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Electronic Device Use: A Review of the Literature on Addictive Behaviors

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16. Abstract

This is a state-of-knowledge report on excessive device use while driving. The purpose of this report is to determine if excessive device use while driving is the result of an addiction, why this behavior persists, and what countermeasures to consider. Reviewers consulted academic, government, and private-sector material from several disciplines including, but not limited to, human factors, traffic safety, psychology, and demography. Over 270 sources were reviewed, with 155 sources critically reviewed using a structured document summary template. Reviewers found that electronic device use does not qualify for the formal definition of addiction described in the Diagnostic and Statistical Manual of Mental Disorders, 5th edition. This is because dependent device users are not proven to demonstrate several aspects of addiction, including: (1) a diminished recognition of significant problems with one's own behavior and relationships, (2) an inability to consistently abstain, and (3) an impairment in behavioral control. However, device dependency can mimic aspects of addiction since dependent users report a craving for their phone, they rely on cellphones to relieve distress, and their emotions are highly influenced by their phones. To describe this type of device dependency, reviewers use the phrase "problematic device use," or PDU. There is not a clearly defined threshold for PDU in the vehicle, but this phrase captures several conceptual alternatives to addiction, including compulsive use, habitual behavior, and consistent maladaptive behavior. PDU is more likely to persist among certain demographics and personality types, including young people, less wealthy people, people with low self-esteem, and people with higher levels of anxiety, impulsivity, extraversion, and sensation-seeking. So-called "addictive design" can also exacerbate the problems associated with PDU by capitalizing on a user's desires for entertainment, accomplishment, or social interaction. Existing countermeasures against distracted driving can be adapted to reach problematic device users. These countermeasures come in three forms: information-enhancing strategies to inform users about their behaviors and risks, behavior-reinforcing strategies to restrict phone use, and capacity-building strategies to address underlying issues.

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List of Acronyms

AAM	Alliance of Automobile Manufacturers
ADAS	advanced driver assistance systems
ADHD	attention-deficit hyperactivity disorder
APA	American Psychiatric Association[1]
BFI	Big Five Inventory
BIS	Barratt impulsiveness scale
CPD	cellphone dependency scale
CPOS	cellphone overuse scale
DBQ	driver behavior questionnaire
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, 5th Edition[2]
EDR	event data recorder
FARS	Fatality Analysis Reporting System
HVE	high-visibility enforcement
IVIS	in-vehicle information system
MPIQ	mobile phone involvement questionnaire
MPPUS	mobile phone [sometimes problematic] problem use scale
MRI	magnetic resonance imaging
MVC	motor vehicle crash
NMP-Q	nomophobia questionnaire
NOPUS	National Occupant Protection Use Survey
OEM	original equipment manufacturer
PDU	problematic device use
PDUr	probematic device user
PMPUQ	problematic mobile phone use questionnaire
PSA	public service announcement
SHRP2	Strategic Highway Research Program 2
SHSO	State Highway Safety Office
SOK	state-of-knowledge
STDS	self-perception of text dependency scale
TPB	theory of planned behavior
TRID	Transportation Research International Documentation
TSCI	Traffic Safety and Culture Index

[1] APA is also an acronym for the American Psychological Association.
[2] [Editor's note: Earlier editions of the DSM used roman numerals, such as DSM-IV. When it was updated in 2013, the publisher, the American Psychiatric Association, APA, changed the style to DSM-5, in part so future updates could be designated 5.1, 5.2, etc., which could not be accomplished with roman numerals. Still, it is common to see many references to DSM-V, although these are technically incorrect. The actual cover of the manual clearly says DSM-5 in large type, and in fact that term is trademarked with the 5, not the V.]

Executive Summary

Introduction and Approach

The ubiquity of electronic devices in people's lives has raised concerns that some people may become addicted to their devices and use them in unsafe situations such as while driving. Distracted driving occurs when drivers divert their attention away from activities critical for safe driving and toward a competing activity—such as electronic device use. This includes any activity where users interact with electronic devices, including touching screens, watching videos, and talking into microphones. Visual distractions are observed to be more dangerous than manual or cognitive distractions, though combinations of distractions as occurs in many technology-based tasks such as texting are often especially risky.

This National Highway Traffic Safety Administration state-of-knowledge report summarizes the most recent research about excessive device use while driving. Reviewers found that excessive device use does not qualify for the formal definition of addiction described in the Diagnostic and Statistical Manual of Mental Disorders commonly known as DSM-5. Nevertheless, excessive device use can mimic some aspects of addiction, so reviewers use the phrase "problematic device use" to describe this behavior. There is no clearly defined threshold for PDU in the vehicle, but it is generally characterized by functional impairments due to this use, and includes visual, cognitive, and manual distractions. Problematic device use is also associated with a recurrent craving to use a device even in an inappropriate situation.

The overall objective of this report is to increase NHTSA's understanding of PDU and its relationship to traffic safety. This review provides information on topics and their inter-relationships including distracted driving, behavioral addiction, electronic device use, and traffic safety. To obtain data sources for this report, the reviewers consulted academic, government, and private-sector material from disciplines including human factors, traffic safety, psychology, and demography. More than 270 sources were reviewed, with 155 sources critically reviewed using a structured document summary template. This resulting report is a multi-disciplinary, current compendium of the literature on PDU while driving that supports the planning and conduct of future research, safety programs, countermeasure implementation, and policy decisions. This report is a resource for researchers, highway safety and health professionals, safety advocates, and members of the public.

The report begins with an overview of general driver distraction and how it compares with PDU while driving (Chapters 1 to 3). This is followed by a discussion of addiction and why PDU is not a behavioral addiction (Chapters 4 and 5). Then, the behaviors, consequences, and individual differences associated with PDU while driving are covered (Chapters 6 and 7). Finally, emerging countermeasures for PDU while driving are presented (Chapter 8).

Research Sources

Problematic device use, especially in the driving context, is an emerging research area with a rapidly growing base of literature. Most of the 1,050 data sources gathered for this report were published from 2015 to 2020, though older studies were included as appropriate to provide context. The predominant types of sources used were academic literature in journals, especially journals related to traffic safety, human factors, and psychology. For most topics the pertinent studies were based on self-reported measures such as surveys. For research sources regarding prevalence and crash risk associated with distracted driving behaviors, the most relevant publications were large-scale naturalistic and observational studies, along with government reports. Studies from the United States were prioritized for maximum applicability to the Nation's social, legislative, and driving contexts. Predominant keywords in the sources used to compile this report were terms related to distracted driving (i.e., "distraction," "attention," and "secondary task"), terms related to device use (i.e., "cellphone," "mobile phone," and "technology"), terms related to addiction, (i.e., "addiction," "dependence," and "habit") and terms related to traffic safety (i.e., "crash," "collision," and "enforcement").

Findings

The primary findings described below are organized into research questions that align with the report chapters.

How Much of a Problem Is General Electronic Device Use While Driving?

Device use while driving in general is prevalent, though this phenomenon has almost exclusively been studied in terms of cellphones.[3] A large proportion of drivers use their cellphones in hands-free mode while driving. This could be due to the widespread belief that this type of use is safer. Yet, drivers are increasingly using the internet and an array of smartphone applications (apps) while driving. Typical functionalities are widespread and generally viewed as acceptable while driving, including playing music and navigation assistance. Other functions pose greater safety risks, like social media use and gaming. Some smartphone apps also have "addictive design" components that make them particularly appealing—and dangerous—to operate while driving. Addictive design components include personalized feeds, endless scrolling, token rewards, and social comparison features. These components could make a driver feel compelled to immediately respond to notifications, regardless of the traffic context.

Device use while driving increases crash risk by up to 30 times and contributes to crash severity. These crashes are difficult to characterize and record because methods for observing and reporting distraction need further development. Cellphone use while driving has serious consequences, including fatalities, injuries, driving performance decrements, and traffic congestion due to increased crashes and interrupted traffic flows. About 90 percent of drivers consider cellphone use while driving to be very or extremely dangerous and support legislation against this behavior. Yet, even among those who report firm anti-distracted-driving opinions, large proportions of drivers continue to use devices on the road.

Who Is Affected by General Electronic Device Use While Driving?

Young drivers roughly 16 to 25 years old are especially likely to use cellphones while driving and age is the most frequently studied demographic variable in relation to device use while driving. Drivers over 65 have much lower rates of cellphone use (handheld phone-calling, handheld device manipulation, hands-free phone calling, and hands-free viewing) behind the wheel than young and middle-aged drivers and are far less likely to report sending or reading text messages while driving.

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3 [Editor's note: "Mobile phones" and "cellphones" are generally considered to be the same things. "Cell" tends to be American usage and "mobile" tends to be British usage. Mobile "devices," on the other hand, may include cellphones but also could be game-playing systems, cameras, GPS and navigation devices, music and movie players, and dictation/recording devices, etc.]

Certain personality traits also seem to be related to higher phone use while driving, including high self-efficacy, high sensation-seeking, and lower executive function. Drivers with these characteristics are also more likely to engage in other distracted driving behaviors as well as other risky driving behaviors such as speeding. Driver choices of whether to use devices behind the wheel are influenced by factors including road environment complexity, road environment familiarity, police presence, passenger presence, and the person they are digitally communicating with, if applicable. Moreover, the *theory of planned behavior* is a useful framework for understanding how psychological factors predict intentions to use mobile devices while driving, particularly attitudes and perceived behavioral control. Theories of habitual behavior are similar to the TPB and they are also predictive of excessive electronic device use.

Can Electronic Device Use Be Addictive?

The exponential increase in cellphone ownership has prompted consideration of cellphone use as a possible behavioral addiction. According to the DSM-5, addiction is "a chronic, relapsing disease of the brain that is characterized by a pathological pursuit of reward." DSM-5 recognizes only one behavioral addiction—gambling disorder, while all other recognized addictions involve substance abuse (e.g., alcohol or heroin addiction). This is because gambling is the only behavior that is proven to qualify as a pathological pursuit of reward. Device use does not qualify because users are not proven to demonstrate three aspects of addiction: diminished recognition of significant problems with one's own behavior and relationships, inability to consistently abstain, and impairment in behavioral control. Instead, excessive device use appears to fall under alternative concepts, such as compulsive use, habitual behavior, or consistent maladaptive behavior.

The term "problematic use" captures aspects from all these concepts, and it is the most appropriate term for the heavy device-use behavior examined in this report. Many psychological scales have been developed to assess problematic cellphone use, suggesting potential for the next update of DSM to incorporate standards for cellphone use. The biopsychosocial model of addiction is useful for understanding how addictions arise and what areas of life they affect. This general model of addiction posits three components that most addictions have: biological, psychological, and sociocultural characteristics. Problematic phone use exhibits varying degrees of all three components, but not as clearly identifiable as established types of addiction.

Problematic cellphone use has a biological component, due to relationships between this behavior and brain chemistry. It also has stronger effects on areas of the brain related to impulsive behavior than those related to inhibiting behavior. Problematic cellphone use also has a psychological component because certain characteristics of many cellphone applications make them particularly compelling and rewarding to use. People with PDU habits can also feel a loss of control over their own usage. This condition also has a sociocultural component because it varies depending on demographics and personality traits. The primary individual differences that predict PDU are young age and low self-esteem. Self-esteem should not be confused with self-efficacy since self-esteem is about one's overall personal worth, not one's ability to perform a behavior. Self-efficacy also has an impact on problematic device, though the impact is not as strong as self-esteem. Although problematic cellphone use lacks all the characteristics of an addiction, it can still cause psychological dysfunction.

Does Problematic Device Use While Driving Have Identifiable Traffic Safety Consequences?

There is no exact threshold for the amount or type of usage that qualifies a driver as engaging in PDU while driving. Furthermore, PDU per se has not been examined in traffic safety research, so the closest proxy is "frequent" device use while driving. It is likely that only a small percentage of drivers -- around 2 to 4 percent-- have problematic cellphone use habits. Drivers who frequently use devices while driving appear to be at an elevated risk of crashes both because frequent device use presents risk and because these drivers are more likely than the general population to perform other risky behaviors as well. A driver with a problematic cellphone use habit is also more likely to have previously been in a motor vehicle crash.

Frequent, long-duration distractions are very risky while driving. People with problematic cellphone use patterns are especially likely to experience these partly due to the "addictive design" components of the apps these drivers tend to use.

What Driver-Specific Aspects Underlie Problematic Device Use While Driving?

There is almost no available research that specifically examines driver factors that mediate PDU specifically in the context of driving. However, this question was addressed by examining research from two separate but related domains: drivers who frequently use devices while driving, and drivers who report symptoms indicative of device dependency but not necessarily problematic use.

Existing research can be organized according to the pathway model described by Billieux et al. (2015) for understanding driver-specific aspects of electronic device use. Significant factors were associated with frequent device use while driving for each of the three primary pathways, as follows.

- **Excessive Reassurance Pathway:** Device dependency mediates the relationship between neuroticism and increased device use while driving.
- **Extraversion Pathway:** There may be different types of PDUrs: high extraversion has been associated with frequent use, but not device dependency.
- **Impulsive Pathway:** High frequency of device use is consistently related to more frequent and lengthy device use; given the neurological connection between impulse regulation and habits, it may follow that drivers are reinforcing impulsive tendencies through habituation, but these traits have not been studied together.

Based on the studies reviewed, it is not possible to claim with certainty that PDU directly contributes to traffic safety problems more than general device use. However, the repeated observations of increased device use while driving suggest that problematic use indirectly contributes to the distracted driving problem by increasing the frequency and duration of distractions, especially during higher risk driving contexts.

What Emerging Countermeasures From Related Domains Are Applicable to Problematic Device Use While Driving?

As of yet, there are no developed countermeasures to specifically address PDU while driving. However, treating PDU behind the wheel can generally be informed by research aimed at treating PDU in daily life. The three strategies for doing this are classified as follows: information-enhancing, behavior-reinforcing, and capacity-enhancing. Information-enhancing strategies inform people of risks of device use, such as public information/outreach campaigns, or in-vehicle feedback messages reporting drivers' phone use to them. Behavior-reinforcing strategies limit device access, such as technologies that block phone use while driving. Finally, capacity-building strategies address underlying issues that lead to PDU while promoting healthy habits. Examples include holistic behavioral interventions and signing personal pledges against cellphone use while driving.

Technological approaches to treating PDU while driving use are among the most developed and promising. These include blocking, filtering, monitoring, and feedback technologies. An emerging filtering technology is adaptive filtering, which adapts allowable digital secondary tasks to a driver's surrounding environment and/or to the driver's past behavior. Monitoring and feedback technologies aim to teach drivers skills and reduce their motivation to use cellphones while driving. This contrasts with blocking and filtering technologies, which merely limit cellphone functionality during driving. Legislation against cellphone use while driving is necessary but insufficient to deter drivers from this behavior, especially since enforcement of these laws can be challenging.

Conclusions

This NHTSA report presents the following novel and applicable conclusions about PDU while driving.

Excessive device use, including device use while driving is not currently classifiable as an addiction. The term problematic device use better fits the effects and outcomes that characterize this behavior. More importantly, however, problematic use is still associated with psychological dysfunction.

Certain demographic factors (such as younger age) and personality traits (such as extraversion) predispose people to PDU. These are similar but not identical to those that predispose people to normal device use while driving in the absence of problematic use symptoms.

PDU while driving can present elevated safety risks. For problematic device users, technology creates frequent, cognitively absorbing distractions that can occur at times that are highly influenced by factors outside the vehicle (e.g., when drivers respond to notifications immediately). Moreover, the heightened traffic safety risk created by PDU is in part due to "addictive design," a software development strategy that applies knowledge of human psychology to make digital content highly compelling.

1. Overview of Driver Distraction and Problematic Device Use

Background

Electronic devices have become an integral part of people's daily lives. Digital activities increasingly occur on mobile devices that can be held in one's hand and used inside vehicles, rather than large televisions or computers. These include laptop computers, tablets, and portable video game consoles. Yet the mobile device that has received by far the most attention in media and academic literature is the cellphone. As of June 2019, 96 percent of the United States population owned some type of cellphone and 81 percent of Americans owned smartphones (Pew Research Center, 2019), cellphones that can access the internet and offer much the same functionality as computers (Cambridge University Press, 2020). Nearly one-fifth of the people surveyed in America access the internet exclusively through smartphones (Pew Research Center, 2019), demonstrating the Nation's growing reliance on these devices.

Cellphones provide personal and professional benefits for people and facilitate community development, safety, and the exchange of information (Delgado et al., 2016; Kaviani et al., 2020; Shaw et al., 2019). In contrast, cellphone use has also been empirically linked to anxiety and depression, declines in physical health, and unsafe driving behaviors (Busch & McCarthy, 2021; Coyne et al., 2019; O'Connor et al., 2017). With the entrenchment of smartphones in everyday life, the distinction between appropriate and maladaptive use has become ambiguous (Gonçalves et al., 2020; Kardefelt-Winther, 2015; Kuss & Billieux, 2017). This NHTSA state-of-knowledge report is an integrated research review regarding unsafe driving behaviors in relation to excessive, or "addicted" cellphone use. Much has changed in safety science and society since the publication of NHTSA's 2008 SOK on distracted driving (Ranney, 2008). For one, the research community has become increasingly concerned about cellphone and smartphone addiction.

The first empirical studies that addressed the psychological factors associated with problematic cellphone use were published in the early 2000s (e.g., Bianchi & Phillips, 2005; Jang, 2002). Currently, prevalence estimates for "addicted" cellphone use range from 0 to 35 percent of people (Billieux et al., 2015; Coyne et al., 2019). This SOK seeks to determine whether cellphone use can be classified as an addiction, and how PDU contributes to distracted driving. By focusing in detail on drivers with PDU tendencies, this SOK is a single compendium of research related to distracted driving as a potentially addictive behavior and its relationship to traffic safety, and it is also a complementary perspective to both the previous SOK on distracted driving and the updated SOK on distracted driving expected to be completed in 2023.

Objective

The objective of this report is to consolidate knowledge on problematic cellphone use and how it interferes with safe driving. The intersection of "addicted" cellphone use and traffic safety has not been extensively studied; therefore, this SOK will characterize problematic cellphone use in relation to behavioral addictions and to typical cellphone use while driving. This report will examine the unique motivations for cellphone use while driving and the unique distracted driving behavior patterns among those with problematic cellphone use habits. The report will also analyze individual differences associated with problematic cellphone use in comparison to those associated with typical cellphone use.

While the current literature does not present a typology of distracted drivers in comparable detail to typologies that have been created for other driving behaviors such as speeding (e.g., Richard et al., 2013, 2020), this SOK suggests that discrete categories of distracted drivers exist. This report has identified users with and without "addicted" cellphone use patterns as separate distracted driving types. A finer separation within these categories has just begun to be investigated in the current literature and may be clarified in future research. This SOK's findings can support the planning and conduct of future studies, safety programs, countermeasure implementations, and policy decisions. This report provides valuable information for characterizing the current understanding of PDU while driving and ensuring that steps against distracted driving are maximally effective for drivers with problematic mobile device use patterns as well as for typical users.

Methodology

This integrative research review was conducted using a best-evidence-synthesis methodology (Slavin, 1986, 1987) in which a research team with expertise in human factors, traffic safety, and psychology screened research articles for their quality and applicability. The document screening process involved using a standardized template wherein researchers recorded many aspects of each study, such as its sample size, independent and dependent variables, key findings, and limitations. The search plan prioritized research published from 2015 to 2020 to capture studies with the most relevant technologies, though older studies were included to provide context and to supplement areas where recent research is sparse. Literature was found through an iterative search process. The keywords from initial searches were used to refine later searches. Databases used included TRID, PsycINFO, PubMed, and Google Scholar. Reports from State and Federal Government agencies as well as from conference proceedings were also included. Only studies deemed to be relevant and of a high quality are incorporated into the review, excepting literature in understudied areas, in which case a caveat on quality is stated. Any discrepancies in understanding of findings among members of the research team were resolved through discussion.

The literature review is presented in a narrative format that is accessible to researchers, highway safety and public health professionals, safety advocates, and members of the public. The report's contents begin with an overview of general driver distraction and how it compares with PDU while driving (Chapters 1-3). This is followed by a discussion of addiction and why PDU is not currently considered a behavioral addiction (Chapters 4-5). Then, the behaviors, consequences, and individual differences associated with PDU while driving are covered (Chapters 6-7). Finally, emerging countermeasures for PDU while driving are presented (Chapter 8).

What Is Driver Distraction?

Definition

Driver distraction occurs when a driver's attention is diverted away from activities critical for safe driving and towards a competing activity (National Highway Traffic Safety Administration, 2010; Vegega et al., 2013; Young, 2008). Distracted driving is not synonymous with inattentive driving, as inattentive driving occurs when attention is insufficient to the driving task such as being sleepy or asleep, even in the absence of a competing activity (Kinnear & Stevens, 2015; Young, 2008). Distraction is one type of inattention.

Tasks that compete with driving, causing distraction ("secondary tasks"), can be digital or analog. Drivers are most frequently distracted by non-technological activities, such as eating, personal grooming, or talking with passengers (Dingus et al., 2016; Schroeder et al., 2013, 2018). Technological distractions include calling or text-messaging with a cellphone, browsing the internet, taking pictures, using any number of apps available on cellphones and tablets, and using embedded in-vehicle systems (Edwards & Wundersitz, 2019). Technological distractions during driving are prevalent, since ubiquitous mobile technology has transformed the driving context (Caird et al., 2018; Kinnear et al., 2015). In fact, some use of technology is situationally appropriate for driving and could even help drivers focus. Navigation and hands-free music apps, especially, are often considered by drivers to be important for driving (Delgado et al., 2018; George et al., 2018). The predominant patterns of device use while driving are covered in more detail in Chapter 2.

Distracted driving, including technology use while driving, can be qualitatively classified into visual, manual, or cognitive distractions (Shinar, 2017; Vegega et al., 2013; Young, 2008). Another classification involves segmenting distractions into voluntary (“top-down") and involuntary (stimulus-triggered/ “bottom-up”) distractions, which can fall into any three of the domains above (Chen et al., 2018; Hoekstra-Atwood, 2015; Marulanda et al., 2015). Visual, manual, and cognitive distractions refer to the different attentional resources essential for safe driving, which secondary tasks can divert. Some examples of technological secondary tasks and the attentional resources they occupy are as follows (Fisher et al., 2017).

- Visual distraction (eyes off road): Reading a text message
- Manual distraction (hand/hands partially or completely off the wheel; foot/feet off the pedals): Scrolling through and selecting a song on a music playlist
- Cognitive distraction (mind off road): Attending to verbal phone conversation and thinking of responses

Secondary tasks imposing visual distractions are particularly risky even compared to manual and cognitive secondary tasks (D’Addario & Donmez, 2019; Liu et al., 2018; Shinar, 2017; Young, 2008). In the driving context, visual perception is essential for navigating safely and anticipating hazards that require responses (Gibson et al., 1938; Morgan & Hancock, 2009). Tasks that take driver eyes off the road fundamentally compromise safe driving, and the risk is magnified when drivers’ hands are engaged in a secondary task. For this reason, texting while driving, and other lesser-studied visual-manual distractions such as browsing the internet and using social media, are associated with higher crash risk than many other secondary tasks such as listening to music or talking to passengers (Bálint et al., 2020; Dingus et al., 2016; Lansdown et al., 2015; Simmons et al., 2016).

Safety Implications

Distracted driving is a major cause of crashes in the United States. From 9 and 10 percent of all fatal crashes in the country have involved distraction in each year since 2010 (NCSA, 2019). Of distraction-affected crashes, approximately 14 percent each year involved cellphone use. Using electronic devices such as cellphones while driving imposes performance decrements that are associated with higher crash probability and severity. Increased variation in speed, deficits in perception, and vehicle control issues are common among drivers distracted by cellphones (Edwards & Wundersitz, 2019; Ferdinand et al., 2014; Shinar, 2017). Importantly, device use contributes to crashes by increasing the likelihood that drivers will experience a safety-critical event while inhibiting their ability to respond to such events in time (D'Addario & Donmez, 2019; Kinnear & Stevens, 2015). Drivers' crash risk depends on the secondary activity they are performing (Bálint et al., 2020; Dingus et al., 2016). Prolonged visual-manual distractions tend to pose the most risk, while distractions that are primarily auditory or cognitive in nature may only slightly increase crash risk relative to baseline driving (Caird et al., 2018).

The majority of drivers express the opinion that device use while driving is a serious threat to their safety (AAA Foundation for Traffic Safety, 2020; Schroeder et al., 2013, 2018). Yet this behavior is relatively prevalent, even among the same drivers who report recognizing the risk. Thirty percent of drivers who perceived distracted driving as "extremely dangerous" reported doing so at least once within the prior 30 days (AAA, 2020). Many drivers believe that, unlike other drivers, their own performance is not impaired by distraction, and that they are able to effectively multitask (Nemme & White, 2010; Sanbonmatsu et al., 2017). However, multitasking is extremely difficult and always has the potential to compromise driving performance (Caird et al., 2018; Young, 2008). Multiple resource theory states that task-sharing between two tasks such as driving and texting tends to degrade the performance of both tasks (Wickens, 2008). The degradations are especially severe when two tasks share the same domains of attentional resources. Visual-manual activities on cellphones such as texting and using social media detract heavily from driving performance because navigating the traffic environment is also a primarily visual-manual task (Stavrinos et al., 2018). Even extensive experience with using electronic devices while driving does not inure drivers from performance decrements during this behavior (Chen et al., 2018; Zhou et al., 2012).

What Is Problematic Device Use?

General Description of the Behavior

Problematic device use is the term that will be used throughout this report to mean the behavior that has also been called excessive, dependent, compulsive, habitual, or addicted device use (e.g., Barnes et al., 2019; Billieux et al., 2015; Clements & Boyle, 2018; Kruger & Djerf, 2017). The designation "problematic device use," is intended to communicate the negative consequences of this type of behavior, without making a claim about the existence of a clinical addiction to device use. Problematic smartphone use has been described as "a compulsive pattern of smartphone usage [that] can result in negative consequences that impair the daily functioning of the user," (Busch & McCarthy, 2021).

Notably, this definition does not equate high levels of use in daily life, e.g., use for many hours a day, to PDU. Frequent, protracted use of cellphones does not always impact people's well-being or cause functional impairment (Coyne et al., 2019; Panova & Carbonell, 2018). With a thorough understanding of addiction literature in the psychological and medical domains, this report's authors have concluded that there is currently insufficient evidence to call PDU an addiction. Behavioral addictions, or non-substance addictions, are a controversial concept within the DSM-5. In it only one behavioral addiction, gambling disorder, is recognized (American Psychiatric Association, 2013). Internet gaming disorder was included in the DSM-5 for the first time in 2013; however, this disorder has no inherent relation to device use and was marked as a "condition in need of further study," (Kuss & Billieux, 2017; Rosenberg & Feder, 2014). There is also no single standard definition for PDU, and there is not a clearly defined threshold for PDU in the vehicle. This behavior pattern is associated with device use for many hours a day and use without separation, self-reported loss of control of device use, and experiencing negative consequences such as declines in health or productivity (Billieux et al., 2015; Panova & Carbonell, 2018). Problematic device use is measured with a variety of scales assessing variables related to these constructs (see Chapter 5; Busch & McCarthy, 2021).

Despite some similarities with substance abuse and gambling disorder—primarily the loss of control users can feel over their own behavior—PDU cannot conclusively be called an addiction (Billieux et al., 2015; Busch & McCarthy, 2021; Panova & Carbonell, 2018). There is insufficient evidence that devices produce tolerance (needing more use to achieve the same satisfaction) and withdrawal (psychophysical disturbance when separated from cellphone) symptoms (Fernandez et al., 2020; Wilcockson et al., 2019). The nuances of how PDU differs from a behavioral addiction are elaborated upon in Chapter 4.

Types of Device Use That May Be Associated With Problematic Device Use

Smartphone users with PDU patterns tend to use certain applications repeatedly and for many hours over the course of daily life outside of the driving context (Busch & McCarthy, 2021; Gonçalves et al., 2016). Cellphones present innumerable opportunities for problematic use outside the driving context, since people can form compulsions around using the hardware of the device itself, and/or around one of the devices' myriad applications (Barnes et al., 2019; D'Angelo et al., 2020; Rosenberg & Feder, 2014). Over 1.8 million applications are available on the iOS App Store (Apple Inc., 2020). Yet a few apps—Facebook, YouTube, Instagram, and TikTok—are vastly more popular than the rest (Neyman, 2017). Highly popular social media apps, in general, and not by coincidence, are also the ones whose designs most lend themselves to PDU (Kloker, 2020; Montag et al., 2019).

More information on such design techniques will be provided in the following section, as well as in Chapters 2, 5, and 8. Problematic device use is not tied to any one device or function of a device. People with typical usage patterns may use the same functionalities as people with PDU habits. For example, usage habits of people who use Facebook run the gamut from typical to problematic. A typical user may even occasionally use Facebook while driving (Braitman & Braitman, 2017; Kaviani et al., 2020; Schroeder et al., 2013, 2018). What makes PDU more dangerous than typical use is that people with PDU habits tend to report feeling lower levels of control over their usage than 'typical' users (Billieux et al., 2015; Clements & Boyle, 2018; Rosenberg & Feder, 2014). In the driving context, this can translate to drivers feeling compelled to operate a mobile device despite their need to focus on the driving task.

Driver Distraction Related to Problematic Device Use

What Kind of Use Is of Concern?

Frequent, long-duration distractions are of the most concern while driving. Tasks that repeatedly draw drivers' eyes away from the road prevent drivers from devoting sufficient visual attention to the driving task (Kinnear & Stevens, 2015; Morgan & Hancock, 2009; Young, 2008). Many activities on mobile devices, especially cellphones, are designed to be highly absorbing, with habit-forming, "addictive design[4]" strategies encouraging users to keep scrolling, watching, or

[4]"Addictive design" is the label given to certain habit-forming software features that immerse users in device operations and tend to create feelings of dependence upon certain software applications and/or the devices with

playing continuously (Kloker, 2020; Montag et al., 2019; Neyman, 2017). Tasks on cellphones, such as commenting on an Instagram post, were not designed with the thought that users might attempt to do so while in high-risk circumstances (e.g., while driving).

Now, some emerging technologies are being developed to adapt smartphone interfaces to the driving task, especially for apps that are frequently used by drivers, like navigation apps (Chapter 8; Weber et al., 2020). However, device use while driving often demands extended time spent gazing away from the roadway and reducing glance durations necessitated by engaging with electronic devices is challenging (Lansdown et al., 2015; Ziakopoulos et al., 2019). In the process of creating frequent, long-duration distractions, apps with "addictive design" strategies are especially likely to cause at least two of the three forms of distraction, visual, manual, and cognitive. When drivers use multimodal, complex phone applications while driving, like interactive gaming applications, their visual attention is more likely to be away from the road for longer (Wickens, 2008). In addition, manual and cognitive resources are essential for safe, timely responses while driving (D'Addario & Donmez, 2019; Shinar, 2017). Unfortunately, their multifaceted interactivity is part of what makes apps with "addictive design" strategies so engaging (Clements & Boyle, 2018).

One example is Snapchat, an app that is reportedly used while on the road by approximately 16 percent of young Australian drivers (George et al., 2018; Truelove et al., 2019). This photo-sharing app involves absorbing, prolonged distractions in the visual, manual, and cognitive domains, all factors associated with high crash risk (Chapter 2; Bálint et al., 2020). Problematic device use is of concern for the same reasons as all distracted driving is an issue—it poses a safety risk by limiting drivers' ability to appropriately perceive and react to their environment. Problematic use, because of software design and driver factors, increases the risk above even the level of "typical" distracted driving.

Pacing of Distractions in Problematic Device Use

The pacing of distractions among users who exhibit PDU is another concerning aspect of this compulsive behavior. Preliminary findings suggest that users that exhibit PDU behaviors check their cellphones more frequently when driving, respond to notifications more quickly, and do both with less regard for their surroundings, when compared with the typical cellphone user (Bayer et al., 2012; O'Connor et al., 2017). This is to be expected because--in non-driving contexts--a defining feature of PDU is the loss of control people report feeling over their own behavior, including a pronounced lack of control over delaying responses to notifications (Barnes et al., 2019; Clements & Boyle, 2018; Horwood & Anglim, 2019; Kloker, 2020). This pattern could "carry over" into the driving context from everyday phone use because cellphones can condition people to expect notifications and act upon these stimuli (Busch & McCarthy, 2021; Kruger & Djerf, 2017; Tanis et al., 2015). When drivers use their phones in situations dictated by cues from their phones rather than by the risk levels of their surroundings, poor safety outcomes are likely (Gliklich et al., 2016; Kneidinger-Müller, 2019; Schroeder et al., 2013, 2018). Drivers who have problematic cellphone use habits in daily life may have more difficulty than the typical cellphone user at moderating their behavior behind the wheel.

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which users access these software applications. The term comes from the academic field of human-computer interaction, not psychology. As such, the "addictive" designation has no empirical relationship to behavioral addiction and should not be understood as an indication that mobile device use is addictive.

Overview of the Problem and Its Coverage in This Report

Problematic device use presents a heightened safety concern, even above typical distracted driving, when people who compulsively use their devices get behind the wheel. These drivers' frequent, prolonged, and externally paced secondary task engagement compromises their ability to drive safely by hindering their awareness and control of the vehicle. While not categorizable as an addiction, PDU is a complex problem for traffic safety and may require additional countermeasures to those designed for drivers with typical cellphone use patterns. This report examines how PDU relates to driving behavior in the following chapters.

Chapter 2 describes the scope of distracted driving for drivers with typical and problematic device usage patterns. Chapter 3 describes the personality and demographic factors that are associated with typical and problematic device usage.

Chapter 4 defines addiction, reviewing current research on substance use disorders and the only recognized behavioral addiction, gambling disorder. Chapter 5 applies the addiction criteria from the previous chapter to excessive electronic device use and explains why "problematic device use" is the most appropriate label for this behavior.

Chapter 6 provides an overview of the prevalence and consequences of PDU while driving.

Chapter 7 examines PDU's underlying factors and characteristics for individual drivers.

Chapter 8 describes emerging countermeasures and technologies that offer opportunities to reduce PDU behind the wheel and in general.

2. How Much of a Problem Is Device Use While Driving?

Introduction

The chapter begins with a discussion of the prevalence of overall device use while driving, with a focus on cellphone use. This report's characterization of cellphone use while driving includes a brief discussion of which phone apps tend to create problematic use habits. This is followed by the crash risks and other consequences associated with the cellphone use while driving. The chapter ends by discussing public attitudes toward cellphone use while driving. Studies examining PDU while driving are included when available and applicable, though these sources are few since this is still an emerging area of study.

Prevalence of Device Use While Driving

Device use is prevalent among American drivers operating motor vehicles. Among the devices, cellphones are the most frequently studied and appear to be the most prevalent (see Chapter 1; Ehsani et al., 2015; George et al., 2018). However, distractions from non-technological sources are more frequent. Observational studies estimate that about 10 percent of drivers are distracted by cellphones during a typical daylight moment in the United States, while an additional 14 percent of drivers are distracted by non-technological sources (IIHS, 2020; NCSA, 2019c).

The Strategic Highway Research Program 2 naturalistic driving study found that its sample of 3,262 drivers spent 7 percent of their total driving time distracted by cellphones and an additional 13 percent of their total driving time distracted by any non-driving-related activity (Dingus et al., 2016). Self-reported or observed rates of distraction from devices besides cellphones have not been thoroughly assessed, though the limited data on that subject suggests that drivers use cellphones far more frequently than they use computers, tablets, cameras, or other portable devices while driving (Ehsani et al., 2015; Shinar, 2017). This indicates the predominance of cellphone use while driving as a research issue relative to other device use while driving. Cellphone use while driving remains a major traffic safety concern, though observational studies of this behavior indicate that it has not increased over the past decade (National Center for Statistics and Analysis, 2019a).

Americans' rates of observed cellphone distractions while driving have mostly plateaued or decreased from 2010 to 2018 (see Figure 1 below; NCSA, 2019c). Self-report data demonstrate a similar trend, as survey data from 2011 to 2018 demonstrate an overall decrease in the percentage of drivers reporting cellphone use while driving (see Figure 2 below; AAA, 2020). Still, drivers of all age groups and regions in the United States continue to self-report frequently driving with cellphone distractions (Gerte et al., 2018; Wilbur, 2019).

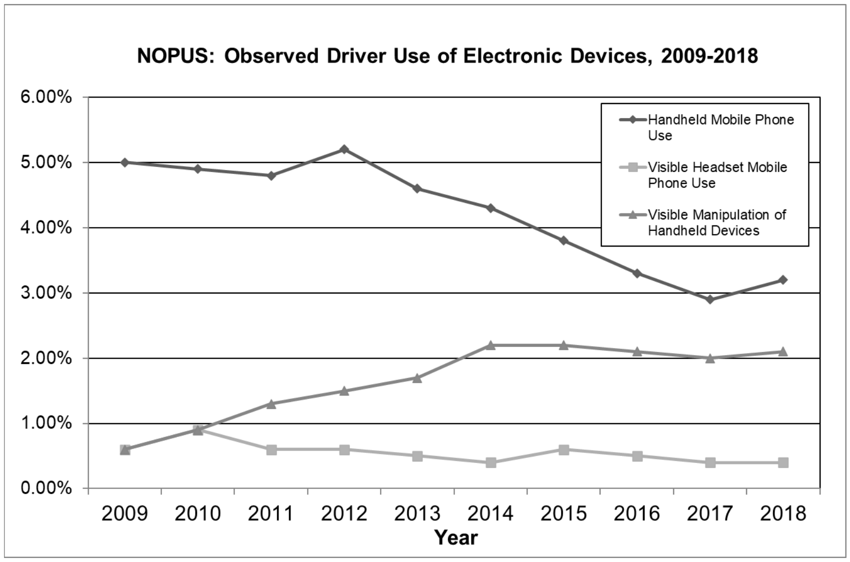

Figure 1. National Occupant Protection Use Survey (NOPUS): Observed driver use of electronic devices, 2009-2018[5]

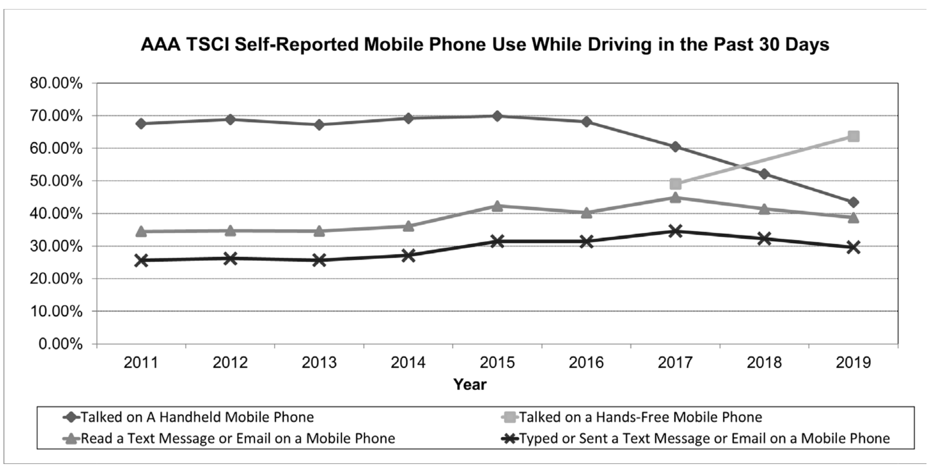

Figure 2. AAA Traffic Safety and Culture Index self-reported cellphone use while driving in the past 30 days

Under the umbrella of cellphone use while driving, researchers distinguish between several behaviors including visible headset cellphone use, handheld cellphone use, and the visible manipulation of cellphones. Handheld cellphone use occurs when drivers hold their phones up to an ear, while visual manipulation occurs when drivers interact with a phone's screen or hardware for activities like text messaging and browsing the internet.

