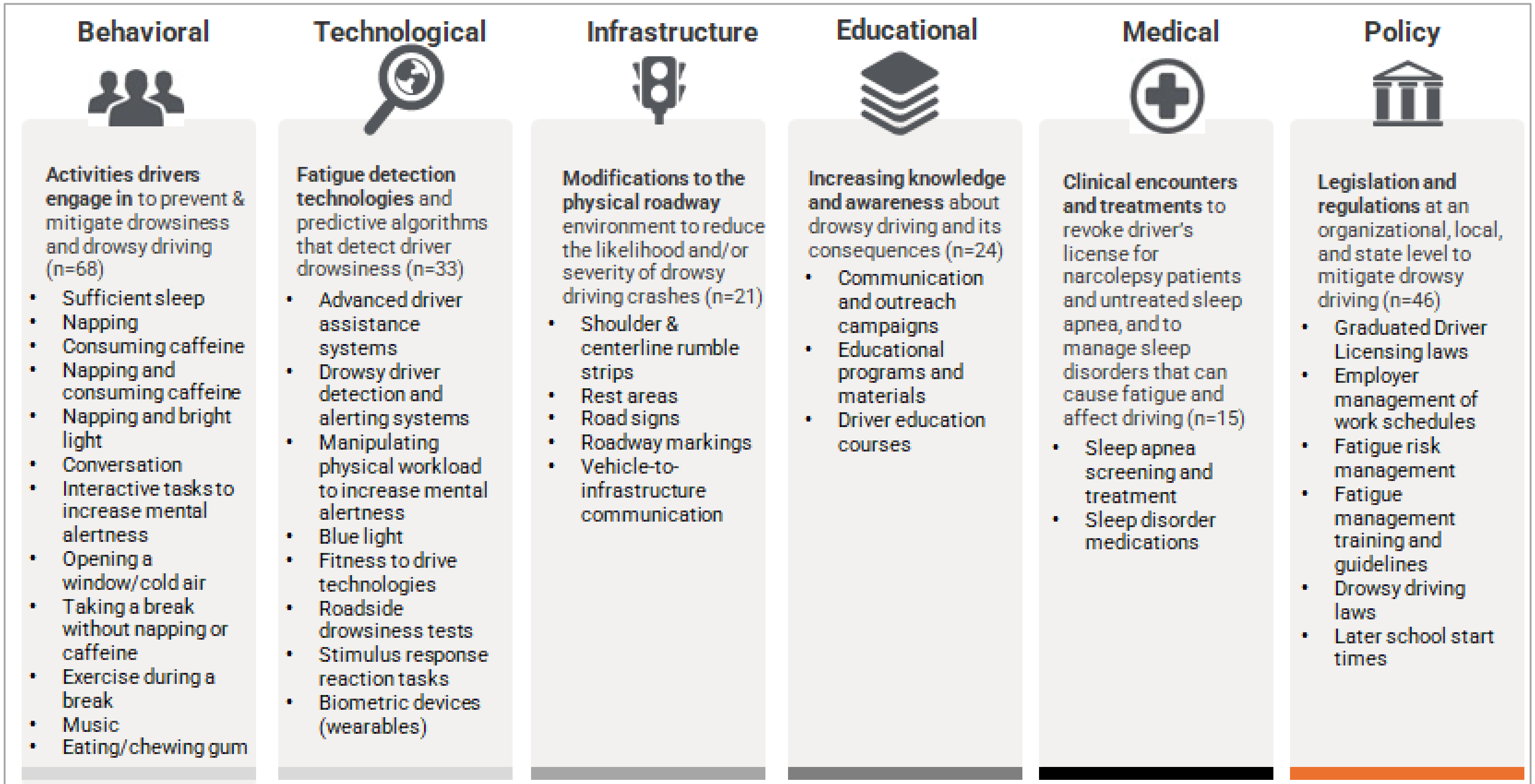
From the 152 articles identified in the literature review and environmental scan as well as the additional articles recommended by experts, NORC identified 207 drowsy driving countermeasures. Each countermeasure was described in a summary table that includes reference information, the title, countermeasure type, countermeasure, countermeasure description, study, design, outcome measures, and results (see Appendix A: Drowsy Driving Countermeasure Summary Table). In some cases, articles described more than one countermeasure. Importantly, the researchers did not rank or rate each countermeasure; project goals were limited to presenting the evidence of effectiveness and identifying areas for future research.

Analysis

During the data extraction process, the researchers assigned each of the 207 countermeasures to one of six countermeasure types: behavioral, technological, infrastructure, educational, medical, and policy. The types were derived using both an inductive and deductive approach based on the literature. Categories of countermeasures were identified within each countermeasure type.

Figure 3 describes the characteristics of each type of countermeasure identified in this study. All articles associated with each countermeasure were reviewed to identify findings.

Figure 3. Drowsy Driving Countermeasures Identified in the Current Study, Grouped by Category.



This figure describes the characteristics and total number of drowsy driving countermeasures identified during the literature review and environmental scan.

Technical Expert Panel

The purpose of the technical expert panel was to build upon findings from the literature. A panel of experts was convened to review the countermeasures, gather new information on countermeasures not yet evaluated or published, discuss the feasibility of implementing the countermeasures, and determine where future research is needed.

The research team collaborated with the AAA Foundation for Traffic Safety to identify expert panelists from the literature reviews and environmental scans. NORC invited nine experts, seven of whom participated in a two-day virtual meeting. Panelists were researchers and practitioners representing government, academia, and nonprofit research and advocacy organizations in the United States, with expertise in drowsy driving, traffic safety, and sleep science, among other topics. The meeting was convened April 26–27, 2021. Experts received an honorarium in acknowledgement of their participation. NORC provided panelists with the results of the literature review and environmental scan findings before the meeting (Appendix A).

During the first day of the meeting, NORC facilitated a discussion on behavioral, technological, and infrastructure countermeasures. The second day focused on educational, medical, and policy countermeasures. The meeting was recorded to ensure the accuracy of notes, and panelists consented to the recording. Panelists were informed that their feedback would be aggregated and de-identified.

Following the meeting, the research team synthesized feedback from the panelists and prepared a meeting summary. The meeting summary was shared with panelists to confirm key findings, and their feedback was incorporated into a final meeting summary. Panelists also shared recommendations for articles to include in the literature review, some of which fell outside of the original search parameters but were still deemed worthy of inclusion. The research team reviewed the articles and included them in the literature review, as appropriate.

Key Informant Interviews

The purpose of the key informant interviews was to gather input from researchers and practitioners with expertise in specific topic areas, such as educational and policy countermeasures. NORC, NADS, and the AAA Foundation for Traffic Safety identified experts from the literature review and environmental scan to participate in key informant interviews. These experts were drawn from governments, academia, as well as research and advocacy organizations in the U.S. and internationally. NORC also invited experts to participate in an interview if they were unable to participate in the technical expert panel meeting. In total, nine experts were interviewed between June 1 and July 22, 2021. Experts were provided with a list of the countermeasures shown in Figure 3 in advance of the interview.

During the interview, experts were asked four questions:

1. Which of these countermeasures do you have experience with through research or implementation?
2. Which of these countermeasures are most helpful for reducing drowsy driving?
3. Which countermeasures warrant further research?
4. Are there any other countermeasures that are not on our list and that we should explore?

Experts were informed that their feedback would be aggregated and de-identified and were asked for consent to record the interviews to ensure the accuracy of summary notes.

The research team synthesized findings from the interviews using content analysis to identify key themes. Experts shared recommendations for articles to include in the literature review, which the team reviewed and included, as appropriate.

Results

The following sections present findings for behavioral, technological, infrastructure, educational, medical, and policy countermeasures. For each countermeasure, key findings from the literature are described, followed by a summary of reflections from experts who participated in the technical expert panel and key informant interviews. The section on each countermeasure closes with implementation considerations and opportunities for future research.

Behavioral Countermeasures

Behavioral countermeasures refer to activities a driver may do before, during, or between drives to prevent or mitigate drowsiness. Examples include getting sufficient sleep, napping, and consuming caffeine, among others. Certain behavioral countermeasures used in tandem may help to reduce drowsy driving for different populations (e.g., novice drivers, young adults, older adults). Behavioral countermeasures are among the most widely studied countermeasures in experimental contexts.

Sufficient Sleep

Obtaining sufficient sleep is an important countermeasure for reducing the risk of drowsy driving (Strohl et al., 1998). According to guidelines from the National Sleep Foundation as well as the American Academy of Sleep Medicine & Sleep Research Society, healthy adults need between 7 and 9 hours of sleep per night (Hirshkowitz et al., 2015; Watson et al., 2015). Sleeping more than 9 hours per night on a regular basis may be appropriate for young adults, individuals recovering from sleep debt, and individuals with illnesses (Watson et al., 2015). Any sleep less than the recommended minimum of 7 hours for adults is considered insufficient, and sleep deficiency may impair driving performance (Matthews et al., 2012).

In a simulator study, sleep-deprived drivers had slower reaction times, were less attentive to their environment, and had impaired decision-making skills—all of which contributed to motor vehicle crashes (Jackson et al, 2013). A study of data from in-depth crash investigations found that drivers who slept for less than 7 hours in the 24 hours preceding the crash had increased risk of involvement in crashes attributable at least in part to their own actions or errors relative to those who slept for the expert-recommended 7 to 9 hours; drivers who slept for less than 4 hours had risks comparable to those of drivers with blood alcohol concentrations exceeding the legal limit in U.S. states (Tefft, 2018). One population at risk of drowsy driving and drowsy driving crashes is shift workers who work at night or have rotating shift schedules (Sallinen & Kecklund, 2010). Insufficient sleep puts shift workers at risk of drowsiness-related crashes and negatively affects health caused by misalignment between work schedules and the biological processes of "circadian wake drive" and "homeostatic sleep drive" (Caruso, 2014; Gurubhagavatula et al., 2021; Williamson et al., 2011). To address this risk, shift workers can engage in sleep banking—also referred to as sleep extending or sleep loading—before work shifts (Patterson et al., 2019). Sleep banking refers to extending sleep time before a period of anticipated sleep loss (e.g., a work shift, drive, military deployment) or to address accumulated sleep debt (Patterson et al., 2019). A systematic review focused on shift workers found that banking sleep prior to shift work improved patient safety and worker performance and reduced acute fatigue (Patterson et al., 2019).

<u>Reflections from Experts</u>

Experts reported that obtaining sufficient sleep is the number one countermeasure to reduce drowsy driving. Several experts noted the importance of sleep banking as a proactive behavioral countermeasure that drivers can engage in before driving. Experts also commented that guidelines for sufficient sleep, quality of sleep, and time of sleep (e.g., day versus night) vary by population (e.g., teens, adults).

Experts also discussed the acute effects of daylight-saving time on motor vehicle crashes. The general population sleeps less after the beginning of daylight-saving time, resulting in increased workplace injuries occurring following the Monday of daylight-saving time compared to other days (Barnes & Wagner, 2009). The change to daylight saving time has also been associated with an estimated 6% increase in rates of fatal crashes in the week following the time change with the strongest associations observed during the morning commute hours (Fritz et al., 2020).

Napping

Napping is commonly recommended as an effective countermeasure for the general public (Faraut et al., 2017). Commercial drivers and night shift workers are at higher risk for drowsy driving nighttime crashes, and therefore more likely to benefit from napping interventions during a work shift (Pylkkönen et al., 2015; Smith et al., 2020). Naps can occur before the drive (e.g., during a work shift) or during a break from driving.