Behavior involving physical manipulation of cellphones is rapidly increasing relative to other forms of cellphone use while driving, like handheld cellphone use. (Atwood et al., 2018; Dingus et al., 2016; NCSA, 2019c). Physical interaction with cellphones has increased since 2009 and remained relatively constant since 2016 according to data from the 2019 AAA Traffic Safety and Culture Index and NHTSA's 2018 NOPUS. Drivers were more frequently observed manually

[5]The "Visible Manipulation of Handheld Devices" category in NOPUS data does not distinguish cellphones from other handheld devices (NCSA, 2019c).

interacting with cellphones than talking on cellphones in a 2018 roadside survey (Insurance Institute for Highway Safety, 2019).

In recent years, drivers' rates of manual interaction with cellphones have become closer to their rates of using cellphones for hands-free calling while driving. This increase in drivers' physical interaction with cellphones is occurring at the same time as the increased prevalence of cellphone applications that have tendencies to establish problematic use habits. Applications for texting/chatting, social media, and games often require extended physical interaction with a cellphone to operate (George et al., 2018). Developers of these apps create incentives for their frequent and protracted use with design strategies such as visible, variable rewards and social reciprocity (D'Angelo, 2020; Neyman, 2017).

These "addictive design" strategies are intended to increase app developers' revenue through methods such as maximizing advertising views/clicks and user data collection (see Chapter 4; Berthon & Campbell, 2019). The observed increase in physical interaction with devices behind the wheel, occurring as applications develop features to emphasize user retention and engagement, raises the question of whether the apps' psychological incentives continue to affect users as they enter the vehicle. In contrast to other types of portable devices such as laptops and music players, smartphones have emerged as the dominant hardware platform for "addictive design" applications.

Smartphones' prevalence and their integration into users' personal and professional lives means that developing software with "addictive design" strategies for smartphones as opposed to other devices is especially lucrative (Kloker et al., 2020). The concern examined in this report is whether these "addictive design" elements are leading to maladaptive phone-use behaviors that carry over into driving and potentially disrupt drivers' ability to drive safely. This report considers the implications of people being so captivated by cellphone applications that they continue their device use patterns formed in everyday life while driving a car—to the possible detriment of public safety.

Characteristics of Cellphone Use While Driving

Cellphone use while driving is the most extensively researched source of distraction compared to any other personal mobile device (Ehsani et al., 2015; Shinar, 2017). Different types of cellphone interactions have different prevalence rates and implications for problematic use. The literature frames cellphone interactions while driving in terms of their modes (i.e., handheld and hands-free use) and cellphone application functions (e.g., text messaging, calling, navigation). This chapter also briefly addresses the relationship between cellphone modes and apps, referred to as interaction design (e.g., notifications, infinite scrolling, and phone unlocking actions), which includes how drivers initiate and respond to communications on mobile devices.

Modes of Cellphone Interaction

Hands-free cellphones have become more widely available and easier to use with technological advancement. Hands-free phone use is slightly more common than handheld phone use (for a review, see Edwards & Wundersitz, 2019). In the 2019 TSCI, 63.7 percent of 3,511 respondents 16 or older reported talking on hands-free phones while driving at least once in the past 30 days, while 43.4 percent of respondents reported talking on handhelds cellphone (AAA, 2020). Over 85 percent of the 6,001 drivers in the 2015 National Survey of Distracted Driving Attitudes and

Behaviors expressed the belief that using a hands-free cellphone while driving is safer than using a handheld cellphone while driving (Schroeder et al., 2018). Other studies have found similar findings, which could explain why hands-free cellphone use while driving is reported more frequently than handheld use (e.g., Hill et al., 2015; Sullman et al., 2018; Zhou et al., 2009).

However, hands-free cellphone use presents its own dangers. A meta-analysis of 106 studies found that hands-free cellphones were moderately to strongly associated ($\geq r = 0.50$) with diminished driving performance in the following measures: hazard detection, reaction time, speed compliance, headway variance, collisions, longitudinal and lateral control, and number of glances away from the road (Caird et al., 2018). Interacting with cellphones in a handheld mode while driving is generally considered riskier than interacting with a cellphone in a hands-free mode because the former imposes demands on both drivers' visual and manual attentional resources (Wickens, 2008; Regan et al., 2008).

Hands-free texting is a relatively new function that has developed from tighter integration between in-vehicle technologies and cellphones, coupled with more effective on-phone voice assistants. The 2019 TSCI found that comparable percentages of drivers reported sending texts hands-free (26.2%) as those doing so manually on handheld cellphones (29.6%) while driving within the past 30 days (AAA, 2020). Similarly, a 2015 survey found that 19.3 percent of respondents reported that when they send text messages, they usually do so using hands-free voice commands (Schroeder et al., 2018). Other than the results from these surveys, the prevalence of drivers sending text messages, listening to text messages, and using voice commands to interact with their mobile or in-vehicle technology is largely unknown. The limited amount of literature on hands-free text messaging shows mixed effects on simulated driving performance (Favarò et al., 2020; Tippey et al., 2017; Zhang et al., 2019). As with hands-free calling, hands-free texting is difficult to observe reliably without in-vehicle observational data.

Cellphone Application Functions

Drivers use apps on their cellphones while driving for traditional functions of phones (calling, texting), in addition to a growing range of other uses. Phone calls are the most commonly used function of cellphones while driving, and this pattern has not changed substantially from earlier surveys (AAA, 2020; NCSA, 2019c; Schroeder et al., 2013; State Farm Mutual Automobile Insurance Company, 2016; Tison et al., 2011). However, internet use while driving has risen rapidly. The 2012, 2013, and 2014 TSCI surveys asked about accessing the internet while driving and found that the percentages of drivers reporting this behavior at least once in the past 30 days grew from 12 percent to 17.3 percent (AAA, 2012, 2013, 2014). Later TSCI surveys have not asked about internet use while driving, though other more recent self-report studies have provided nuanced analyses of drivers' use of the internet and various phone apps while driving. Table 1 below presents findings from surveys regarding the phone apps that participants most frequently reported using while driving. Music and navigation apps are the most frequently used.

Table 1. Phone application use reported by survey respondents while driving

	Percentage of Respondents Reporting Use While Driving						
Survey	Music apps	Social media (e.g., Facebook, Instagram)	Navigation	Browsing internet	Gaming	Watching video (e.g., YouTube, Netflix)	Taking pictures/ videos
Ehsani et al., 2015 N = 1,243 drivers 16-20	71.64%	Not asked	52.64%	23.95%	Not asked	Not asked	Not asked
State Farm, 2016 N = 962 drivers 18-65+	Not asked	22% (read social media) 19% (update social media)	Not asked	29%	10%	Not asked	23% (take pictures) 14% (record video)
Schroeder et al., 2018 N = 460 drivers 16-45+	41.2%	31.7%	51.1%	7.2%	2.1%	2.5%	Not asked
George et al., 2018 N = 612 drivers 17-24	77.8%	21.2%	60.8%	12.7%	7.0%*	7.0%*	17.9%

*Gaming, watching videos, and online shopping were all the same category in this survey.

Cellphone Interaction Design

Interaction design, in the context of this chapter, refers to the presentation and complexity of information that a driver can receive from a device, and the actions a driver needs to take to input information (NHTSA, 2014). Apps that create frequent and long-duration distractions are especially likely to encourage use, even in risky contexts such as driving (Busch & McCarthy, 2021). Such apps tend to incorporate "addictive design" principles, using human psychology to create cravings and a sense of obligation in their users (Kloker, 2020; Montag et al., 2019). For example, scrolling through Instagram can be a highly satisfying activity involving visual and manual attention, since the "infinite scroll" effect produces a psychological reward comprised of endless personalized content (Neyman, 2017). This design approach of getting users habituated to extended and/or repeated visual, manual, and cognitive interactions with an app contributes to the primary distraction-related safety problem when drivers are unable to refrain from using these apps once they start driving.

However, not all cellphone applications involve "addictive design" to continually absorb users' attention. "Addictive design" is most prominent in apps related to social media, video streaming, and gaming (Neyman, 2017). A small subset of newer phone apps in these categories have inherent features that make them rewarding to play while driving specifically—such as an augmented reality game that receives input based on the mobile device's changing location, and a "filter" on a photo-sharing app that displays the user's current speed to friends (George et al., 2018). Other apps, such as those related to navigation and music, tend to not employ "addictive design" strategies to nearly the same extent, since they do not need continuous engagement to operate (See Chapter 6).

Initiating and Responding Behavior

Understanding the implications of initiating and responding behavior further indicates how apps can cue cellphone use while driving. "Initiating" cellphone use while driving refers to making calls and "the writing and sending of text messages that were not in reply to incoming text messages," (Atchley et al., 2011). "Responding" is a subsequent response to someone else's initiating behavior, so it includes answering a phone call or reading a text (Waddell & Wiener, 2014). Responding behavior is performed more frequently than initiating behavior while driving (Brown et al., 2019; Reagan & Cicchino, 2018; Schroeder et al., 2018). Cues from any app in any mode (auditory for hands-free use or haptic for handheld use) have the potential to prompt responses if drivers are conditioned for such responses (Tanis et al., 2015).

People who self-report problematic cellphone use can become psychologically conditioned to attend to notifications from their devices, entering a constant state of alertness to respond (Kruger & Djerf, 2017; Tanis et al., 2015). Developers of apps, using "addictive design" principles, have developed systems of visible, variable rewards in the form of visual, haptic, and/or sound notifications that encourage people to immediately engage or re-engage with their cellphones (Neyman, 2017). A strong habitual response to a notification could pose a distraction, leading to responding (picking up the phone) at an inopportune time, e.g., approaching an intersection (see Edwards & Wundersitz, 2019; Delgado et al., 2016; Shinar, 2017).

Device Use While Driving and Crash Risk

Prevalence of Device- and Cellphone-Involved Crashes

The percentage of all fatal traffic crashes in the United States involving distraction has remained from 9 to 10 percent since 2010 (NCSA, 2019a). In 2018, there were 2,841 fatalities that occurred in distraction-affected crashes, approximately 8 percent of that year's total traffic fatalities (NCSA, 2019b). The numbers of fatal distraction-related crashes vary widely across States, though New Mexico (40% of fatal crashes per year were distraction-related) and Washington (26% of fatal crashes per year were distraction-related) have particularly high percentages of distraction-related crashes. The lowest reported percentages of distraction-related crashes were in Mississippi (2% of fatal crashes per year were distraction-related) and Connecticut (3% of fatal crashes per year were distraction-related), according to Fatality Analysis Reporting System data from 2010-2018 (NHTSA, 2020). The wide variation could be due to a number of factors including State populations, vehicle miles travelled, data reporting methods and quality, and distracted driving legislation (NCSA, 2019b).

Not all of these distracted driving crashes involved cellphone use, and it is possible that differences in cellphone use while driving also explain some of the variation in distracted driving crashes by State. In 2018, about 1 percent of all U.S. motor vehicle crash fatalities involved a driver who was distracted by a cellphone (IIHS, 2020; NCSA, 2019a). Younger drivers have an elevated risk of fatalities from distracted driving crashes involving cellphones. In 2017, drivers 20-29 had the largest proportion of fatal crashes involving cellphone distractions (37%), and drivers 15 to 29 years old comprised 214 of the 404 total fatalities in cellphone-related distracted driving crashes in 2017 (NCSA, 2019a). While young drivers face a particularly heightened risk of severe negative outcomes from distracted driving, vehicle non-occupants are also at risk: Specifically, 16 percent of all distraction-affected fatalities were pedestrians while 2 percent were bicyclists (NCSA, 2019a). The percentages of occupant and non-occupant fatalities were not calculated for cellphone distraction crashes.

The percentage of people injured in distraction-affected crashes as a percentage of total injury crashes remained relatively constant from 2006 to 2016 at around 18 to 20 percent. However, the proportion of distracted driving injury crashes that are attributable to cellphones rose during that time period, from 2 to 8 percent (NCSA, 2019d).

Cellphone Use While Driving and Crash Probability

Using a cellphone generally results in higher odds of a crash than performing other secondary tasks while driving (Edwards & Wundersitz, 2019; Guo & Fang, 2013; Kidd & McCartt, 2015). Naturalistic studies have consistently found that cellphone interactions in a handheld mode—such as dialing the phone, locating the phone, and texting—result in crash odds ratios from approximately 3.0 to 10.0 relative to driving without a secondary task (Dingus et al., 2016; Farmer et al., 2015; Simmons et al., 2016). The effect of hands-free cellphones on crash odds has not been extensively studied. Talking on cellphones has been found to decrease crash odds in some of the literature (Caird et al., 2018; Simmons et al., 2016). These findings do not indicate that hands-free cellphones are safe or a protective factor but do suggest that hands-free conversations are associated with increased glance durations to the forward roadway, albeit with reduced visual scanning.

The visible manipulation of cellphones increases crash probability primarily because operating the devices can require extended glances away from the forward roadway (Hoekstra-Atwood, 2015; Shinar, 2017). For example, sending a text message led to a mean total-eyes-off-road time of 23.3 seconds in a naturalistic study (Fitch et al., 2015). This glance duration far exceeds safety guidelines from NHTSA and from SAE International (formally the Society of Automotive Engineers) for how much eyes-off-road time a secondary task should take to complete, even if the driver periodically glances back to the forward roadway (NHTSA, 2014; SAE International, 2015).

Text messaging further increases crash risk because handling the phone and thinking about the content of messages occupy physical and cognitive resources that are necessary for the driving task (Guo & Fang, 2013; Ortiz et al., 2018). Text messaging was associated with crash odds of 10.30 relative to driving without a secondary task in a meta-analysis (Simmons et al., 2016). The effects of texting on reaction time, braking distance, and other critical measures of driving performance are well-documented (see Driver Performance and Operational Impacts below; Caird et al., 2018; Ferdinand & Menachemi, 2014). Texting was an early example of a cellphone app with tendencies to establish problematic use patterns. In the past decade, these apps have grown in number and complexity (Kloker, 2020).

Many popular apps (e.g., Twitter, Facebook, Instagram, and TikTok) have interaction design features that intentionally keep users absorbed and demand their visual, physical, and cognitive attention (Neyman, 2017). While the connection between problematic as opposed to casual cellphone use and crash risk has not been extensively studied, insights from research on cellphone use and crash risk, especially texting and crash risk, suggest that problematic use patterns would likely magnify crash risk for individual drivers.

Cellphone Use While Driving and Crash Severity

In general, distraction-affected crashes are less severe than alcohol- or speeding-related crashes; however, their relative severity increases when cellphones are the source of the distraction. Specifically, data from 2012-2016 show that distraction-affected crashes involving cellphone use comprised a higher percentage of fatal crashes (14%) than injury crashes (8%), suggesting that crash outcomes are likely to be more severe when cellphones are the distraction compared to other sources (NCSA, 2019b, 2018). Similarly, A SHRP2 data analysis study including 3,546 drivers and 1,465 crashes demonstrated that the odds ratio of a severe crash when using a cellphone while driving (4.83) was much higher than the odds ratio of a severe crash when performing any other secondary task while driving (2.01), suggesting that cellphone use is an especially dangerous secondary task (Kidd & McCartt, 2015).

The association between cellphone use and increasing crash severity could be exacerbated when drivers exhibit behavior patterns characteristic of PDU. Drivers who use cellphones' attention-intensive functionalities and quickly switch tasks while driving place themselves at greater risk of severe crashes (Lansdown et al., 2015). For example, each text message sent per hour of driving was associated with an 8.3-percent increase in the risk of a severe crash in a SHRP2 data analysis (Atwood et al., 2018). Another SHRP2 analysis examining simultaneous involvement in secondary tasks found that the odds of a severe at-fault crash were 4.65 when involved in secondary tasks and 1.68 when involved in just one secondary task, relative to 1.0 when not involved in a secondary task (Bálint et al., 2020). Problematic cellphone use is associated with frequent, multi-functional cellphone use, suggesting that people exhibiting this behavior while driving are at elevated risk for severe crashes (see Chapters 5,6).

Characteristics of Crashes Involving Device Use

Distracted driving crashes occur in a wide range of configurations (Shinar, 2017; Regan et al., 2008); however, characteristics of crashes involving cellphone use show some consistent trends. In a SHRP2 analysis (Bálint et al., 2020) the crash types that most commonly involved distracted driving were rear-end crashes (up to 39% of rear-end crashes involved distractions) and run-off-road crashes (up to 32% of run-off-road crashes involved distractions). The same analysis found that 36 percent of rear-end crashes in the SHRP2 dataset involved a driver using a cellphone. The connection between distracted driving (e.g., cellphone use), and certain crash types—run-off-road and especially rear-end crashes—is logical considering the types of performance decrements imposed by these behaviors (see the Performance Decrements section below; Caird et al., 2018; Kidd & McCartt, 2015).

However, current research has not examined relationships between specific phone functionalities and specific crash types, such as whether texting is more likely than calling to lead to rear-end crashes. Defining and categorizing cellphone-involved crashes is difficult because it is rarely possible to determine what drivers were doing with their phones at the time of the crashes. As FARS does not collect data on whether or not drivers were using a cellphone at the time of crashes, the system also does not contain data regarding what cellphone functionalities were in use as drivers experienced crashes. A recent SHRP2 analysis found that texting was present in 3 percent of all crash/near crash events, 8 percent of severe crashes, and 16 percent of all rear-end crashes. Cellphone calling was less frequent, occurring in 3 to 4 percent of all crash and control segments (Bálint et al., 2020). This is the only large-scale study to quantify the prevalence of a specific cellphone functionality in crashes. Additional research is needed to determine how drivers are using their phones leading up to and during safety-critical events.

Difficulties Associated With Reporting Crashes Involving Problematic Device Use

Current methods for ascertaining whether a driver was using a cellphone at the time of a crash include reports from the driver or other witnesses, checking phone records to see when a driver's phone was in use (with a warrant or subpoena), and examining physical evidence from the crash scene (National Traffic Law Center, 2017; Retting, 2020). Physical evidence can include the presence of electronic devices near the driver and can help officers rule out other potential causes of erratic driving, such as impairment by alcohol or drugs (NTLC, 2017). Testimony from drivers or other witnesses can also help confirm instances of distracted driving, though people are usually reluctant to report that they were distracted due to fear of social and financial sanctions (NCSA, 2019a; NTLC, 2017).

Estimating the role of PDU behavior patterns in crashes is currently impractical because its apparent indicators (driver actions) during a crash are the same as a driver without PDU habits. The collection of crash statistics varies widely between States, and none consistently report the usage of specific apps (e.g., Facebook, Twitter, texting) during crashes involving cellphone use (NTLC, 2017; Sprattler, 2013). Ultimately, the process of determining whether a driver was distracted (i.e., by a cellphone) is imperfect and is vulnerable to human error and subjectivity at every step. Legal processes can also hinder investigations of distracted driving, as search warrants or court orders may be required to obtain electronic data from devices while protecting people's privacy (NTLC, 2017).

Distraction detection technologies for vehicles are currently under development. These systems use algorithms to identify driver distraction based on whether drivers exceed predetermined thresholds in various measures of attention and performance, such as glance duration away from the forward roadway and steering wheel velocity (e.g., Li et al., 2020; Mehrotra et al., 2018). Using technology to identify distraction shows some promise, though it is still vulnerable to inaccuracies as distraction, and especially PDU, are ultimately internal phenomena for drivers (see Chapter 8). To accurately characterize the crash risk and crash severity associated with PDU while driving, improved data collection procedures for ascertaining whether and how drivers were using their devices before and during crashes will be necessary.

Driver Performance and Operational Impacts

Consequences of distracted driving include driving performance decrements and traffic congestion. The most widely reported types of performance decrements due to distracted driving are speed variation, reduced hazard perception and reaction time, as well as vehicle control and positioning issues. Drivers often experience several performance decrements simultaneously when they use a device while driving (Caird et al., 2018; D'Addario & Donmez, 2019). Device use can also be particularly detrimental to maintaining visual awareness of the roadway scene, which is essential for safe driving (Kinnear & Stevens, 2015; Morgan & Hancock, 2009; Regan et al., 2008). These performance impacts underlie the increased crash risk described above in the Device Use While Driving and Crash Risk section. In addition, the current section concludes with descriptions of strategies that drivers employ to reduce their own risk perceptions, although these do not necessarily improve their safety. Finally, the relationship between cellphone use while driving and traffic congestion is briefly discussed.

Perceptual Deficits

Device use while driving diverts drivers' gaze from the forward roadway and hinders their ability to perceive and respond to their environment safely (Wickens, 2008; Regan et al., 2008). In one study, the crash risk of secondary tasks was strongly associated with the amount of total eyes-off-road time demanded by each activity in a meta-analysis of 57 studies (Simmons et al., 2016). Device use while driving tends to impair hazard detection and increase reaction times, along with constricting the area of visual search (Regan et al., 2008). In a literature synthesis including 165 studies about cellphone use, deficits in attention and hazard detection were the most commonly found performance decrement (15.7 percent of the studies) and longer reaction times (11.5 percent of the studies) were another frequent result (Ferdinand & Menachemi, 2014).

A recent simulator study demonstrated deficits in a variety of visual perception-response variables under cognitive distraction, finding that the first eye movement toward a hazard occurred approximately 25 percent later when drivers were distracted (D'Addario & Donmez, 2019). Device use while driving impedes drivers' attention to the roadway, therefore increasing the time required for them to react to their surroundings, also leading to other performance decrements described below.

Speed Variation

A prominent impact of cellphone use on driving is slower, more varied speeds (Ferdinand & Menachemi, 2014; Stavrinos et al., 2017). Drivers' selection of lower speeds is hypothesized to arise from both cognitive, often conscious, motivations to reduce workload and from unconscious physical responses, e.g., easing pressure on the accelerator because one's attention is not on the driving task (Shinar, 2017). Because of the cognitive and physical nature of this performance decrement, both hands-free and handheld cellphone use contribute to speed variation. Handheld cellphone use was associated with greater decreases in speed relative to baseline driving ($r = -.16$), while hands-free cellphone use was associated with greater speed variance ($r = .22$) and reduced compliance with speed limits ($r = -.35$) in a meta-analysis of 93 studies (Caird et al., 2018). Drivers' average speeds in a simulator study decreased by 2.49 kilometers per hour (1.54 mph) while using handheld cellphones and decreased by 2.67 kilometers per hour (1.67 mph) while using hands-free cellphones (Oviedo-Trespalacios et al., 2017). Speed variation can directly lead to crash risk, while simultaneously compounding the dangers of other distraction-related performance decrements, especially longer reaction times (Regan et al., 2008).

Longitudinal Vehicle Control Issues

Decrements in longitudinal vehicle control arise from cellphone use while driving, along with increased speed variance and perceptual deficits (Ferdinand & Menachemi, 2014; Shinar, 2017). Drivers tend to increase their headway distance between their own vehicle and other cars while distracted by cellphones (Regan et al., 2008). Talking on handheld cellphones while driving was consistently associated with increases in headway distance ($r = 0.21$) and talking on hands-free cellphones while driving was consistently associated with greater variance in headway distances ($r = 0.31$) relative to baseline driving in a review of 106 studies (Caird et al., 2018). Another aspect of longitudinal control, brake response time, is also negatively affected by distracted driving; for example, brake reaction times were 10 percent slower in a simulator study with technological distractions (Hoekstra-Atwood, 2015). These results are consistent with the finding from literature reviews, which conclude that longitudinal vehicular control issues are mediated by eyes-off-road duration (Lansdown et al., 2015; Stavrinos et al., 2017).

Lateral Vehicle Control Issues

Measures of lateral control include standard deviation of lane position, time spent outside the lane, mean number of lane exceedances, and standard deviation of the steering wheel's angular velocity. One driving simulator study found that all of these measures worsened when participants sent text messages while driving (Ortiz et al., 2018). Similarly, another simulator study found significant effects on lateral positioning under all phone-use scenarios investigated (effect size = 0.572), as well as significant variation in steering wheel position (effect size = 0.478). The same study found that drivers performing visual and psychomotor (i.e., involving cognitive and motor processes) secondary tasks had significantly more variation in these measures than drivers performing primarily cognitive secondary tasks (Niu et al., 2019). Lateral vehicular control issues are highly correlated with speed variability and increases in reaction time (Shinar, 2017; Tarabay & Abou-Zeid, 2018). The research surrounding vehicle control issues due to distracted driving clearly indicates the interrelatedness of performance decrements caused by cellphone use.

Driver Adaptations While Using Cellphones

The distracted driving literature demonstrates that drivers employ strategies in attempt to lessen their risk of negative outcomes from using cellphones while driving (Dingus et al., 2019). Typically observed adaptation strategies include adopting lower speeds and more abrupt braking than when driving without a secondary task (e.g., Niu et al., 2019; Tarabay & Abou-Zeid, 2018). These actions appear to reflect drivers' attempts to "compensate" for the performance decrements described previously in this section (Schroeder et al., 2018; Zhou et al., 2012). Distracted drivers' actions to lower their risk perceptions are not always conscious choices and may be ineffective at reducing risk (Oviedo-Trespalacios et al., 2017). Survey studies reveal additional driver adaptations to cellphone use while driving and provide insight into their prevalence.

NHTSA's 2015 National Survey of Distracted Driving Attitudes and Behaviors asked 6,001 drivers about their adaptation strategies for using cellphones while driving and found that respondents reported strategies, which varied by phone functionality (Schroeder et al., 2018). The strategies tended to fall into several types: using voice commands, waiting until stopped, pulling over, passenger assistance, or conversation management (see Table 2). These results are consistent with another survey, which found that 44 percent of drivers reported waiting for a red light or stop sign to send a text message (Gliklich et al., 2016). Drivers may under- or over-report their engagement in adaptation strategies based on the question wording or their own awareness level of their behavior (Bailey & Wundersitz, 2019). Ultimately, drivers use types of adaptation strategies with some frequency in attempts to lower their risk of negative consequences from cellphone use while driving.

Table 2. Drivers' self-reported adaptation strategies for four cellphone use behaviors, from NHTSA's 2015 National Survey of Distracted Driving Attitudes and Behaviors

		Cellphone Use Behavior			
		Answering Calls	**Dialing a Phone Number**	**Sending Texts/Emails**	**Using Apps**
Type of Adaptation Strategy	Using voice commands	Not included in survey	Voice-dial; speaking a name or phone number (51.3% of drivers)	Use a voice command feature (19.3% of drivers)	Use a voice command feature (6.2% of drivers)
	Waiting until stopped	Not included in survey	Not included in survey	Wait until you reach a red light or stop sign to send the message (43.8% of drivers)	Wait until you reach a red light or stop sign to use app (36.1% of drivers)
	Pulling over	Answer and then promptly pull over to a safe location (6.9% of drivers) Pull over to a safe location and then speak to the caller (4.8% of drivers)	Not included in survey	Pull over to a safe location to send the message (8.0% of drivers)	Pull over to a safe location to use the app (7.1% of drivers)
	Passenger assistance	Hand the phone to a passenger if you have one (16.6% of drivers)	Not included in survey	Hand phone to a passenger to do your messaging (10.6% of drivers)	Hand phone to a passenger to use the app (10.0% of drivers)
	Conversation management	Answer the call and inform the caller you will call back later (13.7% of drivers)	Not included in survey	Not included in survey	Not included in survey

Traffic Congestion

Distracted driving compromises efficient traffic flow, creating the potential for congestion in saturated conditions (Cooper et al., 2009). Congestion due to distracted driving imposes costs on the nation: longer travel times, economic inefficiencies, and increased pollution from vehicles (Blincoe et al., 2015). Using a computer model, Xiao and colleagues found that distracted driving could reduce traffic flow by up to 5 percent. Traffic flow decreased sharply when a small proportion of drivers were using cellphones in dense traffic and decreased more slowly when a small proportion of drivers were using cellphones in light traffic (Xiao & Shi, 2015). Cellphone use while driving is hypothesized to contribute to traffic congestion because it compromises drivers' perception and decision-making processes that are used in selecting efficient speeds and lanes of travel (Cooper et al., 2009).

A driving simulator study found that distracted driving led to reduced traffic flow (i.e., congestion) as drivers exhibited fewer lane changes and greater fluctuations in speed while talking on a hands-free cellphone and especially while texting (Stavrinos et al., 2013). Traffic congestion can also worsen distracted driving, since some drivers view congested traffic as an opportunity to use their cellphones "safely" (Albert et al., 2016; Zhou et al., 2012). Texting at stoplights, for example, is common (NCSA, 2019c). This behavior was reported by 60 percent of respondents in a survey of 4,964 college undergraduates (Hill et al., 2015). Another survey of 1,211 drivers found that higher percentages of respondents (8-9 percent total) reported sending and reading text messages during stop-and-go traffic than reported doing so at "low speeds" or at "any speed," (Gliklich et al., 2016). Distracted driving has reverberating negative effects on traffic flow, especially at high traffic volumes (Chung & Recker, 2013).

Public Attitudes Toward Cellphone Use While Driving

The American public recognizes distracted driving as prevalent and dangerous, although the perceived risk varies by phone functionality. In the 2019 TSCI, 96 percent of the 3,511 respondents said that drivers manually typing or sending text messages/emails on cellphones is very or extremely dangerous (AAA, 2020). Further, 94.3 percent of respondents had the same views about reading cellphones, as did 79.7 percent of respondents about holding and talking on cellphones. A much smaller percentage, 22.5 percent, of respondents in the 2019 TSCI said that using hands-free technology on a cellphone while driving is very or extremely dangerous. These results are consistent with a large body of survey studies' results indicating that sending texts is perceived as the most unsafe distraction, followed by reading texts, using handheld cellphones, and using hands-free cellphones (Edwards & Wundersitz, 2019; Gliklich et al., 2016; Kim et al., 2019; Schroeder et al., 2018).

Public support for distracted driving legislation is high, and approximately 75 percent of American drivers support legislation against talking on cellphones (handheld or hands-free), while driving and approximately 90 percent support legislation against texting while driving (AAA, 2020; Schroeder et al., 2018). Support for regulations, and for higher fines, is especially strong among older drivers and drivers who report rarely using cellphones while driving (Gliklich et al., 2016). Surveys of the general driving public find high levels of support for distracted driving legislation even though there is a high prevalence of self-reported distracted driving within the same sample (Gliklich et al., 2016; Kim et al., 2019; Sanbonmatsu et al., 2016).

Though no surveys have assessed internal contradictions in individual respondents' opinions on distracted driving legislation, the TSCI examined the contradiction in the context of risk perception. The survey found group-level discrepancies between professed beliefs and self-reported behaviors. For talking on a cellphone while driving, 55 percent of respondents said the behavior is extremely dangerous, yet 32 percent of respondents reported doing so at least once in the past 30 days. For typing or sending a text message or email while driving, 76 percent of respondents said the behavior is extremely dangerous, yet 26 percent reported doing so at least once in the past 30 days (AAA, 2020). This inconsistency is common and could potentially be a hallmark of drivers with PDU patterns.

Summary

The topic of this State of Knowledge review, PDU while driving, is a subset of the larger driver distraction safety issue, which itself is associated with real and ongoing risk to traffic safety. A particular concern with mobile devices is that they have capabilities that afford complex interactions and specific types of distractions. There are modes (e.g., handheld, hands-free) and myriad functionalities (e.g., apps) with which users can interact while driving. This technology platform has seen significant innovation as apps compete for phone users' time and attention.

The innovation within mobile devices has come with unforeseen consequences since these devices are almost always within immediate reach of their users. Moreover, some successful phone apps employ highly compelling software design that encourages frequent and prolonged use. These apps, typically those for social media and gaming functionalities, operate using "addictive design," which encourages repeated interactions with the device, often interrupting whatever else the user was doing. This becomes a traffic safety issue when these people continue these device use behaviors when they should otherwise be focused on safe driving. Consequently, people with problematic cellphone use habits may be at elevated risk for severe distracted driving crashes. Not all device use while driving falls under this report's psychology-based definition of "problematic use." Drivers may adjust an in-vehicle information display or use a music player smartphone app without facing the same level of safety risk as a driver who, for example, compulsively checks their social media apps. However, both typical and PDU are part of a broader pattern of device use while driving and distracted driving.

3. Demographics, Contexts, and Personal Characteristics Associated With Typical Device Use While Driving

Introduction

Problematic device use fits along a continuum of distracted driving. At a general level, its outcome is the same as other forms of distraction—attention away from the primary driving task—as are the modalities of distraction: visual, cognitive, and manual (see Chapter 2). The overarching topic of driver distraction has been extensively examined in the scientific literature and key research findings can provide a broader context for understanding the subset of distracted driving related to PDU. This chapter summarizes key trends and findings from the general distracted driving literature as well as research on driver-specific predispositions toward device use while driving due to demographic, contextual, and personal factors. The chapter is divided into three sections.

- *Demographic factors associated with distracted driving*. This section covers analyses of trends around distracted driving grouped primarily by age category, since existing research tends to focus on age as a predictive demographic variable. Subsequent demographic factors, such as gender, are examined both in relation to and independently of age.
- *Demographic characteristics of distracted drivers are compared to those of drivers who perform other risky behaviors.* Specific driving contexts and distraction. This section covers specific driving contexts that affect the frequency of distractions and driver use of electronic devices. The driving contexts include road environment complexity and familiarity, police presence, passenger presence, and communication partners.
- *Individual differences related to distracted driving.* This section covers personality constructs associated with device use while driving. To further understand decisions to use devices while driving, this section applies the TPB, a commonly applied behavioral framework explaining the sources of intentions to perform behaviors despite awareness of health or safety risks of doing so. Habits are discussed in relation to the TPB and separately.

Chapter 3 introduces some of the underlying factors that affect driver distraction in general, not just in the subtopic of PDU. This information broadly defines the relationship between key factors and device-related distraction while providing context that helps contrast PDU with developing norms regarding typical device use while driving.

Demographics Associated With Distracted Driving

This section discusses the prevalence of, and specific issues related to, distracted driving for each of the three age groups that are frequently studied in the literature. Following this analysis of distracted driving by age group, the overall associations of distracted driving with other demographic variables—gender, education and income, and geography—are examined. This first section of the chapter concludes with a discussion of the differences and similarities between distracted drivers and overall risky drivers.

Young Drivers (Roughly Age 16 to 25)

Today's young drivers (typically 16 to 25) have grown up with cellphones being both ubiquitous and a central medium in American society (Atwood et al., 2018; Pew Research Center, 2019), earning them the label "digital natives." On top of this, drivers 16 to 25 have unique social and personal characteristics that both facilitate distracted driving and increase their likelihood of serious crashes when using devices while driving (Fisher et al., 2016). Adolescence is a time of social pressure and seeking peer approval, which can facilitate both taking risks generally and using devices while driving to contact peers (Scott-Parker & Weston, 2017). Contributing to the issues that young drivers experience is that their brains undergo a burst of development from the start of adolescence until approximately age 25, which often produces impulsivity and poor decision-making tendencies (Delgado et al., 2016). The following sections provide more detail on these points.

Prevalence of Technology Distractions

When it comes to technological distractions in a vehicle, young drivers are primarily distracted by cellphones (particularly smartphones), and exposure to distractions from cellphones is frequent for this age group. Young drivers more frequently report distraction due to cellphones than to advanced driver assistance systems or other devices such as laptops or tablets while driving (Stavrinos et al., 2018; Schroeder et al., 2018). Ninety-six percent of Americans 18 to 29 own smartphones, and 3 percent of own cellphones that are not smartphones (See Figure 3; Pew Research Center, 2019). Therefore, almost all young American drivers can be assumed to own cellphones, which creates continuous opportunities for them to be distracted while driving.

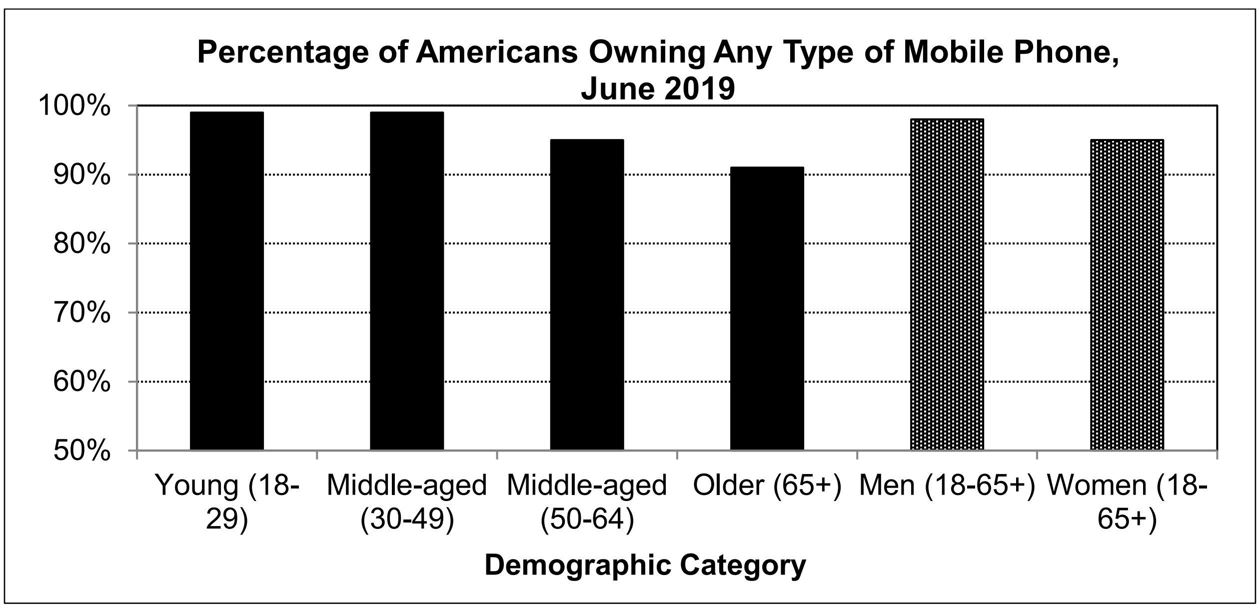

Figure 3. Mobile phone ownership, 2019 (Pew Research Center)

Across study methodologies, young drivers consistently show the highest rates of driver distraction. Young drivers were the most frequently observed age group in the 2018 NOPUS both holding and talking on mobile devices while driving and manually interacting with mobile devices while driving. Young drivers were observed engaging in these behaviors more frequently than other age groups in every NOPUS survey since the first one in 2011 (NCSA, 2019). The self-report TSCI has consistently found that drivers 16 to 24 reported high rates of distraction while driving, though not as high as drivers 25 to 39 (AAA, 2018, 2019, 2020). The most commonly reported behavior for young drivers was talking on cellphones, followed by reading text messages, and then by sending text messages while driving (see Chapter 2).