Napping has been primarily researched in the context of overnight shift work and commercial drivers. Most intervention studies examined naps of 30 minutes to two hours. Oriyama et al. (2013) found that a 15-minute nap did not result in different levels of subjective drowsiness and fatigue compared with a no-nap group in a sample of night-shift nurses. Naps of 30 minutes can increase alertness and reduce drowsiness among shift workers (Geiger-Brown et al., 2016; Martin-Gill et al., 2018). Among night-shift nurses, naps result in better on-the-job performance, improved reaction time, fewer reports of drowsy driving, and improved performance on laboratory tasks reflective of driving (Halm, 2018; Smith-Coggins et al., 2006). Similarly, taking a 3-hour nap decreased subjective drowsiness and fatigue among long-haul truck drivers (Macchi et al., 2002).

Most simulator experimental and intervention studies of drowsy driving have focused on relatively short drives—1 hour or less—intended to mimic a drive home after work (Soares et al., 2020). The efficacy of napping for longer drives is unknown. Research is needed on the optimal duration of naps to reduce drowsy driving during trips of varying lengths. Further research is also needed on the association of nap length with sleep inertia (i.e., feeling of grogginess and reduced level of alertness upon waking) and whether short naps are beneficial when on duty (Hilditch et al., 2017).

<u>Reflections from Experts</u>

Experts discussed napping among shift workers and noted cultural differences prevalent among organizations and employers regarding on-duty napping. One expert explained the concept of shared responsibility in Australia, whereby both the employer and employee are responsible for the consequences of a drowsy driving incident (Zaslona et al., 2018). Shared responsibility can reduce the stigma associated with on-duty napping, and ultimately reduce drowsy driving. Experts also explained the need to change the culture among commercial drivers, so that they are more likely to pull over and rest when drowsy. Experts noted that increased use of road signage about the availability of rest areas could help to normalize the need for a break and nap.

Consuming Caffeine

Caffeine showed effectiveness in reducing drowsiness across several experimental studies. In controlled simulator studies, both caffeinated coffee and energy drinks with caffeine improved driving performance and reduced subjective sleepiness relative to a placebo control group (Bartrim et al., 2020; Horne & Reyner, 2001; Mets et al., 2012; Mets et al., 2011). Similarly, Verster et al. (2017) found that consuming caffeine during a break reduced the number of lapses in lateral control in a simulator experiment more than a break without caffeine. Other studies found that caffeine improved both subjective measures of drowsiness and lane-keeping performance (Biggs et al., 2007; De Valck & Cluydts, 2001). In a meta-analysis of placebo-controlled experimental trials, caffeine improved reaction time, attentional control, information processing, and lateral and longitudinal vehicle control across nine studies (Irwin et al., 2020).

Importantly, caffeine shows effectiveness across different driver groups, both the general driver population and shift workers. In a review, Patterson, Higgins, et al. (2018) identified a benefit of caffeine for maintaining alertness in night-shift medical workers. In a similar review of controlled studies on shift workers, there were improvements in psychomotor performance for groups that consumed caffeine relative to placebos (Temple et al., 2018). In another study, caffeine had similar benefits on lateral vehicle control for a group of commercial drivers (Ronen et al., 2014).

One important moderating factor that has not been systematically explored is caffeine dosage. Over the body of research, doses have ranged from 80 to 300 mg of caffeine, and the dosing method has varied (e.g., coffee, energy drink, slow-release capsule). Overall, it is difficult to assess the effectiveness of one dose versus another because studies have not compared the doses directly. In addition, research on the duration of the benefits of caffeine is needed. De Valck & Cluydts (2001) found that the benefits of an energy drink with caffeine lasted at least 60 minutes afterward. Yet, overall, research has not evaluated the rates by which the benefit of caffeine degrades over time and how it varies among individuals, such as during a multi-hour drive.

Reflections from Experts

Experts noted that caffeine is an effective countermeasure for transient fatigue and provides a short-term benefit; however, it may not be effective for drivers traveling long distances. Experts noted that caffeine dosing is complicated, and the optimal dose may differ from person to person. Further research is needed on the effects of caffeine for different populations, the effects of different types and amounts of caffeine, and the ideal timing of caffeine intake.

Napping and Consuming Caffeine

Consuming caffeine prior to a nap may prevent or mitigate the detrimental effects of drowsy driving. In both laboratory and field studies with overnight shift workers, Schweitzer et al. (2006) compared napping, caffeine, and napping plus caffeine interventions. All interventions improved alertness on a perceptual-motor response task, but the combination of caffeine and napping showed the greatest performance benefit. Caffeine also reduces sleep inertia following a nap. A simulated cross-over laboratory study of shift workers was conducted and found improved vigilant attention and reduced sleep inertia after shift workers consumed caffeine prior to a 30-minute nap (Centofanti et al., 2020). NHTSA recommends consuming caffeine prior to a 20-to-30-minute nap to increase alertness for a short period of time (NHTSA, 2021).

Reflections from Experts

Experts noted that research is needed to explore the benefits of combining caffeine and napping, including identifying the optimal length of naps and dosage of caffeine.

Napping and Bright Light

Limited research has explored the combination of napping and bright light as a countermeasure for reducing drowsy driving. One study by Leger et al. (2009) evaluated the effectiveness of two 20-minute naps followed by bright light pulses for 10 minutes in a sample of nine professional drivers driving on a private road circuit. During the baseline period, the subjects were told to manage their rest as usual. During the second experimental period, they rested in a dark room taking two naps of 20 minutes and then were exposed to bright light (5000 lux) for 10 minutes. The breaks combined with bright light pulses reduced subjective and objective sleepiness at the wheel at any time in a 24-hour cycle. Both the number and the duration of the episodes of sleepiness were reduced by this intervention.

Reflections from Experts

One expert noted that the feasibility of implementing this countermeasure among the general population of drivers is low due to the specialized equipment and detailed protocol required.

Conversation

To combat drowsiness, talking to passengers may help drivers maintain alertness (Anund et al., 2008; Nazari et al., 2017; Zanier et al., 2010). Evidence supporting the usefulness of conversations comes from simulator studies with controlled verbal tasks designed to mimic conversation (Song et al., 2017). In one study, researchers evaluated the effectiveness of a verbal word game task on drowsiness and driving performance in a simulator (Atchley & Chan, 2011). Steering control improved with both the continuous and late verbal task compared with the no-task control. In a follow-up simulator study, an interactive verbal task improved driver alertness as measured by electrophysiological data (Atchley et al., 2014). The authors noted that more research is needed to understand how verbal tasks produce effects.

Reflections from Experts

Experts noted the presence of an adult passenger can be protective against drowsy driving, though evidence is mixed. One expert mentioned that the passenger must be defined in this context (a child versus an adult) as some specific driver-passenger combinations might help the driver to maintain safety (e.g., an adult passenger) while others might be distracting (e.g., a young child) or otherwise increase risk (e.g., a teenage passenger with a teenage driver). Experts suggested that conversation between the driver and passengers can help the driver stay alert during late night or early morning drives, for example. In addition, if the passenger is an adult with a driver's license, the passenger can be available to take over driving if the driver is drowsy. Engaging in a remote conversation with another person (e.g., via cellphone) may also have a protective effect on driver drowsiness, though the communication device could distract the driver, a particular concern in this context as sleep-deprived drivers have been shown in laboratory studies to be more susceptible to distraction (Anderson & Horne, 2013).

Interactive Tasks to Increase Mental Alertness

Research shows mixed results on the effectiveness of drivers engaging in interactive tasks to counteract drowsiness. Several simulator studies have focused on manipulating workload to increase a driver's mental alertness. Typically, these studies have assigned a secondary cognitive task to the driver, such as interactive trivia, working memory tasks, or conversing. Secondary tasks decreased drivers' physiological measures of drowsiness (heart rate variability [HRV] and electroencephalogram [EEG]) and improved driver's ability to stay in their lane and control their speed (Gershon et al., 2009; Large et al., 2018; Oron-Gilad et al., 2008; Takayama & Nass, 2008; Trumbo et al., 2017; Verwey & Zaidel, 1999; Wörle et al., 2020).

Oron-Gilad et al. (2008) found that engaging in trivia was better at preventing driving performance deterioration and increased alertness (HRV) compared to working memory and choice reaction time tasks. More recently, researchers investigated the effect of brain stimulation using acoustic brain entrainment (ABE), an alertness-enhancing technology, among those who listened to music with and without frequency shifts during day and night on-road driving (Moessinger et al., 2021). Drivers exposed to ABE, compared to placebo, exhibited improved arousal as assessed using EEG, reduced subjective sleepiness as measured using questionnaires (KSS), and faster reaction times, all of which were more pronounced during daytime driving.

Reflections from Experts

Experts commented that interactive tasks to increase mental alertness while driving are complex and have been mainly studied in simulator settings. Several experts noted that this type of countermeasure may not be effective in preventing drowsy driving. One expert noted drivers must know when they should engage in the task, avoid engaging in the task at times when the demands of the driving task itself are so high that distraction caused by the task could be unsafe, and engage in the right interactive task. It would be challenging to provide clear guidance to drivers for using such countermeasures in real-world settings. Lastly, one expert noted that autonomous vehicle researchers have considered the types of interactive tasks that can be given to a driver to ensure they remain alert while they are not engaged in the active part of the driving task.

Opening a Window and Cold Air

Opening a window to allow cold air into the car is a passive behavioral countermeasure drivers may employ when feeling drowsy; however, studies suggest that it is ineffective. Limited research has studied the effects of opening a window or turning on the air conditioner (Lyznicki et al., 1998; Nguyen et al., 1998). In one study of self-reported driver performance, 47% of national survey respondents reported opening a window to decrease sleepiness, though it did not improve their driving performance (Anund et al., 2008). In a simulator study of drivers with restricted sleep, cold air from the car's air conditioning system had no significant effect on measures of lane-keeping performance (Reyner & Horne, 1998).

Taking a Break without Napping or Caffeine

While taking a break has been recommended to prevent drowsy driving crashes (Strohl et al., 1998), there has been limited research on breaks without naps or caffeine. In one simulator study, study participants (n=12) took 1-hour breaks between 2-hour nighttime driving trips on a simulator across four sessions (Phipps-Nelson et al., 2011). During breaks, participants performed cognitive tests and then sat quietly. Participants showed improvements in their driving performance and subjective fatigue but little change in EEG-measured or subjective sleepiness.

Verster et al. (2017) found that breaks with caffeine were more effective than breaks without caffeine in the later stages of a drive. An observational study of data from real-world crashes found that prolonged driving (≥3 hours) without a break was associated with elevated crash risk independent of sleep deprivation, likely suggestive of fatigue induced by time-on-task and thus the potential for a break to be beneficial (Tefft, 2018). However, the study did not ascertain whether or not drivers took naps or consumed caffeine during breaks.

Reflections from Experts

Experts stated that while taking a break without napping or caffeine may not prevent drowsiness or drowsy driving crashes, the driver is making a decision that seeks to promote road safety. Ultimately, taking a break from driving, without napping or caffeine, may be warranted to combat fatigue induced by time-on-task. However, if a driver is drowsy, then taking a break without napping or caffeine will not reduce sleepiness.