Specific Issues Relating to Young Drivers and Distraction

Cognitive Development and Driver Inexperience. Adolescents experience a variety of developmental changes that make them more likely to take risks, seek rewards, and make decisions on impulse and with a bias toward the present rather than understanding the full consequences of their actions (Delgado et al., 2016). The human brain is typically still maturing until age 25, and drivers with incomplete decision-making and planning capabilities present an elevated risk (Stavrinos et al., 2018). Furthermore, young drivers often have lower awareness than even slightly older drivers of factors that can diminish their driving performance. In a nationwide survey with 6,001 respondents, drivers 21 to 24 were the most likely of any age group to say that talking on a phone has no effect on their driving performance (53% of respondents gave this answer). Their confidence in their own abilities was higher than that of drivers 18 to 20, as well as drivers older than 24 (Schroeder et al., 2018).

Gender. Gender is not strongly related to differences in distracted driving prevalence among young drivers. Many surveys found similar rates of self-reported distracted driving for both male and female young drivers (e.g., Barr et al., 2015; Brown et al., 2019; Ehsani et al., 2015; Hill et al., 2015). A recent survey of more than 15,000 young drivers found that female drivers were 4 percent more likely than males to report talking on the phone while driving on “at least some driving trips,” and 1 percent more likely to report sending texts, but self-reported rates of reading texts were exactly the same among male and female drivers (Wilbur, 2019). An analysis of SHRP2 data found that young drivers’ distraction did not differ by gender (Atwood et al., 2018). Distracted driving is distinct from other risky behaviors such as speeding and impaired driving, which have higher rates among young males than among young females (Fisher et al., 2016; Shinar, 2017). See the section below for a more detailed analysis of gender and distracted driving, independent of age.

Passengers. Passengers can also be sources of distraction for young drivers (Ouimet et al., 2015). Passengers, especially teen passengers, present a special difficulty for adolescents due to peer pressure (Falk et al., 2014; Simmons et al., 2016; Regan et al., 2008). In a nationally representative survey of high school students in 2008, 38.4 percent of high school seniors reported being distracted by teenage passengers, with 7.5 percent reporting that teenage passengers deliberately distracted them. Distracting behaviors from passengers included “acting wild,” trying to influence driver’s risky behavior, and drinking alcohol (Fisher et al., 2016). A naturalistic driving study found that for teenage drivers, the presence of teenage passengers was associated with an increase in non-technology distractions and a decrease in technology distractions (Delgado et al., 2016). More studies would be needed to further understand the types of device and non-device distractions associated with passengers of different ages for teen drivers.

Parents. Parents model behavior to adolescents, even within the domain of distracted driving (Fisher et al., 2016; Macy et al., 2014; Mirman et al., 2017; Wilbur et al., 2019). Adolescents who reported more monitoring of their driving by their parents reported driving while distracted by any secondary task less frequently than their peers (Merrikhpour, 2017). One phone interview study found that adolescents' self-reported technological and non-technological distracted driving behaviors had a correlation of 0.20 with their parents' self-reported distracted driving behaviors. However, the correlation between adolescents' self-reported distracted driving behavior and adolescents' perceptions of their parents' behavior was much stronger than the correlation between self-reported behavior patterns of parents and adolescents (Carter et al., 2014). This finding indicates that adolescents are strongly influenced by their parents' behavior, but perceptions of parents' behavior inform adolescents' behavior patterns more than reality. It is possible that parents under-reported their distracted driving in this study and that they actually performed these behaviors approximately as much as the adolescents perceived.

Middle-Aged Drivers (Roughly Age 25 to 65)

Distracted driving rates among middle-aged drivers vary more across studies than those of young drivers. Drivers who neither fit into the young nor elder driver group—generally around ages 25 to 65—face a range of distractions that differs from those experienced by younger drivers. Middle-aged drivers are more likely to be parents and/or employees with demanding jobs where constant availability is expected (Engelberg et al., 2015). Distractions from children in the car (Macy et al., 2014), checking in on children by using one's phone while driving (Delgado et al., 2016), and work notifications or stress (Shinar, 2017) are all common among middle-aged drivers. Middle-aged drivers are, overall, more experienced with driving than younger drivers and drivers over 50 are less likely than young drivers to own smartphones (see Figure 3) or use smartphones as "digital natives."

Prevalence of Technology Distractions

Middle-aged drivers' patterns of technology-related distractions differ from those of other age groups. An analysis of data from the SHRP2 Naturalistic Driving Study found that middle-aged drivers' rates of technology-related distraction are lower than those of young drivers but higher than those of older drivers (Atwood et al., 2018). As of June 12, 2019, 92 percent of American adults 30 to 49 reported owning smartphones, and 6 percent owned cellphones that were not smartphones (Mobile Fact Sheet, 2019). These percentages are close to the phone ownership rates of Americans 18 to 29. Cellphone ownership numbers were high among adults 50 to 64, though the distribution of smartphone ownership skewed toward younger respondents. Recent studies with large sample sizes from across the United States demonstrated that middle-aged drivers report high rates of technology-related distraction, though behaviors appear to vary within this age categorization (e.g., Atwood et al., 2018; Schroeder et al., 2018). The 2018 NOPUS indicates that "middle-aged drivers" 25 to 69 frequently talk on and manually interact with cellphones. However, the 2019 TSCI showed a decline in self-reported typing and texting on a cellphone while driving for those older than 40 (AAA, 2020). These results indicate middle-aged drivers are not a homogenous category, and younger members of this age group's distracted driving behaviors might more resemble those of drivers around 25 years old.

Specific Issues Relating to Middle-Aged Drivers and Distraction

Parenthood. Parents' technology-related distraction while driving may have some correspondence to their children's developmental stage. One survey found that parents of 2- to 8-year-olds had almost 5 times higher odds of technology-related distractions while driving than parents of 1-year-olds (Macy et al., 2014). Once children grow older, the temptation to communicate with them frequently can intensify for parents, especially since they know their adolescent or young adult children are likely reachable by cellphone at any time. In a 2017 study parents reported engaging in cellphone use while driving to communicate with their children as frequently as adolescents reported doing so to communicate with their peers. Risk perceptions of distracted driving were also similar within parent-adolescent dyads. The study's authors recommend further research into "distracted families" and the authors claim that parents in the study likely faced "different kinds of pressures to communicate with their physically non-present children than they did with their adult peers" (Mirman et al., 2017).

Work Obligations. Since middle-aged drivers comprise most of the working-age population, it is unsurprising that work obligations are responsible for a significant share of driving distractions among this age group. In a survey of drivers 30 to 64, "obligation to take work calls" was the strongest predictor of high scores on the distracted driving scale (Engelberg et al., 2015). The same survey reported that 31 percent of respondents felt obligated to take work calls while driving. This is over twice the 14 percent of respondents who gave work-related reasons as a motivation to answer a call in nationally representative surveys (Schroeder et al., 2013, 2018). The reasons for the large difference in self-reported work-related phone use are unclear; however, the survey questions and populations were not directly comparable. Whether the trend has increased or not, work obligations are a persistent motivator for middle-aged adults' distracted driving.

Older Drivers (Roughly Age 65+)

Drivers over 65 drive while distracted the least frequently of any age group (Atwood et al., 2018; Schroeder et al., 2018), but they may experience more serious safety consequences when they do. Older drivers' phone ownership trends, along with other age group-specific factors, are discussed in this section. Aging is associated with performance declines in areas such as eyesight and reaction time, which can exacerbate difficulties in information processing under distraction (Regan et al., 2008). Some studies show that driving with passengers reduces older drivers' levels of risk, though future research could more thoroughly corroborate this relationship (Shinar, 2017; Regan et al., 2008). Among employed drivers older than 65, some 30 percent reported taking work-related calls while driving, and self-employment was correlated with a greater frequency of distracted driving (Hill et al., 2017). However, older drivers' overall level of electronic device distraction while driving is low.

Prevalence of Technology Distractions

Cellphone ownership, especially smartphone ownership, is much lower for adults over 65 than the national average (see Figure 3 for phone ownership rates by age; Pew Research Center, 2019). A survey of drivers older than 65 found that in San Diego, California, 82.8 percent of respondents owned smartphones. The survey's authors propose that the number was much higher than typical rates reported by older Americans because the majority of respondents had a household income over $49,999 (Hill et al., 2017). Hill's income-related explanation is consistent with results from the Pew Research Center, represented in Figure 4 below (Anderson

& Perrin, 2017). Smartphone ownership among older drivers is associated with income and educational attainment far more than for young and middle-aged drivers. Although, among all age groups, a higher income increases one's likelihood of owning a smartphone and decreases one's likelihood of owning a cellphone that is not a smartphone. Older drivers' cellphone adoption rates have recently increased much faster than those of young people—older Americans' phone adoption rates almost quadrupled from 2011 to 2016, while phone adoption rates among all other adults did not even double within the same time frame (Pew Research Center, 2019).

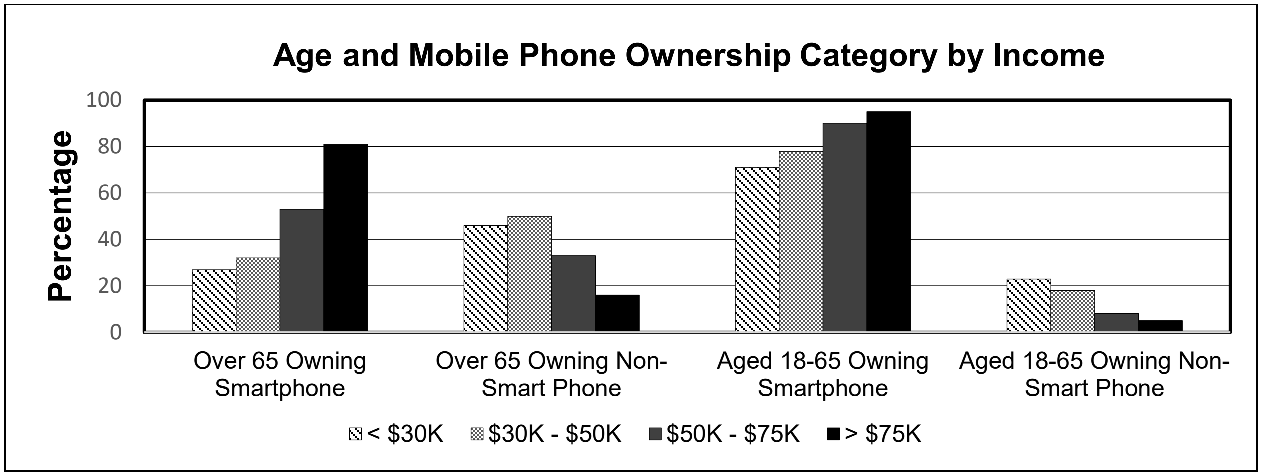

Figure 4. Age and cellphone ownership by income (Pew Research Center, 2019)

Older drivers' usage patterns of cellphones while driving contrast with those of other age groups, especially because of this group's infrequent texting while driving (Schroeder et al., 2013, 2018; Tison et al., 2011). Drivers over 70 were the group least frequently observed manually interacting with cellphones while driving in the 2018 NOPUS. The self-report TSCI survey data from 2019 were consistent with these results. The most pronounced difference in self-reported behaviors between older drivers, especially those over 75, and other age groups, was the lower percentage of older drivers reporting that they read texts (less than 60% of all age groups' average) or sent texts (less than 50% of all age groups' average) while driving in the past 30 days (AAA, 2020). There are some similarities between older drivers' and other age groups' prevalence of technology-related distractions. Older drivers were observed talking on headsets while driving comparably often to other age groups (NCSA, 2019). Older drivers talked on cellphones while driving at similar, albeit lower rates to other age groups (AAA, 2020; NCSA, 2019).

Specific Issues Relating to Older Drivers and Distraction

Performance Decrements. Older drivers often face slowed reaction times, poorer visual acuity, a reduced visual field, and greater tendencies toward inattention (Regan et al., 2008; McCartt et al., 2006). These performances decline compound risks from driving distracted, making information processing more difficult and further reducing awareness of hazards (Regan et al., 2008). Drivers older than 65 extensively engage in self-regulation of their driving in general, employing strategies such as driving less, driving familiar routes, or not driving at night (Shinar, 2017). Older drivers' self-regulation of their device use has not been extensively studied. Though initiating/responding behavior has not been shown to vary with age, it is possible that older drivers use different functions of their cellphones than other age groups.

Passengers. As with other age groups, the potential for older drivers to become distracted due to passengers appears to be related to the age of the passenger. Passengers may alert older drivers to the presence of hazards (Shinar, 2017; Regan et al., 2008), acting as a protective influence against distraction. One study demonstrated a 28 percent reduction in crash risk for older drivers with passengers (Vollrath et al., 2002, cited in Regan et al., 2008). However, this protective effect is less likely to exist when passengers are minors. When passengers under 18 were in the car, over a quarter of surveyed drivers over 65 reported talking on cellphones or texting while driving (Hill et al., 2017). As with middle-aged parents, the age of children in the car had some correlation with how often older adults drive distracted. The older their child passengers were, the more likely older drivers were to report talking and texting on cellphones while driving.

Other Demographic Variables

Although age is a key predictor of technology-related distraction, gender, education, income level, and geography have been shown to influence the frequency of distracted driving.

Gender

Findings from observational studies suggest that females are slightly more likely to drive while distracted than males. Female drivers in NHTSA's 2018 NOPUS were observed holding and talking on cellphones 1.24 times as often as male drivers and were observed manually interacting with devices 1.64 times as often as male drivers (NCSA, 2019). A smaller-scale observational study found similar results; females had an odds ratio of 1.3 for being distracted compared to male drivers (Ortiz et al., 2017). There are numerous observational studies that do not include data on the relationships between age and gender, yet the overall trend in these studies is that female drivers drive distracted only slightly more than male drivers, if any difference is present (e.g., Brennan et al., 2019; NCSA, 2019; Ortiz et al., 2017). Self-report studies demonstrate a lack of clear differences in distracted driving between genders. A Nationally representative survey found approximately 7 percent more male drivers reported engaging in phone calls while driving, and approximately 3 percent more male drivers reported texting while driving than female drivers (Schroeder et al., 2018). In the self-report 2019 TSCI, similar percentages of male (44.5%) and female (42%) reported having held and talked on cellphones in the previous 30 days and the percentages of drivers reporting having texted within the past 30 days were 1 percentage point apart (AAA, 2020).

Education and Income Level

Education and income can be correlated with distracted driving behaviors. A nationally representative survey asked respondents about their education level, income, and history of distracted driving. The survey contained a composite measure that categorized drivers as either "distraction-prone" or "distraction-averse" based on their answers to 11 questions about how often they performed various behaviors. With increased education level, the percentage of distraction-prone drivers increased. Among respondents with graduate degrees, 48.1 percent were distraction-prone, while 34 percent of those with no high school degree were distraction-prone (Schroeder et al., 2018). The survey indicated that, "Drivers classified as distraction-prone tended to be younger, more affluent, and have more formal education than those classified as distraction-averse." More than half of drivers with incomes above $100K were classified as distraction-prone, while only 32 percent of drivers with incomes below $15K were. A 2014 survey of both urban and suburban parents found that those with bachelor's degrees were 2.65

times more likely to self-report cellphone-related distractions while driving than those with a high school diploma/General Education Development credential or less. Significant effects of income independent from education were not found in this study, even though income was measured (Macy et al., 2014).

Geography

Region has some association with rates of distracted driving. A recent nationwide survey reported a lower occurrence of device use while driving in western States (Gerte et al., 2018). NHTSA reported the lowest amount of distracted driving in western States—Alaska, Oregon, Idaho, Washington—in a survey. This NHTSA Region 10 had 27 to 31.9 percent distraction-prone drivers in 2011, which was among the lowest proportions of distracted drivers in the country (Schroeder et al., 2013). Since 2015 the proportions of distracted drivers among NHTSA Regions have begun to converge, and no Region has fewer than 49.1 percent of its drivers categorizable as “distraction prone,” (Schroeder et al., 2018).

Drivers in urban and rural locations did not demonstrate significant differences in their patterns of device use in observational studies (NCSA, 2019) or self-report surveys (Ehsani et al., 2015). The role of urbanicity in distracted driving has not been extensively researched, though rural drivers are hypothesized to have reduced access to distractions from smartphones in vehicles. A 2019 report from the Pew Research Center indicates that rural Americans are less likely to own smartphones, use the internet daily, and have access to high-speed broadband than urban and suburban Americans (Pew Research Center, 2019). To find differences between device use in rural and urban areas, more specific questions regarding cellphone functionalities rather than overall use habits are advantageous. For example, no significant difference was found between rural and urban students’ overall device use, though when rural respondents used their cellphones, they used them significantly more often than urban respondents to look at directions or a map (Ehsani et al., 2015).

Distracted Driving and Other Risky Driving Behaviors

There are few studies researching the prevalence and motivations of drivers who self-report distracted driving along with additional risky behaviors—either concurrently or asynchronously. Distracted driving may have a stronger association with speeding than impaired driving. Speeding was the risky driving behavior with the highest odds ratio among survey respondents who reported cellphone-related distractions (Macy et al., 2014). Speeding and aggressive driving were strongly correlated with talking and texting while driving in a survey study of Canadian drivers (Fisher et al., 2016). Both surveys found weak associations between distracted driving and drowsy driving. The study in Fisher et al. found small correlations between distracted driving and impaired driving, while Macy et al. did not.

Insights about which drivers are likely to drive distracted and engage in other risky behaviors can be found by examining the underlying factors of these behaviors. Distraction and speeding are both precipitated in part by momentary time pressure (Richard et al., 2012; Young et al., 2008). Correlations between distracted driving and alcohol- and drug-impaired driving are small or nonexistent in the literature (Fisher et al., 2016; Macy et al., 2014).

Distracted Driving in Specific Situations

Immediate driving conditions and situations, along with demographics and individual differences, influence drivers' decisions regarding whether or not to engage in distractions at a particular time. Some drivers primarily perform distracting tasks in certain contexts, such as a driver who only checks their phone on monotonous roads (e.g., Oviedo-Trespalacios et al., 2017a). Some drivers add further risk to their distracted behaviors when specific situations arise, such as a teenage driver who conceals their texting in the presence of police (e.g., Gauld et al., 2014). This section will discuss the predominant driving situations and contexts associated with differential patterns of distraction: road environment complexity, road environment familiarity, police presence, passenger presence, communication partner, and presence of passengers. This is followed by a discussion of drivers simultaneously engaging in device use and other risky driving behaviors.

Road Environment Complexity

Drivers are more focused on the driving task in challenging road environments involving poor weather, complex geometries, and dense urban layouts. Observational studies (e.g., Dingus et al., 2016; Precht et al., 2017) and self-report studies (e.g., Edwards & Wundersitz, 2019; Lerner et al., 2008) have found that drivers are less willing to perform distracting behaviors when the weather is not calm or sunny. Drivers have reported reduced willingness to use devices while driving at night (e.g., Mikoski et al., 2019). One simulator study found that driving on roadways with more complex geometry was associated with greater attention on the driving task relative to a secondary task than on roadways with simpler geometry (Oviedo-Trespalacios et al., 2017a). A complex road environment can reduce drivers' focus on secondary tasks due to the high arousal provided by the primary task of driving in this context (Berlyne et al., 1960).

Arousal theory also holds that in such a high-arousal situation, a driver typically would not try to increase their arousal by seeking distracting activities (Hoekstra-Atwood, 2015). Another possible reason for drivers' reduced distraction while in complex road environments could be that drivers are especially careful to adapt their distracting activities to opportune moments when driving in these situations and develop strategies such as only using a phone at stoplights when driving through a city (Chen et al., 2016; Oviedo-Trespalacios et al., 2017b). A relevant question for future research is whether PDU also follows this pattern, or whether it involves more device use at inopportune times. This is a relevant safety issue because when drivers become distracted while driving in complex environments, their hazard perception is greatly impaired (Hoekstra-Atwood, 2015). For example, one simulator study found that participants were approximately 25 percent less likely to anticipate hazards in a complex road environment when distracted by a device compared to when the environment was simple (Ebadi et al., 2019).

Road Environment Familiarity

Drivers are more likely to drive while distracted on familiar roadways (Intini et al., 2019; Tay & Knowles, 2004). A focus group study found that although drivers 16 to 18 are aware that distracted driving is dangerous, they felt comfortable driving while distracted by cellphones when driving a familiar route (McDonald & Sommers, 2015). Complacency in distracted driving due to route familiarity is not just a problem for young drivers, as route familiarity was associated with increased frequency of distracting tasks in studies across the age spectrum (Intini et al., 2019). Increased route familiarity was associated with lower subjective ratings of risk for secondary tasks while driving in a focus group study (Lerner et al., 2008).

A naturalistic driving study using SHRP2 data from Seattle, Washington, found that more frequent and varied secondary tasks, as well as longer durations of distraction, were observed on familiar roads than unfamiliar roads (Wu & Xu, 2018), confirming the self-report findings. Ultimately, route familiarity leads to dangerous distracted driving for two reasons: It reduces attentional demands of the driving task, freeing attentional space for secondary tasks; in addition, it promotes overconfidence, encouraging drivers to perform distracting activities (Intini et al., 2019).

Police Presence

Studies demonstrate drivers' improved self-regulation of distraction when police presence is visible (e.g., Edwards & Wundersitz, 2019; Tay & Knowles, 2004; White et al., 2010). A survey involving hypothetical road scenarios with different police configurations found that drivers in Japan expected to have higher vigilance and lower intentions to perform distracting activities when police were visibly present (Nakano et al., 2019). Deterrent effects on distracted driving were strongest when police officers were present as opposed to just advertisements or stationary police cars, and when police presence was more conspicuous (e.g., flashing lights on police cars). These insights are relevant for high-visibility enforcement campaigns (see Chapter 8). A 2014 HVE campaign in Syracuse, New York, and Hartford, Connecticut, was associated with decreases in observed talking and texting on handheld phones in the enforcement areas after the first wave of HVE relative to control areas (Chaudhary et al., 2014).

While some drivers avoid distractions when police are present, others tend to conceal their distracting activities, further increasing their crash risk (Edwards & Wundersitz, 2019). A 2018 survey found that Australian drivers who reported more frequently "keeping [their] phone low (e.g., in lap or on passenger seat) for avoiding police" were significantly more likely to report a greater number of texting events per drive (Oviedo-Trespalacios et al., 2018). Young drivers in another survey reported frequent concealed texting and calling: approximately 50 percent of respondents self-reported concealed texting 1- or 2 times per week, and approximately 40 percent of respondents self-reported concealed phone calls 1or 2 times per week (Gauld et al., 2014).

A survey of young drivers found that concealed cellphone use can reduce perceived risk of apprehension, thereby increasing the feeling of anticipated regret from not texting while driving (Gauld et al., 2014). Increasing perceived risk of apprehension, through countermeasures such as HVE, has potential to reduce rates of concealed device use (Edwards & Wundersitz, 2019; Oviedo-Trespalacios et al., 2018). Attempts to hide texting behavior could imply that this population is aware that their behavior is problematic.

Passenger Presence

In the physical presence of at least one passenger, drivers tend to exhibit reduced technology-related distractions (Edwards & Wundersitz, 2019; Foss & Goodwin, 2014; NCSA, 2019), though drivers can still be at elevated risk due to distraction from passengers themselves (Bingham et al., 2016; Dingus et al., 2016; Precht et al., 2017). Adult drivers with child passengers demonstrate a unique trend: an increase in the frequency of self-reported technology distractions as child passengers' ages increased (Macy et al., 2014). This and another study of adults over 65 (Hill et al., 2017) with child passengers suggest that although technology distraction occurs among adult drivers with child passengers of any age, it is not typical among older drivers. While drivers report feeling personal responsibility for child passengers' safety (Dingus et al., 2016; Richard et al., 2012), this is not always a sufficient deterrent in some drivers from engaging in technology-related or other distractions.

Communication Partner

Drivers' use of devices while driving is influenced by whom they are communicating with on these devices, and the nature of their relationships with those people (Tison et al., 2011). Adolescents feel immense pressure to remain socially connected to their friends through digital communication, even while driving (Delgado et al., 2016; McDonald & Sommers, 2015; Sanbonmatsu et al., 2016). A study of adolescents and their parents with observational and survey components demonstrated that adolescents felt much stronger impulses to connect with their peers using devices while driving than with their parents (Mirman et al., 2017).

In addition to adolescents, drivers of all ages frequently cite the people they are communicating with as decision factors for their distracted driving (State Farm, 2016). Especially among middle-aged and older drivers, people report increased likelihood of distracted driving if communication is work-related (Edwards & Wundersitz, 2019; Engelberg et al., 2015; Hill et al., 2017). Reasons for this may include employers expecting constant availability and drivers' desire for efficiency (Salmon et al., 2019; Shinar, 2017). Regardless of a specific communication partner's relationship to a driver (i.e., personal or professional), perceived importance of the communication has the potential to override risk perceptions in drivers' decision-making processes (Delgado et al., 2016; Edwards & Wundersitz, 2019; McDonald & Sommers, 2015; Mirman et al., 2017; Nelson et al., 2009).

Personality Traits Related to Distracted Driving

Driver distraction seems to be influenced by certain personality traits (Oviedo-Trespalacios et al., 2017b), particularly self-efficacy, sensation-seeking, and executive cognitive function, as well as their ingrained cellphone use habits. These traits tend to be stable over time and influence behavior by shaping people's thought patterns and perspectives (Glendon et al., 2006). The influence of driver traits on distracted driving has been examined in the context of the theory of planned behavior, which is a behavioral framework using survey responses to explain people's intentions to perform risky behaviors (Azjen, 1991). The personality traits associated with distracted driving may differ somewhat between drivers with typical use patterns and drivers with problematic use patterns (see Chapter 6).

Self-Efficacy

Self-efficacy is not to be confused with self-esteem, as it is an evaluation of one's own ability to perform a behavior, not one's overall personal worth.

High self-efficacy—high confidence in one's own ability to control their driving behavior—is often associated with increased distracted driving (Fisher et al., 2016). Drivers that reported greater confidence in their own ability to drive distracted demonstrated lower risk perceptions of distracted driving and of roadway hazards overall (Beck et al., 2019; Sanbonmatsu et al., 2016; Wohleber et al., 2016). These people performed compensatory behaviors meant to lower their risk perceptions less frequently while driving distracted (Chapter 2; Oviedo-Trespalacios et al., 2017b). Comparative optimism, which involves a higher confidence in one's own ability relative to one's peers, is a potentially dangerous expression of the trait self-efficacy (White et al., 2004). This disproportionate confidence in one's own driving ability is widespread among some driver groups and is a major factor that drivers use to rationalize their distracted driving (Edwards & Wundersitz, 2019; McCartt et al., 2006; White et al., 2004). Higher levels of self-efficacy and comparative optimism tend to be found in younger drivers and male drivers (Gwyther et al., 2012; Palat et al., 2019). While high self-efficacy with regard to driving skills predicts device use while driving, low self-esteem seems to predict PDU overall (see Chapter 5).

Sensation-Seeking

Sensation-seeking describes the degree to which a person enjoys and pursues novel, risky experiences (Regan et al., 2008). This trait has been widely studied and is associated with elevated levels of risk-taking in a variety of driving behavior domains, including device distraction (Edwards & Wundersitz, 2019; Linkov et al., 2019). Strong associations between sensation-seeking and distracted driving have been found among drivers in several age groups (Palat et al., 2019), though adolescents are the primary demographic of study in relation to sensation-seeking and distracted driving (Scott-Parker & Weston, 2017). Adolescents with greater sensation-seeking tendencies are more likely than their peers to self-report device-related distractions while driving (Beck et al., 2019; Chen et al., 2016; Delgado et al., 2018). The influence of sensation-seeking on distracted driving is theorized to be especially strong during adolescence because of a unique combination of factors that heighten both impulsivity and desire for peers' approval during this life stage (Delgado et al., 2016; Fisher et al., 2016).

Executive Cognitive Function

Deficits in executive cognitive function—the ability to plan and carry out goal-oriented behavior—are associated with increased device use while driving and with more severe performance decrements while distracted (Nowosielski et al., 2019; Pope et al., 2017). Low executive function and high impulsivity were associated with high self-reported willingness to text and drive among college students (Hayashi et al., 2017). The inverse relationship between executive function and distracted driving has been corroborated by studies examining other mental characteristics that are conceptually related to executive function, such as mindfulness, cognitive capture (Gauld et al., 2017; Murphy et al., 2020), and working memory (Louie & Mouloua, 2019). Drivers with attention deficit hyperactivity disorder (ADHD), a condition often characterized by difficulties with goal-directed planning and focused behavioral execution (i.e., executive function), appear to be especially prone to distracted driving and its resultant performance decrements (Classen et al., 2013; Groom et al., 2015; Fisher et al., 2016; Shaw et al., 2019).

People meeting the criteria for ADHD had significantly more self-reported Facebook use while driving than controls, as well as cravings to use Facebook that were 30 percent stronger and more directly related to self-esteem (Turel et al., 2016). Beside ADHD, limited research exists on distracted driving among drivers with other diagnosable cognitive conditions that could affect executive function, though Alzheimer's, Parkinson's, and mild cognitive impairment (Pavlou et al., 2017) have tentatively been shown to exacerbate performance decrements due to distraction while driving.

Theory of Planned Behavior

Along with personality constructs, people differ in terms of their beliefs and decision-making processes, which are concepts captured in the theory of planned behavior. The TPB is a psychological framework developed to explain decisions to engage in risky behaviors in situations where a person has incomplete control of their environment (Azjen, 1991). The TPB is used to predict behavioral intentions and has been applied frequently and widely across traffic safety domains, including distracted driving. TPB studies frequently find that constructs are predictive of intentions. The TPB does not identify a universally relevant predictor variable or intervention for distracted driving, but rather, it illustrates factors in drivers' decision-making processes regarding this behavior (see Figure 5 below). The relative weights of these factors in drivers' decision-making processes are represented by proportions of the variance in intentions that each construct accounts for.

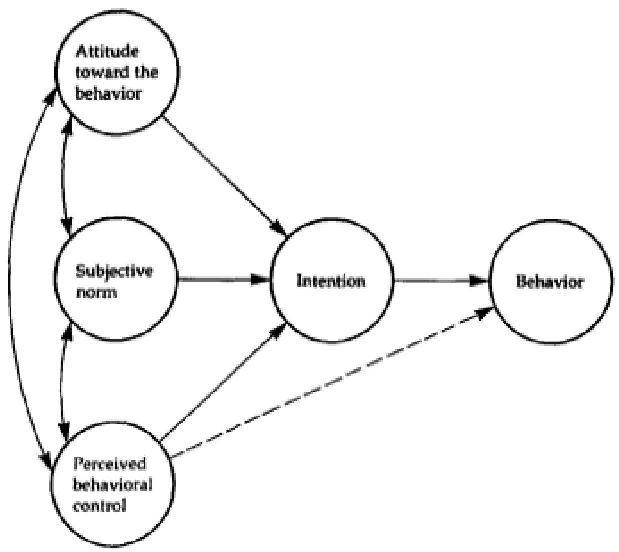

Figure 5. Azjen's Theory of Planned Behavior (from Azjen, 1991)

This section below summarizes how the TPB's three main constructs—attitude, subjective norms, and perceived behavioral control—are associated with intentions to drive distracted. Attitude is the most predictive construct overall, with studies reporting that the belief that drivers will experience positive outcomes from using devices is a strong indicator of their intentions to do so. Subjective norms generally explain a smaller percentage of the variance in distracted driving intentions than attitudes, and drivers' perceptions of what other drivers actually do are more strongly correlated with distracted driving intentions than perceptions of what drivers should do. Perceived behavioral control has weak associations with distracted driving intentions, especially when measurements of the construct focus on drivers' perceived ability to drive safely while using devices. In addition to the three main constructs, the TPB can accommodate additional variables that have a theoretical role in predicting intentions to perform a given behavior (Azjen, 1991; Gauld et al., 2014). Habit is sometimes one of these variables and it is discussed in relation to the TPB below.

TPB-Attitudes

Attitudes within the TPB are defined as "the degree to which a person has a favorable or unfavorable evaluation or appraisal of the behavior in question," based on advantages and disadvantages of possible behavioral outcomes (Azjen, 1991). Attitudes are the most consistently predictive TPB construct in the distracted driving literature, accounting for large portions of the variance irrespective of the type of behavior (e.g., texting or calling) and driving context (Sullman et al., 2018; Walsh et al., 2007). For example, in one survey study, attitude was the only construct that predicted intentions to both initiate and respond to digital communications while driving, accounting for approximately 10 percent of the variance in intentions for both behaviors (Nemme & White, 2010). Attitudes in the TPB inherently incorporate risk perceptions. Attitudes explained about 40 percent more of the variance in intentions to text while driving than did risk perceptions alone, though crash risk perceptions were still predictive (Prat et al., 2015).

Examples of attitudes toward distracted driving:

- Using a cellphone while driving in the next week would likely result in using time effectively (Sullman et al., 2018).
- Using a cellphone while driving in the next week would likely result in being involved in a crash (Sullman et al., 2018).
- "Texting while driving is unpleasant/pleasant," (Shevlin et al., 2019). Participants responded to this statement using a 7-point Likert scale where 1 meant "unpleasant" and 7 meant "pleasant."

TPB-Subjective Norms

The original TPB included one measure of subjective norms: "the perceived social pressure to perform or not to perform the behavior," (Azjen, 1991). Subjective norms are less consistent than attitudes in their predictive power for behavioral intentions to drive distracted. Some survey results demonstrate social norms accounting for low percentages of the variance in intentions, around 22 percent (e.g., Brown et al., 2019; Rowe et al., 2016), while other studies have found high values, around 61 percent (Waddell & Wiener, 2014). This could be due in part to the segmentation of subjective norm constructs in recent studies. Many TPB-based scales now measure subjective norms as two independent constructs: injunctive norms and descriptive norms. Injunctive norms are what others/loved ones believe one should do, while descriptive norms are what one believes others/loved ones are actually doing (Azjen, 1991).

Descriptive norms are more predictive of intentions to drive while distracted than injunctive norms in the current literature. Descriptive norms explained up to 39 percent of the variance in intentions to drive distracted in a TPB-based survey, while injunctive norms were not significantly predictive (Chen & Donmez, 2016). Studies concentrating on adolescent drivers further demonstrate the superior predictive power of descriptive norms over injunctive norms (e.g., Carter et al., 2014; Merrikhpour, 2017). Within descriptive norms, perceptions of peers' behavior, rather than perceptions of parents' behavior, accounted for higher percentages of the variance in intentions to use cellphones while driving (Merrikhpour, 2017). Similarly, a TPB study linking social norms to self-reported distraction found that perceptions of peers' behavior were more predictive than perceptions of parents' behavior (Carter et al., 2014).

Examples of injunctive norms about distracted driving:

- It is likely that my friends would approve of me using a cellphone while driving in the next week (Sullman et al., 2018).
- "Most people who are important to me think I should text and drive" (Shevlin et al., 2019).

- “Sensible people believe that I should/should not drive whilst talking on a hand-held [cellphone]” (Rowe et al., 2016). Participants responded to this statement using a 7-point Likert scale where 1 meant “should not” and 7 meant “should.”

Examples of descriptive norms about distracted driving:

- “Most people who are important to me text while driving” (Shevlin et al., 2019).
- “Most of my friends would read/send a text message while driving in the next week” (Brown et al., 2019).

TPB-Perceived Behavioral Control

Perceived behavioral control in the TPB has two aspects: one’s “self-efficacy with respect to the behavior,” and one’s “control over the behavior,” i.e., drivers’ belief in their own ability not to drive distracted (Azjen, 1991; Azjen, 2002; Benson et al., 2015). The first aspect of perceived behavioral control, “self-efficacy,” is similar to the personality trait of the same name and is described above in the Self-Efficacy section. The second aspect is “control beliefs,” which can describe drivers’ confidence in their own ability to resist the temptation to perform distracting tasks while driving. Perceived behavioral control is a minor predictor at best of drivers’ intentions to drive while distracted, explaining around ten percent of the variance (e.g., Brown et al., 2019; Gauld et al., 2014; Rowe et al., 2016; Zhou et al., 2012). In studies where perceived behavioral control does emerge as a significant predictor, its self-efficacy aspect is more predictive than its “control beliefs” aspect (Murphy et al., 2020; Nemme & White, 2010; Prat et al., 2015).

Examples of self-efficacy statements regarding distracted driving:

- “I am confident that I could read or send a text while driving” (Shevlin et al., 2019).
- “I am confident that I could monitor/read social interactive technology on my smartphone while driving in the next week” (Murphy et al., 2020).

Examples of control beliefs about distracted driving:

- “The decision to text while driving is entirely up to me,” (Shevlin et al., 2019).
- “The decision to text while driving is beyond my control,” (Shevlin et al., 2019).
- “I have complete control over whether I will read/send text messages while driving in the next week,” (Brown et al., 2019).

Habits

Ingrained habits appear to exert some influence on drivers’ use of technology while driving when the sampled drivers are not known to be experiencing problematic cellphone use (Edwards & Wundersitz, 2019; Hoekstra-Atwood, 2015; Marulanda et al., 2015). When measuring intentions to drive distracted, past behavior accounted for around 7 percent of the variance in a TPB study of young drivers (Shevlin et al., 2019), which is sizable for a single TPB construct. Few TPB studies directly measure past behavior or habit, and those that do rarely distinguish habitual cellphone use while driving from habitual cellphone use in daily life (Edwards & Wundersitz, 2019). Examining people who use cellphones in non-problematic versus problematic ways may reveal differential influences of habit on cellphone use while driving. Habitual use of cellphones while driving and habitual use in daily life each predicted cellphone use while driving in a TPB study that measured the constructs separately (Zhou et al., 2012). Drivers’ number of text messages sent per day in non-driving contexts demonstrated a strong correlation with number of texts sent per hour of driving in a study that matched SHRP2 naturalistic driving data to cellphone records (Atwood et al., 2018).