Exercise during a Break

Engaging in physical exercises (e.g., push-ups, running or jogging, sit-ups) that require no equipment is another strategy to keep drivers alert, though the results show mixed effectiveness. Exercise as a countermeasure is typically performed during breaks, such as when drivers pull into a rest area (Lyznicki et al., 1998). One common countermeasure drivers' employ is to take a walk during a rest break (Anund et al., 2008; Zanier et al., 2010); however, this has not been evaluated under controlled settings. In the context of aviation, a small study on army pilots used 10 minutes of treadmill exercise every two hours as a drowsiness countermeasure during a sleep restriction protocol (LeDuc et al., 2000). The authors found short-lived benefits in measures of reaction time following exercise; however, these benefits faded quickly, and within the hour after exercise, objective measures of drowsiness increased relative to right after exercise. More research is needed to evaluate similar interventions in the context of driving.

Music

Another passive, self-initiated countermeasure drivers commonly use to distract themselves when feeling drowsy is turning on the radio (Lyznicki et al., 1998). The evidence of music as a drowsy driving countermeasure is limited. Reyner and Horne (1998) found that listening to the radio decreased subjective drowsiness (KSS) but had no impact on EEG-measured drowsiness. Horne and Reyner (1995) suggested that listening to music may distract drivers from accurately self-diagnosing their level of drowsiness. However, one simulator study found listening to the radio was associated with small improvements in reaction time (Fagerström & Lisper, 1977).

Eating or Chewing Gum

Few studies have evaluated the effectiveness of eating or chewing gum on drowsiness and driving. A comparison study among 11 emergency medicine residents working overnight shifts found no significant difference in lane departure or braking reaction time in those using gum versus no gum (Dela Cruz et al., 2019).

Implementation Considerations and Opportunities for Future Research of Behavioral Countermeasures

The evidence in favor of sufficient sleep, napping, and consuming caffeine is overwhelmingly strong, but the evidence for other behavioral countermeasures is mostly mixed, not favorable, or unavailable. The literature on behavioral countermeasures points to several areas for future research. Verbal tasks have promising results and could be further evaluated. Most of the research literature on naps has been conducted with groups of commercial drivers and shift workers. Though naps would equally benefit non-commercial drivers, future research is needed to understand the beneficial results of naps among non-commercial drivers as it pertains to driving experiences, whether the driving circumstances are similar to commercial drivers, and if implementing napping would be equally practical among this population. Finally, although research suggests a benefit of pairing napping with other countermeasures, including consuming caffeine and using bright lights, these benefits have only been explored in a few small studies under limited conditions.

One general limitation of the many studies on behavioral countermeasures is the lack of knowledge about how long potential benefits of a countermeasure last. Controlled simulator or on-road research with longer drives and validated protocols mimicking real-world motivational conditions is needed to understand how different behavioral countermeasures influence performance, decision making, and crash risk.

A particular challenge of understanding the impact of behavioral countermeasures is that often times multiple countermeasures are implemented simultaneously. It is therefore difficult to isolate the individual contribution of each countermeasure. Another challenge is the variation in the implementation of a given countermeasures across different studies. With caffeine, for instance, dosage ranged from 80 to 300 mg across studies with different dosing methods. Similarly, the duration of naps examined varied across studies from as short as 15 minutes to as long as 3 hours. Measures of drowsiness and driving performance differed across studies as well.

Finally, while experimental research is important, experts also noted that studies in naturalistic settings are needed to assess effectiveness. An essential measure of success is a countermeasure that works in a real-world setting. Naturalistic studies can assess whether drivers know when to use a countermeasure, are able to use and benefit from the countermeasure, and choose to use it in real-world settings.

Technological Countermeasures

The ability of technology to detect, warn, and, in some cases, compensate for driver fatigue has been studied over the years, with some technological countermeasures showing more promise than others. In-vehicle technology that increases drivers' mental alertness, either through mental or physical activity, can potentially reduce driver drowsiness. Driver monitoring systems and advanced vehicle safety systems can potentially reduce crashes due to distraction and drowsiness.

Advanced Driver Assistance Systems

Advanced driver assistance systems (ADAS) are vehicle safety technological features that monitor driver input and the environment around the vehicle, warn the driver if a collision is imminent, and may automatically brake or steer the vehicle to avoid a collision if the driver does not act. These systems are designed to prevent or mitigate crashes irrespective of their cause, and thus theoretically should help to prevent crashes attributable to driver drowsiness. Major categories of ADAS include longitudinal monitoring and control systems that warn the driver and/or automatically brake if the system detects that a frontal collision is imminent, and lateral monitoring and control systems that warn the driver and/or automatically steer if the system detects that the vehicle is at risk of deviating from its travel lane in the absence of turn signal activation. Such systems are now widely available as optional or even standard features in the vast majority of new vehicles sold in the United States.

Research from the Insurance Institute for Highway Safety (IIHS) and the Highway Loss Data Institute (HLDI) found that forward collision warning in conjunction with automatic emergency braking reduced front-to-rear crashes by 50%, front-to-rear crashes with injuries by 56%, and large truck front-to-rear crashes by 41% (IIHS-HLDI, 2021; NHTSA, 2015). A simulator study of drivers 18–80 years old that examined whether forward collision warning systems reduce the risk of rear-end crashes among drivers experiencing task-induced fatigue found that the systems significantly reduced collision risk in a simulated rear-end crash scenario, particularly among study subjects older than 60 (May et al., 2006). Lane departure warning has not reduced rates of crashes reported to insurers, but has reduced rates of single-vehicle, sideswipe, and head-on crashes reported to the police (Cicchino, 2018; IIHS-HLDI, 2021; Sternlund et al., 2017). A simulator study found that lane departure warning systems significantly reduced the number of lane departures, the time and length of departures, and out-of-lane area for drowsy drivers (Rimini-Doering et al., 2005).

Reflections from Experts

Experts noted that advanced driver assistance systems, such as automatic emergency braking systems, can effectively prevent drowsy driving crashes. Specifically, they noted that even if systems are not designed specifically to address drowsiness, they are undoubtedly effective in preventing crashes and alerting the driver if they become drowsy (e.g., lane departure warning). One benefit of driver assistance systems is they do not rely on the driver changing their behavior. Many experts discussed the difficulty of changing individual behavior, and driver assistance systems alleviate some of the burden for the driver by alerting them when drowsiness, distraction, or other impairments occur, and possible intervening to prevent a crash. Some experts, however, expressed concern that a drowsy driver could rely excessively on such systems and use them to attempt to drive when they should instead pull over and nap. This is a potential concern because despite their substantial effectiveness, such systems cannot prevent all crashes and are not intended to take the place of an alert, attentive driver.

Drowsy Driver Detection and Alerting Systems

Drowsy driver detection and alerting systems include vehicle-based measures such as steering inputs or lane position or operator-based measurements such as the percentage of eyelid closure over the pupil over time (PERCLOS) or head movements to infer drowsiness (Grace & Stewart, 2001). Drowsy driver detection and alerting systems are available as an optional or standard feature in many new vehicles sold in the United States today (NASEM, 2016). Many of them present an auditory warning and/or a visual notification (e.g., a coffee cup icon) if the system determines that the driver may be drowsy (e.g., as assessed by unusual variability in the vehicle's lane position or other measures).

A high-fidelity simulator study conducted by NADS lab examined the effectiveness of both single- and multi-stage warnings similar to those available in many existing vehicles. In the study, participants performed 45-minute simulated drives during late night and early morning, and drowsiness was manipulated by continuous hours awake (Gaspar et al., 2017). While both types of countermeasures effectively reduced drowsy lane departures when compared against no countermeasure, the multi-stage alerts—those that increased in intensity—were more effective in reducing the frequency of lane departures and lane position variability.

A variety of portable aftermarket systems are designed to be installed inside of vehicles. For example, one such system, the DD850 Driver Fatigue Warning System, calculates PERCLOS over 1- to 3-minute intervals and derives an index of drowsiness. The driver is given feedback with audible alerts, and visual information is presented on the duration of the eye closures and distance driven during that time (May & Baldwin, 2009). Although there has not been an evaluation of the effectiveness of the DD850 in reducing drowsy driving, researchers examined a similar PERCLOS-based system developed at Carnegie Mellon Research Institute (Grace & Stewart, 2001; Mallis et al., 2000). The system provided drivers with minute-to-minute feedback via a gauge that changed from green to yellow to red and delivered an alarm when drowsiness reached certain levels.

<u>Reflections from Experts</u>

Experts stated that the key question related to drowsy driver detection and alerting systems is whether drivers will change their behavior when they receive an alert. Although these systems can alert drivers that they may be drowsy, the systems cannot take the drivers off the road. As new technologies are developed, experts stated the need to test how to deploy them effectively. Experts suggested exploring whether drivers react to alerting symbols on the dashboard (e.g., coffee cup) or researching technologies that could link to GPS navigation systems to tell drivers where to get a cup of coffee. One expert suggested that if systems were integrated with GPS and incentivized drivers, drivers may be more prone to pull off the road when drowsy. Lastly, one expert noted that drowsy driver detection and alerting systems could be effective in a commercial driving setting. For example, systems that reliably detect drowsiness and send a message to a dispatch center to intervene (rather than relying on drivers to respond to the alert) might be more effective than a system that only alerts the driver. Research on the practicality of such technologies is needed.

Manipulating Physical Workload to Increase Mental Alertness

Limited evidence suggests that technology designed to manipulate the physical workload of the driver may increase drivers' mental alertness. In one study, drivers completed a 3-hour simulated trip and were monitored for periods of drowsiness (Llaneras et al., 2018). The countermeasure examined included artificial wind gusts to increase steering demands and make it more difficult for the driver to maintain lane position. The study found that increasing the driver's steering demands brought drivers back to an alert state.

An on-road study by Lee et al. (2020) examined the effects of a motion seat, which cycled at 1-minute increments between an "open" position—inducing extension of the body by movement/tilt of backrest and cushion—and "closed" position. Participants experienced half of the 90-minute drive in a static seat, which was expected to induce task-related fatigue, and the other half in the motion seat. Physiological indicators of drowsiness (e.g., PERCLOS) did not increase in the motion seat condition, and subjective ratings of mental fatigue were significantly lower. The motion seat did not present a secondary task to the driver, making it potentially less distracting than some of the interactive behavioral tasks. However, this is the only study identified in this review that examines this type of technology.

Blue Light

Limited evidence shows that exposure to short wave-length blue light can alert the nervous system as a non-pharmacological countermeasure and result in improved physiological (e.g., heart rate) and subjective wakefulness, as well as behavioral measures. A few studies examined the effects of presenting drivers with blue light in an attempt to increase alertness. A simulator study found that subjects exposed to a blue-enriched white light had faster response times in a psychomotor vigilance task (Rodríguez-Morilla et al., 2018). However, their driving performance was degraded, and they did not feel less sleepy than when exposed to other lighting conditions. A randomized, double-blind, placebo-controlled, cross-over study examined driver performance on a 250-mile stretch of roadway at night (Taillard et al., 2012). Subjects randomly received either continuous blue light exposure during the drive, coffee, or a placebo of decaffeinated coffee. Results showed significantly lower mean standard deviations in lane position and inappropriate lane crossings when exposed to the countermeasures (the blue light or having a coffee) compared to the placebo condition. There was no significant difference between the two countermeasures.