Causality cannot be determined from these survey studies, but based on the psychological literature surrounding habit, it is likely that repeated device use in daily life outside of driving serves to 'condition' people for device use while driving (e.g., Friedman et al., 2004; Miyake et al., 2000). A recent survey found that high scores on a scale assessing PDU symptoms were associated with frequent self-reported device use while driving for both adults and adolescents (Mirman et al., 2017). More information on PDU and distraction will be provided in Chapters 5, 6, and 8.

Summary

The findings reviewed in this chapter demonstrate that drivers who are affected by distracted driving are far from a homogenous group. They vary in terms of demographics, driving contexts, and individual differences. Much research concerning demographics and distracted driving focuses on adolescent drivers. Young drivers have a variety of psychosocial characteristics and technology-use patterns that may predispose them to device use while driving, perhaps in a problematic way. As digital natives, young drivers may be willing to extend their technology-focused behaviors to their driving, in contrast to middle-aged and older drivers that have had years of experience of living and driving without these technologies. However, middle-aged and older drivers are still prone to device use while driving, but the research shows that these drivers use devices less frequently than young drivers and they are more likely to use devices to communicate with colleagues and family members rather than with peers.

Different driving contexts can influence decisions about device use while driving. Simple, familiar roads have been demonstrated to be conducive to distraction. However, most drivers engage in some degree of self-regulation of device use while driving. Specifically, they tend to avoid this behavior around police, when passengers are present, and under more demanding driving conditions. An important question is whether this self-regulation is affected by PDU, since driver difficulty avoiding device use under demanding driving conditions could potentially pose a safety risk.

Individual differences among drivers also play a role in distracted driving decisions. High levels of the traits self-efficacy and sensation-seeking, as well as low levels of executive function, all predict device use while driving. Habit exerts some influence on drivers' choices about cellphone distractions while driving but is likely more relevant for drivers who use devices problematically as opposed to casually. In addition, constructs used to predict behavioral intention (e.g., TPB constructs), particularly attitudes, are especially relevant for understanding device use while driving. The population profile of those affected by distracted driving is nuanced and determined by a confluence of demographic factors associated with distracted driving, driving contexts and distraction, and individual differences related to distracted driving.

4. What Is Addiction, and How Are We Using This Terminology?

Introduction

To consider the potential for "addictive" device use within and outside of the driving context, it is critical to understand the definition of addiction. Addiction has typically been studied in terms of substance use, so this definition is presented first. This chapter argues from a multifaceted perspective on the concept of addiction, taking into account its diverse contributing factors as described by the biopsychosocial model. Behavioral addictions can have similar causes and effects to substance use disorders, and the relationship between the two types of conditions is described. Only one behavioral addiction, gambling disorder, is recognized by the American Psychiatric Association, so device use behavior requires a different classification. Three alternatives are presented, and the usage of the term "problematic device use," which refers to compulsive and/or functionally impairing device use throughout this report, is explained. This chapter provides context for exploring PDU and driving in the later chapters: its characteristics, motivating factors, consequences, and countermeasures.

Definition of Substance Addiction

The term "addiction" is often used to describe a chronic, relapsing disease of the brain that is characterized by a pathological pursuit of reward. Addiction is characterized in the Diagnostic and Statistical Manual of Mental Disorders, 5th edition DSM-5 by the following experiences (APA, 2013):

- inability to consistently abstain
- impairment in behavioral control
- craving
- diminished recognition of significant problems with one's behaviors and relationship
- a dysfunctional emotional response

Typically, addiction is used to describe substance use disorders, where people with addiction have an intense and problematic focus on using a substance(s) such as alcohol or drugs to the neglect of other areas of life (Bickel et al., 2007). Brain imaging studies have shown that addiction causes neurochemical and functional changes in the areas of the brain that relate to judgment, decision making, learning, memory, and behavior control (Volkow et al., 2013), making behavior change difficult even with awareness of problematic use. In addition to substance use, several other behaviors have also been shown to produce short-term rewards that result in diminished control (Grant et al., 2010). Whether an addiction is to a substance or a behavior, addiction is complex and causes an intense and problematic focus that affects many areas of a person's life.

Biopsychosocial Model of Addictive Behaviors

In the past, attempts to understand and treat addiction have focused on it being a purely biological or a purely sociocultural problem and thus have not been very successful (Volkow et al., 2013). A purely biological approach to addiction would treat it only as a dysregulation of brain chemicals, while a purely sociocultural approach would attribute a person's addiction solely to their environment. Each of these conceptualizations are flawed, and these siloed viewpoints hinder the treatment of addictions (Donovan & Marlatt, 2005). The biopsychosocial model, which has now been widely accepted in the addiction field (Donovan & Marlatt, 2005; Griffiths, 2005), interprets the phenomenon of addictive behaviors as an interplay of factors in three spheres: biological, psychological, and sociocultural (see Figure 6). Problematic device use is expected to arise from these three spheres of factors within people, similar to behavioral and substance addictions.

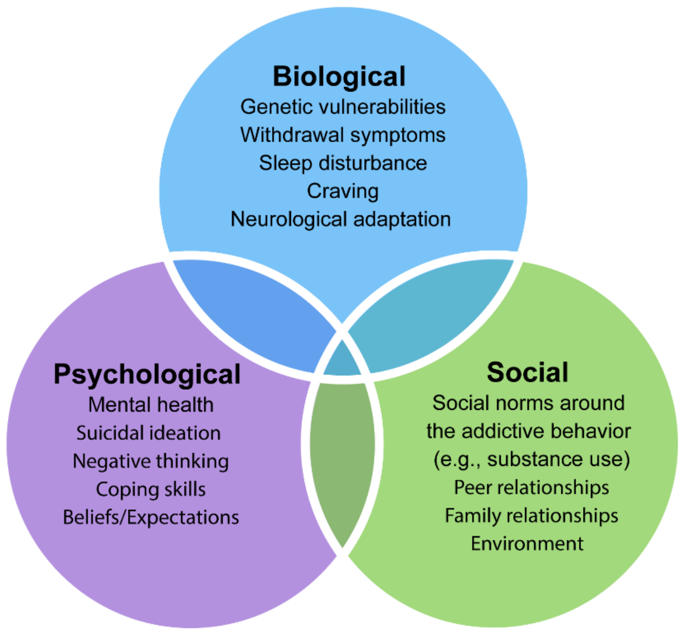

Figure 6. Biopsychosocial model of addictive behaviors

Addiction is a multifaceted behavior that is strongly influenced by contextual factors, including variations in behavioral involvement and motivation across different demographic groups, structural characteristics of activities/substances, and the developmental or temporal nature of addictive behavior (Griffiths, 2005). To give an example related to device use, young people are especially likely to experience problematic cellphone use patterns, which has often been attributed to the ways in which the brain develops during puberty to seek rewards and social activity (Casey et al., 2000; Steinberg, 2008). The biopsychosocial model adds useful nuance to this finding because it also recognizes that cellphones in and of themselves may be psychologically addictive (Busch et al., 2021; Montag et al., 2019), and that people may use cellphones more or less over time, depending on how norms evolve within their social circle (De-Sola Gutiérrez et al., 2016; Salehan et al., 2013). Even though PDU cannot be conclusively called an addiction according to DSM-5 guidelines, the biopsychosocial model is useful for comparing this behavior to addiction and understanding its antecedents.

What Is Behavioral Addiction and Its Relationship to Substance Addiction?

Behavioral addictions are similar to substance use disorders in that they involve the failure to resist an impulse, drive, or temptation to perform an act that is harmful to the person or to others, resulting in a negative impact on functioning across several domains. One could argue that the behavior need not be harmful but could be potentially harmful to the person or others for classification as a behavioral addiction. What is required is the negative impact on functioning and the failure to resist performing the act despite the potential for harm. Both behavioral addictions and substance use disorders also have onset in adolescence and young adulthood and higher rates in younger age groups than among older adults (Chambers & Potenza, 2003).

The concept of "behavioral addiction" is controversial and the DSM-5 (APA, 2013) currently only recognizes one non-substance-related disorder, gambling disorder. It defines gambling disorder in the following way.

> "Persistent and recurrent problematic gambling behavior leading to clinically significant impairment or distress, as indicated by the individual exhibiting four or more of the following in a 12-month period:
>
> - Needs to gamble with increasing amounts of money in order to achieve the desired excitement;
> - Is restless or irritable when attempting to cut down or stop gambling;
> - Has made repeated unsuccessful efforts to control, cut back, or stop gambling;
> - Is often preoccupied with gambling;
> - Often gambles when feeling distressed;
> - After losing money gambling, often returns another day to get even;
> - Lies to conceal the extent of involvement with gambling;
>
> Has jeopardized or lost a significant relationship, job, or educational or career opportunity because of gambling;
>
> Relies on others to provide money to relieve desperate financial situations caused by gambling."

Similarities to substance use disorders are clear, as the criteria for gambling disorder mirror the criteria for substance use disorders. Though only gambling disorder is recognized in the DSM-5, there is acknowledgment that there are other behavioral disorders that show similarities to substance use disorders and gambling disorder (APA, 2013). These disorders, such as compulsive shopping, kleptomania, and repetitive skin picking, have historically been conceptualized as existing along an impulsive-compulsive spectrum, and are typically classified as impulse control disorders and/or referred to colloquially as behavioral addictions (Grant et al., 2010). No behavioral disorders explicitly related to smartphone use are recognized, though internet gaming disorder was included in an appendix for conditions to be further studied in the DSM-5 (Rosenberg & Feder, 2014). The psychological research community is looking more deeply into the potential existence of behavioral addictions besides gambling. Comparisons to substance use addictions remain the "benchmark" for determining whether a behavior is addictive.

Skeptics of the behavioral addiction concept argue that the physical signs of drug addiction are absent in behavioral addiction (Alavi et al., 2012). Substances provide physiological input beyond what the body can produce by behavior alone. Substance use disorders are classified by several physically oriented criteria such as tolerance and withdrawal; these criteria are not typically present in behavioral addictions (Van Rooij & Prause, 2014). Skeptics further assert that behaviors may not be as severe as those seen in substance use disorders and that it may be over-inflating mental health problems to conceptualize excessive behaviors in this way, leading to over-diagnosis, over-prescription of pharmaceuticals, and possible stigma associated with the term "addiction" (Kardefelt-Winther, 2015).

In addition, substance use disorders tend to be chronic throughout a person's life, while behavioral addictions may not be. As of now, longitudinal research on the chronic versus episodic nature of behavioral addictions is limited. A 5-year study found that the trajectories of symptom severity over time were not steady, and were episodic rather than continuous in nature, suggesting a distinction between addiction and excessive behaviors (Thege et al., 2015). Proponents of the idea that addiction encompasses behavioral addictions as well as substance use disorders posit that all addictions consist of shared components: salience, mood modification, tolerance, withdrawal, conflict, and relapse (Griffiths, 1996, 2005). Researchers also emphasize that in order to make a diagnosis of behavioral addiction, functional impairments must be present at work, in social relationships, or in other social situations (Alavi et al., 2012). All components of addiction, as well as functional impairments, can be present in a person's device use (Busch et al., 2021).

However, people's relationships with devices such as cellphones vary widely. Looking for issues in a person's life using the biopsychosocial model could help identify whether their device use is pathological or merely at a typical, albeit high, level (Chapter 5). It is argued that a multifaceted approach to the study of addictive behavior is the most pragmatic way forward in the field.

Alternative Concepts to Behavioral Addiction

Alternative concepts to behavioral addiction that could play a role in "addictive" or PDU include compulsive use behavior, habitual behavior, and maladaptive behavior prompted by external factors. Compulsions refer to the intense urge to perform a specific behavior, such as smoking a cigarette, shoplifting, or checking Facebook. Compulsions are an integral part of addiction, but there are two primary differences between compulsion and addiction. First, a compulsion does not necessarily involve pleasure-seeking, whereas addiction does (Busch et al., 2021). Second, a person is more likely to recognize or have awareness of compulsive use as problematic behavior whereas awareness of addictive behavior as problematic may be less likely (Hartney, 2020). Ultimately, compulsive use behavior is a narrow term, whereas addiction is broader.

Habitual behavior is also similar to addiction in that both involve repetitive behaviors. The formation of a habit is accompanied by decreased attention to self-monitoring, making it less likely that self-regulatory incentives will be consciously applied to moderate the behavior (Coyne et al., 2019). Habits are essentially behavioral acts without self-instruction or conscious thinking (LaRose & Eastin, 2004), and habits can have both positive and negative effects (Wood & Neal, 2007). It is important to note that the occurrence of severe, negative life consequences is necessary to distinguish addiction from behavior that is merely impulsive or habitual (Griffiths et al., 2005). At face value, consistent maladaptive behavior also seems conceptually similar to behavioral addiction. Maladaptive behavior arises out of an attempt to escape life's difficulties and can be defined as a type of behavior that inhibits a person's ability to adjust to a particular situation. However, instead of improving the situation, maladaptive behaviors may perpetuate unhealthy circumstances (American Addiction Centers, 2020). Consistent maladaptive behavior involves participation in a negative behavior with potentially severe consequences. Unlike addiction, though, these maladaptive behaviors can often be stopped if the individual makes a concerted effort to do so. Consistent maladaptive behavior is more a sign of deficient self-regulation rather than addiction (LaRose et al., 2003). Addiction also involves physiological symptoms that cannot be avoided.

Each of the alternative concepts presented above has similarities to addiction such that they involve failure to resist an impulse, drive, or temptation to perform an act that may be harmful to the person or to others but are distinct in that they may not lead to the functional impairment or physiological symptomatology that categorizes addiction as listed in the DSM-5.

For the purpose of exploring these concepts within the context of electronic device use, the term "problematic use" better captures the full spectrum of compulsive use, habitual behavior, and maladaptive behavior that may be associated with repeated and potentially harmful electronic device use, rather than "behavioral addiction." Literature reviews on electronic device use have found insufficient evidence to label unhealthy levels of this behavior an addiction and have also settled on "problematic device use" or "problematic phone use" as a more appropriate term (Billieux et al., 2015; Busch et al., 2021; Panova & Carbonell, 2018). There may be people who experience clinically significant impairment or distress in the absence of a device, but it is likely a small percentage of the people who display PDU. Thus, problematic use is more of an umbrella term that encapsulates a broader population than the addiction framework would (Billieux et al., 2015; Wilcockson et al., 2019). In addition, there is a lack of established physiological components related to PDU (see Chapter 5 for initial research in this area). Extant literature uses both the problematic use and behavioral addiction terminology but given the uncertainty and complexity surrounding the use of the term "addiction," we use the broader term of "problematic use" throughout the current report.

Summary

While PDU cannot conclusively be called an addiction, this behavior can certainly be associated with components of addiction—such as salience and mood modification—and can lead to functional impairment in personal and professional contexts. Even outside of use while driving, PDU can be unhealthy and distressing for the affected individual. Similarities between this behavior and substance use disorder demonstrate the potential health concerns of PDU. The biopsychosocial model, originally conceptualized for substance addictions, is also useful for understanding how biological, psychological, and sociocultural factors can give rise to PDU. Further research could offer insights into the unique characteristics of PDU, such as how it varies between people and groups, and how it affects the brain's chemistry. Understanding how PDU resembles and differs from a behavioral addiction is valuable for conceptualizing how it may affect people in an especially risky situation—driving a car.

5. Problematic Electronic Device Use and the Biopsychosocial Model

Introduction

This chapter examines PDU through the lens of the biopsychosocial model in order to characterize this condition, since PDU does not fit the criteria to be designated a behavioral addiction. Building upon the definitions provided in Chapter 4, this chapter explores the ways in which PDU affects the brain, how PDU results from "addictive" software design strategies, and how this type of behavior relates to culture. The chapter then describes the individual differences that are associated with PDU, including those based on demographic factors, such as: young age; female gender; and low education and socioeconomic status. Personality traits associated with PDU are also examined, including anxiety, impulsivity, extraversion, and low self-esteem. The chapter ends by discussing why PDU within the driving context still presents a safety risk, despite not being categorizable as a behavioral addiction.

Problematic Device Use in Relation to Behavioral Addiction

Mobile device use, particularly cellphone use, is thoroughly integrated into American life (Delgado et al., 2016; Kaviani et al., 2020; Shaw et al., 2019). People use cellphones and smartphones for an increasing variety of tasks and for increasing amounts of time per day—over 229 minutes per day in 2020, with continued growth in this number expected (O'Dea, 2020). Coupled with the increased use is mounting concern among the scientific community that cellphone use is addictive (De-Sola Gutiérrez et al., 2016; Panova & Carbonell, 2018). However, examining PDU in relation to the only recognized behavioral addiction (gambling disorder), and in relation to the DSM-5 criteria for behavior as addictive, demonstrates that PDU is not a behavioral addiction.

PDU is a health condition that can lead to serious negative consequences (of which crashes while driving are just one). It is characterized by functional impairments due to one's device use, along with recurrent cravings to use the device. Functional impairments are defined broadly as reductions in the health of physiological processes or quality of participation in life activities (World Health Organization, 2001). A literature review estimated that up to 35 percent of cellphone users could have symptoms of problematic cellphone use (Billieux et al., 2015). The following subsections will demonstrate why PDU is not a behavioral addiction, in order to display a more accurate and nuanced psychological profile of this behavior.

Mapping Behavioral Addiction to Problematic Electronic Device Use

As discussed in Chapter 4, the device use literature contains terminology related to both addiction and problematic use. Table 3 presents a possible adaptation of the DSM-5's gambling disorder criteria to electronic device use. This table is not a scale of PDU for people, but rather an illustration of the criteria PDU itself would have to meet to be considered a behavioral addiction.

Table 3. Gambling disorder criteria adapted to electronic device use

Gambling Disorder Criteria	Adapted for Electronic Device Use
a. Needs to gamble with increasing amounts of money in order to achieve the desired excitement	a. Needs to use an electronic device with increasing amounts of time to achieve the desired effect
b. Is restless or irritable when attempting to cut down or stop gambling	b. Is restless or irritable when attempting to cut down or stop device use

Gambling Disorder Criteria	Adapted for Electronic Device Use
c. Has made repeated unsuccessful efforts to control, cut back, or stop gambling	c. Has made repeated unsuccessful efforts to control, cut back, or stop device use
d. Is often preoccupied with gambling	d. Is often preoccupied with device use
e. Often gambles when feeling distressed	e. Often uses an electronic device when feeling distressed
f. After losing money gambling, often returns another day to get even	f. After negative consequence of device use is felt (e.g., ticket for device use while driving), often continues device use at the same level and in the same situation
g. Lies to conceal the extent of involvement with gambling	g. Lies to conceal the extent of involvement with device
h. Has jeopardized or lost a significant relationship, job, or educational or career opportunity because of gambling	h. Has jeopardized or lost a significant relationship, job, or educational or career opportunity because of device use
i. Relies on others to provide money to relieve desperate financial situations caused by gambling	i. Relies on others to relieve desperate situations caused by PDU

It is possible that most of the above criteria for gambling disorder can describe typical experiences when adapted for PDU, particularly cellphone use (Grant et al., 2010; Harris et al., 2020). For example, people affected by gambling disorder and those affected by PDU are both likely to turn to their problematic behavior during times of distress and continue to engage in their problematic behavior after suffering negative consequences for it (Busch & McCarthy, 2021; Rosenberg et al., 2014). Other tendencies that are analogous to those of gambling disorder could occur among PDUrs as well, such as jeopardizing or losing opportunities or relationships (Harkin & Kuss, 2020; Jenaro et al., 2007; Kwon et al., 2013; van Deursen et al., 2015). Yet, a broader conceptual view of behavioral addiction demonstrates that, unlike gambling disorder, PDU does not fit into this category.

Does Problematic Device Use Have the Characteristics of a "Real" Addiction?

Problematic device use does not seem to be a behavioral addiction, despite sharing some similarities with characteristics of addiction. As stated in Chapter 4, the DSM-5 has a set of parameters that a behavior must meet to be considered a behavioral addiction, and these are broader than the diagnostic criteria for gambling disorder. Behavioral addiction is characterized in the DSM-5 by the following. inability to consistently abstain; impairment in behavioral control craving diminished recognition of significant problems with one's behaviors and relationships a dysfunctional emotional response

In order to classify PDU as a behavioral addiction with some degree of confidence, it would need to consistently demonstrate all of these elements. Problematic cellphone use might appear to fit into the APA's five overall behavioral addiction parameters, but only two of these categories are consistently present for problematic cellphone users. "Craving" to use the device and a "dysfunctional emotional response" are common for problematic cellphone users (Busch & McCarthy, 2021; De Sola-Gutiérrez, 2016).

Problematic cellphone users crave using their cellphones, and fixation on their devices intensifies when they are forced to abstain from using them (Jenaro et al., 2007; Wilcockson et al., 2019). Problematic cellphone users also demonstrate dysfunctional emotional responses in general, including frequently experiencing anxiety and negative moods, relying on their cellphones to relieve distress, and having their identity and emotions be highly influenced by content on their smartphone (Harkin & Kuss, 2020; Sapacz et al., 2016).

The other three parameters of behavioral addiction are not demonstrated to be present for problematic cellphone users. One of these, "diminished recognition of significant problems with one's own behavior and relationships," has not been assessed with any longitudinal studies of cellphone use. This “diminished recognition” is likely not present, since the strength of people’s self-reported feelings that their cellphone use is compromising their quality of life is directly related to their amounts of smartphone use (Busch & McCarthy, 2021; Harris et al., 2020). The close relationship between these two variables in studies with self-report data indicates that PDUrs are typically aware of the personal and interpersonal issues their behavior creates.

Two of the DSM-5’s overall parameters of behavioral addiction are key features of gambling disorder, but they are not consistently present in cases of problematic cellphone use. These include “inability to consistently abstain” and “impairment in behavioral control.” The following paragraphs in this section will explore each of these two elements in more detail.

Current research has not demonstrated that problematic cellphone users have an “inability to consistently abstain” from their cellphone use. Longitudinal studies assessing treatment interventions for problematic cellphone use have not been conducted. Yet current research does demonstrate that, for short periods of time, people do not generally experience adverse psychological or physiological symptoms (i.e., withdrawal) when denied the ability to use their cellphones (Kneidinger-Muller, 2019; Panova & Carbonell, 2018; Sapacz et al., 2016). Although people’s cravings to use their cellphones do increase when denied the opportunity, they are capable of not using these devices, at least for short periods (Wilcockson et al., 2019). Some researchers posit that “nomophobia”—the fear of being without a cellphone—is a condition that attests to problematic cellphone users’ inability to consistently abstain from cellphone use (King et al., 2014; Regan et al., 2020). However, nomophobia represents separation anxiety from an object rather than discomfort from being unable to perform a certain behavior (Bragazzi & Puente, 2014; Kaviani et al., 2020). Further, it can constitute a rational, non-problematic response in today’s world, where cellphones are essential for many tasks in daily life (Panova & Carbonell, 2018). “Inability to consistently abstain” does not accurately describe problematic cellphone use.

Despite popular media portrayals of problematic cellphone use, “impairment in behavioral control” is not typically found among people with this condition. Most current studies operationalize people’s control over their device use according to their usage time, using survey items such as, “I often use my smartphone for longer than I had intended to” (Harris et al., 2020; Kwon et al., 2013). However, people agreeing with this statement do not necessarily experience impairments in control over their smartphone use. Using one’s cellphone for longer than intended could arise from cognitive absorption in the device, fulfilling professional or personal obligations, or from enjoying one’s device use and continuing to do so past planned times out of genuine enjoyment, not compulsion (Panova & Carbonell, 2018). High levels of device use, even past intended times, do not mean that a person has impaired control over their device use. Relatedly, large amounts of time spent using cellphones does not necessarily indicate tolerance (i.e., “needing to use a cellphone for increasing amounts of time in order to achieve the same desired effect [on mood],”), as myriad personal factors could explain high usage times other than tolerance (Billieux et al., 2015). Based on the ways in which PDU affects the brain (see the *Biological Factors* section, below), this condition seems to be a more of a habit than an addiction, since it is not marked by impairments in behavioral control.

Based on the criteria presented in Table 3, PDU initially appears similar to gambling disorder. Many of the criteria from the DSM-5 for gambling disorder could have analogues among heavy smartphone users. Despite apparent resemblances—i.e., “craving” and “a dysfunctional emotional response”—PDU differs from gambling disorder in two fundamental ways, preventing it from being classified as a behavioral addiction. Namely, gambling disorder involves an "inability to consistently abstain," and "impairment in behavioral control," while PDU lacks these elements. Since PDU does not clearly fit into the category of a behavioral addiction, characterizing this condition requires a different framework. The approach this report will use to understand PDU is the biopsychosocial model, which can classify contributing factors to addictions, as well as to any other health condition. Below, we outline the biological, psychological, and sociocultural factors related to PDU.

The Biopsychosocial Model and Problematic Device Use

The complexity of PDU illustrates that this condition involves an intersection of biological, psychological, and sociocultural factors. While the biopsychosocial model (see Chapter 4) typically pertains to the traits and circumstances that give rise to addictions, literature from this perspective is rare for PDU—only a few longitudinal studies have been conducted (Coyne et al., 2019). Existing longitudinal studies in this area demonstrate that the individual differences contributing to problematic cellphone use largely remain stable throughout adolescence (Lu et al., 2014; Thomée et al., 2011). Determining the contributing factors to problematic cellphone use is an active research area, and information on this subject is provided below in the context of the biopsychosocial model where possible. However, by necessity, some of the following analysis using the biopsychosocial model considers effects or correlates of PDU rather than causes, which are more difficult to ascertain.

Biological Factors

Addiction uses existing biological processes in the brain that govern reward, pleasure, and habit to reinforce maladaptive behaviors. Recent findings suggest that PDU acts upon similar areas of the brain as addictive substances and behaviors do (Kuss, Pontes, & Griffiths, 2018; Noël et al., 2013), but some differences exist. Unlike substance and gambling addictions, PDU may have a stronger effect on brain systems related to impulsivity than on brain systems related to inhibition (Volkow et al., 2012; Noël et al., 2013). Recent research has delved further into the examination of PDU by conducting magnetic resonance imaging to examine brain structure and function among those who have been labeled as PDUrs. MRI offers an objective way to compare behavioral addictions and other addictions as it offers insight into the neural systems underlying these possible disorders. Figure 7 shows the location of these neural systems and their place in a larger brain "circuit" related to impulsive and inhibitory thoughts and behaviors. Problematic device use disrupts this circuit's typical functioning, damaging its health by reducing its volume of "gray matter," (Horvath et al., 2020; Wang et al., 2015; Zhang et al., 2016). Gray matter is comprised of neurons, multifunctional cells often known simply as "brain cells" (Suckling & Nestor, 2017). The reduction in gray matter volume represents a brain area that sees less use, rather than physically shrinking.

The neural activities in two key brain systems are implicated in substance addiction: the reflective-inhibitory prefrontal system and the impulsive amygdala-striatal system (Jentsch & Taylor, 1999; Volkow & Fowler, 2000; Arnsten & Li, 2005; Bickel et al., 2007). The prefrontal cortex is the primary brain region associated with the inhibition of impulses, which is closely related to decision-making, planning, personality, and one's sense of self (Arnsten & Li, 2005; Casey et al., 2008; Steinberg, 2008). The prefrontal cortex works with other areas of the brain, as represented in Figure 7, to suppress unwanted urges and responses. The amygdala-striatal (mesolimbic dopamine-dependent) neural system is associated with impulsive behavior and is critical for the incentive motivational effects of a variety of rewards (Wise & Rompre, 1989; Everitt et al., 1999). In addition, the insula has been robustly associated with addictive behavior (Suckling & Nestor, 2017; Zhang et al., 2016a), with accumulating evidence supporting differential contributions of anterior versus posterior regions. Specifically, the anterior insula has been associated with stimulus-related salience processing and craving, whereas the posterior insula has been attributed to perceiving bodily homeostasis, i.e., the sensation of one's body "functioning normally" (Zhang et al., 2016a). Although these brain regions are associated with addictive behavior and substance abuse, it is important to keep in mind that these regions are not solely activated by addictive behavior and they are also used for mundane daily activities (Meshi et al., 2015; Wise & Rompre, 1989).

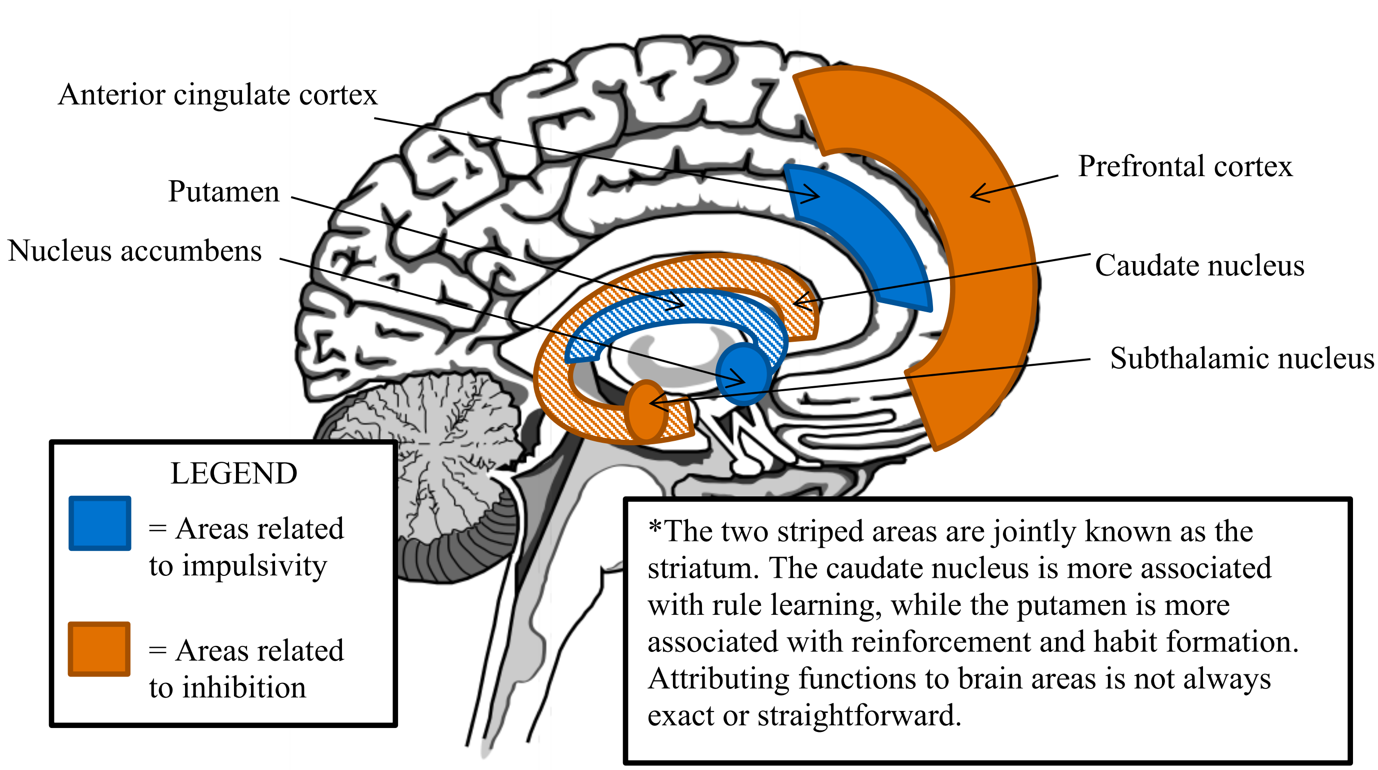

Figure 7. Brain areas involved in problematic cellphone use

Similarities between problematic electronic device use and substance-related and behavioral addictions have been found, especially regarding abnormal neural integrity of lateral prefrontal, orbitofrontal, cingulate and parietal areas, insula (Kuss, Pontes, & Griffiths, 2018), and in areas of the brain that contribute to impulsive behavior and sensitivity to reward: the amygdala and the striatum (Bickel et al., 2007; Galandra et al., 2018; Jentsch & Taylor, 1999; Robbins et al., 1989; Volkow & Fowler, 2000). When areas of the brain are integrated more tightly than is normal, repetitive patterns of thoughts and behavior centered on cues tend to develop (Volkow et al., 2016).

Results from Horvath et al. (2020) show that, compared to controls, people with problematic phone use showed significantly lower gray matter volume in the insula and in regions of the temporal cortex; significantly lower anterior cingulate cortex activity; and anterior cingulate cortex volume and activity was associated with "addiction" severity. Decreased gray matter volume of the insula has been reported in substance-related addiction (Suckling & Nestor, 2017) and people with internet gaming disorder have also shown decreased grey matter volume in the left insula and the anterior cingulate cortex (Wang et al., 2015). Furthermore, there is some evidence that people with PDU show abnormally high levels of activation in their anterior cingulate cortices and nucleus accumbens, both of which mediate impulsivity in the brain (Di Chira et al., 1999; Meshi et al., 2015; Turel et al., 2014). People may consciously experience these brain changes as intense impulses (i.e., impulses to use devices) and/or strong cravings for rewards (i.e., from devices).

While many substance addictions are known to alter the prefrontal cortex, comparable results have not consistently been found for PDU (Galandra et al., 2018; Kuss, Pontes, & Griffiths, 2018; Volkow et al., 2016). Throughout the PDU literature, studies demonstrate that people with this condition tend to have a hyperactive amygdala-striatal system while not having the hypoactive prefrontal cortex activity that would be expected for an addiction (Noël et al., 2013; Turel et al., 2014). Turel and colleagues found that while the activation of the amygdala-striatal (impulsive) brain system was positively associated with one's social media "addiction" score (i.e., the level of addiction-like symptoms presented), there was no association between this score and activation of the prefrontal cortex (inhibition) brain system. The findings, therefore, suggested that people with at least low to medium levels of addiction-like symptoms have a hyperactive amygdala-striatal system, which makes social media "addiction" similar to many other addictions. However, they do not have a hypoactive prefrontal lobe inhibition system, which makes it different from many other addictions, such as to illicit substances. Hence, technology "addictions" may not present the exact same brain etiology and possibly pathogenesis that drives substance and gambling addictions.

People with symptoms of PDU tend to report feeling as though they have little control over their device use, but the brain regions that mediate self-control (i.e., inhibitory behavior) do not appear different between people who use devices problematically and the general population (Galandra et al., 2018; Kuss, Pontes, & Griffiths, 2018; Volkow et al., 2016). Therefore, current neurological data do not point to PDU resulting in concrete impairments in behavioral control. There is evidence that neurological correlates of PDU contribute to habit formation, but habitual behavior is not the same as a loss of control (Kuss, Pontes, & Griffiths, 2018; Volkow et al., 2016). For example, a person who uses their smartphone in a normal, non-problematic way may check their device for a few minutes shortly after waking up every morning. This may be a habit, but the individual is not continually compelled to use the device.

Psychological Factors

Psychology shapes the experience of PDU along with biology. For addiction, as for all behavior, psychological factors exert a powerful influence on the brain, and vice versa (Volkow et al., 2016; Wise & Rompre, 1989). With gambling disorder, the thrill of winning money—or even the excitement of a prospective win—is a powerful psychological incentive to return to gambling despite experiencing significant negative consequences previously (Grant et al., 2010; Rosenberg & Feder, 2014). Problematic device use creates its own version of this phenomenon, using software design to psychologically influence consumers' behavior (Kloker, 2020; Neyman, 2017). Such software design strategies are known as "addictive design," despite their lack of correspondence with recognized addictions. These design strategies have mostly been studied for smartphones (see Chapter 2). Smartphones have a greater breadth of applications and uses than cellphones without internet access and apps, which could mean that smartphones have a greater potential for abuse (De-Sola Gutiérrez et al., 2016).

“Addictive design” is a large part of what makes cellphone and smartphone use psychologically compelling, producing sensations of immersion and dependence in some users (Montag et al., 2019). Typical categories of applications that employ “addictive design” strategies are social media and gaming apps. In contrast, smartphone applications such as the clock, settings, or calculator apps, are unlikely to establish PDU patterns. Table 4 below presents examples of “addictive design” techniques, adapted from Montag and colleagues’ 2019 study.

Table 4. “Addictive design” features

	Built-In Psychological Mechanisms	**Example/Illustration**
Individual Rewards	Show users of an app what they like	Facebook has a great interest in studying the behavior of each person in detail, so that information presented in the “Newsfeed” is personalized for the user.
	Endless scrolling/streaming	As soon as one video finishes on a website such as YouTube, the next video begins with either similar content or the next episode of a TV show and so forth.
	Endowment effect/ mere-exposure effect	Every time players visit the app platform and invest more time in the construction of the virtual world, it will get harder for them to detach from the game or even delete the app.
Social Rewards	Social comparison and social reward	Perhaps one of the most prominent features of social reward mechanisms in social media is the iconic ‘thumbs up.’ A ‘thumbs up’ (‘Like’) demonstrates either positive social feedback on one’s own post or gives another person this feedback.
	Social pressure/reciprocity	In WhatsApp, a messaging application, if a user sends a message to a friend, the sender is presented with two gray ticks, which means that the message has successfully arrived at the recipient’s phone. If the recipient reads the message, the grey ticks turn blue. When both sides know about these rules, social pressure emerges.

Psychologically, humans crave rewards, and “addictive design” appeals to those cravings. Rewards include a sense of accomplishment, as can be gained from capturing virtual monsters in games like *Pokémon Go*. A player with a large collection of high-level Pokémon creatures would be reluctant to delete the *Pokémon Go* app because they have invested so much time and energy into it—even if the game was causing them to neglect their responsibilities (Hamari et al., 2019). This is an example of the endowment effect. Showing users what they like can also generate a sense of reward, as content that has been personalized for the individual will, at least in theory, maximize their pleasure (Montag et al., 2019). For example, video streaming apps such as YouTube and TikTok become more appealing to a user the more the person watches, because the algorithms of these apps “learn” each user’s tastes and recommend them the content that will keep them interested, thereby also using the “infinite scroll” strategy (Neyman, 2017).