Fitness to Drive Assessment Technologies

Technologies and tests can assess readiness to perform, fitness for duty, and fitness to drive based on a variety of tasks (e.g., eye-hand coordination, reaction time, divided attention, cognitive processing). Such technologies seek to assess the vigilance or alertness of operators in order to determine their fitness to drive before they enter the vehicle (Allen et al., 1990; Hartley et al., 2000; Stein et al., 1990). Results of studies examining the usefulness of such technologies, however, have been mixed. Posturographic sleepiness monitoring is one way to predict hours of wakefulness, which could facilitate sleepiness testing as found in one study (Forsman et al., 2007). The Act and React Test System (ART-90) has been used among commercial truck drivers in Europe and is reported to have successfully predicted 68% of driving errors and 50% of conflicts (Hartley et al., 2000). Other systems (e.g., FACTOR 1000, Truck Operator Proficiency System [TOPS], and the Occupational Safety Performance Assessment Test [OSPAT]) require additional validation data or have shown little ability to predict performance (Basner & Dinges, 2012; Hartley et al., 2000; Lyznicki et al., 1998; Stein et al., 1990). A study of the FIT 2000 Workplace Safety Screener, which used involuntary eye reflexes to predict fatigue, did not find it to be a valid screener, as it only assessed 40% of participants as being at high risk for fatigue even after having been awake for 48 hours, by which time the vast majority should have been fatigued (Watson et al, 2006).

Roadside Drowsiness Tests

Roadside drowsiness tests use technology to assess drowsiness or changes in drowsiness outside of the vehicle. These include measuring the driver's EEG signals, ocular measures, or respiratory signals such as respiratory rate variability, to estimate the extent to which a person may be drowsy. In theory, such tests could be used by law enforcement officers or others to determine whether a driver is drowsy. These measures, however, are limited in their ability to capture lower levels of drowsiness (Bajaj et al., 2020; Guede-Fernández et al., 2019; Mulhall et al., 2020; Sparrow et al., 2019).

Wolkow et al. (2019) developed recommendations for current and future drowsy driving countermeasures to improve road safety in Australia as a response to the high number of road deaths caused by drowsy driving. The road safety strategy was implemented in 2011 with the goal of reducing driving fatalities by 30% in 2020; however, only a 9% reduction had been achieved as of late 2018. The recommendations included investing in blood- and saliva-based drowsiness biomarker research and ocular measure devices to develop roadside alertness tests and monitoring devices (Wolkow et al., 2019). Wolkow et al. also recommended developing a regulatory framework to support enforcement practices that would lead to rapid roadside drowsiness tests among suspected drowsy drivers.

Reflections from Experts

Experts noted that alertness tests (e.g., blood-based or saliva-based tests) to identify when a person may be drowsy could be a promising countermeasure and are currently being researched.

Stimulus Response Reaction Tasks

Another approach to measuring drivers' drowsiness is to examine the driver's ability to respond to a presented stimulus (i.e., a light or sound) by performing an action. In such systems, a driver's delayed response or non-response to the stimulus is taken to be indicative of a lack of attentiveness, in which case the system alerts the driver. One such system, the AlertOmatic, gave drivers a warning that sounded like a vehicle's horn when they failed to respond to stimuli (Hartley et al., 2000; May & Baldwin, 2009). Another, the Knight–Warrior Sleep Alarm, is a driver-activated system that emitted a minimal auditory alarm at a specified time interval (Hartley et al., 2000; May & Baldwin, 2009). The driver had 1 to 3 seconds to deactivate the alarm, or a loud siren would sound. Neither of these systems was validated for on-road use. Another system, the Roadguard, alerted drivers via a buzzer. A simulation-based study, however, did not find that the system improved driving performance (Haworth & Vulcan, 1991). The challenge with these types of systems is that drivers can respond even when in a light sleep state; therefore, they may continue to drive and may not even be aware that their driving performance has degraded. Additionally, these types of systems may cause further distraction to drivers.

Biometric Devices (Wearables)

Wearable technologies have the potential to unobtrusively evaluate drowsiness. These devices can be worn on the wrist like a watch, on a finger like a ring, as a patch or on clothing. They can also be paired with smartphones to collect data. In 2018, the Sleep

Research Society sponsored a workshop, *International Biomarkers Workshop on Wearables in Sleep and Circadian Science*, which convened a committee of experts to study wearable technologies for developing sleep and circadian biomarkers. The committee found there was limited validation of wearable technology available at that time, and that the use of consumer wearables in sleep and circadian research and clinical sleep medicine is "premature and must be carefully evaluated case-by-case" (Depner et al., 2020). The committee also proposed guidelines for using wearables in research and clinical settings and called for collaboration between researchers and industry stakeholders in research and the development of standards for wearables as the use of sleep and circadian wearables increases.

Implementation Considerations and Opportunities for Future Research for Technological Countermeasures

Technological countermeasures, such as driver monitoring systems, can detect fatigue at the point at which it begins to impact driving performance. However, these systems require additional research and evaluation. Specifically, research is needed to determine the best measures to recognize the early stages of drowsiness. Research is also needed to determine the best method for alerting a driver who is showing signs of drowsiness and how drivers respond to the alerts. Further, the development of a valid, reliable, relatively unobtrusive measure of fatigue, conceptually roughly analogous to a breathalyzer, could create new opportunities to enhance or supplement other countermeasures.

Most research regarding technological countermeasures has been simulator-based. Real-world validation of technologies intended to measure driver drowsiness is necessary but can be difficult to implement, expensive, and raises issues regarding safety and liability.

Real-world observational studies of data from motor vehicle crashes have found that advanced driver assistance systems such as forward collision warning, lane departure warning, automatic emergency braking, and lane keeping assistance systems are highly effective in reducing rates of certain types of crashes in general. Some limited evidence suggests that they are effective in reducing the risk of drowsy driving crashes; however, more research is needed to examine their effectiveness specifically in the context of drowsy drivers.

Infrastructure Countermeasures

Infrastructure countermeasures are modifications to the physical roadway environment to reduce the likelihood or severity of drowsy driving crashes. There are several categories of infrastructure countermeasures: rumble strips, rest areas, road signs, roadway markings, and vehicle-to-infrastructure (V2I) communication. Research in this area has focused mostly on rumble strips and road markings, with some studies on the impact of rest areas. In general, infrastructure countermeasures address drowsy driving in the late stages of drowsiness. That is, these infrastructure elements are designed to prevent drowsy driving crashes or mitigate the severity of such crashes, but they are not specifically designed to keep drivers alert or reverse the physiological or cognitive course of drowsiness.

Shoulder and Centerline Rumble Strips

Rumble strips are raised or grooved elements on roadway shoulders or along the centerline of the road. Shoulder rumble strips are widely used on freeways and sometimes on other types of roads, to prevent vehicles from driving off the road; centerline rumble strips are used mainly on undivided two-lane roads to prevent head-on crashes. They are intended to alert drivers through vibrations and rumbling sounds that their vehicle has deviated from the lane. Many studies of real-world crash data before and after installation of rumble strips have demonstrated their effectiveness in reducing the rates of the relevant crash types overall (Neuman et al., 2003a, 2003b; Watling et al., 2016). However, less is known about their efficacy with respect to drowsy driving crashes in particular.

A 2015 NHTSA expert forum on drowsy driving cited rumble strips as one of the most cost-effective countermeasures for reducing crashes associated with drowsy and distracted driving (NHTSA, 2015). However, while rumble strips may reduce crashes at the locations at which they are installed, they do not prevent or counteract sleepiness. Thus, there is concern that a driver momentarily awakened by driving over a rumble strip is still vulnerable to sleepiness and might subsequently crash elsewhere. For example, Watling et al. explored the stability of the effect of rumble strips on sleepiness, finding that the first rumble strip hit reduced physiological sleepiness though subsequent jolts did not increase alertness (Watling et al., 2016).

<u>Reflections from Experts</u>

Experts noted that rumble strips can be effective in alerting drivers when they are drowsy and preventing crashes. Experts also specifically noted the importance of shoulder rumble strips in reducing crashes in rural areas. In addition, experts suggested that transverse rumble strips—which run across rather than along the traffic lanes—may be particularly useful to alert sleepy or fatigued drivers of upcoming changes in the driving environment (e.g., a sharp curve, stop sign, speed limit reduction, or toll collection site). While rumble strips are effective in preventing crashes, they will not prevent a drowsy driver from continuing to drive and crashing further down the road where rumble strips are not present.

Rest Areas

Highway rest areas are designated areas where drivers can stop to rest. Drivers are encouraged to stop and rest when drowsy and to prevent or relieve task-related fatigue during long drives even when not drowsy (Tefft, 2018). However, drivers may be unwilling to use rest areas for various reasons, including concerns about security. Some states focus on ensuring rest area security to increase driver willingness to stop at rest areas (Lyznicki et al., 1998; Stutts et al., 2005). There have also been recommendations to locate rest areas closer together to give drivers more options to stop and rest.

Studies have examined the association of rest area availability with crashes, including drowsy driving crashes. McArthur et al. (2013) examined the frequency of crashes on road segments in relation to the proximity of the road segments to rest areas and found that road segments within 20 miles of a rest area had fewer crashes, and found that crash frequency increased significantly for rest areas spaced more than 30 miles apart. Jung et al.

(2017) found that supplemental rest areas were associated with fewer drowsy driving crashes on a freeway in South Korea. Adanu et al. (2021) found that crashes resulting in severe injuries were more likely to occur on interstate highways with no rest areas, and crashes further from rest areas tended to be more severe.

Reflections from Experts

Experts discussed the importance of rest areas for commercial drivers and the general public. Although drivers are encouraged to use rest areas, there are only a few rest areas available in some states; some states have been closing rest areas in recent years as a cost-cutting measure.

Experts also noted safety issues at rest areas and the limited number of parking spaces, which results in commercial drivers parking on the side of the road if they need to take a break. Experts stated that commercial drivers may want to use rest areas, but the infrastructure does not support them. For example, New Jersey has a system of rest areas, but there are signs indicating that drivers cannot idle there due to environmental regulations. This would discourage drivers from napping in their vehicles in cold or hot weather. Thus, more work is needed to ensure that rest areas are available, appealing, and useful to drivers who need them.

Road Signs

Road signs (often variable message signs) can notify drivers of the risk of drowsy driving or encourage them not to drive while drowsy. One study tested drowsiness information via variable message signs on a simulated interstate drive (Merat & Jamson, 2013). The authors found that drowsiness—measured by PERCLOS—was reduced for participants with the sign intervention compared to a control drive. However, no difference in driving performance, as measured by lateral deviation, was observed with the countermeasure. In another study, investigators modeled the impact of a drowsy driver advisory message at two rural highway sites (Rahman & Kang, 2020). The authors compared crash rates to similar sites that did not have advisory messages posted and found a benefit of the drowsy driving advisory messages. However, more research is needed, including studies that control for differences in roadway features.

Reflections from Experts

Experts said that road signs can be informative (e.g., the risks of drowsy driving) or persuasive (e.g., do not drive while drowsy). Experts indicated that road signage with persuasive or warning messages are unlikely to be effective in reducing drowsy driving. One potentially effective way of using road signs is to provide information about the distance to the next rest area. Experts also noted that road signs can convey the message that a specific rest area is a safe place to nap or rest. Such messages could facilitate a drowsy driver pulling off the road.

Experts also discussed a novelty factor associated with roadway signs: over time, signs become a part of the landscape, and all drivers who live there have seen them. Therefore, they likely ignore the signs. One possible way to work around this issue is using electronic signage, which allows for a periodic change in messages. This is an area that needs further research.

Roadway Markings

A National Academies of Sciences, Engineering, and Medicine (NASEM) report on countermeasures to prevent drowsy driving crashes (Stutts et al., 2005) describes two changes to pavement markings—enhanced pavement markings and improved roadway delineation—as promising yet untested countermeasures to reduce drowsy driving crashes. Enhanced roadway delineation might include wider edge lines, raised pavement markings, and post-mounted chevron signs (Nazari et al., 2017). The report concluded that although these roadway marking countermeasures reduce overall crashes, it is unclear if they reduce drowsy driving crashes, specifically (Stutts et al., 2005).

Vehicle-to-Infrastructure Communication

V2I communication allows the vehicle to connect with infrastructure elements of the driving environment. (e.g., traffic signals). One study modeled crash types from police-reported crashes to identify how many may have been preventable with V2I technology in place (Najm et al., 2010). The authors concluded that V2I communication may have been able to prevent a large percentage of crashes, including single-vehicle roadway departures, which are commonly attributed to drowsiness. More research is needed to determine the direct impact of V2I on drowsy driving. This includes specifying the critical infrastructure elements required to communicate with the vehicle and how to convey the V2I information and/or apply it to activate assisted driving interventions.

Implementation Considerations and Opportunities for Future Research for Infrastructure Countermeasures

Infrastructure modifications are not primarily intended to address driver drowsiness or drowsy driving, but rather to reduce crashes in general. Rumble strips are effective in reducing crash rates, though more research is needed to understand their impact on crashes caused by drowsiness. Experimental studies and pre-post intervention analyses are needed to determine the effectiveness of infrastructure countermeasures for reducing drowsy driving and drowsy-driving crashes. In particular, more research is needed to determine whether transverse rumble strips might help to reduce drowsy driving crashes at certain types of locations, and to further elucidate the relationship between the availability and characteristics of rest areas and their safety benefits.

Educational Countermeasures

Educational countermeasures that focus on increasing the public's knowledge and awareness about the symptoms and warning signs of drowsiness have been implemented to reduce drowsy driving. Specific groups with an increased risk of drowsy driving crashes who can potentially benefit from educational approaches include those with untreated sleep disorders, shift workers, people who take prescription medications with side effects, and young adults (Nelson et al., 2001; Strohl et al., 1998). These populations may benefit from education that focuses on recognizing the symptoms and warning signs of drowsy driving and ways to reduce crash risk (Higgins et al., 2017). While education is a necessary countermeasure, programs focused on increasing awareness and knowledge alone are not sufficient to change behavior (Higgins et al., 2017). Educational countermeasures are most effective when integrated with other types of countermeasures, such as policy and/or enforcement. This section describes communication and outreach campaigns, educational programs and materials, and driver education.

Communication and Outreach Campaigns

States and national organizations conduct public awareness communication and outreach campaigns to educate drivers about drowsy driving and its prevention. Campaign goals generally focus on raising awareness of the risks of drowsy driving and changing driver behavior (NHTSA, 2015). Some campaigns are designed using evidence-based approaches and are evaluated for effectiveness in changing driver behavior, while others are not evidence-based and systematically studied. In addition, some studies rely on self-reported data to determine the effects of the campaign.

Examples of public awareness communication and outreach campaigns focused on drowsy driving and its prevention include the National Sleep Foundation Drowsy Driving Prevention Week®, an annual campaign to reduce the number of people who drive while sleep deprived, among others (American Academy of Sleep Medicine, 2020; National Sleep Foundation, 2019, 2021; Nelson et al., 2001; "Sleep Smart Drive Smart," 2004; Wolkow et al., 2019). Also, several states have designated a "drowsy driver awareness" or "drowsy driving prevention" day or week to increase public awareness (Governors Highway Safety Association, 2016).

NHTSA's *Countermeasures that Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, Tenth Edition* concludes that there is insufficient evidence to conclude communications and outreach campaigns directed to the general public are an effective countermeasure for reducing drowsy driving (Venkatraman et al., 2021).

Reflections from Experts

Experts noted that education alone does not affect driver behavior in the short term and may not change driver behavior in the long term. Educational countermeasures work best when layered with other countermeasures. Some experts called for a large-scale education campaign on drowsy driving in the United States, noting the public does not think drowsy driving is as dangerous as other crash risks. Experts noted that research is needed to identify the most effective messages and approaches for conveying information about drowsy driving to different populations. Experts also discussed the importance of tailoring messages for different populations.

Educational Programs and Materials

Educational programs and materials, such as pamphlets, brochures, infographics, and toolkits, can inform the public about the importance of sleep to their health and the risks of drowsy driving. Educational programs and materials focus on different topics, such as healthy sleep habits, causes of drowsiness, and warning signs of drowsiness when driving (Lyznicki et al., 1998).

Education programs for college students, specifically, may help to reduce drowsy driving and promote healthy behaviors (National Safety Council, 2021). Studies described interventions for teens and college students focused on drowsy driving and sleep health. For example, a high school drowsy driving two-day curriculum for 9^{th}–12^{th} graders illustrated the dangers of distracted driving, including how to recognize and respond to signs of drowsy driving (Linden et al., 2019). The investigators found that most students reported learning new information about drowsy driving and said they would be more likely to speak up as a passenger with a drowsy driver. In another example, a randomized study of an online sleep education intervention for first-year college students, which included the effect of sleep deprivation on driving, found that intervention participants self-reported positive behavior changes, such as stopping use of electronics earlier and having a more regular sleep schedule (Hershner & O'Brien, 2018).

Educational programs to reduce drowsy driving have also focused on employees. For example, the Federal Transit Administration in cooperation with the Transit Development Corporation (now part of the American Public Transportation Association) developed an educational toolkit for reducing transit operator fatigue (Gertler et al., 2002). The toolkit, developed as part of the Transit Cooperative Research Program, offers strategies for preventing fatigue, detecting a fatigued state, and minimizing the performance effects of fatigue when it occurs on the job. In another example, the Federal Motor Carrier Safety Administration developed a presentation that discusses the importance and benefits of sleep, the consequences of sleep deprivation, and sleep habits to reduce drowsy driving (Federal Motor Carrier Safety Administration, 2014).

Finally, education programs have focused on increasing awareness of chronic medical conditions and sleep disorders that impact driving, including symptoms and treatment (Venkatraman et al., 2021). This has included collaborating with driver license medical advisory boards to increase their awareness of these conditions as they review driver fitness for licensing, and increasing physicians' awareness of these conditions and their potential effects on driving so that they can treat and counsel patients to reduce the risk of drowsy driving (Richard et al., 2018). NHTSA's guide, *Countermeasures that Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, Tenth Edition*, notes that education regarding medical conditions and medications has not been systematically examined and there are insufficient data to determine its effectiveness for drowsy driving (Venkatraman et al., 2021).

The American Academy of Sleep Medicine released a position statement that sleep is essential to health, underscored the need to emphasize sleep health in K–12 and college education, clinical practice, and the workplace; and recommended more research focused on the effects of sleep deficiency and circadian dysfunction on population health (Ramar et al., 2021).

Reflections from Experts

Experts discussed the importance of including sleep medicine education into the curriculum for all medical students, so that they will be well equipped as physicians to discuss the importance of sleep health with their patients. Experts also noted that education materials for health care professionals should include guidance about how to communicate about the dangers of drowsiness, including discussing prescription medication side effects, with patients. Further, experts discussed the importance of educating parents about sleep health. One expert stated that researchers, health care providers, and law enforcement professionals can help parents understand the importance of modeling good sleep habits.

Driver Education Courses

In addition to print materials and outreach and awareness campaigns, states incorporate information on drowsy driving into driver education courses. The American Thoracic Society recommends that all drivers receive education about recognizing the symptoms and consequences of drowsiness (Mukherjee et al., 2015). Driver education requirements vary across states. Thirty-two states require some form of driver education and commonly include 30 hours of classroom instruction, 6 hours of behind-the-wheel lessons, and 6 hours observing others' driving to understand traffic laws (National Conference of State Legislatures, 2014). A review by NHTSA in 2015 reported that 47 states and the District of Columbia had information about drowsy driving in their driver's manuals, and 17 states include drowsy-driving education in their driver's education curricula (NHTSA, 2015). However, the quality of information varies widely (Governors Highway Safety Association, 2016; NHTSA, 2015).

Implementation Considerations and Opportunities for Future Research for Educational Countermeasures

Educational countermeasures are necessary, but not sufficient, in reducing drowsy driving. The most effective educational campaigns, in general, are multi-faceted and sustained in the long term (Stutts et al., 2005). Opportunities for future research include evaluations of educational campaigns on drowsy driving, including studies that identify effective messages and approaches (Stutts et al., 2005). Beck et al. (2018) conducted a focus group study of motivational factors associated with drowsy driving behavior among college students and identified messaging strategies for preventing drowsy driving; the authors recommended future studies using qualitative and quantitative methods and with different samples. Longitudinal studies and broader samples are also needed to assess the long-term effects of educational programs focused on sleep and driving on drowsy driving in young drivers (Alvaro et al., 2018; Beck et al., 2018). Finally, further research is required to determine whether drowsy driving education courses help prevent drowsy driving.

Medical Countermeasures

Sleep disorders can affect driving by causing daytime sleepiness. Studies have found that drivers with the sleep disorders of insomnia, obstructive sleep apnea, and narcolepsy have an increased risk of involvement in motor vehicle crashes (Governors Highway Safety Association, 2016; Stutts et al., 2005; Sassani et al., 2004; Bharadwaj et al., 2021). Sleep apnea disrupts breathing so that breathing starts and stops, interrupting sleep. Narcolepsy is categorized by overwhelming daytime sleepiness, even after adequate nighttime sleep (National Heart, Lung, and Blood Institute, 2011). Insomnia is defined as "having trouble falling asleep or staying asleep or having unrefreshing sleep despite ample opportunity" (National Heart, Lung, and Blood Institute, 2011). Treatments to address sleep disorders may improve sleep quality and decrease the risk of drowsy driving crashes. This section describes medical countermeasures to reduce drowsy driving.

Sleep Apnea Screening and Treatment

Sleep disorders are commonly undiagnosed and untreated (Governors Highway Safety Association, 2016), suggesting that countermeasures to address drowsy driving should focus on increasing awareness of sleep disorders and their symptoms (Richard et al., 2018).

There are no federal mandates that require screening of sleep apnea in commercial motor vehicle drivers or that specify the criteria to be used to screen for sleep apnea (Gurubhagavatula & Sullivan, 2019). In 2016, the Federal Motor Carrier Safety Administration's (FMCSA) Medical Review Board and Motor Carrier Safety Advisory Committee released recommendations regarding commercial vehicle drivers and sleep apnea. The two groups recommended that FMCSA implement policies for sleep apnea screening among commercial vehicle drivers who have specified risk factors, such as high body mass index, heart disease, or a large neck size (FMCSA, 2016). If a commercial vehicle driver is diagnosed with sleep apnea, they must be effectively treated and screened by a certified medical specialist to operate a commercial vehicle (FMCSA, 2016). Furthermore, researchers have recommended that FMCSA conduct education and outreach activities to increase awareness about sleep apnea (Wolkow et al., 2019).