A wealth of psychology research has shown that variably delivered rewards, i.e., rewards that arrive inconsistently, are especially effective for reinforcing human behavior (Kloker, 2020). Smartphone apps are full of such rewards, from push notifications that arrive at apparently random times, to highly anticipated replies to messages, to the luck-based item procurement in

Japanese-influenced "*gacha*" cellphone games (Brown et al., 2020; Kruger & Djerf, 2017; von Meduna et al., 2020). Push notifications are a well-established and common way for app developers to try to get and hold a user's attention. For example, a banner might appear at a certain time to alert a user to something new on the app. The average smartphone user in the United States receives 46 app push notifications per day (Business of Apps, 2019). There are two key elements behind every successful notification: an intriguing and actionable trigger, and calibrated timing. The apps with the most habit-forming designs offer compelling content through external triggers (push notifications) timed to line up with users' internal triggers (boredom).

Along with more individual rewards, "addictive design" taps into humans' desire for social rewards. The most transparent use of this is on social media websites and applications, which encourage social comparison as users count how many "likes," "favorites," or "shares" their posts received relative to those of their fellow users. Such social rewards are gratifying, although chasing them excessively can lead to problems with self-esteem. Adolescents across the world have felt compelled to go on severe diets and digitally alter photos of themselves to earn others' approval (Vogel et al., 2014). Cycles of pursuing social reward can be psychologically difficult to break. This is especially true when an app's features create social pressure by encouraging reciprocity. Smartphone users have developed powerful norms for responding to digital communications. While standards vary somewhat among groups, not replying to an email or message for "too long," especially if the other party is alerted that the message has been read, is seen as impolite (Lopez-Fernandez et al., 2014; Montag et al., 2019). In short, even if one can resist the individual rewards "addictive design" offers, the social rewards can keep users feeling obligated to use these psychologically engaging apps.

The psychological aspects above describe specific features of mobile devices, predominantly smartphones, that form the basic behavior-shaping aspects that can compromise safety while driving. Specifically, these aspects include:

- *Captivating content*, such as a Twitter feed that can be continually refreshed for new material, can be so tempting for problematic cellphone users that they feel compelled to interact with this content on their smartphone even while driving. In doing so, they may become cognitively absorbed with their smartphone while driving and may not adequately focus on the driving environment.
- *Notifications* that appear at unpredictable times can prompt immediate responses from problematic smartphone users, many of whom have conditioned themselves to instantly react to this stimulus. Consequently, these drivers are at greater risk of having their attention captured by their device at an inappropriate time.
- *Social pressure* could motivate problematic cellphone users to voluntarily respond to communications when they otherwise should not because they are concerned about being perceived as ignoring or "snubbing" contacts that they care about. Features designed for relationship maintenance and social reciprocity can make constantly engaging with social connections on smartphone apps feel necessary. Using social media or messaging apps while driving can cause dangerous cognitive distractions as drivers concentrate on their communication, and lead to disruptions in attention as drivers respond to continual notifications.

In combination, these aspects of smartphone apps can pull drivers' attention away from the driving task and compel them to engage in a secondary task, possibly at unsafe times. Even if they do not respond immediately, the mere presence of an unread message may serve as a cognitive distraction. Moreover, if their behavior is at the problematic end of the device use spectrum, the duration and salience of these effects would be stronger than with normal device users. Thus, PDU potentially has important safety implications if it also occurs behind the wheel.

Sociocultural Factors

Electronic devices exist within the societies and cultures of the people who use them, meaning that their usage, both typical and problematic, is varied throughout the globe. Smartphones are among the most frequently studied devices when looking at variation in digital activity among people and groups (De-Sola Gutierrez et al., 2016; van Deursen et al., 2015). In fact, studying this variation among users complicates the definition of PDU, since we must consider scenarios such as whether problematic use thresholds would be different for a business executive or a high school student. Further considerations include cultural variations such as whether extensive calling is more culturally acceptable than extensive gaming, and how a study's setting (e.g., a workplace setting, the State, or the country under consideration) impacts these types of judgements (Busch & McCarthy, 2021; Panova & Carbonell, 2018). Billieux and colleagues' literature review synthesizing global research on problematic cellphone use made strides toward categorizing this behavior into three "pathways" that could explain some people's PDU behavior in a variety of social and cultural contexts (Billieux et al., 2015). Figure 8 below shows Billieux and colleagues' pathway model, which is an influential typology for problematic cellphone use.

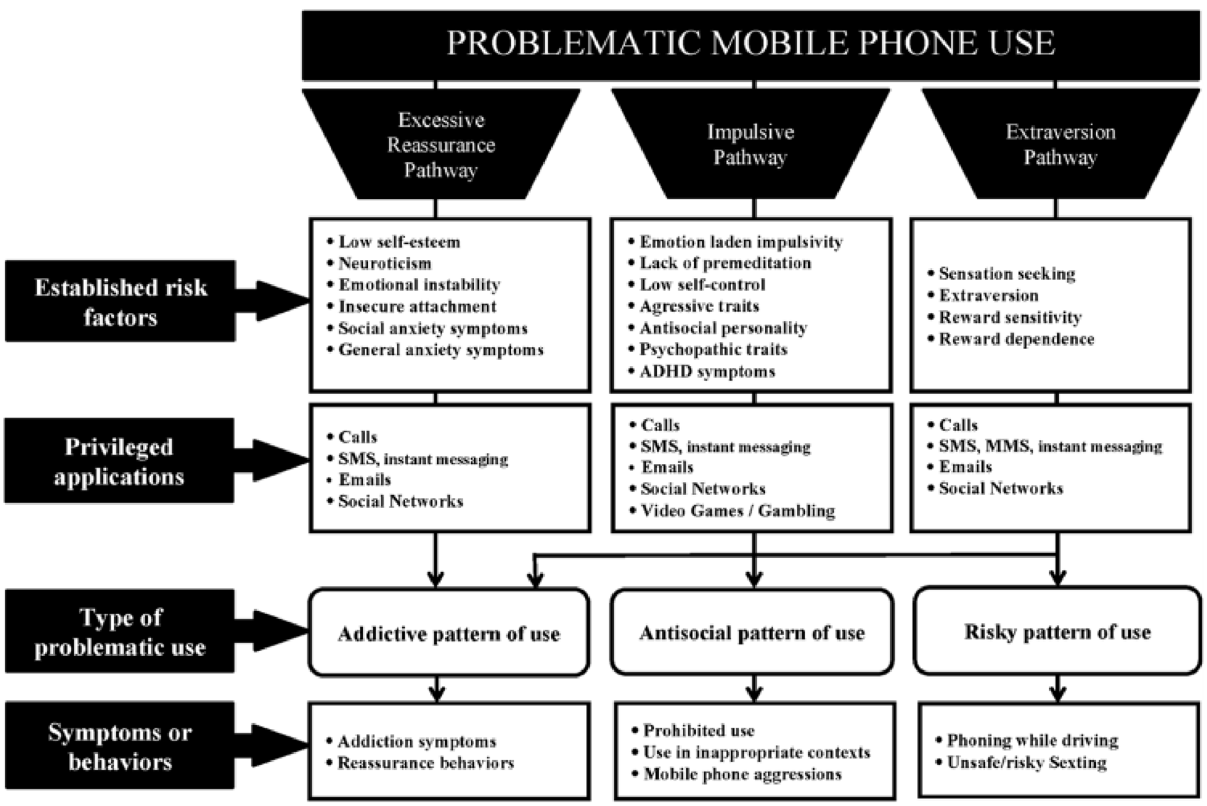

Figure 8. The pathway model of problematic cellphone use (Billieux et al., 2015)

Though Figure 8 shows that cellphone use while driving results from a risky pattern of use, the authors note that these pathways are not mutually exclusive, thus this behavior could flow from addictive patterns of use and antisocial patterns of use as well. Addictive use could cause people to feel the need to use their phone, even while driving, and an antisocial pattern of use could cause a person to disregard others' safety, thereby feeling entitled to use a cellphone while driving.

Generalizing about which cultures use cellphones more or in certain ways is difficult—and in fact may not be as helpful as looking at the pathway model above and the rest of the biopsychosocial model in concert. Current studies tend to isolate their assessments of problematic use within highly specific cultural groups, such as small subsamples of South Korean university students, British adolescents, or German adults (Kwon et al., 2013; Lopez-Fernandez et al., 2014; Winkler et al., 2020). Studies conducted within the United States are no more generalizable than studies from elsewhere, as this country has significant intrinsic variability in culture and smartphone use at regional, State, and local levels (see Chapter 3). Furthermore, few studies have been conducted about variations in cellphone usage patterns among groups in the United States. Future studies on PDU could highlight differences in patterns of behavior between people in the United States and other countries, and among social groups within the United States (Elhai et al., 2019; Lopez-Fernandez, 2017).

Psychological Scales for Measuring Problematic Device Use

The biopsychosocial model provides researchers with a clear foundation for understanding PDU and the factors associated with it. A challenge with this type of research is how to measure device use, since it is a relatively new behavior, subject to evolving norm and use patterns. A large number of validated psychometric scales have been developed in the past decade, which are leading to more reliable quantitative approaches for understanding and classifying PDU, with a concentration on problematic cellphone use. These scales often measure individual differences associated with PDU and complement the biopsychosocial model in offering interpretations of this psychological condition.

Scales for measuring PDU are sometimes called scales for measuring "device addiction," despite "device addiction" being unrecognized by the DSM-5. Scales of problematic cellphone use vary widely, and the inconsistency in this behavior's measurement contributes to uncertainty about its definition and expression. The following scales in Table 5 below are frequently cited in the literature. Many more scales measuring PDU exist than are listed here (Busch & McCarthy, 2021; Harris et al., 2020).

Table 5. Scales of problematic cellphone use

Instrument	Source
Mobile Phone Dependence Questionnaire	Toda et al., 2006
Mobile Phone Problem Use Scale	Bianchi & Phillips, 2005
Problematic Mobile Phone Use Questionnaire	Billieux et al., 2008
Cell Phone Over-Use Scale	Jenaro et al., 2007
Mobile Phone Addiction Index	Leung, 2007
Excessive Cellular Phone Use Survey	Ha et al., 2008
Mobile Phone Involvement Questionnaire	Walsh et al., 2010
Problematic Mobile Phone Use Scale	Güzeller & Coşguner, 2012
Smartphone Addiction Scale	Kwon et al., 2013

Individual Differences Affecting Problematic Cellphone Use

Many studies examining PDU frame their results within the broader biopsychosocial model, since it provides a holistic understanding that integrates connections across factors. However, certain factors emerge as consistent predictors of problematic use and there are practical advantages to identifying the factors for targeting safety messages. This section summarizes the key driver-specific factors associated with PDU.

Individual differences perpetuating PDU have been most thoroughly studied with regard to cellphones. Longitudinal studies in this area are currently scarce, though existing longitudinal research provides evidence that individual differences are important factors enabling problematic cellphone use (Coyne et al., 2019; De-Sola Gutiérrez et al., 2016). The traits that are most strongly associated with problematic cellphone use are in Table 6. Traits associated with problematic cellphone use are similar to those associated with distracted driving in general (see Chapter 3). The relationships between these factors and problematic cellphone use are summarized in the following sections.

Table 6. Individual differences associated with increased likelihood of problematic cellphone use

Trait	Dimension Associated with Problematic Device Use
Age	Younger age
Gender	Female gender, though this is inconclusive
Education and Socioeconomic Status	Lower education and socioeconomic status
Personality	Anxiety, impulsivity, extraversion, sensation-seeking
Self-Esteem	Low self-esteem

Age

In general, researchers have shown that older people spend less time on their phones than younger people, with the highest times reported for people younger than 20, principally younger adolescents, approximately 14 years old (De-Sola Gutiérrez et al., 2016; Lopez-Fernandez et al., 2014). There are a number of possible reasons for this, including adolescents' developmental stage being associated with increased craving for excitement and social engagement (Coyne et al., 2019; Steinberg et al., 2008; Walsh et al., 2010) along with low levels of self-regulation (Leung, 2008; van Deursen et al., 2015).

In addition, today's adolescents have grown up surrounded by digital technology and are highly adapted to using mobile devices (Wang et al., 2019). Ninety-six percent of Americans ages 18 to 29 own smartphones, whereas only 53 percent of those 65 and older own one (Pew Research Center, 2019). With so many features of mobile technology being easy for them to use and designed with them in mind, it is no surprise that adolescents are especially likely to experience PDU (Barnes et al., 2019). Research on PDU and age would be well-served by more studies involving young children, adults, and elderly populations (Busch & McCarthy, 2021). Yet studies that do involve a wide age range have found that problematic smartphone use is most prevalent among younger people (Kuss, Kanjo, et al., 2018; Zhitomirsky-Geffet & Blau, 2016).

Gender

Studies examining problematic cellphone use tend to either find that female participants reported more severe PDU, or that gender differences are inconclusive. Gender differences are especially likely to be inconclusive beyond adolescence, suggesting that gender differences in device use may diminish as people grow older (Bianchi & Phillips, 2005; Salehan & Negahban, 2013).

However, a caveat to these studies is that some gender differences in device use have been attributed to oversampling of females (Kwon et al., 2013; Sapacz et al., 2016). For studies where there are clear gender differences not attributable to sampling biases, females are typically found to spend more time using social media applications than males, leading to females' cellphone use being more frequently categorized as problematic (Barnes et al., 2019; Jenaro et al., 2007; Sahin et al., 2013; van Deursen et al., 2015).

Females' cellphone use, compared to males' use, is typically more oriented toward intense, communicative interpersonal relationships and toward maintaining diffuse social connections through indirect communication (Sahin et al., 2013). Thus, text messaging and instant messaging were common among female problematic cellphone users in a survey study (Roberts et al., 2014). The survey also found that, among females, time spent on Pinterest and Instagram significantly predicted PDU, while Facebook was a stronger indicator of problematic cellphone use for males (Roberts et al., 2014). Rather than text-based communication, males are typically found to use their cellphones mostly for making phone calls, and the application type most linked to problematic cellphone use for males is gaming (De-Sola Gutiérrez et al., 2016; Roberts et al., 2014; Walsh et al., 2010). Ultimately, differences in device use between males and females may be highly subject to culture, and recent literature reviews have argued that gender is not an optimal predictor of PDU (Busch & McCarthy, 2021; Billieux et al., 2015).

Including nonbinary people in studies of device use and gender would increase the generalizability and representativeness of research on device use (Tannenbaum et al., 2016). Currently, research in this field has an exclusive focus on male and female people, leading to an incomplete picture of device use and gender. People with a wider array of gender identities may have patterns of device use—and variations in other metrics described in this report, such as personality traits—that existing studies have not recorded (Breslin et al., 2019; Tannenbaum et al., 2016).

Education and Socioeconomic Status

Education and socioeconomic status, which are closely tied to each other, influence access to devices and their usage. In the United States, 26 percent of Americans making less than $30,000 a year depend on their smartphones for internet access, while just six percent of Americans making over $75,000 do (Pew Research Center, 2019). Similarly, in a number of other countries, lower education and lower income are linked with increased smartphone use (Leung, 2008; Lopez-Fernandez et al., 2014; Sahin et al., 2013). Higher-income families tend to have more internet access options other than smartphones, such as computers or tablets. They may also have more time and resources to assist with their children's entertainment and education so that high-income families' children can grow up more detached from smartphones (Barnes et al., 2019; Lopez-Fernandez et al., 2014; Marler, 2018). However, in some contexts, higher education and socioeconomic status may contribute to problematic smartphone use, as studies have found that students studying at institutions far from their homes are more prone than their peers to use smartphones problematically. These students tend to attribute their higher levels of smartphone dependence to the isolation and loneliness felt when studying far from home (Mazaheri & Najarkolaei et al., 2014; Tavakolizadeh et al., 2014).

Personality

People's personalities can predispose them to problematic cellphone use through mechanisms as implied by the biopsychosocial model and the pathway model above. Common traits associated with problematic cellphone use are anxiety, impulsivity, extraversion, and sensation-seeking. Anxiety-prone personality is frequently attributed to problematic cellphone use (Kim & Koh, 2018; Sapacz et al., 2016; Wilcockson et al., 2019).

For example, one study of U.S. adults found that anxiety had an association of r = 0.24 with problematic smartphone use, while depression had an insignificant correlation of r = 0.10 (Elhai et al., 2016). Anxiety facilitates problematic cellphone use because anxious people tend to seek reassurance from social connections (Billieux et al., 2015; Coyne et al., 2019; De-Sola Gutiérrez et al., 2016) and use cellphones to distract themselves from strong emotions (Busch & McCarthy, 2021; Kwon et al., 2013). When being separated from one's cellphone results in anxiety, this condition is called nomophobia, and nomophobia has strong associations with PDU (Bragazzi & Del Puente et al., 2014; King et al., 2014).

Impulsivity as a personality trait describes the extent to which a person moderates their impulses (Barratt, 1959). This trait is typically measured with a version of Barratt's (1959) impulsiveness scale—of which two out of three dimensions (motor impulsiveness and attentional impulsiveness, but not planning impulsiveness) have been found to positively correlate with cellphone use (Pivetta et al., 2019; Stanford et al., 2009). Since smartphone apps' "addictive design" principles make them highly engaging, people with impulsive personalities are especially likely to have trouble resisting their pull. Impulsivity is associated with problematic cellphone use (De-Sola Gutiérrez et al., 2016; Regan et al., 2020), as well as with excessive use of social media and gaming apps (Busch & McCarthy, 2021; Kwon et al., 2013).

Extraversion is another personality trait that has been found to contribute to problematic cellphone use (Billieux et al., 2015; De-Sola Gutiérrez et al., 2016). Similar to some highly anxious people, extroverts seek frequent social contact through cellphones—albeit to boost positive moods rather than to assuage negative ones (Kuss & Griffiths, 2017). Introversion had a significant negative association with problematic cellphone use among college students, further indicating that problematic cellphone use is more common among those who prefer larger amounts of social contact, i.e., extroverts (Roberts et al., 2015). Finally, sensation-seeking is a personality trait infrequently associated with PDU in daily life, though occasionally correlations are found (Bianchi & Phillips, 2005; Leung, 2007). Primarily, sensation-seeking is associated with device use while driving rather than device use in other contexts (see Chapter 3; Brown et al., 2020).

Self-Esteem

Low self-esteem is shown to predict high and problematic levels of cellphone use (Kim & Koh, 2018; Walsh et al., 2010). Like anxious people, people with low self-esteem tend to use cellphones to seek reassurance of their relationships' stability, and of their own personal worth (Bianchi & Phillips, 2005). This pattern can develop into problematic use when the cellphone becomes integral to a person's self-concept and identity (Harkin & Kuss, 2020). Other related concepts to low self-esteem are associated with problematic cellphone use, including loneliness, an avoidant style in relationships, and the need for social approval (Bhardwaj & Ashok, 2015; Kim & Koh, 2018; Takao et al., 2009). Several researchers assert that low self-esteem leads people to increase their cellphone use, and there is also a consensus in the literature that problematic cellphone use tends to lead to lower self-esteem by promoting comparison of oneself to others (Elhai et al., 2016; Schmuck et al., 2018; Vogel et al., 2014). Problematic cellphone use can further degrade self-esteem in people who already struggled in this area, making the behavior difficult to stop.

Normal Versus Problematic Device Use

Although PDU is not a behavioral addiction and lacks the markers that indicate dependence, it appears to be different from normal use, and is associated with certain driver-specific factors. An important practical question is how PDU differs from normal use. Unfortunately, there is no quantitative boundary between normal device use, as is practiced by most people, and the PDU practiced by relatively few members of society (Busch & McCarthy, 2021). Rather, key differences between problematic and normal device users appear to be that PDUrs have recurrent cravings to use their device and experience functional impairments as a result of their device use (Billieux et al., 2015). The concept of craving device use is subjective and is typically operationalized as the amount of time spent using a device. In studies assessing problematic cellphone use, frequent and extensive social media use has moderate correlations ($r = 0.15$ to $r = 0.50$) with higher scores on scales of problematic use (Roberts et al., 2014; Salehan & Negahban, 2013).

Time spent using apps for gaming (Lopez-Fernandez, 2017; Zhtimosky-Geffet & Blau, 2016), and internet browsing (Elhai et al., 2016; Jenaro et al., 2007) are also associated with higher scores on scales of problematic cellphone use. Specific apps whose usage time per day is associated with higher scores of problematic cellphone use include Pinterest, Instagram, and Facebook (Roberts et al., 2014). This makes sense, as these applications are likely to employ “addictive design” strategies (see *Psychological Factors* above; Montag et al., 2019; Neyman, 2017). Ultimately, time spent using certain types of apps, or using smartphones at all, is not an objective measure of whether a person’s use is problematic. A person may spend many hours a day using their smartphone without experiencing reduced control over the behavior or functional impairments (Billieux et al., 2015; Elhai et al., 2016). Functional impairments in a variety of life areas including physical, mental, social, and financial health are key indicators of whether a person’s device use is problematic (Billieux et al., 2015).

In smartphone use research, problematic use has been defined as a “recurrent craving to use a smartphone in a way that is difficult to control and leads to impaired daily functioning,” (Busch & McCarthy, 2021). As discussed above, PDU may feel difficult to control, but is not associated with the concrete impairments in behavioral control characteristic of addiction. Problematic smartphone use is associated with a variety of functional impairments that are seldom present in typical device use, including declines in physical activity, reduced self-esteem, and cognitive fixation on one’s device (Berthon et al., 2019; Panova & Carbonell, 2018). Another functional impairment resulting from PDU is the impact on driving performance among people with PDU—for these drivers, distractions are more frequent and riskier than for those who use devices normally. The concepts of recurrent cravings to use their device and functional impairments provide a potential avenue for developing a systematic approach for identifying PDU. However, the current reliance on subjective scales and evolving societal use patterns suggests that differentiating problematic use from normal use remains a challenge.

Traffic Safety Issues Related to Problematic Device Use

While it is not classified as behavioral addiction, PDU is associated with behaviors and actions that can be dangerous while driving. For PDUrs, cravings could motivate people to use their cellphones throughout the day, even while driving (Kaviani et al., 2020). Adolescents who self-reported high levels of cellphone use were more likely than their peers to rate the benefits of texting while driving as outweighing the costs (Gauld et al., 2017). Most drivers may have some amount of craving to use mobile devices while driving, but for people with PDU, these cravings are stronger than average (Turel et al., 2014; Wilcockson et al., 2019). These strong cravings, which could be mediated by highly active brain regions related to impulsivity, might make drivers more likely to decide that using a device while driving is worthwhile, despite any safety risks.

Along with cravings, PDU involves habitual, stimulus-driven responses, presenting another issue during driving (Friedman et al., 2004; Miyake et al., 2000). Problematic device use contributes to the formation of tightly linked neural circuits in the brain based on learning and reward (Bickel et al., 2007; Galandra et al., 2018; Zhang et al., 2016). Notifications, such as push notifications and ringing from phone calls can therefore prompt an immediate response, as people with PDU have trained themselves to be alert for such stimuli (Kruger & Djerf, 2017; Tanis et al., 2015). This habitual response can present a serious safety concern if a notification arrives at an inopportune moment, such as when a driver is about to enter a busy intersection. Habitual device use among PDU users has another implication for driving outcomes—when a person frequently uses a device in ‘daily life’ (e.g., at home, school, work, and social events), these habits could carry over into use in the vehicle.

Studies have demonstrated the direct connection between frequent overall cellphone use and frequent cellphone use while driving (e.g., Atwood et al., 2018; Bayer et al., 2012; Gauld et al., 2017; Marulanda et al., 2015). More research is needed to quantify people’s daily cellphone use while driving and compare it to cellphone use outside of the driving context. Despite media campaigns’ messages that the car should be a space exempt from mobile device use, the pervasive societal impact of mobile electronic devices such as smartphones makes it almost inevitable that drivers will take them into their vehicles. For people with PDU, a cellphone is likely to engage their attention, even in risky driving situations.

Summary

The most thoroughly studied type of PDU is problematic cellphone use, and the vast majority of the literature on this condition examines it in non-driving contexts. Overall, problematic cellphone use has some similarities to the only recognized behavioral addiction, gambling disorder, but it does not consistently involve behavioral addiction’s features of “inability to consistently abstain” and “impairment in behavioral control.” Looking at PDU’s effects through the lens of the biopsychosocial model demonstrates that this behavior can still adversely impact lives without it being an addiction. Preliminary findings indicate that PDU disrupts brain circuitry related to impulsivity while reinforcing habitual device use. Further, the “addictive design” that draws people toward PDU makes this behavior highly appealing. Adjacent to the biopsychosocial model, some individual differences make people more likely to continue habits of PDU. People who are younger in age, not at a high education level or socioeconomic status, anxious, impulsive, extroverted, and/or low in self-esteem are especially likely to have problematic cellphone use. These aspects culminate in device use behaviors that are more compelling, more frequent, and more likely to occur at inopportune times than normal device use behaviors—which can have serious safety consequences if they are occurring during driving.

6. What Evidence Is There of Problematic Electronic Device Use While Driving and Its Consequences?

Introduction

A unique contribution of this report is the synthesis of literature at the intersection of PDU and traffic safety research. This chapter attempts to cover a breadth of subtopics that are still emerging. Most of the included studies were published in the last two years, so some issues are addressed at a high level due to the lack of current research. This introduction includes a summary qualifying the research body to help situate the incomplete view that researchers presently have of PDU while driving. It is expected that this understanding could change rapidly in the next few years as more research is conducted. The conclusion of this chapter will summarize the current gaps in the understanding of PDU while driving. Any device use while driving can be dangerous and thus problematic (see Chapter 2), but drivers who persist in using devices despite their belief that using devices while driving is dangerous may be grappling with symptoms of PDU while driving.

Drivers with these conflicting beliefs are not uncommon. The TSCI found that, of the 55 percent of respondents who reported talking on a cellphone while driving is extremely dangerous, 32 percent of those same respondents reported doing so at least once in the past 30 days. Additionally, 76 percent of all respondents reported that they believe typing or sending a text message or email while driving is extremely dangerous, yet 26 percent of those same respondents reported doing so at least once in the past 30 days (AAA, 2020).

Similarly, Lantz and Loeb found 82 percent of their sample were willing to text while driving even though they acknowledged it being a dangerous activity (Lantz & Loeb, 2013). Such discrepancies between drivers' knowledge about the risks of distracted driving and their own self-reported behavior could indicate that some of these drivers may have PDU patterns. There is no established threshold for how often or in what context a driver must use a device while driving to be considered a problematic user. Nor is there a consistent definition on the strength of characteristics a driver must exhibit to distinguish problematic use from casual device engagement while driving. Thus, for the purpose of Chapters 6 and 7, the articles reviewed focus on frequent device use while driving. Some of these studies are explicit about examining problematic or compulsive device use in the driving environment, while others investigate the underlying factors (e.g., psychosocial factors) that motivate increased frequency of device engagement while driving (relative to other drivers in a study sample). Most of the current research on PDU while driving looks at cellphone use in particular.

Studies That Specifically Examine Problematic Device Use and Driving

The searches for Chapter 6 and 7 materials that cover both PDU and traffic safety research were conducted in tandem since the literature is sparse and the general search terms used were expected to return articles relevant to both or either of the chapters. The searches were run without date parameters from the following databases: TRID, PubMed, or PsycINFO. The reports were then used in the applicable chapters (6 or 7). If a report was not included in these chapters, it was either not catalogued in these databases, published in a language other than English, not relevant to the scope of the search, or it is new.

Of the 50 critically reviewed and included reports, 58 percent of the studies were from the United States, 14 percent from Australia, 14 percent from Western Europe, 6 percent from Canada, and 6 percent from other locales. These were mostly survey studies (36 reports; see Figure 9). The other articles' primary methodologies are on-road studies (6), simulator studies (5), laboratory studies (2) and one focus group (1). Most of this research was performed on convenience populations of college students (20 out of 50) or other young populations (14 out of 50). These populations are easier to sample and younger drivers consistently self-report, and have been observed engaging in, high rates of device use while driving (see Chapter 3). However, this does mean the knowledge base on PDU while driving for middle-aged and older drivers is underdeveloped. Younger middle-aged drivers (25 – 35 years) have recently reported higher rates of distraction compared to younger drivers (AAA, 2018, 2019, 2020), and should thus be a high-priority population to study in the coming years. Only nine studies intentionally recruited community samples across age groups, and two papers (from Canada) are the only studies with a representative sample of their target populations (young people and high school students). None of the studies from the United States recruited a representative sample and only three U.S. studies used an all-ages sample.

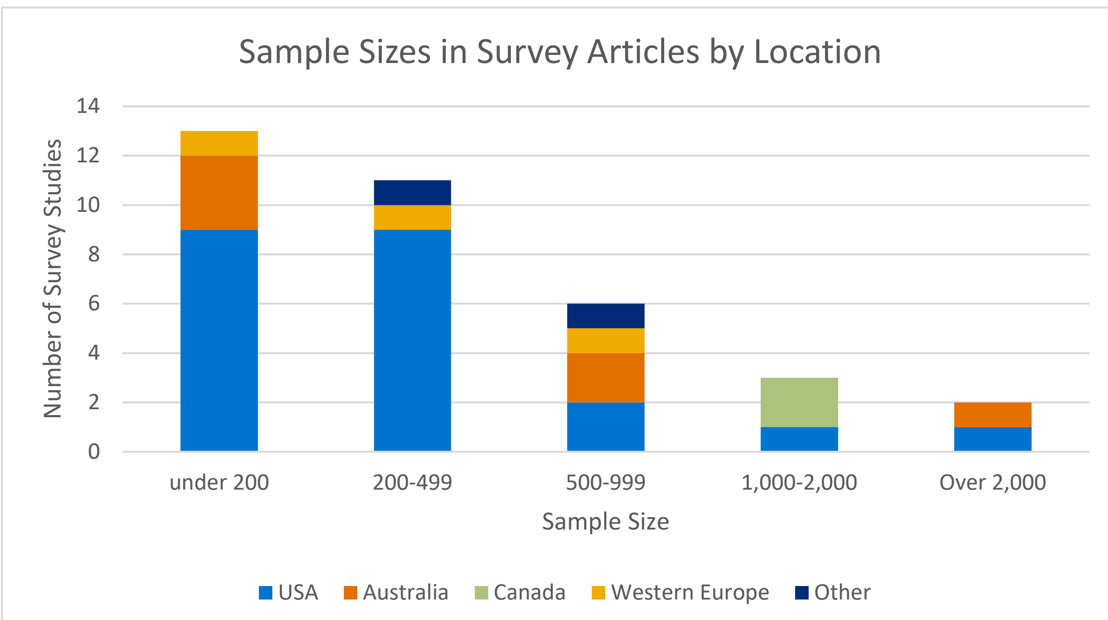

Figure 9. Survey Studies by sample size and location

Of the 50 studies reviewed in this chapter, 36 were survey studies. The distribution by study sample size was skewed toward smaller samples, but 11 studies sampled over 500 participants. Ideally, all studies examining PDU while driving would screen or clearly identify results associated with drivers and device users. However, 14 of the 50 studies did not screen (or did not report screening) their sample for drivers and 30 studies did not screen (or did not report screening) their sample for participants who had access to a mobile device. The consequence of the decision to include non-drivers in these samples is that the problematic or frequent device user groups may not be accurately distinguished between drivers and non-drivers and estimates of prevalence of device use while driving may be biased. Additionally, some PDU scales were administered to the general population including questions about phone use while driving (e.g., the Problematic Mobile Phone Use Questionnaire). The reasoning behind this is sound: if a person is inclined to perform a behavior when it is physically hazardous to do so (e.g., driving), this is a criterion for identifying PDU. However, all device-distracted driving may not stem from dependency or other addiction-adjacent concepts (Sadoff et al., 2015). The issue in practice is that these studies tend to include results on device use while driving without a caveat specifying how many of the respondents are drivers.

Prevalence and Consequences

Prevalence

This section summarizes the best available information on the prevalence of PDU while driving. Information about prevalence is necessarily incomplete because there is not a clearly defined threshold for problematic use in the vehicle, and large-scale surveys about device-use behavior do not specifically address problematic use per se. Instead, Figure 10 shows data that is different but related to problematic use; specifically, the proportions of drivers that report frequently conducting device-related secondary tasks while driving compared to those that report never or infrequently engaging in this behavior.

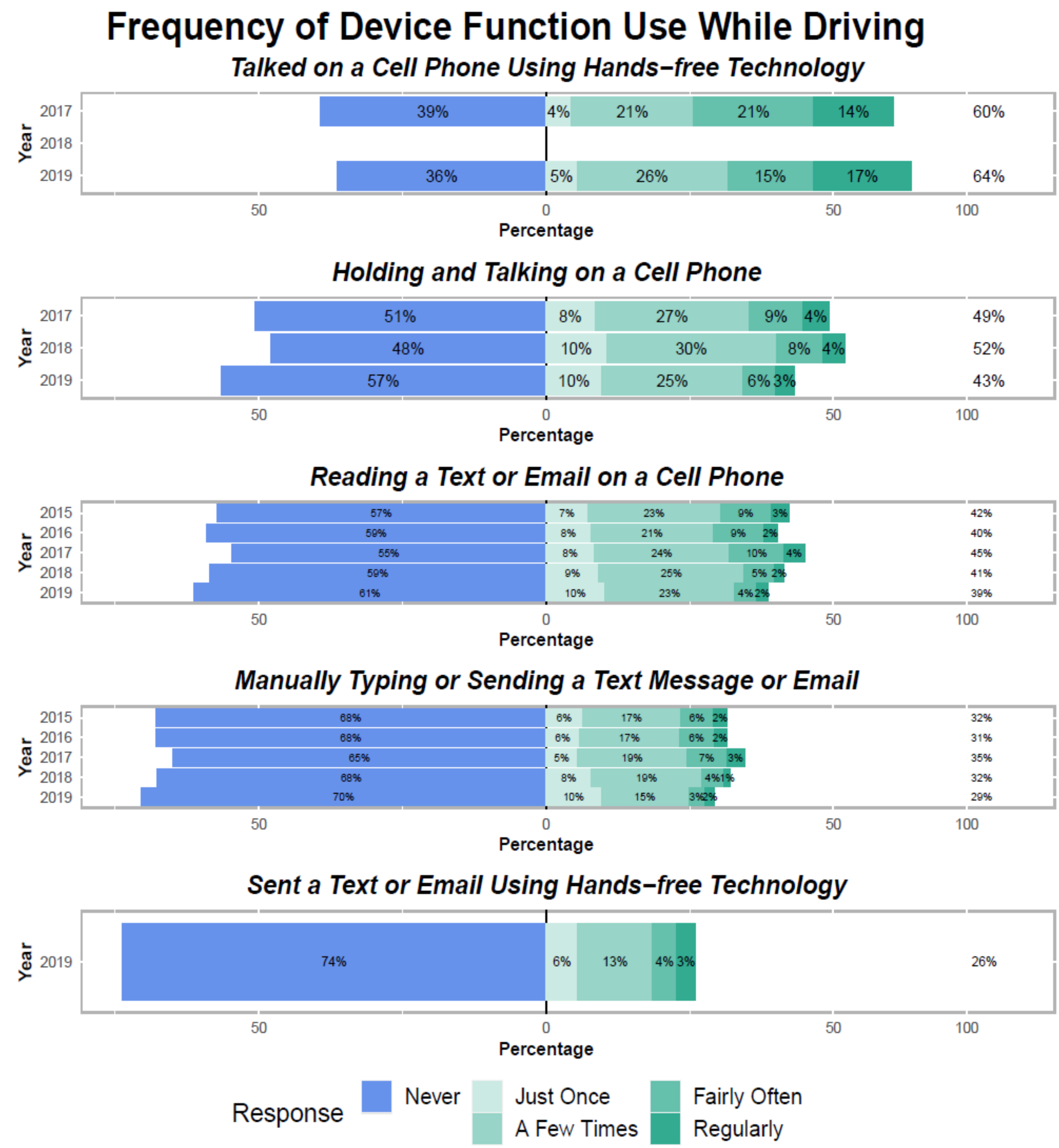

Figure 10. Frequency of device function use while driving

This figure shows the responses to distracted driving questions from the TSCI from 2015 to 2019. If data is missing for a year, it is because the question was not included in that year's survey. The questions were framed as "in the past 30 days how often have you…" Examples of hands-free technology were Bluetooth and CarPlay.

The trend from the TSCI data is that around 2- to 4 percent of drivers of all ages report regularly using their devices while driving in the past 30 days, except in the case of hands-free calling, which is much higher (14- to 17%). The percentage of young drivers frequently using devices while driving may be larger than that of the general population: a U.S. thesis study of over 2,000 university staff and students (53% of the sample was under 25) found higher proportions of frequent device use than were reported in the TSCI (Gray, 2015). When asked about device use while driving in the past week, the proportion of Gray's respondents replying "Always" or "Most of the Time" to interacting with devices while driving were 5 percent for initiating/sending text messages; 12 percent for replying to text messages; and 21 percent for reading text messages. The survey did not have an item about hands-free technology use, but only 7.5 percent of the respondents reported having Bluetooth technology that they used in their vehicle. Overall, 64 percent of Gray's sample—which may have included non-drivers—indicated that they had initiated, read and/or sent text messages while driving in the past week (see Chapter 2 for a discussion on initiating and responding).

Gray (2015) attributed the difference in prevalence across tasks to the relative risk of these activities (e.g., initiating a text message being riskier since it involves manually manipulating the device). This idea is partially supported by an Israeli survey of 757 drivers who self-reported their smartphone usage where more drivers reported engaging in behaviors that they did not believe compromised safety. Out of all respondents, 73 percent reported phone calls while driving (60% frequently and 40% occasionally) and 35 percent of respondents reported texting while driving (25% frequently and 75% occasionally).

The proportions of drivers who believed phone calling while driving compromised safety were smaller (77% of non-users; 43% of occasional users, 27% of frequent users) than the proportion of drivers who believed texting did so (93% of the non-users, 87% of occasional users, and 73% of frequent users) (Musicant et al., 2015). The risk of engagement and perceived risk may only have partial influence on the pattern. The 2019 TSCI discordance analysis found that a quarter to a third of drivers self-reported engaging with their devices in the past 30 days, even though they also reported believing that interacting with a handheld cellphone was dangerous, it was a behavior they completely disapproved of, or they believed they were very likely to be caught for engaging with them (AAA, 2020). Similarly, in Musicant et al. (2015), the majority of drivers who frequently texted while driving did so even though they believed their behavior compromised safety. However, the proportions of drivers who perceived smartphone use compromised safety were lower as use frequency increased

Although the prevalence of drivers showing problematic phone use characteristics based on psychological measures within the driving population does not yet exist, an Australian study found that drivers with more general problematic phone use characteristics were more likely to report frequent use while driving (Oviedo-Trespalacios et al., 2019). The study used a driving and non-driving community sample of cellphone users and stratified their mobile phone problem use scale scores based on percentile, dividing them into 5 percent problem phone users, 15 percent at risk of being problem users, 65 percent regular users, 15 percent occasional phone users. The drivers in the problem phone user category self-reported more handheld and hands-free mobile use while driving compared to casual, habitual, and regular users (Oviedo-Trespalacios et al., 2019).