A few commonly used treatments for sleep apnea are the use of a CPAP machine, which treats sleep apnea by increasing airflow during sleep, use of a mouthpiece to reposition the jaw and tongue, or surgery for more severe cases (National Heart, Lung, and Blood Institute, 2011). One study of two motor carriers' sleep apnea programs conducted focus groups with commercial vehicle drivers and interviewed staff involved in sleep apnea programs to assess perceptions about the programs (Mabry et al., 2012). Drivers reported various benefits, including better quality of sleep, more energy, improved health, and less fear about falling asleep while driving. Participants noted some drawbacks however, such as discomfort with the CPAP.

The evidence surrounding CPAP as a sleep apnea therapy primarily supports its continued usage among affected drivers. Studies have compared drivers receiving CPAP treatment to drivers with untreated sleep apnea or drivers without sleep apnea found that CPAP decreased the risk of motor vehicle crashes (Cassel et al., 1996; Findley et al., 2000; Sassani et al., 2004). These studies attributed the decreased risk to an improvement in sleep quality and a decrease in daytime sleepiness, though some patients still reported excessive daytime sleepiness despite appropriate CPAP treatment, potentially attributable to comorbidities such as depression and periodic leg movement disorder (Dongol & Williams, 2016). However, a recent observational study comparing motor vehicle crash involvement among CPAP-treated patients versus patients with untreated sleep apnea and patients who discontinued CPAP treatment against their doctors' advice found no statistically significant differences in crash rates between the groups (Myllylä et al., 2020).

One important consideration is that, while a significant body of research supports CPAP reducing daytime sleepiness, many of these studies focused solely on patients with pathological levels of daytime sleepiness. CPAP did not improve objective sleepiness or quality of life for people unaffected by pathological daytime sleepiness. Further research is needed to determine whether CPAP treatment reduces crash involvement for patients without pathological daytime sleepiness and other patient characteristics that influence crash risk (Sánchez et al., 2009).

Reflections from Experts

Experts discussed barriers to the diagnosis of sleep apnea that can delay treatment, such as lag times between treatment initiation and treatment benefits and patient compliance with treatments. Also, one expert noted that, while sleep apnea can be a symptom of certain medical conditions, poor sleep and associated drowsiness can also be a symptom of other medical conditions (e.g., chronic pain, acid reflux).

Another expert shared that educating health care providers, such as primary care physicians, about the importance of sleep is one way to communicate sleep health information directly to the general population. This expert recommended that providers explicitly ask patients about their sleep habits to diagnose sleep disorders.

Experts also discussed the proposed federal regulations for commercial truck drivers diagnosed with sleep apnea. One expert suggested that streamlined screening and referral guidelines for sleep apnea would reduce stigma associated with the disorder and help employees in various industries (including commercial trucking) seek treatment. Another expert said that while there has been a push to improve screening and referral practices for sleep apnea in commercial vehicle drivers, carrier programs to screen drivers are not widespread.

Finally, one expert noted that sleep disorders and other medical conditions causing drowsiness may lead to the loss of a commercial or personal driver's license, which is also a countermeasure to drowsy driving.

Sleep Disorder Medications

Untreated sleep disorders such as insomnia and narcolepsy can lead to unsafe driving. Treatments for insomnia include both non-pharmacological interventions as well as medications. Some drugs that treat insomnia have been found to significantly impair next day driving performance. McElroy et al. (2021) conducted a systematic review and meta-analysis of the effect of insomnia treatments on next day driving performance across 14 studies. The authors found clinically significant impairments to driving performance associated with several drugs used to treat insomnia, but reported no evidence of driving impairment associated with the drug lemborexant (McElroy et al., 2021). The authors also discussed other drugs that impair next day driving performance, specifically benzodiazepine hypnotic drugs.

People with narcolepsy report more frequent drowsy driving than people with other types of sleep disorders (McCall & Watson, 2020). Untreated narcolepsy, when diagnosed, can lead to loss of driving privileges. Treatments and lifestyle modifications can help to reduce risk for people with narcolepsy. One study found that people with narcolepsy may have a higher risk of hospitalization for motor vehicle crash injuries and that stimulants, such as modafinil, could mitigate such risk (Tzeng et al., 2019). While narcolepsy treatments can be effective in improving wakefulness, there are few studies examining the specific effects of these treatments on drowsy driving (McCall & Watson, 2020). Certain treatments (e.g., modafinil) may improve driving performance in patients with narcolepsy, though not to the level of unaffected drivers (McCall & Watson, 2020).

Reflections from Experts

Experts discussed the importance of medication management as a strategy for health care providers to prevent drug effects and interactions that could cause sleepiness in patients. Experts noted that health care providers have limited time with patients and may not have a complete medication list to reference during a visit. One expert further noted that the burden falls upon the patient to know what medications they are on and ask their health providers about effects of the medications on drowsiness. This expert noted that if sleep education were emphasized during health care providers' education and training, providers may be more likely to ask about patient sleep habits and identify medications that cause drowsiness as a side effect or when combined with other medications. This expert recommended developing guidelines for health care providers to track medications that commonly have interaction effects that can cause drowsiness. It was noted that there is a need for additional research into the relationship between comorbidities, sleep deprivation, and drowsy driving crashes as well.

Similarly, experts noted a history of substance use disorder must be considered given the relationship between substance use and drowsy driving crashes. One expert also noted that there is a need for more research examining the impact of marijuana legalization on drowsy driving crashes.

Implementation Considerations and Opportunities for Future Research for Medical Countermeasures

People with sleep disorders can benefit from treatments that improve sleep quality and daytime wakefulness while also potentially lowering the risk of drowsy driving. Traffic safety practitioners and health care professionals may wish to consider education and outreach campaigns to increase awareness of sleep disorders (Adamos et al., 2013). Health care professionals can incorporate sleep health into patient care, seek to identify patients who may have sleep disorders, and educate patients on improving their sleep and preventing drowsy driving (NHTSA, 2015).

Policy Countermeasures

Drowsy driving countermeasures include state legislation and policies. A wide variety of legislation mentions drowsy driving, but most laws do not explicitly focus on drowsy driving; instead, drowsy driving is commonly included in statutes that also include distracted or reckless driving. Two states, Arkansas and New Jersey, have laws that explicitly address drowsy drivers involved in crashes that result in an injury or a death. Policy countermeasures are also implemented by employers and within organizations. Employers may develop and implement fatigue risk management systems to improve employee safety and sleep health. Workers commonly at risk for drowsiness and poor sleep health include shift workers such as law enforcement officers, health care workers, and commercial vehicle drivers. Graduated Driver Licensing systems for young novice drivers have reduced crashes overall, though they have not been evaluated for drowsy driving specifically. This section describes policy countermeasures to reduce drowsy driving.

Graduated Driver Licensing Laws

Graduated Driver Licensing (GDL) systems are designed to reduce crashes and injuries among young inexperienced drivers. All states and the District of Columbia have GDL systems (CDC, 2016). GDL systems generally apply to new drivers younger than a certain age (typically 18), typically during the learner's permit period and the first 6 or 12 months of licensed driving (referred to as the "intermediate" or "provisional" stage of the licensing process). They typically consist of a minimum age for obtaining a learner's permit; requirements to possess the permit for a certain length of time and/or obtain a certain number of hours of supervised driving practice before obtaining a license that allows any independent driving; and prohibitions on driving during certain nighttime hours and carrying young passengers during the first several months of licensed independent driving (CDC, 2016).

Studies have found that more comprehensive GDL programs are more effective at reducing crashes among young drivers (CDC, 2016). GDL programs that include nighttime restrictions, extended learner permit periods, an age minimum for new drivers, and passenger age restrictions were associated with reductions in crashes and fatalities (Chen et al., 2006; Williams, 2007; Wolkow et al., 2019). Nighttime restrictions may reduce the number of drowsy driving crashes by targeting times when drowsy driving crashes are more likely to occur (Governors Highway Safety Association, 2016; NHTSA, 2015).

NHTSA has rated GDL nighttime restrictions as a highly effective and low-cost countermeasure (Richard et al., 2018). While the effectiveness of GDL programs in reducing drowsy driving crashes is unknown, GDL programs have been proven to reduce overall crashes, injuries, and fatalities among youth (Governors Highway Safety Association, 2016; Stutts et al., 2005; NHTSA, 2015).

<u>Reflections from Experts</u>

One expert described the importance of GDL night driving restrictions that include earlier nighttime hours for newly licensed drivers. Another expert agreed that earlier nighttime restrictions get new drivers off the road sooner, reducing the chances of nighttime crashes. This expert stated that most states have later GDL nighttime driving restrictions (e.g., 11 pm–12 am), but earlier nighttime driving restrictions (e.g., 9 pm–10 pm) may further reduce the risk of drowsy driving at night. Importantly, however, it was also noted that GDL systems only apply to a very small percentage of drivers (i.e., those who are within their first several months of having obtained their first license).

Employer Management of Work Schedules

Employer management of work schedules can help reduce sleepiness among professional drivers and shift workers who may work irregular hours and nighttime hours (Lyznicki et al., 1998; Mitler et al., 1988; Sparrow et al., 2016). Commercial vehicle operators are required to comply with hours-of-service regulations (Governors Highway Safety Association, 2016). These rules specify the maximum amount of time drivers are permitted to be on duty, including driving and non-driving time, and the number and length of rest periods to help ensure that drivers stay awake and alert (Federal Motor Carrier Safety Administration, 2020). However, some researchers have expressed concerns that hours-of-service regulations are too prescriptive and do not acknowledge biological factors that drive mental fatigue, such as circadian and homeostatic processes (Gurubhagavatula et al., 2021; Honn et al., 2019). When workers must operate outside of normal daytime hours, existing regulations are not as effective in preventing occupational hazards (Gurubhagavatula et al., 2021; Honn et al., 2019).

A Federal Motor Carrier Safety Administration study on commercial truck and motor coach drivers found that changes such as minimizing nighttime driving hours and providing safety training reduced fatigue-related driving incidents and changed driver perceptions of the role of drowsiness in safety (Crum & Morrow, 2002). In addition, a systematic review of the impact of schedule changes on drowsiness among all types of shift workers found that shifts less than 24 hours long were associated with fewer adverse outcomes for patient and employee safety compared to shifts of 24 hours or longer (Patterson, Higgins, et al., 2018). Further, in a study across two hospitals, one with a 30-minute unpaid meal break and one with a fatigue mitigation policy, there was no difference on subjective drowsiness for medical night shift workers taking breaks unless they had a quiet place to rest (Wilson et al., 2018).

Reflections from Experts

Experts discussed the importance of scheduling and workplace policies for reducing drowsy driving before, during (if applicable), and after work shifts. Work shifts can be scheduled to encourage adequate sleep before a drive. Experts noted that workplace policies implementing good scheduling practices and enforcing hours-of-service policies within transportation occupations (e.g., aviation, rail) can reduce fatigue-related crashes. Some experts noted that certain occupations and employers lack guidance on shift scheduling. For example, EMS personnel traditionally work long shifts (e.g., 24–72 hours), though these vary by employer. Additionally, an expert noted the importance of implementing good scheduling practices for non-commercial drivers and the need for education on recommended hours of sleep among the general population. When designing appropriate shift work schedules, employers must pay close attention to timing and duration of work shifts, workload, and commute time that might adversely affect their employees' ability to get adequate sleep (Gurubhagavatula et al., 2021). Tools and resources to assess fatigue and drowsiness are also needed to facilitate employer management of work schedules.

Fatigue Risk Management

Fatigue risk management systems have been described as a "scientifically based, data-driven addition or alternative to prescriptive hours of work limitations which manages employee fatigue in a flexible manner appropriate to the level of risk exposure and the nature of the operation" (Lerman et al., 2012). Fatigue risk management systems have been implemented in various sectors, including commercial vehicles and health care (Phillips et al., 2017; Robbins et al., 2021). Employers have implemented fatigue risk management systems, which may include fatigue risk management plans (Crum & Morrow, 2002; International Association of Oil & Gas Producers & International Petroleum Industry Environmental Conservation Association, 2016; Stutts et al., 2005; NHTSA, n.d.; National Institute for Occupational Safety and Health, 2020).

Fatigue risk management plans establish company policies on managing and mitigating fatigue during work hours. Fatigue risk management plans often include components such as education and training, scheduling restrictions, and policies for non-punitive reporting of fatigued driving. Fatigue risk management aims to provide a system that allows employers to monitor and measure an employee's schedule to ensure that employees understand the policies surrounding flexible operating in an environment where potential fatigue risk can occur.

NHTSA (2017) determined that employer fatigue risk management plans had not been systematically evaluated, and that there is insufficient evidence of their effectiveness as a drowsy driving countermeasure. A panel convened by NASEM identified fatigue risk management systems and plans as promising countermeasures in the aviation, rail, and pipeline industries and recommended they be researched further as potential models for commercial motor vehicle operation (NASEM, 2016). Further research is needed to determine if they also are effective among other populations at risk of fatigue-related crashes such as health care workers and law enforcement.

Reflections from Experts

Experts stated that fatigue risk management systems provide a structural framework that places all countermeasures into context to be deployed collectively in a coordinated fashion. They are an additional layer of protection from drowsy driving, but are not a substitute for hours-of-service regulations. Additionally, the systems can be continuously improved so that lessons learned are incorporated into future operations.

One expert stated that companies must communicate fatigue risk management systems to their employees to ensure that employees understand the importance of the policies, employer expectations, compliance rules, and monitoring processes. Also, another challenge is addressing the stigma in the workplace related to reporting fatigue. Experts noted that employers and employees have a shared responsibility to work together to promote health and safety. Specifically, the employee has a responsibility to report if they are fatigued and therefore not fit to drive, and the employer has the duty to provide adequate opportunity for employees to rest and recover. Workplace policies and culture must support the identification and mitigation of fatigue risk.

Experts commented that the Occupational Safety and Health Administration does not currently endorse fatigue risk management systems, but that it should address the negative effects of 24-hour work shifts on physical and mental health. In addition, experts discussed how companies without fatigue risk management policies can provide employee assistance programs that include resources for sleep management. For example, employers may offer health insurance benefits for screening sleep disorders, education on healthy sleep habits, flexibility with sick days due to fatigue, and benefits for parental leave.

Fatigue Management Training and Guidelines

Ensuring individuals understand the risks and signs of sleepiness can promote better decision-making while driving (Higgins et al., 2017). Employers use fatigue management training and guidelines to educate and train employees, including commercial drivers, EMS workers, and other professionals working long hours and irregular shifts, about the dangers of drowsy driving.

In one simulation-based study, a brief (15–30 minute) fatigue and sleepiness evaluation training program on hazard anticipation, hazard mitigation, and attention maintenance was found to improve these skills among drivers who had been awake for 12 hours, relative to a control group given no training (Hamid et al., 2016). For all three skills, drivers performed significantly better during the post-test than the pretest, whereas the drivers in the control group performed significantly worse. While fatigue and sleepiness also increased in the post-test, the training effects were still observed.

Studies have suggested the positive impact of fatigue management training programs for shift workers (Barger et al., 2018; Transportation Research Board, 2012). Trainings include multiple formats (e.g., lectures, workshops); durations (e.g., 1-hour presentations, 8-week courses); instructors (e.g., fatigue experts, teammates, peers); and delivery methods (e.g., in person, online, email). Fatigue training and education among EMS shift workers reduced the number of drowsy driving episodes and motor vehicles crashes, ultimately improving personnel safety and performance, patient safety, and acute fatigue (Patterson, Higgins, et al., 2018). Additionally, a report by NHTSA titled *Asleep at the Wheel* describes approaches used by a variety of employers to incorporate sleep wellness and fatigue management programs into their business environments (NHTSA, 2015). The report also highlights the work of the National Institute for Occupational Safety and Health, the Network of Employers for Traffic Safety, and the National Safety Council to develop employer programs and education to prevent drowsy driving.

Reflections from Experts

Experts stated that education is necessary but not sufficient in reducing drowsy driving as part of employer programs; education must be used in conjunction with other countermeasures (e.g., technology, medical, employer workplace policies). Experts also described challenges associated with employer risk management training programs. For example, small employers may not have the knowledge or resources to implement high-quality programs. As a result, employees may not receive proper education and training to prevent drowsy driving. Also, employees working in different industries participate in different programs; fatigue management training lacks standardization across industries.

Drowsy Driving Laws

Drowsy driving laws are designed to reduce the number of drowsy drivers on the road. Two states have enacted laws that specifically focus on drowsy driving—New Jersey and Arkansas. In New Jersey, "driving a vehicle or vessel while knowingly fatigued shall constitute recklessness. 'Fatigued' as used means having been without sleep for a period in excess of 24 consecutive hours." (An Act concerning vehicular homicide and amending N.J.S.2C:11-5., 2002). The charge of vehicular homicide applies when a death occurs by a vehicle or vessel and the driver meets the criteria for fatigue. In Arkansas, fatigued driving is an offense under negligent homicide. A person commits negligent homicide if they "cause the death of another person, not constituting murder or manslaughter, as a result of operating a vehicle, an aircraft, or a watercraft," and fatigued means "having been without sleep for a period of twenty-four (24) consecutive hours or having been without sleep for a period of twenty-four (24) consecutive hours and in the state of being asleep" (An Act to Amend the Offense of Negligent Homicide; and for Other Purposes, 2013).

According to NHTSA, traffic safety laws require significant public awareness and enforcement to be effective. It is difficult for police officers to identify a drowsy driver, suggesting that laws making drowsy driving illegal may not be effective in deterring this behavior. Efforts to increase awareness and educate drivers about drowsy driving laws are important (NHTSA, 2015).

Reflections from Experts

Experts described one benefit of drowsy driving laws, noting that laws increase the likelihood that law enforcement officials will cite drowsy driving as the cause of a crash, though this is still quite rare. Experts shared anecdotes where, even when the driver admitted to falling asleep before a crash, the driver was not cited for drowsy driving due to the absence of a specific statute.

Reliable, complete data are critical for creating and enforcing laws and regulations and making the case for investing resources to address drowsy driving. Multiple experts underscored the need for reliable data on driver drowsiness. While highway safety practitioners naturally desire more comprehensive and complete data on drowsy driving among drivers involved in crashes, one expert noted that when a police officer arrives on the scene of a crash several minutes after it occurred, it is typically impossible for the police to determine whether drowsiness played a role in the crash unless the driver or a witness reports it. A useful and feasible improvement in data systems would thus be to design data collection forms to clearly differentiate whether a driver was known to have been drowsy, known not to have been drowsy, or whether the driver's drowsiness was unknown. This would enable researchers to use statistical models to estimate the probability of drowsiness in cases where the role of drowsiness was uncertain. This, however, is impossible when the data do not distinguish between "not drowsy" versus "unknown if drowsy" (Tefft, 2012).

Finally, experts commented that while the current state laws define drowsy driving as being without sleep for 24 consecutive hours, shift workers such as resident physicians are often required to work shifts in excess of 24 hours. Therefore, health care professionals and others who work long shifts must have time built into their shift to nap and additional fatigue countermeasures in place to ensure that they do not violate any applicable drowsy driving laws.

Later School Start Times

Many students do not get the recommended amount of sleep due to early school start times (Danner & Phillips, 2008; Foss et al., 2019; Governors Highway Safety Association, 2016; NHTSA, 2015). The American Academy of Pediatrics (AAP) has recommended later school start times since 2014 (AAP, 2014), and, in 2021, the American Academy of Sleep Medicine took the position that middle school and high school start times should be 8:30 am or later (Ramar et al., 2021). Several states have signed legislation encouraging schools to consider the feasibility of adopting later start times for students; however, most middle and high schools have start times before 8:30 am (Governors Highway Safety Association, 2016; Wahlstrom et al., 2014).

A few studies have evaluated the effect of later school start times on drowsy driving crashes in school districts that have shifted their start time. Danner and Phillips (2008) used a questionnaire to assess students' amount of sleep and rates of motor vehicle crashes before and after a one-hour delay in school start time in one study county. They found that students reported an increase in hours of nightly sleep and a 16.5% reduction in crash rates in the study county for two years following the change (Danner & Phillips, 2008). Another study showed similar results across eight high schools in Minnesota, Colorado, and Wyoming, where there was a 13% reduction in crashes after shifting to a later school start time (Wahlstrom et al., 2014). Similarly, a study of the impact of later school start times in one North Carolina county found the shift to later school start times was associated with significant decreases in teen driver crash rates during the hours when teenagers would be driving to and from school relative to crash rates in several comparison counties that did not change their school start times (Foss et al., 2019). However, the authors noted that more research is needed to determine whether the observed associations were attributable to reductions in drowsy driving or to other factors such as changes in driving exposure.

The U.S. Department of Health and Human Services' *Healthy People 2030* identified school start times as a research objective (i.e., "increase the proportion of secondary schools with a start time of 8:30 am or later), meaning that it is a high-priority public health issue that does not currently have evidence-based interventions or reliable baseline data available (Office of Disease Prevention and Health Promotion, n.d.).

Reflections from Experts

Experts discussed the health and safety benefits of starting middle schools and high schools at a later time. One expert noted that reducing drowsiness is the key to decreasing drowsy driving crashes among teen drivers. Another expert said that later start times for high school students would not only impact driving safety, but also improve academic and athletic performance. It was also noted that California recently passed legislation that will require non-rural high schools in the state to begin their school day no earlier than 8:30 am by the 2022–23 school year (An Act to add Section 46148 to the Education Code relating to pupil attendance, 2019), presenting an opportunity and an imperative to evaluate its impact.

Implementation Considerations and Opportunities for Future Research for Policy Countermeasures

NHTSA (2015) and Governors Highway Safety Association (2016) emphasize the importance of accurate and complete data to inform drowsy driving countermeasures. However, the lack of quality data limits advocacy efforts for drowsy driving policies. Broadly, the policy countermeasures discussed in this section commonly expand and support other countermeasures. Further evaluation is needed to determine the effectiveness of these policy countermeasures in reducing drowsy driving crashes.

Conclusions

Drowsy driving continues to be a significant public health problem in the United States. There are many different types of countermeasures to prevent and mitigate drowsy driving crashes and highlight the consequences of drowsy driving. The research described in this report sought to document drowsy driving countermeasures; describe the practical application of drowsy driving countermeasures, including their limitations; and explore which countermeasures can be implemented more widely. The following conclusions summarize key findings as well as opportunities for future research.