Quantified Prevalence. Unfortunately, none of the previously mentioned surveys anchored their scales with a quantified value of device engagement (duration, number of texts, etc.), so the amount of the distracted driving behavior a frequent phone user may exhibit was not standardized. The following studies are included to provide some indication of the quantified spread of device use while driving as a rate, proportion of drive time, and number of interactions performed.

An analysis of data from the SHRP2 Naturalistic Driving Study found on average, drivers made one call (Males: M = 1.1, SD = 1.2; Females: M = 1.3; SD = 1.2) and sent one text per hour of driving (Males: M = 1.4, SD = 2.2; Females: M = 1.7; SD = 2.6). The maximum call rate was 9.5 and the maximum text rate was 15.9 per hour of driving (Atwood et al., 2018). Dutch drivers spent an average of 9.2 percent (SD = 16.1, Min = 0 percent, Max = 73.7%) of their total driving time interacting with their phone in an analysis of 2015-2017 data from the UDRIVE naturalistic driving study where researchers observed a random sample of trips (656 trips from 28 participants). This time included messaging as well as searching and holding their phone (Christoph et al., 2019).

Holding the phone without manipulating it was the most performed interaction with the phone, followed by hands-free conversation and handheld interaction. An on-road study from Israel found a community sample of young drivers used their smartphone an average of 1.71 times a minute while driving (Kita & Luria, 2018). A representative sample of Ontario students in publicly funded schools (grades 7 to 12) found that for licensed students, 36 percent reported writing a text message or email while driving and 56 percent of these students reported texting while driving four or more times in the past 12 months (Cook et al., 2018). In a smaller sample of 515 university students (not screened for drivers or phone use/ownership), 94 percent of the participants reported texting while driving in the past year, with 45 percent of the participants who reported texting while driving, saying that they sent or received more than six texts per day while driving (Struckman-Johnson et al., 2015).

Outside of the academic literature, private companies report problematic phone use data that provide qualitative insight but lack sufficiently detailed methodology to be formally assessed. Zendrive (Ianzito, 2019), a private U.S. insurance and driving-behavior analytics company, analyzed anonymous cellphone data from 1.8 million drivers, and also surveyed 500 drivers about distracted driving. Almost half (47%) of the survey respondents stated that they used phones during at least 10 percent of their driving time, and Zendrive classified these people as "phone addicts" though they would not meet the type of behavioral addiction criteria laid out in the DSM-5. Zendrive classified 66 percent of people 25 to 44 as phone addicts (10 percent of driving time using a cellphone), compared to 36 percent of drivers ages 45 to 70. These people interacted with their phones (which could involve everything from reading a text to checking a map or selecting a song to play) an average 49 times for every 100 miles they drove, compared to an average 11 times for the "non-addicted" driver.

People classified as phone addicts spent three times more drive time actively using their phones, and they actively ignored the road 28 percent of the time they were driving. These drivers were also on the road 1.5 times more than the general population, and they were generally viewed by other drivers as more of a public danger than drunk drivers. The current literature on the prevalence of problematic phone use while driving points to an approximate population of concern, somewhere between 2- to 4 percent of drivers, who frequently engage with devices while driving. It is likely that this population of concern skews towards younger drivers. Frequent cellphone users are more likely to be problematic cellphone users generally (see Chapter 5), although we do not know what proportion of them exhibit problematic use while driving. In addition, the naturalistic and survey data reported above suggests that if these frequent users are using their devices over a median amount of use while driving, then their amount of use is most likely greater than one call an hour, one text an hour, or over 9-10 percent of total driving time.

Consequences

Driving Consequences and High-Frequency Device Use While Driving. High-frequency device use while driving is associated with crashes, but overall, it is unclear if higher risks are specifically attributable to frequent use. An analysis of data from the SHRP2 Naturalistic Driving Study found that for all crashes and severe crashes only, drivers with higher text rates per day and text rates per hour of driving had significantly greater crash rates, including severe crashes (Atwood et al., 2018). In contrast, comparable levels of phone calls were not significantly related to crash rates. Similarly, another study that used a convenience sample found that a higher frequency of texting while driving was significantly related to more near-crashes while texting on the phone (Terry & Terry, 2015). Drivers who use devices while driving may be risky drivers generally. Atwood et al. (2018) proposed that the higher crash rates resulted from drivers with a high texting rate while driving were also more likely to engage in other risky behaviors while driving.

Specifically, people who reported frequent cellphone use while driving (a few times a week or more) performed more risky driving behaviors (e.g., driving faster, more lane changes, more hard brake maneuvers) than the rare-use group (a few times a month or less while driving). Drivers who frequently used cellphones while driving also had higher Manchester Driver Behavior Questionnaire (DBQ) violation scores (moderate correlation; $r = .26$; $p < 0.01$) and reported more positive attitudes toward speeding, even in heavy traffic (Zhao et al., 2013). Similarly, an Australian survey study found a strong correlation for male ($r = 0.58$, $p <= 0.001$) and female participants ($r = 0.50$, $p <= 0.001$) between increased phone use in the car and risky driving in general (Oxtoby et al., 2019). The tendency of drivers who use a cellphone while driving to also engage in other risky driving behaviors, makes it difficult to clearly attribute the cellphone use patterns to the adverse safety consequences.

Driving Consequences and Drivers Exhibiting Problematic Device Use Symptoms. It is unclear whether drivers who self-report characteristics associated with PDU generally are more likely to experience crashes or other poor driving outcomes. In one U.S. survey of an undergraduate psychology student population, drivers with Cellphone Overuse Scale (CPOS) scores indicating greater problematic use were more likely to have a history of motor vehicle crashes (MVC). Each 1-point increase on the 6-point CPOS anticipation factor was associated with a 13 percent increase in risk for previous MVC (O’Connor et al., 2013). However, in a follow-up study using the CPOS II, no relationship was found between CPOS II scores and MVC history; although greater self-reported phone use while driving was related to MVC history (O’Connor et al., 2017).

In a survey of U.S. drivers using an Amazon Mechanical Turk sample, participants who had had a MVC in the past year reported more DSM-5 based criteria symptoms of problematic texting and higher emotional reaction scores (related to Self-perception of Text Message Dependency Scale) than those who did not report a MVC in the past year although participants did not report whether the MVC was related to distracted driving (Liese et al., 2019). While there is some evidence that higher-frequency device use while driving is related to negative consequences, it is not currently clear if a relationship exists between drivers who exhibit more psychological symptoms of PDU and driving safety outcomes. The literature on performance decrements due to cellphone use while driving does not offer a clear picture of problematic use specifically. Problematic cellphone use while driving can occur in many short bursts, a few long bouts of continuous use, or as different patterns among people and groups. Therefore, it is difficult to estimate the specific impacts of PDU on driving performance. Findings about performance decrements during general distracted driving and during cellphone use remain relevant to understanding PDU while driving.

Studies That Examine Behaviors That May Overlap With Problematic Device Use

The contemporary literature on PDU while driving and frequent device use while driving behaviors is concentrated on interactions drivers have with their devices: sending, receiving, monitoring for messages, receiving notifications, and reading (see Prevalence and Chapter 3). There are no current studies that focus on PDU for devices other than cellphones or smartphones while driving (e.g., tablets and handheld game consoles). However, further research is emerging on the types of activities (e.g., gaming and watching videos) performed while driving by frequent-use drivers and the associated driving contexts.

Device Functionality and Problematic Use

As discussed in Chapter 3, certain applications are used more frequently than others by distracted drivers. Some of these applications are particularly interesting in the context of PDU while driving, particularly those that are customized for use while driving or those implemented using "addictive" design principles (see Chapter 5). Some examples of current applications that incentivize use while driving are Snapchat, specifically the app's speed filter that removes content after seconds (King, 2016); location-based augmented reality games such as Pokémon Go (George et al., 2018; Smith, 2017); and vlogging (video blogging) while driving using social media apps (Gallina, 2020). Some of these applications specifically use addictive design principles to keep users engaged in an application, even while driving.

Uber Driver, an application used to assist professional drivers and drivers who wish to casually carpool find riders, uses gamification, push notifications and variable rewards based on arbitrary earnings goals to improve driver retention and extend the length of a driver's session by eliciting feelings of achievement. This app also creates feelings of social pressure and obligation by queuing up additional rides while a driver is still finishing an ongoing ride (Neyman, 2017).

High-frequency use by phone functionality was examined in a large scale Australian survey of drivers who owned smartphones (Kaviani et al., 2020). The most frequent forms of illegal cellphone use (based on local laws) while driving were handheld texting (43%) and calling (23%), while the most frequent forms of non-restricted cellphone use while driving were calling hands-free (76.2%), navigation (67.8%) and music (55.0%). These results agree with other surveys on what device functionalities drivers use while driving (see Chapter 2). However, when ranking the forms of illegal cellphone use by number of frequent users, social media had fewer frequent users than texting, but a greater number of frequent users than handheld calling even though fewer drivers overall used social media than handheld calling while driving (Figure 11).

Self-reported frequency and type of smartphone functions engaged in while driving (n = 1,028).

Type of Use	Frequency % (n)			Total
	Infrequently	Occasionally	Frequently	
Text	23.9% (246)	13.1% (135)	6.4% (66)	43.4% (447)
Call	12.1% (125)	7.4% (77)	3.3% (34)	22.9% (236)
Social media	5.6% (58)	5.5% (57)	3.7% (39)	14.9% (154)
Email	6.9% (71)	4.3% (45)	1.8% (19)	13.1% (135)
Dating	0.5% (6)	0.2% (3)	0.4% (5)	1.3% (14)
Internet Browsing	3.0% (31)	1.7% (18)	1.4% (15)	6.2% (64)
Video	1.5% (16)	0.4% (5)	0.5% (6)	2.6% (27)
Gambling	0.3% (4)	0.1% (2)	0.1% (1)	0.6% (7)
Other	1.9% (20)	2.5% (26)	1.6% (12)	5.6% (58)
Text (hands-free)	13.0% (134)	8.1% (84)	4.0% (42)	25.2% (260)
Call (hands-free)	22.3% (230)	23.1% (238)	30.7% (316)	76.2% (784)
Music	10.0% (103)	10.1% (104)	34.9% (359)	55.0% (566)
Navigation	15.1% (156)	20.1% (207)	32.5% (335)	67.8% (698)

Figure 11. Activities and types of smartphone applications frequently engaged in by Australian drivers while driving (Kaviani et al., 2020)

Truelove et al. (2019) found that drivers who used Snapchat while driving made up 16.3 percent of their urban community sample of young drivers from Queensland, Australia (although 69.2 percent of the sample reported knowing other drivers who use Snapchat while driving). Overall, 1.8 percent were frequent users ("often" or more frequent). The most common reasons given for using Snapchat while driving in the Truelove et al. (2019) survey were to send a video/photo of something they saw while driving (58%), to send a video/photo of themselves driving (11.1%), and to relieve boredom (9.9%). Fewer users attributed their most common reason for using Snapchat while driving to using the speed filter (7.4%); to replying to a Snapchat (7.4%) and to keeping their messaging streak up with one of their contacts (6.2%).

Respondents were asked to choose their most common motivations, not to check all motivations that applied, so these results may underestimate the impact of driving-specific functionality and addictive design principles on Snapchat use while driving. Some device interactions have a high percentage of frequent on-road users (hands-free texting while driving, navigation, music), possibly because these activities are not prohibited or have been available longer in the vehicle environment. Thus, drivers may believe they are safer and be more likely to use them frequently.

There is currently no research that clarifies if frequent or PDURs are motivated differently by design factors associated with device functionality (driving-specific functionality or addictive design principles) than casual users.

Are Some Behaviors More Problematic Than Others?

Beyond applications that can incentivize use in the driving context, "addictive design" is a large part of what makes cellphone and smartphone use psychologically compelling (Montag et al., 2019). These designs exploit people's motivating structures identified in neurology and psychology research in order to compel or incentivize users (Alter, 2017). Smartphones have a greater potential to be compelling because of their greater range of capabilities (e.g., social networking) compared to regular cellphones (Salehan & Negahban, 2013). Overviews of different types of addictive design are provided in Chapters 5 and 6. Although drivers report ignoring their devices and choosing not to interact with them while driving (Parnell et al., 2020), the ability of PDURs to ignore devices while driving has not been compared to normal device users, or between applications using more or fewer addictive design implementations. The current existing literature on problematic use drivers and high frequency use drivers focuses on subtasks that drivers perform using their cellphones: sending, receiving, and monitoring tasks while driving. Sending texts while driving has been shown to be a more automatic (i.e., habitual) behavior than reading. It may be that users who are less self-aware may have high momentum to complete sending behavior once it is cued by their cellphone (Bayer & Campbell, 2012). In addition, compulsive checking behaviors could explain some device use while driving behaviors (Busch & McCarthy, 2021). A study used to validate the CPOS-II scale found participants experiencing a higher anticipation of incoming calls and messages reported using their phone more while driving. However, other factors of compulsive phone use (emotional attachment to the phone, time impact aspects) were not related to more frequent phone use while driving. The authors posit that feeling greater anticipation of incoming calls and messages may establish a compulsive need for users to check their phone and thus motivate repeating this behavior within the vehicle even if this is a trait developed outside of the driving environment. (O'Connor et al., 2017).

Drivers may engage in responding activities more often than initiating behavior (Chapter 2; Atchley et al., 2011) because responding occurs as a reaction to a cue that is not harmonized with the driver's context and interaction may be elicited through a habitual response. Whereas when initiating, the driver may plan to execute the behavior at an appropriate moment. The reasons behind higher likelihood or higher frequency of engagement in reading, initiating, and responding tasks have been investigated, but the results are mixed. A representative survey study of young people from Ontario, Canada, found that increased sending behavior was related to young drivers' beliefs that a greater percentage of their peers texted while driving, but not to risk perceptions. Increased reading behavior while driving was related to greater perceptions of risk and less perceived behavioral control over their texting while driving (Berenbaum et al., 2019).

A survey of a convenience sample of American undergraduate students who owned a cellphone and were drivers asked about three texting while driving behaviors: reading, replying to, or initiating a text message. Perceived risk was a significant predictor for initiating a text (high perceived risk was associated with a lower likelihood of engaging in the behavior). The authors speculated that although replying and initiating text messages is functionally similar, a driver initiating a text is making a conscious choice to engage in the behavior and so they factor the task risk more heavily than if they were replying to a text. In the latter case, other factors, such as social pressure to reply (see Chapter 7), may take precedence (Atchley et al., 2011). Berenbaum et al. (2019) hypothesized the result differences stem from young people being predisposed to engage in sensation-seeking behavior or optimism bias, where the young adults believe an activity is risky for others, but not themselves. As smartphone capabilities have grown, research has not categorized different types of tasks or interactions and peered into the underlying motivations for different task types and how addictive design principles may interact with these factors. The current research focuses on sending, receiving, and monitoring tasks, but how these behaviors differ between frequent and occasional device users while driving has not been studied. Sending and replying may be motivated by high anticipation along with behavior habituation leading to a compulsion. Risk perception may be related to why drivers perform these behaviors, although it is not fully understood how PDU drivers consider or disregard risk perceptions, especially with respect to other considerations (e.g., social pressure to respond).

Conclusion

Many drivers persist in using devices, even though they believe this behavior is dangerous. These drivers may be exhibiting symptoms of PDU while driving. However, there is no established threshold for how often or in what context a driver must use a device while driving to be considered a problematic or “addicted” user. This is hardly surprising as most “behavioral addictions” still lack reliable diagnostic criteria or useful assessment tools (Potenza, 2015). In addition, many studies do not anchor their surveys on quantified values of use while driving, further obfuscating a potential working definition of PDU while driving. The trend from the TSCI data is that around 2- to 4 percent of drivers of all ages may be frequent device users, but phone data from Zendrive indicates this may be a much larger figure. The frequent-use group skews toward young drivers and toward device interactions and applications that are not prohibited, or that drivers may consider less risky. High-frequency device use while driving is associated with crashes, due to the intrinsic risk of device use while driving and the tendency for these drivers to also engage in other risky driving behaviors. However, it is unclear whether drivers who exhibit characteristics associated with PDU are generally more likely to experience crashes or other poor driving outcomes. Associated device use behaviors, such as application choice, also pose a concern due to functionalities that are made to be used while driving and applications using addictive design principles. In addition, how device use characteristics between high and low-frequency users and between drivers who exhibit PDU symptoms and controls is currently unknown, although the general distracted driving literature suggests that drivers are most likely to text about topics that are task-oriented (status updates or sending directions) opposed to communication to maintain social relationships, increase alertness, or reduce boredom (Atchley et al., 2011). Risk perceptions, habits, compulsion, and social pressure may play a role in incentivizing device use. These factors and additional individual differences are discussed further in Chapter 7.

7. Driver-Specific Aspects of Problematic Electronic Device Use

Introduction

The purpose of Chapter 7 is to examine driver-specific aspects of PDU and driving. This chapter provides an analysis of the relationships between the PDU literature and the traffic safety literature, which have not been compared and contrasted prior to the current report. Drivers are unlikely to be aware of when frequent, long-duration use patterns are indicative of PDU symptoms (Busch & McCarthy, 2021). Nor do they tend to justify their behavior with statements such as, "I am addicted," or "I could not help myself," even when providing free form descriptions for why they interact with any device while driving (Parnell et al., 2020). Thus, the material in this chapter is from research that examines drivers who frequently use devices while driving, in addition to drivers who report symptoms indicative of device dependency.

This chapter covers a breadth of subtopics that are still emerging. Most of the discussed results are from surveys, but observational on-road findings are also cited. The discussion begins with demographic factors related to PDU while driving, followed by individual differences in drivers' psychology and device use while driving behaviors organized by themes from Billieux and colleagues' (2015) pathway model (see Chapter 5). The factors most consistently related to PDU while driving--with respect to both frequency and dependency—include more device use in everyday life, more neuroticism, greater social anxiety-type traits, and greater ADHD symptoms. Factors consistently related to frequent device use were higher perceived behavioral control self-efficacy, high impulsivity, poor self-control, habits, and moral norms that align with device use while driving. Factors related to the social context of driving are also analyzed; work-related communications and driving in contexts that are boring or familiar seem to motivate device use while driving. This chapter also covers amelioration strategies based on psychosocial interventions, and drivers' opinions about possible deterrents.

Correlates of General Device Use While Driving and Problematic Use Behavior

Chapter 3 covered the driver-specific aspects of device-distracted drivers and Chapter 5 covered the traits of people exhibiting PDU patterns. These two groups are similar in that they are generally younger, and they have personalities high in sensation-seeking (Table 7). The main differences in the findings for these two groups are:

- Higher education and socioeconomic status predict device-distracted driving, while lower education and socioeconomic status predict PDU.
- Device-distracted drivers tend to have high driving self-efficacy, while low self-esteem and extraversion are associated with PDU (Zaman & Lache, 2015).
- More device-distracted drivers tend to live in the Eastern or Southern States (Gerte et al., 2018), but regional differences have not been studied for PDU in a representative survey of U.S. populations.

Table 7. Individual differences associated with increased likelihood of device use while driving

Trait	Dimension Associated With Device-Distracted Driving	Dimension Associated With Problematic Device Use
Age	Younger age	Younger age
Gender	Female gender, though this is inconclusive	Female gender, though this is inconclusive
Education and Socioeconomic Status	Higher education and socioeconomic status	Lower education and socioeconomic status
Geography	Eastern and Southern States	No conclusions at this time
Self-Efficacy (i.e., confidence in one's own driving skill)	High self-efficacy	No conclusions at this time
Personality	High sensation-seeking	Anxiety, impulsivity, extraversion, sensation-seeking, low self-esteem
Executive or Cognitive Function	Low executive function	No conclusions at this time

The following sections examine the traits of the population that reports PDU in the context of driving and/or frequent device use while driving.

Demographics

Age

Observational and survey evidence suggests younger drivers are the most affected by and involved in PDU while driving. An analysis of data from the SHRP2 Naturalistic Driving Study found that drivers under 30 had significantly higher texting rates per hour of driving than older age groups (30-64, 65+), but the rates between drivers 16 to 29 were not significantly different. Drivers 65 and older had significantly lower call rates per hour than all other age groups (Atwood et al., 2018). The findings from Atwood and colleagues are similar to an earlier Australian survey study in which a larger proportion of drivers younger than 26 reported high frequency phone use while driving (once a week or more) and these younger drivers were more likely to report addictive cellphone tendencies (e.g., anxiety when unable to use a cellphone) than the older drivers (Walsh et al., 2007).

Gender

Although more females tend to develop problematic smartphone use behaviors than males (Roberts et al., 2014; Salehan et al., 2013; van Deursen et al., 2015), this does not directly translate to more females exhibiting PDU while driving. In the SHRP2 naturalistic data, there was not a significant gender difference in texting rates per hour of driving, although female rates trended higher (Atwood et al., 2018). In an on-road study of novice U.S. drivers, females demonstrated marginally higher levels of cellphone use while driving over 52 weeks (Creaser et al., 2015). Similarly, a U.S. survey did not find gender differences in the frequency of texting while driving, but females reported a higher measure of cellphone dependency (Struckman-Johnson et al., 2015). International surveys have produced similar findings. An Australian survey of cellphone owners and users (non-drivers may have been sampled) used the MPPUS to identify PDU based on tolerance, withdrawal symptoms, craving, negative life consequences, and desire to escape from others.

Generally, higher MPPUS scores were related to younger age groups and female gender. Whether or not someone was a problem user (95th percentile MPPUS score) was related to cellphone use while driving, younger age, and higher education, but not gender (Oviedo-Trespalacios et al., 2019). Gender or gender socialization may be related to how traits contribute differently to motivate drivers' behaviors and to why females, although more prone to cellphone dependency, do not consistently exhibit more frequent use behavior while driving. In a large-scale survey of Australian drivers who own their own smartphone, females reported significantly higher nomophobia—anxiety associated with being without one's cellphone (see Chapter 5)—than male drivers (Kaviani et al., 2020). Overall, participants who reported that they engaged in illegal cellphone use while driving had significantly higher nomophobia scores than those who did not, but only a single factor of nomophobia, being unable to access information, was related to increased illegal cellphone use while driving. Even though females reported a higher value of cellphone dependency, due to this uneven predictive value of nomophobia factors, males were 22 percent more likely to engage with their cellphone illegally while driving than females (Kaviani et al., 2020). Two other surveys found that measures of general phone use (Oxtoby et al., 2019) and cellphone dependency (Struckman-Johnson et al., 2015) were the strongest predictors of frequent device use inside the vehicle for females, but for males the strongest predictors were a belief in their capacity to use their devices while driving (Struckman-Johnson et al., 2015) and maladaptive social skills (Oxtoby et al., 2019).

Other Demographic Factors

Age and gender are the demographic factors predominantly studied when considering device use while driving and PDU in general. Preliminary research on other traits suggest that behavioral differences may be found along driving experience, race, general device use, and urbanicity of residence. Findings from Creaser and colleagues' on-road study (2015) suggest that for teen drivers device use while driving increases as they initially gain experience. In particular, over a 12-month period**,** teen drivers increased their average rates of calling and texting while driving even though cellphone use was banned in the State where they were obtaining licensure. In international surveys self-reported measures suggest that more frequent cellphone use while driving and having higher education are associated with being a PDU user (Oviedo-Trespalacios et al., 2019). A representative survey study of Ontario, Canada, students in grades 7 to 12 found that young drivers were more likely to report a higher frequency of texting while driving if they were white, spent 1, 2 or 3+ hours on social media per day, and were urban students (Cook et al., 2018). No significant relationships were found with gender or whether students had taken driver education courses. These participants were not asked if they owned cellphones. Additional representative studies of device use while driving would be needed to more fully understand the demographic factors related to this behavior in the United States.

Demographics Conclusion

The population of concern for PDU while driving likely encompasses about 2- to 4 percent of drivers (see Chapter 6). Current research indicates adolescents and young adult drivers comprise most of the population of concern when it comes to PDU while driving, although since the two main studies cited used different age delineation systems, it is not clear when a significant drop-off in high frequency/PDU while driving occurs at a certain age. Although drivers identifying as female report significantly greater symptoms or tendencies associated with device dependency than males, the gender difference is not consistent for on-road, high-frequency device use or PDU. This may be due to a one-way relationship between device use while driving and device dependency; although drivers engaged in greater device use while driving are more likely to be

PDUrs generally, they do not necessarily use their devices while driving (Billieux et al., 2015; Kaviani et al., 2020). Another possibility is that, while female drivers experience greater cellphone dependency, males are more prone to risky driving behaviors (Freeman et al., 2017), thus diminishing the difference in PDU while driving between male and female gender groups (Zaman & Lache, 2015). Survey studies also suggest that the high frequency/PDU population is more urban, more educated, and spends more hours on their devices or social media during the day. Other genders, education, socioeconomic status, and regional differences have yet to be studied across all age groups.

Psychosocial Factors (Are Some Drivers More at Risk?)

Many studies on PDU and driving have examined the role of driver-specific traits. These traits overlap with characteristics of populations engaged in device-distracted driving, illegal behavior (driving while using a hand-held mobile device is illegal in many jurisdictions), risky driving, and general problematic cellphone use. A challenge for the current analysis though, is that these studies tend to treat measures of problematic device or frequent cellphone use as a single factor and rarely link these measures back to the APA aspects of behavioral addiction (Chapter 4; APA, 2013).

In this overview of driver-specific traits related to high frequency/PDU while driving, the traits are organized into psychological and social elements. Individual differences in psychology are organized by themes from Billieux and colleagues' (2015) pathway model (see Chapter 5). Similar to the general PDU literature, relevant studies focus on characteristics of the population of concern versus control populations. However, they do not include the longitudinal studies necessary to confirm antecedents that predispose a driver towards PDU while driving. The social traits are organized into the social context related to participating in interpersonal communications using a device while driving, social norms, and the driving environment context.

The pathway model (see Figure 12) categorizes problematic phone use behavior into three "pathways" that could explain the type of problematic use a person has and the associated symptoms or behaviors (e.g., phoning while driving). These include the excessive reassurance pathway, the impulsive pathway, or the extraversion pathway. Hayashi and colleagues (2017) suggest an alternative grouping of the psychological factors associated with texting while driving: (1) attitudes, tendency, and intention, (2) risk perception and risk tendency, (3) impulsivity and lack of self-control, and (4) emotional regulation. However, we will defer to the pathway model since it is straightforward, influential in the literature, and has been empirically evaluated (e.g., Pivetta et al., 2019). Due to the feedback loop that can occur between impulse and habit (see Chapter 5), we have organized literature related to habit development with the impulsive pathway traits.

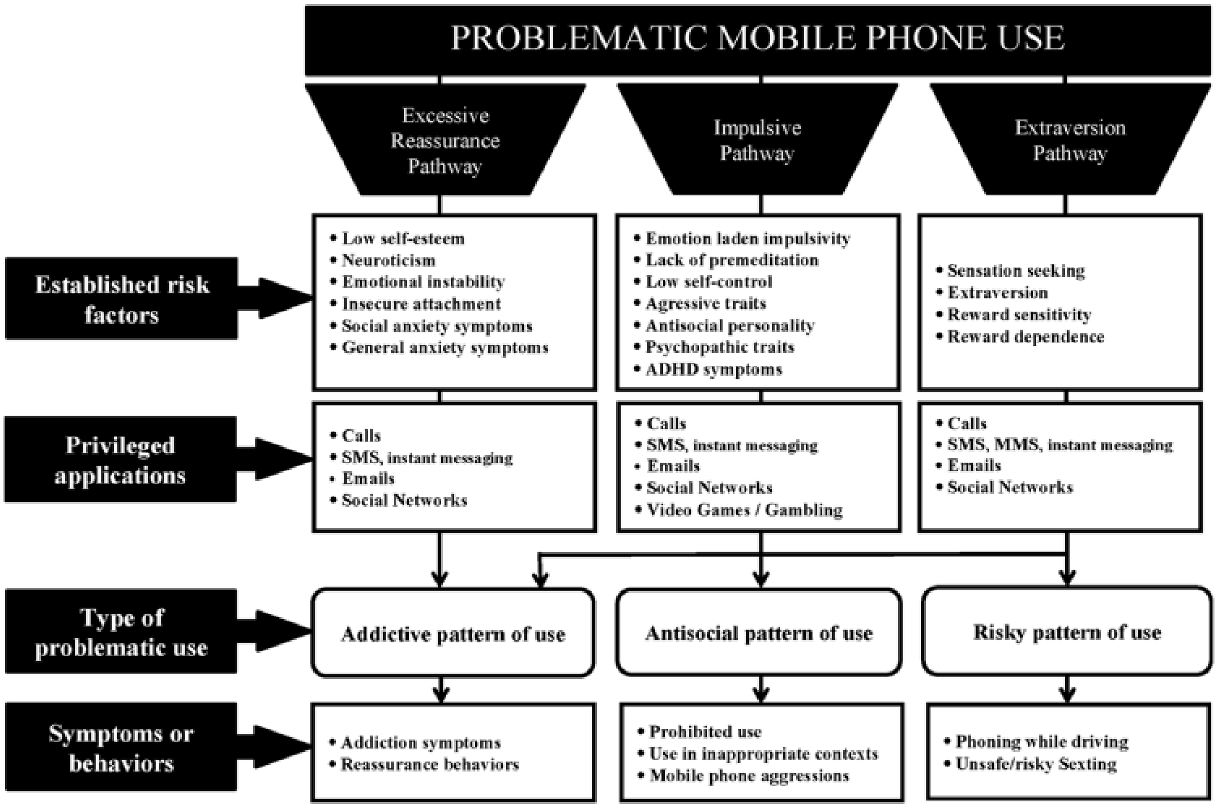

Figure 12. The pathway model of problematic cellphone use

Psychology

Excessive Reassurance Pathway (Anxiety and Self-Esteem)

The excessive reassurance pathway has established risk factors of neuroticism, insecure attachment, social anxiety symptoms and emotional instability, general anxiety symptoms and low self-esteem, leading most directly to an addictive pattern of cellphone use in daily life (Billieux et al., 2015). These traits have not been widely studied in the device-distracted driving literature, but low self-esteem and general anxiety have been linked to general problematic cellphone use (Chapter 5). According to the pathway model, this direct relationship arises when people's cellphone use becomes a coping mechanism for their anxiety and low self-esteem or when people prioritize relationship maintenance and constant social connectivity over driving safely.

Neuroticism. The personality trait neuroticism, which is a trait associated with anxiety and insecurity, has been linked to on-road measures of frequent device use and self-reported device dependency. An Israeli study used the smartphone addiction scale and the "Big Five" inventory (BFI) to examine smartphone use while driving based on the number of touches per minute on a smartphone (Kita & Luria, 2018). The BFI measures five dimensions of personality: (1) extraversion, (2) agreeableness, (3) conscientiousness, (4) neuroticism, and (5) openness to experience. The number of cellphone touches per minute, sampled randomly from 5,000 of the young (17- to 22-year-old) drivers' journeys, was moderately related to higher smartphone "addiction" symptoms ($r = 0.23$; $p < 0.01$).

Neuroticism and device use while driving also had a significant positive relationship that was mediated by smartphone "addiction" symptoms (Kita & Luria, 2018). The study's authors postulate that higher levels of neuroticism indicate greater social insecurity and therefore a stronger need to respond to smartphone notifications immediately.

Insecure Attachment. Insecure attachment is characterized by anxious or avoidant attachment styles. Only one study has examined this factor and self-reported intention to respond to a smartphone while driving. This survey was conducted with university students in Arizona and covered attachment styles and participants' self-reported urge to answer smartphones while driving (Bodford et al., 2017). It found that people with anxious attachment towards their smartphones reported stronger urges to answer phone calls while driving, while those with higher avoidant attachment scores had less urge to answer.

Social Anxiety and Emotional Instability. In almost all studies of PDU, social anxiety and emotional instability systems are recorded in varying ways. In Kaviani and colleagues' Australian survey (2020), higher anxiety about being without one's cellphone (known as nomophobia) was associated with more time spent on a smartphone during the day. Moreover, participants who reported that they engaged in illegal cellphone use while driving had significantly higher nomophobia scores than those who did not. A particular dimension of nomophobia was associated with engaging in illegal cellphone use while driving—specifically feeling anxiety without their cellphones because they are not able to access information (Kaviani et al., 2020).

An online survey of young Australian adults found a relationship between increased cellphone use while driving for males (but not females) and poorer social connectedness, as well as higher social anxiety motivations for cellphone use. For females, only general cellphone activity frequency was a significant predictor of cellphone use while driving (Oxtoby et al., 2019). Nomophobia, emotional dependency on a cellphone, and poor social connectedness each had nuanced associations with device use while driving. Specifically, these traits or aspects of these traits affected male behavior more than female behavior. This area of the literature has yet to converge on a clear understanding of why this gender difference exists on how these anxiety-related traits affect problematic phone use while driving.

General Anxiety and Low Self-Esteem. Other studies suggest problematic phone use while driving is related to anxiety generally and poor self-esteem, although methodological issues with these studies warrant additional research. A survey study of American undergraduate students found that greater anxiety and poorer perceived control to resist using a cellphone while driving were related to increased intention to use a cellphone while driving in the next week, although the scales used had been heavily adapted and not evaluated for scale validity (Bradish et al., 2019). Results from a French survey suggest problematic phone use measured using the PMPUQ and its dangerous use subscale (which covers questions about cellphone use while driving) are linked to implicit self-esteem. Only 63 percent of the respondents had a driver's license and non-drivers were not removed from the sample (Lannoy et al., 2020). Emotionally reactive drivers who experience symptoms related to PDU may also have poor driving outcomes, but the existing research and lack of validated psychological instruments do not support strong conclusions.

Excessive Reassurance Pathway Conclusion. The excessive reassurance pathway of Billieux and colleagues' model is characterized by low self-esteem, neuroticism, emotional instability, insecure attachment, social anxiety symptoms, and general anxiety symptoms. In the frequent/PDU while driving literature, these traits appear to be related to increased PDU while driving and the urge to perform this behavior. The studies reviewed suggest that device dependency may mediate the relationship between neuroticism and increased device use while driving. Drivers with anxious attachment styles may have a more intense urge to respond to their device while driving, whereas drivers with avoidant attachment may feel less compulsion. Anxiety around losing access to information, along with frequent everyday cellphone use, may motivate illegal device use while driving behavior. Some studies suggest that general anxiety, social anxiety, and low self-esteem are related to increased device use while driving, but these traits warrant future examination using robust research methodologies.

Impulsive Pathway

The established risk factors for the impulsive pathway in the pathway model are emotion-laden impulsivity, lack of premeditation, low self-control, aggressive traits, antisocial personality, psychopathic traits, and ADHD symptoms. So far, only traits directly related to executive cognitive function (i.e., the ability to plan and carry out goal-oriented behavior; see Chapter 3) have been studied in a driving context. These traits include impulsivity, lack of premeditation, low self-control, and ADHD symptoms. This pathway, along with the extraversion pathway, directly leads to risky patterns of use including using a cellphone while driving according to the pathway model (Billieux et al., 2015). In this case, the relationship emerges from poor impulse control that leads to unrestricted device use cravings and acting on those cravings.

Impulsivity and Self-Control. Survey instruments that measure impulsivity tend to be strongly related to measures of general problematic phone use (see Chapter 5). These relationships appear to extend to problematic and high-frequency device use while driving, but the links are generally weak. A small-scale study of teenage drivers found that higher impulsivity measured by the Barratt Impulsiveness Scale, along with sensation-seeking, were related to an increased number of high-risk cellphone unlocks (i.e., when the vehicle was travelling over 25 mph) (Delgado et al., 2018). However, other surveys have found that impulsiveness is a weak predictor for greater amounts of texting for these drivers (Lantz & Loeb, 2013; Struckman-Johnson et al., 2015). A survey study of an all-ages community sample out of the United Kingdom used the Problematic Mobile Phone Use questionnaire to directly test the variable relationships laid out in the pathway model (Billieux et al., 2015), including impulsivity and problematic smartphone use in a driving context (Pivetta et al., 2019).

Higher motor impulsivity (acting on impulse) and attention impulsivity (poor concentration) were both related to increased antisocial use and addictive use of smartphones. However, dangerous use (smartphone use while driving) and higher planning impulsivity (lack of planning with the future in mind) were only related to each other. Path analysis showed more dangerous use was significantly related to more addictive use and antisocial use, indicating that motor and attention impulsivity may indirectly contribute to smartphone use while driving. Despite the preliminary nature of this research, the findings indicate that impulse control, possibly due to lack of forethought, may be a minor but still contributing factor for drivers who exhibit problematic and frequent device use while driving.

Impulsivity: Executive Function and Delay Discounting. One research group performed a series of experiments examining impulsivity and frequent texting while driving using decision making tasks rather than self-report measures (Foreman et al., 2019; Hayashi et al., 2015, 2016, 2017, 2018, 2019). These tasks measure a cognitive aspect of impulsivity related to decision making known as delayed discounting. In these tasks, delayed discounting is modelled as the product of two competing neurobehavioral systems: the impulsive system that values immediate rewards and the executive system that values delayed rewards and may be needed to inhibit the impulsive system (Hayashi et al., 2019). The initial studies found that high-frequency phone texters discounted or undervalued delayed rewards at a greater rate than the infrequent texters, suggesting that they were more impulsive since they preferred instant gratification (Hayashi et al., 2015). However, in two follow-up experiments (Hayashi et al., 2016, 2017), the two frequency groups did not exhibit a significant difference in response to a traditional delay discounting task. On self-reported survey scales, drivers in the high-frequency group indicated higher levels of impulsivity (measured using BIS) and lower levels of executive function related to strategic planning and impulse control as measured by the executive function index (Hayashi et al., 2017). These results agree with Delgado and colleagues' on-road findings (2018) where a greater number of high-risk smartphone unlocks were related to higher impulsivity as measured by the BIS, but not as measured by delay discounting scores. These results suggest that, although high-frequency device use drivers may exhibit higher impulsivity generally, caution should be used when characterizing a driving population with only self-reported measures.

The experiments by Hayashi and colleagues gave participants novel texting and driving delay discounting tasks. Across these tasks, all drivers were more willing, in a hypothetical driving scenario, to respond to a text immediately while driving (rather than wait until arrival at a destination) if the sender was closer to them socially, if they were further from the destination, and if the crash probability was lower as perceived by the participants. Compared to low-frequency texters, high-frequency texters were more willing to respond immediately at shorter distances to the destination, under high-risk conditions, and to senders who were less close to them socially (Foreman et al., 2019; Hayashi et al., 2016, 2018, 2019).