Obtaining Sufficient Sleep, Napping, and Consuming Caffeine Reduce the Risk of Drowsy Driving

This study identified three behavioral countermeasures supported by evidence that they are effective in reducing the risk of drowsy driving: obtaining sufficient sleep, consuming caffeine, and napping in conjunction with consuming caffeine.

First, obtaining sufficient sleep is the number one countermeasure for reducing the risk of drowsy driving by preventing drowsiness from occurring in the first place. Healthy adults need between 7 and 9 hours of sleep per night, and any sleep less than the recommended minimum of 7 hours for adults is considered insufficient and could impair driving performance (Matthews, et al., 2012). While not a substitute for sufficient sleep, caffeine is an effective countermeasure for transient fatigue and provides a short-term benefit, though the optimal dose may differ from person to person. Evidence also supports the effectiveness of napping and consuming caffeine, and specifically, consuming caffeine prior to a 20-to-30-minute nap, to increase driver alertness for a short period of time (NHTSA, 2021).

Notably, there is insufficient or mixed evidence on the effectiveness of other behavioral countermeasures in preventing or mitigating drowsy driving, such as napping and bright light, conversation, interactive tasks to increase mental alertness, exercise during a break, and taking a break without napping or caffeine. Evidence on eating, chewing gum, or opening the car window as a countermeasure is also insufficient, though some research suggests that these are not effective as countermeasures to reduce drowsy driving.

Further research is needed on the effects of caffeine for different populations, the effects of different types and amounts of caffeine, and the ideal timing of caffeine intake. Additional research is also needed to understand how long the potential benefits of behavioral countermeasures such as caffeine and napping last; the benefits for specific populations (e.g., general population of drivers, people who work shifts); and the effects when combined with other countermeasures.

Advanced Driver Assistance Systems are Effective in Preventing Crashes, Though More Research is Needed on their Effectiveness in Reducing Drowsy Driving Crashes Specifically

Advanced driver assistance systems, although not designed to address drowsy driving specifically, can help to mitigate the consequences of drowsiness, for example by preventing the vehicle from departing the road or automatically applying the brakes in a crash-imminent situation. This study found that advanced driver assistance systems such as forward collision warning, lane departure warning, automatic emergency braking, and lane keeping assistance systems have evidence of effectiveness in reducing rates of crashes in general. Theoretically they have the potential to reduce crashes due drowsiness, though additional research is needed.

Other technology-based countermeasures have mixed or insufficient evidence including vehicle-based drowsy driver detection and alerting systems, technology to manipulate physical workload to increase mental alertness (e.g., by increasing steering demands), blue light, fitness to drive evaluation technologies, roadside drowsiness tests, stimulus-response reaction tests, and biometric devices (wearables).

Research is needed to determine the best method for alerting drivers who show signs of drowsiness and impelling them to take appropriate action (i.e., stop driving and rest). Most research on technological countermeasures to detect drowsiness has been simulator-based. Real-world validation is necessary but can be difficult to implement for safety and feasibility reasons. Several real-world studies of data from crashes and insurance claims have shown clear safety benefits associated with advanced driver assistance systems.

Rumble Strips are Effective in Preventing Crashes, Though More Research is Needed on their Effectiveness in Reducing Drowsy Driving Crashes

Infrastructure countermeasures are modifications to the physical roadway environment to reduce the likelihood or severity of drowsy driving crashes. Infrastructure countermeasures can prevent drowsy driving crashes or mitigate the severity of crashes, but they are not specifically designed to keep drivers alert or to reverse drowsiness. Research shows that shoulder and centerline rumble strips are highly effective in reducing crash rates, though more research is needed on their effectiveness with respect to drowsy driving crashes. While rumble strips are effective in preventing crashes, they will not prevent a drowsy driver from continuing to drive and crashing further down the road where rumble strips are not present.

Highway rest areas are another infrastructure-based countermeasure. They do not combat drowsiness directly, but they provide opportunities for drivers to employ other effective countermeasures such as taking a nap and consuming caffeine. While not researched extensively, existing research suggests that the presence of rest areas is associated with reduced crash frequency and severity. However, more research is needed to evaluate the effects of rest areas in preventing drowsy driving crashes.

Education is Important for At-Risk Populations but Insufficient in Reducing Drowsy Driving and Must Be Combined with Other Countermeasures

Educational countermeasures focus on increasing the understanding of the risks and signs of drowsiness to change behavior and promote better decision-making. Additionally, education on sufficient sleep can make individuals aware of the consequences of sleep deprivation and how it interferes with cognitive ability. The literature suggests that education is a necessary countermeasure to reduce drowsy driving. However, education alone is not sufficient to reduce drowsy driving; it must be combined with other countermeasures (e.g., technology, medical, policy). Examples of populations at risk of drowsy driving that would benefit from tailored education on drowsy driving include teen drivers and their parents, health care professionals, and shift workers.

Teen Drivers and Their Parents

Teens need more sleep than adults (8 to 10 hours), but they may not get adequate sleep given the amount of screen time and activities they engage in and early school start times (Hirshkowitz et al., 2015). The lack of adequate sleep can lead to drowsy driving. It is important that teens are educated about the need for adequate sleep and the risks of drowsy driving. Education for parents on the importance of sufficient sleep for their children is another way to reach teen drivers and prevent drowsy driving.

Health Care Professionals

Sleep education is important not only for health care providers so that they can guide their patients, but also for health care professionals themselves who must manage their own risk of drowsy driving given long shifts. However, primary care providers and specialists may not receive adequate sleep-related medical education and training (Ramar et al., 2021). Sleep educational curricula could include approaches to provide instruction and education on sleep and sleep disorders during medical or graduate school (Ramar et al., 2021).

Shift Workers

Shift workers have a high risk of drowsy driving–related crashes due to circadian disruption in addition to sleep deprivation. Shift workers may benefit from education on the signs and symptoms of drowsiness and the consequences of drowsy driving.

Sleep Disorders Treatments Are Available, Though More Research is Needed on Their Effects on Drowsy Driving

Drivers with sleep disorders, including insomnia, obstructive sleep apnea, and narcolepsy, have an increased risk of crash involvement. Medical countermeasures include increasing awareness of and treating sleep disorders that can cause drowsiness and affect driving. For example, treatments such as continuous positive airway pressure machines can increase airflow during sleep for people with sleep apnea, and treatments for narcolepsy can improve wakefulness. However, more research is needed on the effectiveness on drowsy driving of these and other medical countermeasures. Also, there are barriers to screening, referral, and treatment for sleep disorders, among both commercial motor vehicle drivers and the general population. The literature suggests that health care professionals should incorporate sleep health into routine care and educate patients on improving their sleep, seeking treatment for sleep disorders, and preventing drowsy driving.

Policy Countermeasures Require Further Research to Understand Their Effectiveness in Preventing or Mitigating Drowsy Driving

Drowsy driving policy countermeasures include state legislation and policies as well as employer-based policies. New Jersey and Arkansas have laws that expressly address drowsy drivers involved in crashes that result in injuries or death. However, research and data are needed on the effectiveness of these laws in reducing drowsy driving or drowsy driving–related crashes.

Shifting secondary school start times to 8:30 a.m. or later has been identified as a potential drowsy driving countermeasure. Some research in jurisdictions that have shifted school start times later suggests that the shift may have reduced rates of teen driver crashes (e.g., Danner & Phillips, 2008; Foss et al., 2019), however, more research is needed to confirm these findings and examine effects in other jurisdictions.

GDL systems, which restrict newly licensed teenage drivers from certain high-risk conditions such as driving at night and carrying passengers, have been shown to reduce rates of crashes, injuries, and deaths of teenage drivers. However, the extent to which GDL systems may help to reduce drowsy driving crashes in particular is unknown and requires further research.

Finally, fatigue risk management systems and employer management of work schedules have not been consistently evaluated and require further research to understand their effectiveness in preventing or mitigating drowsy driving or drowsy driving–related crashes.

Areas for Future Research and Action

The experts identified key cross-cutting areas for future research and action, which were also supported by the literature.

Drowsy Driving Countermeasures Need to be Tested in Naturalistic Settings or with Real-World Data to Assess Effectiveness

Many drowsy driving countermeasures have been tested in laboratory settings where drowsiness and the driving task can be experimentally manipulated. While these studies are critical, research is also needed in naturalistic settings using real-world data to understand countermeasure effectiveness, the nuances of reducing drowsy driving among different populations in different settings, and the most effective combination of countermeasures in real-world traffic and environments. A countermeasure may be successful in a laboratory setting, but drivers may react to drowsiness or use the countermeasure differently in real-world situations. Naturalistic and observational studies can help to increase our understanding of drowsy driving countermeasures and their effectiveness.

Reliable and Informative Driver Drowsiness Data is Needed to Understand and Address Drowsy Driving

Reliable and informative data are critical to understanding the prevalence of drowsy driving in the United States, communicating the consequences of this behavior, and evaluating countermeasures. Drowsy driving and drowsy driving crashes are widely regarded as underreported, both because it is difficult for police officers to determine after a crash whether the driver was drowsy before the crash, and because drowsiness is rarely the only cause of a crash; usually there are other more readily identifiable contributing factors that are reported (e.g., the driver left the roadway or stuck an obstacle). Therefore, law enforcement officials rarely report drowsy driving at the scene of a crash. Law enforcement officials need information about the signs and symptoms of drowsy driving and should always consider whether drowsiness played a role in causing a crash.

Since it is difficult for police to ascertain the role of drowsiness after a crash has already occurred, it is especially important for crash reporting to include more readily observed factors shown in research to be correlated strongly with the involvement of drowsiness (e.g., time of day; departure from the lane or road; lack of any apparent attempt to avoid the crash). A standardized checklist could help law enforcement identify fatigue-related crashes, and it could also help researchers to estimate the overall prevalence of drowsiness in crashes even if the involvement of drowsiness is not necessarily ascertained in every individual crash. Further, electronic data collection and reporting of drowsy driving indicators could help address the gap in available data and improve the consistency of the data that are collected.

Similar to other traffic safety issues such as substance-impaired driving and distracted driving, reliable information can help increase understanding and awareness of the scope of drowsy driving as a problem in the United States, aid in evaluating countermeasures, and help make them actionable. Data can also underscore the need for actionable legislation, policies, and enforcement to address this issue.

Drowsiness-Related Stigma in the Workplace Needs to be Addressed

Drowsy driving has significant consequences for employers and employees. Employees who drive while drowsy are at risk for crash, injury, and potentially death. The consequences to an employer when an employee is involved in a drowsy driving crash can include absenteeism, loss of productivity, increased health care costs resulting from injuries, as well as potential liability for property damage or injuries involving other road users. Employers and employees must work together to prevent drowsy driving. Fatigue risk management systems, in which both employers and employees share responsibility for managing causes of fatigue, can help employers and employees reduce fatigue-related risks at work (Honn, et al., 2019).

It is important to acknowledge the existence of stigma associated with disclosing fatigue or medical conditions that cause fatigue in the workplace. This stigma appears to be prevalent and may deter employees from seeking help. Promoting a workplace culture where employees can openly report drowsiness or task-related fatigue is possible, and there are guidelines for how to manage these risks (Dekker, 2008). Ultimately, addressing drowsiness-related stigma in the workplace is critical to reducing drowsy driving.

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