From this series of discounting experiments, it appears that more frequent self-reported texting while driving is associated with higher impulsivity. It is unclear if the novel texting and driving discounting tasks used by Hayashi and colleagues still produce a valid measure of impulsivity, but they may still be useful for understanding how drivers weigh contributing factors (e.g., distance to destination, crash risk, social value of the sender) that may influence their decision to engage with a device while driving. Overall, it is likely that impulsive drivers are more likely to be frequent users of devices while driving, but the validity of these measures should be confirmed across age groups using robust observational data.

Executive Function and ADHD. ADHD is often characterized by difficulties with executive function, including goal-directed planning, focused behavioral execution, and impulsivity. Deficits in executive cognitive function are associated with increased device use while driving, and with more severe performance decrements under distraction (Nowosielski & Trick, 2019; Pope et al., 2017). Two common hypotheses in the literature are that ADHD traits make drivers more susceptible to frequent device engagement, and that the negative impact of distractions on their driving performance is greater compared to controls. Current studies use drivers with clinically diagnosed ADHD, but some use a self-reported measure of ADHD symptomology.

More frequent engagement and higher intentions to engage in device use while driving is related to higher ADHD symptoms in the general driving population. In one U.S. survey, greater ADHD symptoms were related to increased stress and reduced self-esteem in university students who used social media while driving for their commute (Turel & Bechara, 2016). The first three factors together predicted stronger cravings to use social media generally, which then led directly to increased social media use while driving. Similarly, a study of Vermont high school students found that greater ADHD symptoms were associated with stronger intentions to text while driving in the future and increased perceived acceptability of texting while driving (Nichols, 2018).

Drivers with clinically diagnosed ADHD may have greater performance decrements under distraction. A high-fidelity simulator study examined driving and secondary task performance for young drivers with ADHD (abstaining from medication on the day of the experiment) and found performance decrements depended on the driving environment (Reimer et al., 2010). In a low-complexity driving condition (highway scenario) ADHD drivers exhibited poorer driving performance (e.g., driving over the speed limit) but comparable performance in a forced-pace secondary task relative to controls. The opposite occurred in high complexity driving (urban scenario) where ADHD drivers exhibited poorer secondary task performance but comparable driving performance relative to controls. The researchers theorized that since people with ADHD tend to have their attention captured by high-stimulus inputs or demands, that these drivers devoted higher levels of attention toward the secondary task when the demands of the driving environment are low. This is a consistent with a phenomenon observed in the general driving population, albeit more pronounced, where drivers' focus on secondary tasks is reduced in a complex driving environment due to the high-workload demanded by the primary task of driving (Berlyne, 1960; Oviedo-Trespalacios et al., 2017).

Drivers' more frequent device use and device use cravings have been associated with stronger ADHD symptoms in the literature. In addition, drivers with ADHD may be more susceptible to the effects of PDU while driving, not because they are unskilled at performing the primary task when multitasking, but due to their attention management tendencies. Under low-workload driving conditions, drivers with ADHD may be more susceptible than the general population to the attention-capture effects of a cognitively arousing secondary task (e.g., device use), but this effect diminishes as the driving task becomes more complex (Reimer et al., 2010).

Developing the Habit of Texting While Driving, Outside of the Vehicle. A common view of the device-distracted driver is that the individual driver is electing to engage in a secondary task while driving (Horrey et al., 2008). However, a driver's attention may be captured through different mechanisms (NHTSA, 2020). Previous research has categorized common driver distractions as:

- *Voluntary*: intentional engagement in secondary tasks;
- *Involuntary*: an inability to suppress non-driving related information or stimuli; and
- *Habitual distractions*: the inability to inhibit automatic responses (Chen et al., 2018; Hoekstra-Atwood et al., 2017; Marulanda et al., 2015).

Problematic device use can involve habitual, stimulus-driven responses (Friedman & Miyake, 2004; Miyake et al., 2000) that can emerge regardless of individual intentions (Bayer & Campbell, 2012). Habits have been defined as "a form of automaticity in responding that develops as people repeat actions in stable circumstances," (Verplanken & Wood, 2006). Cellphone users may repeat controlled, goal-driven behavior enough that these behaviors (e.g., checking for updates) become automatic in non-driving contexts. Once the cellphone user moves into the roadway environment, they may have trouble inhibiting these automatic responses to established cues, even though these behaviors are now contextually inappropriate. In an analysis of data from the SHRP2 Naturalistic Driving Study, higher rates of texting generally and texts per hour of driving were significantly and strongly correlated (r = 0.86) as were call rates per day and calls per hour of driving (r = 0.81), indicating a relationship between behavior established outside the vehicle and the frequency device use while driving (Atwood et al., 2018). In the PDU literature, process-related smartphone use (e.g., using functions related to consuming or producing media rather than for social connection) is a strong determinant of developing both habitual and problematic behavior (Elhai et al., 2017; van Deursen et al., 2015).

Frequent use in the driving context can also increase feelings of dependency in some people in that context due to cues that prepare them to perform this behavior (see Chapter 5). In an Israeli survey study, perceived need (the degree to which respondents would feel the absence of a cellphone feature while driving) was related to texting and phone calling frequency while driving. A large percentage of frequent users would feel the absence of their cellphone to a great extent (51%, compared to 11% of occasional users; Musicant et al., 2015). Once people habitually associate the driving context with cellphone use, the influence of their daily cellphone use habits within the vehicle becomes even stronger.

Habitual behavior is not the same as a loss of willful control (Kuss et al., 2018; Volkow et al., 2016), although PDU may reinforce neurological pathways that relate to impulsive thoughts and behaviors as well as to habitual behavior (see Chapter 5). Mobile devices may have cues that pose elevated safety risks within the driving context, since their alerts are often quite salient (e.g., push notifications may be imbued with meaning conveyed using perceptual channels: audio, visual, and vibrotactile). The aspects of mobile device, and particularly cellphone, system interaction design that create these distracting triggers are known collectively as “addictive design” (see Chapters 2, 5).

Habits and the Theory of Planned Behavior. The TPB (see Chapter 3) is a framework that is useful for understanding intentional behaviors and that researchers use to guide their understanding of frequent device use by drivers. By adding habits into an extended TPB model, researchers can begin to examine the role of habits in behaviors that may be partly automatic (Hansma et al., 2020). Within the TPB, habits have been found to relate to engagement in device-related distractions (Hansma et al., 2020). Capturing automaticity based on self-reports may inherently underrepresent the amount of automatic behavior since there is an underlying construct of nonconscious behavior (Bayer & Campbell, 2012), so observational and experimental studies are needed to capture the true prevalence of automatized mobile device interactions while driving.

Bayer and Campbell (2012) are often cited in the PDU while driving literature since theirs was the first major U.S.-based publication to investigate habits in the context of distracted driving behaviors. They found the habit of using a cellphone while driving explained more of the variance in self-reported frequency of texting while driving than overall frequency of texting in non-driving contexts did. Habit also accounted for a significant amount of variance in device use after other TPB variables were included. Participants’ driving confidence and social norms were significantly related to frequency of cellphone use while driving, but perceived behavioral control and attitudes were not (Bayer & Campbell, 2012). Other TBP studies have found similar relationships between habit and device use while driving (Briskin et al., 2018; Hansma et al., 2020).

Habits predict increased frequency of device use while driving, but tend to play a smaller role than other TPB constructs (accounting for a smaller proportion of model variances; Bayer &

Campbell, 2012; Hansma et al., 2020; Murphy et al., 2020). The consistent trends with the standard TPB constructs are that drivers who report more frequent device use while driving tend to report greater perceived behavioral control efficacy (Bayer & Campbell, 2012; Berenbaum et al., 2019; Hansma et al., 2020; Murphy et al., 2020; Struckman-Johnson et al., 2015) and attitudes that are favorable to device use while driving behavior (Chen & Donmez, 2016; Hansma et al., 2020; Murphy et al., 2020).

Impulsive Pathway Conclusion. The impulsive pathway is characterized by impulsivity, lack of foresight, low self-control, ADHD symptoms, aggressive traits, antisocial personality, and psychopathic traits. So far all of these psychological constructs except for aggressive, antisocial, and psychopathic traits have been studied in the context of PDU in the driving environment and are related to frequent device use or measures of device dependency. There is also evidence, beyond what is in the pathway model (Billieux et al., 2015), that habits play a small, albeit consistent, role in PDU while driving.

Self-reported impulsiveness is consistently related to frequent on-road and self-reported device use while driving. Additional research could confirm the following initial findings: that this relationship extends to increased device dependency, that it is primarily with planning impulsivity, and that it is stronger for female drivers. Greater self-reported ADHD symptoms are associated with more behavioral intention to use devices and stronger cravings leading to more frequent use while driving. Clinically diagnosed but untreated ADHD could affect how drivers manage attention: in low workload driving, their driving performance may suffer more than the general population when engaging in secondary tasks.

While habits can appear to be a distinct type of device use dependency (i.e., loss of control), they are instead "automated" behaviors that may be triggered and repeated in inappropriate contexts (e.g., the driving environment). There is some evidence that frequent use outside of the driving environment is related to frequent device use while driving, and that frequent device use while driving can create perceived need for the device in that context. There is consistent evidence that stronger habits predict increased device use while driving either directly (Bayer & Campbell, 2012; Briskin et al., 2018; Hansma et al., 2020; Moore & Brown, 2019) or indirectly through behavioral intention (Murphy et al., 2020).

The initial research into the impulsive pathway factors is mainly based on self-report measures using undergraduate samples, although a few relevant driving simulator and all-ages studies have been run. When modelled with other factors (e.g., attitudes, perceived risk, perceived behavioral control, moral norms), impulsive pathway factors tend to account for less of the variance than these TPB-related constructs.

Extraversion Pathway (Big Five Personality Traits and Sensation-Seeking)

According to Billieux and colleagues' pathway model (2015), the established risk factors for the extraversion pathway are extraversion, sensation-seeking, reward sensitivity, and reward dependence. The current PDU literature has explicitly examined extraversion and sensation-seeking traits, but not reward sensitivity and reward dependence. This pathway directly leads to risky patterns of use, including using a cellphone while driving. According to the pathway model, this relationship can manifest through a perceived need to seek out stimulation, a desire to socialize with others, or from neuroses around relationship maintenance (linking this pathway back to the excessive reassurance pathway).

Extraversion. Extraversion is the internal social drive to interact with others and is related to frequent device use while driving. An experiment found that stronger personality traits related to the BFI aspects of extraversion, openness to experience, and neuroticism predicted increased self-reported messaging behavior while driving (Briskin et al., 2018). Similarly, an Israeli study found a significant positive relationship between frequency of device use while driving and extraversion, but a significant negative relationship with increased openness to experience (Kita & Luria, 2018). However, only the positive relationship between neuroticism and device use while driving was mediated by smartphone "addiction" symptoms (Kita & Luria, 2018). This suggests that while greater extraversion and low openness to experience predict frequency of device use while driving, PDU while driving may be more dependent upon drivers' neuroticism.

The BFI has also been used in studies that attempt to profile different types of device-distracted drivers. One survey study profiled young drivers (university students) from the United States using model fit indices that divided them into groups based on their self-reported frequency of distracted driving (Braitman & Braitman, 2017). The frequency measure was a composite score that included non-device related activities but was weighted based on activity risk. So, for example, cellphone interaction was weighted more heavily than talking to passengers. Extraversion was the only trait difference observed amongst the low-, medium-, and high-engagement groups. The low-frequency group scored significantly lower on extraversion scores than the other two groups, further bolstering extraversion's association with PDU while driving. Maier and colleagues (2020) also found similar relationships between frequent device use while driving and extraversion when they grouped German drivers based on their BFI responses and self-reported smartphone use while driving.

Sensation-Seeking. Strong associations between sensation-seeking and distracted driving generally have been found among drivers in several age groups (Palat et al., 2019), especially younger drivers (Chapter 3). A small-scale study of teenage drivers found that higher sensation-seeking along with higher impulsivity were related to an increased number of high-risk phone unlocks (i.e., when the vehicle was travelling over 25 mph) (Delgado et al., 2018). Similarly, a survey study of Canadian drivers' engagement in technology-related distractions found that drivers who reported stronger psychological characteristics related to sensation-seeking, impulsivity and venturesomeness also reported more frequent device use while driving. High levels of sensation-seeking—an especially common trait among PDUrs in general (De-Sola Gutiérrez et al., 2016)—could explain some of the discrepancy between driver's stated beliefs that device use while driving is dangerous and their admissions of frequently performing this behavior. For some of these drivers, knowing that device use behind the wheel is risky could make this behavior more tempting.

Boredom Proneness. Boredom proneness is also a motivation for sensation-seeking behavior, especially in low-workload driving (de Waard, 1996). A thematic analysis of open-ended interviews with male drivers ages 18 to 25 in Australia found that drivers used cellphones or weaved in and out of lanes as coping strategies to resist driver boredom (Steinberger et al., 2016). Similarly, a small study in Sweden observed long-haul truck drivers for 6 hours and interviewed them about their distracted driving. (Iseland et al., 2018). These drivers discussed using cellphones as a coping mechanism to disrupt boredom, fight drowsiness, or address loneliness, especially when routes are monotonous. An online survey of Australian adults 18 to 25 found that, for males, higher boredom proneness, higher social anxiety motivations for cellphone use, higher habitual phone use, and general phone activity frequency were all related to increased cellphone use while driving (Oxtoby et al., 2019). Thus, for some drivers, phone use may be a misguided approach for dealing with their boredom on the road.

Extraversion Pathway Conclusion. There is observational and survey evidence that high-frequency device use while driving is performed by drivers with stronger sensation-seeking and extraversion traits. Only one study examined the relationship between attributes associated with the extraversion pathway and phone dependency (as opposed to frequent use) in the context of device use while driving, but it did not find a relationship between extraversion and the dependency measure. Reward sensitivity and reward dependence have not been directly studied in the problematic phone use while driving literature.

Psychology Conclusion

Researchers have approached the psychological predictors of PDU while driving from different domain perspectives. Problematic device use as a pathology, like other behavioral addictions and compulsions, still needs reliable diagnostic criteria, useful assessment tools, and effective and proven treatments (Ascher, 2015; see Chapter 5). The existing literature does not consistently examine the psychological predictors of PDU while driving by stratifying drivers into device users who exhibit cellphone dependency versus those who do not, or drivers who frequently use their device versus those who do not. The most common design does stratify frequent versus occasional users, but the thresholds of use are either not defined, or are subjective to the respondent. Device dependency is usually treated as a continuous measure related back to one of the various measures described in Chapter 5.

Given these caveats, the existing research provides clear evidence that device dependency mediates the relationship between neuroticism and increased device use while driving. Driver anxiety may also motivate PDU while driving, whereby people with anxious attachment styles may have a more intense urge to respond to their device while driving, and drivers who are anxious about losing access to information may use their devices more frequently while driving.

PDU while driving is also consistently related to greater device habits (often developed outside of the vehicle) and higher impulsivity in drivers. Given that ongoing PDU in general affects the areas of the brain that mediate impulsivity (see Chapter 5), it may be useful to directly examine how habits may interact with impulsivity to contribute to PDU while driving behavior. It may follow that impulsive drivers who engage in PDU may be reinforcing and exacerbating their impulsive tendencies as they relate to device use. Most of the research has looked at habits as an extension of the TPB, and in these models, perceived self-efficacy and moral norms tend to more strongly predict frequent device use while driving. There is also observational and survey evidence that high-frequency device use while driving is performed by drivers with stronger sensation-seeking and extraversion traits because these traits relate directly to device use while driving, as well as to developing stronger device use habits in daily life.

The research around personality traits and frequent device use while driving highlights the shortcomings of the Billieux framework. Specifically the findings from Briskin and colleagues (2018) and Maier and colleagues (2020) suggest these traits may coincide and influence each other in ways that are not captured in previous groupings (Billieux et al., 2015; Hayashi et al., 2017). In addition, some psychological factors that are currently outside of the pathway model appear to be important and contribute to device use frequency, including perceived self-efficacy, habits, and possibly attitudes and perceived behavioral control. Optimism bias may be another trait to investigate, given that comparative optimism (as part of self-efficacy) is often used by drivers to rationalize their distracted driving (Chapter 3), and there is evidence that drivers with near-miss collisions more frequently use their devices while driving than those who have had and not had collisions (Berenbaum et al., 2019).

Social Driving Context Factors

In the biopsychosocial model, a person's context, including social norms, social context, and social pressures, contributes to how the person engages in problematic behaviors. Social usage and social stress are related to developing general PDU (van Deursen et al., 2015). Conducting interpersonal communication is one of the main ways distracted drivers use their phones on the road (Chapter 2; Chapter 6). Another part of the social context is the environment where the behavior occurs. In substance addiction, certain circumstances can fuel maladaptive behaviors or allow relief for the affected individual (Becoña, 2018). In the same way that an alcoholic's substance use could be related to heavily drinking with specific people, communications from specific people or for a specific social reason may encourage a problematic phone user's distracted driving.

Social Context

Feeling obligated to use a device for work is a strong motivator for frequent device use while driving. In a community sample of Californian middle-aged drivers, the strongest predictor of frequent device use while driving in driving contexts was feeling obliged to take work calls (Engelberg et al., 2015). Similarly, in an Australian study, drivers who drove for business purposes were twice as likely to use a cellphone daily while driving, compared to those driving for personal reasons (Walsh et al., 2007). An Israeli survey found that of those who made calls while driving (73% of all respondents), 69 percent reported the calls were for both work and private purposes, 25 percent reported the calls were mainly for personal purposes and 6 percent reported their calls were mainly for work purposes (Musicant et al., 2015). Participants who reported work purposes as their main reason were more likely to report being frequent device users than occasional users while driving.

When using a cellphone for personal purposes, usage frequency is affected by the relationship between the driver and the communication partner. For example, a study of 47 parent-adolescent dyads found that parents were more likely to use a cellphone while driving to communicate with their children, compared to children communicating with their parents. For all participants, higher frequency of self-reported cellphone use while driving was related to greater addiction symptoms measured using the MPPUS and lower risk perceptions (Mirman et al., 2017). The relationship between the strength of risk perceptions and cellphone use while driving was similar within parent/child dyads, but MPPUS scores were not. For parents, higher MPPUS scores were related to more cellphone use while driving for both types of communication partners: children or peers. Higher MPPUS scores were related to more cellphone use while driving for adolescents when the communication partner was a peer, but not a parent (Mirman et al., 2017). Therefore, adolescents displayed patterns of problematic cellphone use when communicating with peers, but not with parents. Similarly, Foreman and colleagues (2019) conducted an experiment to examine the role of the social importance of the communication partner on texting while driving. They found that all drivers were more likely to respond to a text immediately while driving (as opposed to waiting until a destination to respond) in a hypothetical scenario if the sender was closer to them socially. However, drivers who reported high-frequency device while driving were less discriminating and more willing to respond immediately to senders who were less socially close to them.

Similar to general device-distracted driving (see Chapter 3), the frequency of device use while driving is often lowered by the physical presence of passengers (Edwards et al., 2019; Foss & Goodwin, 2014; NCSA, 2019). In a study on naturalistic driving data from Dutch drivers in the UDRIVE dataset from 2015 to 2017, researchers took a random sample of their trips and video coded episodes of cellphone use (Christoph et al., 2019). The coded data revealed that drivers spent 9.2 percent of driving time engaged in cellphone related tasks, but these instances were significantly lower when a passenger was present in the vehicle (3% versus 11%).

Social Norms

For all drivers and younger drivers in particular, social norms predict increased device engagement frequency while driving. Social norms are often examined as a construct in TPB-based surveys and models (see Chapter 3 for norm definitions and examples). These are often framed around the respondent's belief that: (1) people/drivers in general perform a behavior (i.e., descriptive norms), (2) that people who are close/important to them approve of a behavior (i.e., injunctive subjective norms) or (3) if the behavior aligns with their own principles (i.e., injunctive moral norms). Positive norms are favorable to conducting a behavior, which in this case is more frequent device use while driving.

U.S. studies have generally found that respondents whose principles align positively with device use while driving (moral norms) and who perceive more positive social norms around device use while driving report more frequent device use while driving. A survey of U.S. undergraduate students found that positive injunctive social norms were significantly related to frequency of cellphone use while driving (Bayer & Campbell, 2012). Briskin and colleagues (2018) also found similar results on their undergraduate sample. Stronger normative beliefs favorable to device use (particularly moral norms), closer proximity to one's phone, and stronger phone-related habits directly predicted increased frequency of self-reported messaging behavior while driving. Positive injunctive social norms also increased the likelihood that a person would keep their cellphone accessible in order to be available to others and respond promptly to messages while driving (Briskin et al., 2018). Meldrum and colleagues' survey (2018) of a U.S. university population found that drivers who perceived more of their close friends and drivers in general performing texting while driving, reported more frequent texting while driving behavior.

Canadian studies using samples that are representative or represent a broader range of ages found that subjective and descriptive social norms do not influence older drivers to the same extent as younger drivers. A survey representative of young people from Ontario found that increased frequency of sending and reading text messages while driving was significantly related to positively aligned moral norms. Furthermore, increased frequency of sending (but not reading) messages while driving was related to greater descriptive peer norms (believing a higher percentage of their peers texted while driving) (Berenbaum et al., 2019). In contrast, another Canadian survey that included a broad community sample of drivers found that for drivers 18 to 30 certain norms were a stronger predictor of frequent device use while driving, but these norms were not significant for the older age group. For drivers over 30 a higher level of a risk and sensation-seeking personality were stronger predictors, but these factors were only marginally significant for the younger group (Chen & Donmez, 2016).

Overall, stronger moral norms indicating that a driver's principles support device use while driving appear to be consistently related to frequent device use while driving. However, neither subjective nor descriptive norms consistently predict frequent device use while driving. If there is a relationship, subjective norms may have more of an impact on younger drivers. Injunctive and descriptive norms relating to close friends or peer groups do seem to relate to increased frequency of sending behaviors while driving, although these have not been studied in older populations.

Driving Environment

Drivers may modulate or pace their device use behavior in response to different driving environments (see Chapter 2 for a discussion of driving contexts and distracted driving). The reasons for behavior frequency adjustments appear to relate to drivers' moment-to-moment risk assessment and cognitive arousal.

Being bored or driving in unstimulating roadway conditions is a recurring theme for why and when drivers use their devices. Fifteen percent of drivers responding to an Israeli study reported that "when I am bored/stuck in traffic" was their most common reason for texting while driving (Musicant et al., 2015). Open-ended interviews with young male Australian drivers found that drivers' coping strategies for boredom included using their phone and listening to music (Steinberger et al., 2016). Additionally, participants associated driver boredom with slow and constant speeds, low traffic, routine drives, and driving with cruise control engaged. Some participants found boredom-inducing driving scenarios to be relaxing, whereas others found them to be boring or annoying after a longer period of time.

A few studies have found increased device use while driving when the vehicle is on the road, but stationary, such as when at a stop sign (Gliklich et al., 2016). Dutch drivers sampled in the UDRIVE dataset conducted 25 percent of their visual/manual cellphone tasks when the drivers were not moving, although most of their interactions occurred on highways (Christoph et al., 2019). Drivers from an Australian survey study reported they were more likely to use a cellphone while in a traffic jam or waiting at traffic lights than when driving at 100, 60 or 50 km/h. They also reported being more likely to use a cellphone on a familiar road than on an unfamiliar road (Walsh et al., 2007). Average drivers reported being less willing to use devices while driving under poor weather and difficult traffic conditions (Gray, 2015; Musicant et al., 2015). The 2018 and 2017 NOPUSs, however, observed more drivers holding and talking on mobile devices and manually interacting with them while driving in "not clear weather conditions" than in "clear weather conditions."

Social Context Conclusion

Bayer and Campbell describe a cellphone as a "social appendage" (Bayer & Campbell, 2012) and frequent device use is often in service of interpersonal communications. Social obligations, norms, and how drivers weigh risk under different driving conditions can help explain why many drivers may not approve of texting while driving but perform the behavior anyway (see Chapter 6).

Drivers who exhibit frequent device use while driving are often motivated by participating in work-related communications more than personal communications. For younger drivers, perceptions of increased behavior from peer groups and approval of the behavior from friend groups consistently motivate frequent device use while driving. Younger drivers' frequent device use while driving was related to device dependency when communicating with their peers, but not their parents while driving. Device use frequency is lowered in the presence of a physical passenger, although it is not clear how much of this effect is due to social norms or because the driver can offload device interaction to the passenger.

Drivers frequently engage with their devices in driving environments that are boring or routine (e.g., waiting in traffic, at a light or travelling on a familiar road) and more complex driving and traffic conditions are more likely to deter drivers' device use.

Potential Amelioration Strategies

This section focuses on device use while driving deterrents that drivers self-report in surveys or interviews, as well as mitigation strategies suggested by study authors to address underlying traits related to frequent or PDU while driving. Implemented and evaluated mitigation strategies are covered in Chapter 8.

Different mitigation strategies may be required for drivers exhibiting PDU than for drivers exhibiting occasional device use, especially given that some high-frequency and PDU while driving may be related to habits and executed with limited control and conscious awareness. For example, legislative efforts alone may not be enough to reduce device-use while driving among certain audiences (Busch & McCarthy, 2021; Quisenberry, 2015). Fines and public service announcements that entreat drivers to not use devices (e.g., "Put your phone away, and do not let yourself use it until you are out of your car," DMV.ORG, 2018) may also have limited effectiveness, especially given the ubiquity of cellphones as an everyday tool for everything from emergency calls to navigation to playing music.

Psychosocial Interventions

Current evidence suggests that device use dependency and habits may contribute to PDU while driving. These factors do not remove the individual responsibility of the driver or excuse their behavior from a legal perspective (Sadoff et al., 2015), but it suggests that treatments that are effective for other problematic behaviors may be useful mitigation strategies. However, people can disrupt automatic patterns using mindfulness training and behavioral intervention for a number of proposed behavioral addictions (Dakwar, 2015). People receiving treatment for proposed behavioral addictions are generally responsive to 12-step techniques and cognitive behavioral therapy, although this treatment has not been formally evaluated for problematic texting behaviors (Sadoff et al., 2015).

Mindfulness training and other interventions focus on behaviors that are associated with enhancing self-discipline, decreasing anxiety, and increasing altruism in order to reduce habit formation (Briskin et al., 2018). Mindfulness training can take several forms, including mindfulness-based cognitive therapy, mindfulness-based stress reduction classes, and mindfulness meditation. These strategies are often suggested in the literature on PDU while driving. Mindfulness interventions help weaken the relationship between texting while driving and habitual response (Bayer & Campbell, 2012; Terry & Terry, 2015). Mindfulness interventions can address frequent texting while driving while also benefiting the emotional regulation of the individual, helping to reduce other risky and self-destructive behaviors (Feldman et al., 2011). There is also more evidence that this type of training is more effective than trying to modify personality traits (Moore & Brown, 2019; Terry & Terry, 2015).

Risk Perception

A large portion of drivers who frequently use their cellphones or report device dependency believe that device use while driving is a dangerous activity. For example, Chapter 6 describes how 76 percent of all respondents reported that they believe typing or sending a text message or email while driving is extremely dangerous, yet 26 percent of those same respondents reported doing so at least once in the past 30 days (AAA, 2020). Additionally, some smaller survey studies found that most drivers, even the majority of high-frequency texting drivers report that smartphone use while driving is dangerous or compromises safety (Hayashi et al., 2015, 2016; Musicant et al., 2015). These drivers could lack control over their behavior or believe that even though the behavior is risky, they are capable of performing the behavior successfully without incurring negative outcomes. They may also adjust their risk assessment of the driving context to accommodate their desire to perform the distracted driving behavior (see Driving Environment section above).

For some drivers, device dependency, risk acceptance or risky impulsiveness, and drivers' beliefs that they are able to use their devices while driving without compromising safety may lead them to continue to frequently use their devices while driving, despite perceiving this to be a risky behavior for drivers in general. Thus, outreach efforts might target drivers' widespread misperceptions that monitoring/reading smartphone tasks while driving safely is easy to do (Murphy et al., 2020). Rather than present information about the risks of device-distracted driving, presentation media or live demonstrations may need to focus on adjusting drivers' overly optimistic estimations of their own performance (Struckman-Johnson et al., 2015).

Self-Reported Driver Deterrents

It is important to take individual differences into account when forming mitigation strategies since different drivers can have different underlying motivations for performing a behavior. In studies of frequent and dependent device use while driving, some survey data has been collected on behavioral deterrents. Problematic users tend to not be as affected by traditional deterrence (e.g., negative imagery in public service announcements, fines, and police presence) as drivers who used their devices infrequently while driving.

In a study examining drivers' reactions to public service videos on texting while driving, people who frequently texted while driving tended to reject test videos that used imagery that invoked negative emotions and reported that they did not find these ads credible (Burton et al., 2015). In contrast, infrequent texters were more affected by negative imagery and found these ads more credible. Rather, the frequent texters found ads that depicted positive imagery (e.g., the positive consequences of not texting) to be more relatable and more credible. In a survey of Australian drivers, those with strong intentions to use a cellphone while driving reported that not having a hands-free kit would be the sole deterrent to using a cellphone while driving. In contrast, the risk of a crash, fines, heavy traffic, or police presence were deterrents for drivers who weakly intended to use a device while driving (Walsh et al., 2007).

A few other studies on PDU queried their entire sample for deterrents but did not compare preferred deterrents between device use frequency or dependency groups. In Struckman-Johnson and colleagues' U.S. college sample (2015), most females (72.2%) and fewer males (39.6%) reported they would stop texting and driving if shown graphic pictures of texting crashes (e.g., featuring fear appeals). Three interventions that had over 80 percent of respondents agreeing that they would deter them from texting while driving were: lower car insurance (for abstaining), police arrest, and being in a crash. Only 60 percent of respondents reported a police warning would deter them from texting while driving. A smaller group of all respondents, 5.4 percent male, and 2.4 percent female, reported that nothing would make them stop texting while driving (Struckman-Johnson et al., 2015). This is a similar percentage to the PDU "population of concern," (see Chapter 6).

In a survey of Israeli drivers, 31 percent of respondents who made phone calls while driving and 7 percent of respondents who texted while driving reported that nothing would deter them from their behavior (Musicant et al., 2015). For those that could be deterred, traffic conditions were the most commonly reported deterrent for calling (58%) and texting (70%). Police enforcement, however, was not a large deterrent, and only 12 percent of respondents who texted while driving and 4 percent of respondents who made phone calls while driving indicated it as a deterrent. This was surprising since other surveys had found police enforcement would discourage the majority of Israeli drivers from speeding and other traffic violations (Musicant et al., 2015).

Similarly, other studies have found that the threat of police enforcement is not a major deterrent. In a survey of a U.S. university population, respondents who used their devices while driving reported that road conditions (weather, construction) were more likely to influence whether they read or sent text messages than police presence or risk of fines (Gray, 2015). Another study found that drivers' perceived risk of enforcement did not affect their intentions to use cellphones for any purpose while driving (Walsh et al., 2007).

There is minimal information on deterrents that would be more effective for problematic versus occasional device use while driving. The initial surveys indicate that traditional enforcement measures and threat appeals may only be effective for the subset of drivers comprised of occasional device use drivers. Traditional enforcement may also incentivize drivers exhibiting problematic phone use to engage in high-risk behavior in order to evade police detection while using their devices. Gauld and colleagues (2014) studied young Australian drivers and found drivers who had higher Mobile Phone Involvement Questionnaire scores were more likely to conceal texting while driving. Threat appeals can reduce impulsive decision making associated with texting while driving, but fear-arousing threat appeals can sometimes increase risky driving behaviors, so other emotional bases should be used (Hayashi et al., 2019). Positive imagery, more advanced driver assistance programs, and lower car insurance rates (for abstaining), may incentivize more high-frequency device use drivers to abstain from this behavior while driving. There also appears to be a small subset of drivers who believe that nothing would curb their device use while driving behavior.

Summary

This chapter examined driver-specific aspects of PDU and driving. However, the findings make it clear that there is insufficient research to properly examine this relationship directly. Therefore, findings were primarily based on studies from two separate but related domains: those that examined drivers who frequently use devices while driving, and those about drivers who report symptoms indicative of device dependency, but not necessarily problematic use.

The primary organizing framework for this summary was Billieux and colleagues' pathway model (2015), which describes three primary mechanisms for psychological factors to lead to PDU. The studies show that this model has explanatory value, and several of the component factors were found to be associated with both high-frequency device use and use while driving. In particular, the existing research provides clear evidence that device dependency mediates the relationship between neuroticism and increased device use while driving. Drivers' anxiety may also motivate PDU while driving, whereby people with anxious attachment styles may have a more intense urge to respond to their device while driving, and drivers who are anxious about losing access to information may use their devices more frequently while driving.

PDU while driving is also consistently related to more frequent device use in general (often developed outside of the vehicle), higher impulsivity in drivers, and ADHD. Most of the research has looked at habits as an extension of the TPB, and in these models, perceived self-efficacy and moral norms tend to more strongly predict frequent device use while driving. There is also observational and survey evidence that high-frequency device use while driving is performed by drivers with stronger sensation-seeking and extraversion traits because these traits relate directly to device use while driving.

Social factors also seem to play a role in the relationship between high-frequency device use and driving. Social obligations, norms, and how drivers weigh risk under different driving conditions may explain why many drivers may not approve of texting while driving but perform the behavior anyway (see Chapter 6). Furthermore, drivers who exhibit frequent device use while driving are often motivated by participating in work-related communications more than personal communications. For younger drivers, perceptions of increased behavior from peer groups and approval of the behavior from friend groups consistently motivate frequent device use while driving. Younger drivers' frequent device use while driving was related to device dependency when communicating with their peers, but not their parents while driving.

One of the concerns with device use while driving is that some drivers exhibit frequent device use despite reportedly knowing the associated risks or dangers of their behavior. Most of the traffic research reviewed for this chapter focused on the underlying reasons for this incongruency of belief versus behavior, whereas the psychology research focused on PDU while driving as one facet of how PDU could be expressed by their study population. More recent research is starting to tie these perspectives together, but key findings from this chapter are based on a fractured picture where device use frequency, behavioral automaticity, and compulsion are proxies for PDU.

The research literature also provided some information about amelioration strategies based on psychosocial interventions, and drivers' opinions about possible deterrents. These strategies have not been investigated in any systematic way, but they provide initial information about directions to take with future countermeasures that are based on empirical data.

Several of the same factors that appear to lead to PDU also seem to be associated with increased device use while driving. This conclusion is based on indirect evidence extrapolated to traffic safety. Aside from this suggestive link, it is clear from the studies reviewed in the current chapter that it is not possible to claim with certainty that PDU contributes to traffic safety problems. However, at this time, the repeated observations of increased device use while driving suggests that PDU may at least indirectly contribute to the distracted driving problem to an extent.

8. Emerging Countermeasures

Introduction

Problematic device use has not been extensively researched in the current literature, particularly as it relates to driving. Although all cellphone use while driving presents a safety risk, problematic use elevates the potential for unsafe outcomes by potentially increasing the duration and frequency of cellphone interactions and increasing the likelihood that these interactions will occur at inopportune times. Research aimed at reducing device use of any kind behind the wheel is relatively new, and studies focusing on mitigating PDU specifically are rare. Therefore, this chapter focuses on methods for reducing PDU behind the wheel by extending insights from two areas: (1) research into reducing distracted driving in general, and (2) research into limiting people's problematic device usage in daily life (e.g., at home, school, or work). Reducing PDU while driving sits at the intersection of these two knowledge domains and requires novel perspectives.

The countermeasures in this chapter can be grouped into technological approaches and societal approaches. Thoughtfully integrating technological and social elements may lead to more impactful interventions. From research concerning PDU in non-driving contexts, there are three main strategies to reduce this behavior (Busch & McCarthy, 2021).

- *Information-enhancing:* This strategy involves providing people with information about their usage time and the consequences of their behavior, in terms of both their safety risk and their well-being. This information can be quantitative (e.g., number of hours spent on one's phone per day) or qualitative (e.g., evidence that excessive phone use is harming one's sleep quality). Information-enhancing countermeasures are unlikely to deter PDU on their own since drivers are generally aware of the risks associated with driving while distracted by a device. However, these countermeasures may be paired with behavior-reinforcing and capacity-building countermeasures.
- *Behavior-reinforcing*: This strategy involves imposing restrictions on use, such as an automatic phone lockout after a given amount of usage time per day or a ban on cellphone use in the bedroom during normal sleeping hours. Such restrictions have mostly been studied in non-driving contexts but could be applied in the vehicle, e.g., by apps that lock phone functionalities when they detect that the vehicle is in motion. Behavior restrictions reinforce people's goals to limit their device use.
- *Capacity-building*: Encouraging people to pursue activities that allow them to overcome the underlying issues that led to their PDU, while also gaining self-regulation skills and engaging in a pastime that does not involve cellphone use. Capacity-building activities include psychotherapy, yoga, meditation, participating in sports, playing music, or making art.

Each of the technological or social countermeasures for PDU behind the wheel discussed in this chapter attempts at least one of the above three strategies. Research into the efficacy of each countermeasure and—for technological countermeasures—research into the user acceptance of each countermeasure, is presented here. Drivers' acceptance of technological countermeasures is particularly important because the reach and implementation of these countermeasures depends on drivers buying vehicles and mobile devices that support these features, and on drivers choosing to activate them. Trends in the literature are presented where possible, although these are limited by the variations in experimental designs and study measures. More research is needed to comprehensively evaluate and refine technological and social changes that could lead to reducing PDU while driving.

Technological Approaches

Technological countermeasures for cellphone use while driving primarily fall into three categories, blocking, filtering, and monitoring/feedback. Blocking technologies employ a behavior-reinforcing strategy since they disable most device functionalities. Filtering technologies also apply behavior-reinforcing principles, though filtering is less restrictive than blocking and is more focused on using devices more safely while driving rather than reducing their use. Monitoring technologies mainly use information-enhancing through feedback to drivers and, in some cases, their contacts, to motivate behavior change. Collision avoidance, lane keeping, and other similar driver assistance technologies will not be discussed in this chapter because they do not attempt to reduce device use while driving (Kidd et al., 2017).

The following section presents evidence regarding the effectiveness and user acceptance of blocking, filtering, and monitoring and feedback technologies. This evidence primarily comes from studies on reducing device use while driving in general, and the findings are also interpreted here as they could apply to PDU. Technologies based on blocking, filtering, and monitoring and feedback have each been found effective at deterring device use while driving in various circumstances. None of these types of technology is far superior to the others in terms of efficacy. Drivers' acceptance of these technological countermeasures largely depends on an intervention's perceived usefulness and the degree to which drivers perceive it as limiting of essential cellphone functionalities.

Blocking

Cellphone apps that block incoming communications (also known as "phone blockers"), silence or delay notifications from incoming communications such as calls or text messages while the user is driving (Albert et al., 2016). About one-third of phone blockers have an option to automatically send a message to anyone who tries to call or text a driver letting the contact know that the phone's user is driving and will respond later (Oviedo-Trespalacios, King, et al., 2019). Even though cellphone blockers come pre-installed on most modern smartphones, only about one-fifth of drivers over 18 were observed to use them on a majority of their trips (Reagan & Cicchino, 2018). This section discusses the effectiveness and user acceptance of blocking technologies, which are the most widely studied technological approach for reducing device use while driving. For people with problematic cellphone use habits, cellphone blocking technologies could be considered a behavior-reinforcing strategy, although these people may be more likely to bypass or deactivate the feature.

Blocking Technologies: Effectiveness

Phone blocking technologies are consistently found to be effective at reducing cellphone use while driving (Arnold et al., 2019; Oviedo-Trespalacios, King, et al., 2019). For example, survey respondents who report using Apple's Do Not Disturb blocker app were 78 percent less likely to report sending text messages or emails "a few times a week" while driving than those who did not use phone blockers (Reagan & Cicchino, 2018). An experimental study found that new drivers assigned to use cellphone blocking apps reported constant or decreasing rates of cellphone use while driving (number of texts and calls per mile), while the control group's device use increased over a 1-year period (Creaser et al., 2015). A caveat to these results is that approximately 15 percent of the teen participants in each treatment group reported using workarounds such as system bypass strategies or borrowing their friend's cellphone while driving. Cellphone blockers might have greater potential to reduce device use while driving among those who download these applications voluntarily.

While cellphone blocking apps are generally effective at reducing device use while the driver's vehicle is in motion, they can increase use while the vehicle is not in motion. Such behavior is common, as it is estimated that approximately 9.7 percent of drivers are using their cellphones at stoplights at a typical daylight moment in the United States (NCSA, 2019b). Phone blockers were associated with a 10 percent increase in numbers of phone touches while drivers' vehicles were stationary or travelling below 5 mph in a naturalistic driving study, even though phone touches while vehicles were in motion decreased by 25 percent (Albert et al., 2019). Reducing the number of times that drivers touch their cellphones while a vehicle is in motion may not reduce distracted driving. In fact, some drivers may not consider device use while stopped to be "distracted driving" at all, leading to the underreporting of in-car cellphone use in surveys (Gliklich et al., 2016; Schroeder et al., 2013). Moreover, in certain jurisdictions, using electronic devices while one's vehicle is stopped is not prohibited (Bloch, 2020). Contrary to some drivers' beliefs, using cellphones at lower speeds or while stopped does not necessarily increase safety (Caird et al., 2018). More frequent instances of drivers using their devices while the vehicle is stationary or travelling slowly could be an unintended negative consequence of cellphone blocking applications.

Blocking Technologies: User Acceptance

Drivers' acceptance of cellphone blockers is influenced by the degree to which drivers view the technology as restrictive of essential phone functionalities (Oviedo-Trespalacios, King, et al., 2019; Reagan & Chiccino, 2018; Richard et al., 2018). The features that drivers rated as most important to their acceptance of phone blocking apps included the following (Delgado et al., 2018; Oviedo-Trespalacios, Nandavar, & Haworth, 2019).

- Emergency calling (911) is allowed.
- Hands-free calling is allowed.
- Incoming text messages are silenced.
- Phone sends an automatic reply to incoming texts.

The functionalities that are considered essential vary by person, but frequently prioritized functionalities include navigation and music apps (George et al., 2018; Schroeder et al., 2013). Drivers in some studies have demonstrated poor awareness of which phone functionalities impose the largest distractions (Hoekstra-Atwood, 2015; Chen et al., 2018; Marulanda et al., 2015) and many drivers, especially adolescents, have strong impulses to use communications technologies (Kaviani et al., 2020; Reagan & Cicchino, 2018). For example, in one on-road study, 15 percent of adolescent drivers found ways to bypass their cellphone blocking applications while driving (Creaser et al., 2015).

Age appears to mediate the relationship between self-reported cellphone use and user acceptance of blocking technologies. Among drivers 16 and 17, frequent self-reported texting while driving was associated with reduced willingness to give up using most phone functionalities (such as sending emails or reading social media) while driving (Delgado et al., 2018). In contrast, among adult drivers with a median age of 47.2, self-reported calling and texting while driving were significant positive predictors of willingness to install phone blocking apps (Oviedo-Trespalacios, Nandavar, & Haworth, 2019). Younger drivers tend to see their own distracted driving behavior as less of a problem than adult drivers (Berenbaum et al., 2019; Day et al., 2018). This could be because young drivers frequently express high levels of confidence about their own driving skills and have grown up with ubiquitous smartphones (Coogan et al., 2014; White et al., 2010). People who are not aware of, or concerned about, their own distracted driving may have little impetus to voluntarily use cellphone blocking applications.

Blocking Technologies: Problematic Cellphone Use

Cellphone blocking technologies have the potential to change drivers' problematic cellphone use patterns. In non-driving contexts, restricting cellphone use acts as a behavior-reinforcing strategy to curb problematic use habits (Busch & McCarthy, 2021). For example, restricting adolescents' cellphone use in their bedrooms was associated with significant increases in scores of subjective happiness and decreases in scores of smartphone "addiction" (Hughes & Burke, 2018). Restricting cellphone use during driving time could encourage people to lessen their cellphone use overall. While separating those people with problematic use habits from their devices is effective at decreasing use, such measures are likely to face problems with acceptance (Albert et al., 2019; Busch & McCarthy, 2021; Delgado et al., 2018). Blocking may cause anxiety, irritation, and otherwise negatively impact people with problematic cellphone use habits since these effects have been observed when cellphones are unavailable in non-driving contexts (Fernandez et al., 2020; Kneidinger-Müller, 2019). However, other people may find that having a specific place (e.g., the car) in which they are denied access to their cellphone is a relief from the pressure to be 'constantly connected,' which is typical of PDU (Harkin et al., 2020).

Filtering

"Filtering" technologies adjust the interaction paradigm of secondary tasks typically conducted using cellphones to be less demanding and more suited to the driving task. Filtering technologies work by reducing the complexity of the user interface and/or by changing the control modality from visual and manual to auditory (Jung et al., 2019). As with blocking technologies, filtering approaches rely on behavior-reinforcing strategies because they limit drivers' opportunities to engage in problematic use behaviors while the vehicle is in operation (Oviedo-Trespalacios, King, et al., 2019).

Filtering while driving primarily occurs in vehicles where the phone is paired (usually via a Bluetooth network) to the vehicle and operates through the vehicle's in-vehicle information system. The increasing integration between IVIS displays and cellphones arose from collaboration and competition between the vehicle and cellphone industries and certain guidelines pertaining to IVIS. Vehicle OEMs offer "head units" for interfaces that are controllable through integration with smartphones, such as Apple CarPlay and Android Auto (Blau, 2015; Strayer et al., 2019). These IVIS-smartphone hybrid displays provide valuable traffic, weather, navigation, vehicle, and car maintenance data, as well as infotainment functionalities (Bosler et al., 2017).

Guidelines from NHTSA and another from the Alliance of Automobile Manufacturers covers how secondary tasks' complexity should be restricted based on driving performance goals. NHTSA's Visual-Manual Guidelines specify that secondary tasks involving IVIS should be designed so that drivers can complete them while driving with only glances away from the roadway of 2 seconds or less in duration and with a cumulative glance time away from the roadway of less than 12 seconds (NHTSA, 2014). The visual-manual guidelines are more restrictive and more recent than the Alliance of Automobile Manufacturers' guidelines, so many current-model vehicles primarily conform to the AAM guidelines (NHTSA, 2020). Similar guidelines have not yet been established for mobile devices that are not integrated with IVIS.

Filtering Technologies: Effectiveness

Filtering technologies reduce drivers' use of cellphones, shifting their secondary tasks to voice-controlled and/or touch-screen user interfaces that are adapted for the driving context. Data on IVIS filtering interfaces' effectiveness at reducing cellphone use appears to be mostly collected by private entities, such as vehicle OEMs, Google, and Apple (Ramnath et al., 2020). One Consumer Reports study found that 28 OEM IVIS systems in different car models received "hands-off-phone" ratings of 50 to 68 percent, indicating that participants reported using the car's system rather than their phone for calling, navigation, and texting 50 to 68 percent of the time, depending on the system (Barry, 2019). This survey of more than 60,000 drivers suggests that drivers with IVIS systems equipped in their vehicles use IVIS rather than their phones often for common secondary tasks. Typical tasks that drivers with IVIS-equipped vehicles report using IVIS systems for, instead of their cellphones, are navigation (75% of drivers) and music (25% of drivers; Oviedo-Trespalacios, Nandavar, & Haworth, 2019). Drivers' frequent use of IVIS is encouraging, as it suggests further opportunities for development and adoption of technologies that adapt secondary tasks to the driving context.

In the process of reducing drivers' use of cellphones, filtering technologies can create their own distractions. Some research suggests that IVIS filtering technologies may be more distracting than cellphones (Lansdown, 2012; Neyens & Boyle, 2007; Ziakopoulos et al., 2019). For example, the total eyes-off-road-time for each task on an IVIS navigation system ranged from 12.12 to 33.87 seconds, while cellphone tasks resulted in 5.23 to 9.68 seconds total-eyes-off-road-time per task in simulated driving (Purucker et al., 2017). Most contemporary IVIS technologies, including Android Auto, Apple CarPlay, and embedded OEM systems, are associated with significant impairments in driving performance (Kidd et al., 2017; Mehler et al., 2016; Ramnath et al., 2020; Strayer et al., 2019). However, it's unclear if these numbers may be reduced by including IVIS technologies in the heads-up display. Additionally, improvements in on-road glance durations were observed using a Google Glass voice control system, possibly suggesting a future direction for filtering technologies (He et al., 2018; Tippey et al., 2017). Filtering technologies employing voice control of secondary tasks appear to be unlikely to induce distraction. An extensive array of studies found that voice control functionalities in isolation, rather than filtering technologies overall, improve many measures of driving performance (see Simmons et al., 2017 for a meta-analysis).

Filtering Technologies: User Acceptance

Driver acceptance of filtering technologies can largely depend on these technologies' usability. Usability issues—system errors and delays—had moderate negative correlations with user acceptance in two IVIS systems: the Chevrolet MyLink and Volvo Sensus (Mehler et al., 2016).

Menu complexity had an even stronger association with acceptance of IVIS technology (r = -.77) than loading delays in another study (Biondi et al., 2019). Focus group commentary attests that some drivers will turn off the IVIS and complete secondary tasks on their cellphones if they become frustrated with a complex or malfunctioning IVIS (Oviedo-Trespalacios, Williamson, & King, 2019).

The extent to which filtering technologies accommodate drivers' desired level of control is the other major factor in determining user acceptance of these technologies. Drivers are much more likely to accept a filtering technology if it does not impose harsh restrictions on their preferred secondary tasks or their driving in general (Delgado et al., 2018). For example, voice control systems (for texting and general IVIS commands) were rated significantly more positively than technologies that prevent text messages from being sent or calls from being made (Albert et al., 2016). In some cases, a high degree of filtering secondary tasks could cause frustration if drivers feel their autonomy or competence are being challenged, similar to beliefs that are prevalent among drivers who do not use seatbelts (Oviedo-Trespalacios, Williamson, & King, 2019; Schneider et al., 2017). In addition, user acceptance tends to be higher for IVIS systems that offer personalization options, either in terms of changing the style of the user interface or allowing selected secondary tasks while restricting others (Antrobus et al., 2015; Mollenhauer et al., 2016; Weber et al., 2020). Since drivers demonstrate an imperfect knowledge of which secondary tasks are most distracting (e.g., Delgado et al., 2018; Schroeder et al., 2013), designers of filtering technologies should limit the choices of allowable secondary tasks in ways that are responsive to scientific assessments of the relative riskiness of different phone operations within the driving context.

Filtering Technologies: Problematic Cellphone Use

Filtering technologies, especially adaptive systems that accommodate drivers' behavior patterns, could be highly relevant for drivers with PDU patterns. Such restricted cellphone use could act as a behavior-reinforcing strategy for these people in a similar manner to cellphone restrictions that have been studied in non-driving contexts (Busch & McCarthy, 2021; Wilcockson et al., 2019). Partial restriction of use while driving, e.g., allowing hands-free calling but blocking texting, may be more tolerable for people with PDU patterns than total phone lockouts, since these people tend to report high levels of anxiety and irritability when unable to use their phones at all (Fernandez et al., 2020; Kaviani et al., 2020; Wilcockson et al., 2019).

Monitoring and Feedback

Technologies that monitor drivers' cellphone use in the car and technologies that provide feedback informing drivers of their risky behaviors use complementary strategies to motivate drivers to reduce their device use. Monitoring technologies like driver monitoring systems (DMSs) use cameras or other sensors to record drivers' phone use in the car and/or their performance decrements due to distraction (Albert et al., 2016; Oviedo-Trespalacios, King, et al., 2019). This data can then be sent to people or organizations with an interest in tracking a driver's behavior, such as their parents, work supervisor (in the case of professional drivers), or their insurance company (Albert et al., 2016; Kinnear & Stevens, 2015; Ponte et al., 2016). Some technologies display monitored data as feedback, presenting information to the driver (Donmez et al., 2007). This feedback can be delivered in real-time or viewable post-drive. Feedback can be delivered via a smartphone, IVIS display, or specialized device.

Monitoring and feedback technologies are closely related to each other, as feedback requires monitoring driver behavior, and monitoring technologies typically incorporate feedback. Unlike blocking and filtering technologies, monitoring and feedback technologies do not necessarily restrict cellphone use while driving. Instead of a behavior-reinforcing strategy for reducing PDU, monitoring and feedback technologies use information-enhancing and, sometimes, capacity-building strategies.

Monitoring and Feedback Technologies: Effectiveness

Many feedback technologies focus on delivering feedback to the driver in real-time, informing them that they appear to be distracted or that their driving performance has declined. Real-time feedback is generally less detailed than post-drive feedback, taking the form of brief visual or auditory alerts rather than charts or commentary in order to minimize distractions (Donmez et al., 2008; Creaser et al., 2015; Simons-Morton et al., 2013). Real-time feedback technologies have been associated with reduced cellphone use, and commensurate with overall improvements in driving performance (Peer et al., 2020; Voinea et al., 2020). Real-time feedback warnings against distraction provided by an IVIS display were associated with fewer, shorter off-road glances in a simulator study (Donmez et al., 2007). Furthermore, drivers looked at the display less frequently, suggesting that real-time driving performance feedback did not cause distraction.

Post-drive feedback's effectiveness is contingent upon drivers carefully processing the displayed information about their performance (Donmez et al., 2007). As a result, strategies have been tested to increase the quality of drivers' engagement with post-drive feedback. One post-drive feedback presentation strategy associated with subsequent improvements in driving performance is gamification, i.e., using game design elements to display performance information and motivate improvement (Dijksterhuis et al., 2016; He et al., 2018; Xie et al., 2016). Particularly for young drivers, who tend to seek conformity with their social group, presenting post-drive feedback about their distraction engagement along with normative information about their peers' distraction levels while driving shows promise for reducing cellphone use (Merrikhpour & Donmez, 2017). When driving after viewing social norms-based feedback on previous drives, young drivers had fewer interactions with the vehicle's display in later drives and longer glances to the forward roadway (Donmez et al., 2019). A combination of real-time and post-drive feedback appears to be most effective for increasing duration of glances to the forward roadway while driving, suggesting strong learning effects (Donmez et al., 2008; Merrikhpour & Donmez, 2017). Overall, the longitudinal effects of feedback regarding distracted driving on drivers' behavior are unknown (Klauer et al., 2016).

Monitoring technologies that send data to a parent or professional supervisor can also be effective, especially when this authority figure provides feedback. For young drivers, using phone apps that send phone use and driving performance data to their parents was associated with significant reductions in numbers of calls and text messages initiated per hour (Creaser et al., 2015; Farah et al., 2014). Parental access to teens' driving data was associated with significant declines in teens' numbers of safety-critical driving events in other studies, while real-time feedback had no significant effects (Simons-Morton et al., 2013; Klauer et al., 2016). Monitoring drivers' performance and sending the data to third parties is also effective for reducing phone use among professional drivers (Ponte et al., 2016). Receiving performance feedback from supervisors was associated with significant declines in cellphone use while driving, over and above real-time feedback from a flashing light (Bell et al., 2017).

Emerging research suggests that monitoring technologies can be effective at reducing device use while driving by involving drivers' insurance policies (Oviedo-Trespalacios, King, et al., 2019). Insurance policies issuing frequent financial rewards and penalties based on driving behavior is a form of driving feedback that might be useful in combination with or in isolation from typical real-time or post-drive feedback displays. Drivers 16 and 17 reported that insurance policies with continuous rewards or deductions based on behavior would be highly effective at reducing their cellphone use while driving (Delgado et al., 2018). Specifically, 63 percent of drivers were in favor of policies that penalized them for device use while driving, and 75 percent of drivers were in favor of policies that rewarded them for refraining from device use while driving. Experiments have found improvements in driving performance when financial incentives are present, primarily reductions in headway distance variability and increased time spent glancing at the forward roadway (Dijksterhuis et al., 2016; Peer et al., 2020). Academic research about insurance policies that reward or penalize device use while driving is scarce (Tselentis et al., 2017).

There is preliminary evidence that a type of monitoring technology external to the vehicle can reduce cellphone use while driving—cellphone enforcement cameras. From late 2019 through March 2020, cameras to detect cellphone use were installed in New South Wales, Australia (Centre for Road Safety, 2020). The cameras use artificial intelligence to evaluate images for evidence of cellphone use, after which the images are manually reviewed before tickets are issued. During the six-month pilot period, over 104,000 traffic citations were issued for cellphone use—over twice the usual 40,000 citations for cellphone use issued per year in New South Wales (Faulks, 2019). This is the first cellphone camera enforcement program in the world. Other programs are now being piloted, such as one in Saudi Arabia that observed a 32 percent reduction in cellphone use while driving after the installation of cameras (Alghnam et al., 2019). Another option for external monitoring of drivers' phone use is using technology to detect whether their phones are in operation by using radio frequencies—this technology was developed around 2012, but no studies of its implementation exist (Heineman, 2012; Oviedo-Trespalacios et al., 2018). Cellphone automated enforcement programs suggest that pairing monitoring technology with monetary penalties or legal consequences, as well as pairing monitoring technology with feedback, may be effective countermeasures for cellphone use while driving.

Monitoring and Feedback Technologies: User Acceptance

Monitoring and feedback technologies do not inherently restrict the functionality of cellphones. Therefore, their acceptance does not necessarily relate to the availability of certain cellphone features (Oviedo-Trespalacios, King, et al., 2019). Instead, perceived usefulness and perceived ease of use are among the most salient variables influencing user acceptance of monitoring and feedback designed to mitigate cellphone use while driving (Rahman et al., 2018; Roberts et al., 2012; Voinea et al., 2020). In general, such technologies tend to receive high ratings of perceived usefulness and perceived ease of use—especially post-drive feedback (Arnold et al., 2019; He et al., 2018). The more positive ratings for post-drive feedback could be due to the fact that real-time feedback typically is presented as brief flashing lights or auditory alerts in order to minimize distraction, while post-drive feedback can accommodate more detailed information (Donmez et al., 2008). Alongside the timing of feedback, the content and tone of feedback may have some impact on drivers' perceptions of the feedback's usefulness. The quality and delivery of feedback is difficult to quantitatively evaluate, as was noted by authors of studies wherein parents or work supervisors gave feedback to drivers (Bell et al., 2017; Farah et al., 2014).

Monitoring and filtering technologies, particularly those that involve sending data to a third-party, have associated privacy concerns that can impact their acceptance (Oviedo-Trespalacios, King, et al., 2019). For example, the distracted driving enforcement cameras recently implemented in New South Wales have prompted public discussion about whether people have the right to drive without government surveillance in their own vehicles (Faulks et al., 2019). Parental monitoring is also a concern; young drivers have expressed reluctance to use technology that would give their parents access to a record of their driving behavior (Delgado et al., 2018). Some young drivers report that monitoring and filtering technologies feel like constant supervision, and that they could erode trust within parent-child relationships (Guttman & Gesser-Edelsburg, 2011). When hypothetical technologies do not create privacy concerns by sending data to any of the drivers' contacts or authority figures, studies have found high acceptance ratings for monitoring and feedback technologies (Donmez et al., 2019; Ramnath et al., 2020; Roberts et al., 2012). It is possible that perceived usefulness, and other features of some of these technologies, such as financial incentives, could supersede perceived threats to privacy, increasing user acceptance.

Societal Approaches

Societal approaches to reducing PDU include individual outreach (e.g., education), large-scale outreach (e.g., media campaigns), and legislation. The former two types of countermeasures tend to use information-enhancing and, to a lesser degree, capacity-building strategies to address device use. Penalties for violations could indirectly act as behavior-reinforcing mechanisms, though current legislation only addresses general, not problematic, device use while driving.

The following three sections characterize each type of societal approach while providing evidence of its impact wherever possible. Note that user acceptance of countermeasures is not discussed in this section because the buy-in of programs aimed to change people's perceptions and intentions around device use is an integral part of such programs' effectiveness.

Individual Outreach (Education)

In the United States, standard driver education programs include specific content on distracted driving. Distracted driving curriculum standards are present in the 2017 American Driver and Traffic Safety Education Association Novice Driver Education Curriculum Standards, the 2017 Novice Teen Driver Education and Training Administrative Standards, and the 2017 Driving School Association of the Americas Curriculum Content Standards (American Driver and Traffic Safety Education Association, 2017; Driving School Association of the Americas, 2017; National Driver Education Standards, 2017). The levels of detail and quality in distracted driving curriculum vary across States, and no systematic evaluation has been conducted (Richard et al., 2018). As with driver education curricula, State and national graduated driver licensing phone restriction requirements have unknown effects on general distracted driving and on electronic device use while driving (Foss et al., 2009; Goodwin et al., 2012; Richard et al., 2018; Truelove et al., 2019).

Educational programs tend to focus on cellphone distractions while driving, not PDU. The overall effect of public outreach on device use while driving is currently unknown, and the effectiveness of education program materials oriented toward changing the social norms (i.e., expectations of efficiency and constant connectivity) have not been reviewed. Most research on distracted driving educational programs concerns how education programs convey the safety risks of device use while driving. Additionally, some educational materials related to distracted driving are focused on increasing hazard perception and response, not on limiting device use, which can improve safety outcomes but makes little effort to change social norms or driver attitudes (Classen et al., 2019).

While it has not been extensively researched, distracted driving education that targets society-wide factors encouraging this behavior could be uniquely positioned to reduce PDU behind the wheel. For example, educational efforts encouraging people to accept longer wait times for replies to mobile communications could reduce drivers' perceived urgency of using smartphones while driving, thereby reducing this behavior (Fischer, 2015; Kinnear & Stevens, 2015). Similarly, persistent mobile communication from close social connections with expectations of instant replies pose a tangible risk to drivers, as evidenced by drivers being substantially more willing to reply to a text from close social contacts while driving (Foreman et al., 2019). Education could target drivers' frequency of checking on text messages from parents and romantic partners, which are two specific behaviors that are major contributors to distracted driving (Delgado et al., 2018; LaVoie et al., 2016). In addition, education stressing that distraction on the roadways is unacceptable can start at a young age, as reviews have found that educational programs for children targeting cellphone use while walking have resulted in changes in behavior and intentions (Classen, 2019; Kinnear & Stevens, 2015).

Large-Scale Outreach (Media Campaigns)

Public outreach campaigns are a standard countermeasure for distracted driving, with most messages centered around either cellphone use or inattentive driving generally (Richard et al., 2018; Arnold et al., 2019). Such messages could be adapted for PDU, but currently no known campaigns relate distracted driving to PDU. Campaigns focused on distracted driving vary widely in terms of their format and type of sponsor. Awareness campaigns about cellphone use while driving can range from a single-day event to a months-long marketing effort, and typically include some combination of features such as posters, spokespeople, video presentations, and opportunities to sign pledges not to drive distracted (Arnold et al., 2019).

Anti-distracted driving campaigns can take the form of public service announcements, of which over 1,000 were available on YouTube in 2014 (Steadman et al., 2014). State Highway Safety Offices are either fully or partly funding 69 percent of distracted driving campaigns (Fischer, 2015). Along with SHSOs, the main other entities that create distracted driving public outreach campaigns are the U.S. Department of Transportation (including NHTSA), corporations (primarily car manufacturers, telecommunications companies, and insurance companies), nonprofits, celebrities, and healthcare organizations (Fischer, 2015). Some campaigns are created by young drivers themselves, who are typically the target audience of such programs (Arnold et al., 2019).

Concrete data about the effectiveness of youth-led distracted anti-driving campaigns is scarce. Below, Table 8 describes some recent campaigns targeting cellphone use while driving, categorized according to the type of organization that created the campaign. These types of organizations frequently partner with each other to deliver a single program, sometimes making characterization of which type of organization created a program difficult (Steadman et al., 2014). Overall, the three most prominent anti-distracted driving campaigns are likely *U Text. U Drive. U Pay* (and previous versions thereof) by NHTSA, *It Can Wait* by AT&T, and *EndDD* by the Casey Feldman Foundation. Many distracted driving programs started around 2010, which was roughly contemporaneous with the extensive market penetration of smartphones (see Chapter 3).

Table 8. Prominent recent distracted driving campaigns by type of organization[6]

Org.Type	Campaign Name	Characteristics	Years	URL
State Highway Safety Offices and State DOTs	*Put It Down* (Florida Department of Transportation)	Has reached over 40 million people through a variety of traditional print marketing materials and digital advertising	2011 - ongoing	https://www.fdot.gov/Safety/programs/distracted-driving.shtm#pid
	Washington's State High School Distracted Driving Grant Project (WashDOT and State Farm)	Incentivized teens to produce materials against distracted driving by awarding money for their school groups	2011 - 2015	https://wtsc.wa.gov/wp-content/uploads/dlm_uploads/2014/09/500_Distracted_Driving_HS_Grant_2013.pdf
Federal Agencies	*U Drive. U Text. U Pay*. (NHTSA)	Focuses on increasing enforcement and reducing distraction through PSAs, information, etc.	2014 - ongoing	www.nhtsa.gov/campaign/distracted-driving
	Faces of Distracted Driving (U.S.DOT)	Shares stories of families who are victims of crashes involving distraction through a video series	2010 - ongoing	www.youtube.com/watch?v=3MKVtsLkGOc
	Stop the Texts, Stop the Wrecks (NHTSA and Ad Council)	Includes teen-submitted and professional media and PSAs.	2012 - ongoing	https://stoptextsstopwrecks.org/
Corporations	*Texting While Driving: It Can Wait* (AT&T)	Has funded spin-off, State-specific programs, and produced extensive media	2010 - ongoing	www.itcanwait.com/
	ThinkFast Interactive (Fee-based educational program)	Uses a game show presentation format to teach teens about key traffic safety and life skills topics	1997 - ongoing	https://thinkfastinteractive.com/
Nonprofits	*On the Road, Off the Phone* (National Safety Council)	Warned against distracted driving through a series of video PSAs, including PSAs made by teens	2010 - 2011	https://youtu.be/Uq58r3LFy4g
	"What do you Consider Lethal?" (Impact Teen Drivers)	Consists of media such as posters, and presentations highlighting dangers of distracted driving	2007 - ongoing	www.whatdoyouconsiderlethal.com/
	EndDD (The Casey Feldman Foundation, based in Pennsylvania)	Operates in 36 States with interactive presentations, often given by trial lawyers and containing components for parents and teens.	2009 - ongoing	www.enddd.org/
Celebrities	*No Phone Zone* (Oprah Winfrey in partnership with FocusDriven)	Supported by over 60 celebrities, including Oprah, Sandra Bullock, and Sir Elton John	2010	http://www.oprah.com/pressroom/oprah-winfreys-national-no-phone-zone-day_1
Healthcare	*Decide to Drive* (American Academy of Orthopedic Surgeons, in partnership with AAM)	Offers contests for teens to submit media discouraging distracted driving	2013 - ongoing	www.decidetodrive.org/about/
	Ride Like a Friend, Drive Like You Care (Children's Hospital of Philadelphia)	Used a peer-to-peer methodology and events were conducted at hospitals	2013 – 2014	www.teendriversource.org

[6] The main sources used for this table were *Countermeasures That Work* (Richard et al., 2018) and the Governor's Highway Safety Association Report *Distracted and Dangerous* (Fischer, 2015).

Large-Scale Outreach: Evidence Regarding Impact

The goal of public outreach campaigns is to reduce involvement in risky behaviors among heavy engagers and to deter light engagers from heavy engagement (Burton et al., 2015). Changing social norms is the mechanism by which public outreach campaigns, including those for distracted driving, work toward this goal. Norms are difficult to change, and neither information about risk alone, nor information about laws alone, are sufficient to change societal perceptions of risky driving behaviors (Atchley et al., 2012). Evaluations of large-scale public anti-distracted driving campaigns in terms of their effect on behavior or norms are rare; program assessments primarily focus on participant feedback, such as whether they subjectively enjoyed the program or felt it made an impact on them (Arnold et al., 2019; Fischer, 2015). Despite the relative lack of data on the effects of large-scale outreach campaigns, message framing and interactive components can increase campaigns' impact, particularly among drivers with problematic cellphone use habits.

Message framing, i.e., the tone or emotion that messages elicit, is important for campaigns against distracted driving. Traditionally, media messaging against distracted driving has had a negative framing, showing material meant to deter drivers from this behavior through appeals to fear. In 2014, 34 percent of anti-distracted driving PSAs on YouTube contained imagery of car crashes (Steadman et al., 2014). This type of content was much more common than positive material highlighting drivers taking responsibility for their own safety and that of others. A recent study demonstrated that among teenagers, positively framed messages received higher ratings of persuasiveness, believability, and relevance (Gauld et al., 2019). Teens were more likely to report intentions to reduce smartphone use while driving after viewing positively framed ads. Negatively framed and positively framed campaigns each have utility. A negatively framed ad was associated with greater reductions in intentions to text and drive among those who infrequently did so, but a positively framed ad had stronger deterrent effects for those who sent over 160 texts per month while driving (Burton et al., 2015). Positively framed messages may be especially suited to targeting distracted driving among those with problematic cellphone use habits because such campaigns can express relatable situations without a judgmental tone.

Interventions with an interactive component can have more impact on intentions to use devices while driving than marketing materials alone. Most long-lasting campaigns have some way for their audiences to engage actively with the content, such as by signing a pledge to change their behavior, verbally answering questions during presentations, or producing their own materials against distracted driving (Classen et al., 2019; Fischer, 2015). It is possible that interactive campaigns could particularly resonate with people who have PDU patterns by encouraging them to set goals for reducing their behavior and take accountability for their own actions. Such measures could be capacity-building strategies, which ultimately lead to increased self-confidence (Busch & McCarthy, 2021).

Legislation

Legislation is another societal approach to distracted driving. In 2001, the first ban on handheld cellphone use while driving was enacted in New York (Bloch, 2020). Laws against using mobile devices behind the wheel are associated with reductions in the prevalence of distracted driving (Flaherty et al., 2020; Qiao & Bell, 2015). However, changes in social norms are also needed to achieve lasting reductions in unsafe behaviors (Truelove et al., 2017). When properly enforced, laws can shift social norms—this shift has occurred for drunk driving, but norms surrounding device use while driving are still evolving (Atchley et al., 2012). For traffic laws to influence drivers' behavior in the long term, enforcement is critical (Abouk & Adams, 2013; Arnold et al., 2019; Kinnear & Stevens, 2015). Special considerations must also be made for drivers with problematic patterns of cellphone use, since legislation may inadvertently motivate these drivers to use devices in riskier ways than the typical distracted driver, such as by concealing their device from police officers' view (Gauld et al., 2014).

Distracted driving laws are challenging to enforce because the enforcement procedures can vary widely within the same jurisdiction depending on a driver's age and the type of secondary task they appear to be performing—aspects that can be difficult for law enforcement officers to verify (Otto et al., 2019; Rudisill et al., 2019). For example, in some jurisdictions, some ages of drivers and some types of secondary tasks receive primary enforcement (police officers can stop drivers if a violation is observed without first identifying another violation, such as speeding), while others receive secondary enforcement (police officers can only stop drivers if another violation is identified first). As of 2020 four States had laws mandating secondary enforcement for novice drivers under 18 years old using cellphones, but primary enforcement for adult drivers observed text messaging, creating potential difficulties for consistent enforcement (GHSA, 2020). In addition, some State laws only specify that it is unlawful for a driver to use an electronic communication device "while the motor vehicle is in motion"—further complicating enforcement in common situations such as drivers engaging in cellphones at stop lights (Bloch, 2020).

The most effective types of legislation aimed at reducing crashes due to cellphone use while driving appear to be primary enforcement laws and laws targeting specific tasks rather than distraction or cellphone use in general (Fisher et al., 2017; Flaherty et al., 2020). In a sample of 13,408 adolescent drivers from across the United States, the passage of primary enforcement laws against texting was associated with a 30 percent decline in self-reported texting while driving (Qiao & Bell, 2015). Consistently enforced and specific legislation has a strong potential to deter people from device use while driving.

One effective method of enforcement for device use while driving is HVE. HVE campaigns involve elevated focus on a particular traffic safety issue by both a police department and media. Only a handful of studies have evaluated HVE, though it is generally found to be effective at increasing both the number of tickets issued for distracted driving and awareness of the issue (Cosgrove et al., 2011; NHTSA, 2014; Richard et al., 2018). By the end of four waves of enforcement in Hartford, Connecticut, and Syracuse, New York, observed cellphone use while driving was about 1 percent lower than in comparison cities that did not implement HVE (Chaudhary et al., 2014). Changes in awareness of distracted driving enforcement were much more dramatic than behavior changes—awareness of high-visibility distracted driving enforcement in both Hartford and Syracuse grew by about 30 percent. HVE is expensive and can be influenced by a number of extraneous variables, making its implementation and evaluation difficult.

Laws against cellphone use while driving can be associated with psychological difficulties for drivers with problematic cellphone use habits, and inadvertently result in drivers using cellphones in ways meant to avoid enforcement. Complete bans on cellphone use, even for hands-free functions, might be challenging for drivers with PDU habits. Laws that demand total separation from their cellphone may be especially difficult to follow due to the anxiety and irritation caused an unfulfilled compulsion (Rosenberg et al., 2014; Wilcockson et al., 2019).

This is not necessarily a reason to change these laws; rather it is a reason to explore treatments for PDU. Currently, distracted driving laws have the potential to push drivers with problematic use patterns to use cellphones in riskier ways than most drivers would, in order to continue use (Busch & McCarthy, 2021). For example, concealed cellphone use while driving was reported more frequently by young drivers who scored higher on a scale indicating problematic cellphone use ($r = 0.31$; Gauld et al., 2014). Manipulating a cellphone in one's lap rather than near the dashboard or normal hand position for steering could create an even larger crash risk than typical cellphone use because, by doing so, drivers reduce their central and peripheral visual attention to the roadway. As with every approach mentioned in this chapter, when informed by considerations of PDU, legislation has the potential to reduce device use while driving and minimize unintended consequences of countermeasures.

Conclusion

A significant proportion of drivers report that they call and text behind the wheel despite knowing that doing so is risky. Evidently, knowledge about the risk of doing so is insufficient to stop drivers from using mobile devices in their cars. Reducing this behavior, especially among the drivers who feel they have especially low levels of control over it—PDUrs—will require emerging technologies and new perspectives.

Reducing PDU while driving will necessitate applying insights from research in several domains, including general device use while driving, PDU in non-driving contexts, and emerging findings related to PDU while driving. Information-enhancing, behavior-reinforcing, and capacity-building strategies are integrated to varying degrees within most of the countermeasures described in this chapter. However, effectiveness at reducing device use and levels of user acceptance vary across approaches, and little data on technologies to mitigate distracted driving is publicly available. The strategies described in this chapter could be a starting point for developing targeted countermeasures, especially when combined with information detailed in this SOK report describing characteristics of drivers with problematic cellphone use habits.

PDU while driving is a sparsely studied issue, but not an intractable one. As the field evolves, technological approaches must contend with some drivers being particularly attached to using certain cellphone functionalities, such as navigation and music, while driving. Complete cessation of phone use while driving (i.e., blocking) may serve as a strong behavior-reinforcing strategy for some drivers with problematic use habits. Certain drivers may find restrictions on their phone use liberating, while others will feel compelled to use their phones in high-risk alternative ways.

Future research would likely benefit from also exploring information-enhancing and capacity-building strategies, as can be offered by monitoring and feedback technologies. Filtering technologies present possibilities for modifying behavior in between the 'extremes' of blocking or monitoring and could be highly adaptable to drivers' device use habits in future vehicles. Societal approaches previously applied to distracted driving can more fully address PDU by incorporating research concerning the psychological treatment of PDU and evaluating outcomes in terms of observed and self-reported behavior. With the right mix of countermeasures for driver groups and people, there is potential to reduce the outward risky behaviors and give people increased agency over their phone use in their vehicles and throughout daily life.

9. Conclusion

The current report was written to improve understanding of (1) PDU and (2) its relationship to traffic safety through a comprehensive review of the literature. While there are many types of electronic devices that drivers can use in the vehicle, this report focuses on cellphones and smartphones—cellphones that can access the internet and provide much of the same functionality as a computer (Cambridge University Press, 2020). Cellphones are the most extensively studied (and, likely, most extensively used) portable electronic devices in vehicles.

After reviewing literature in the fields of psychology, human factors, traffic safety, and software development, the research team found that electronic device use while driving is not a demonstrated addictive behavior. Electronic device use in daily (i.e., non-driving) contexts does not meet the scientific community's agreed-upon criteria for a behavioral addiction, present in the DSM-5. Similarly, electronic device use while driving does not meet the criteria of a behavioral addiction. To describe compulsive use that is associated with psychological and behavioral dysfunction (Busch & McCarthy, 2021), many researchers use the term "PDU." Problematic device use encompasses the concepts of habitual, compulsive, or excessive maladaptive behavior and appears to be the most accurate characterization of the behavior that is sometimes incorrectly labelled as "addictive device use" or "addictive device use while driving." Problematic device use has a multifaceted relationship to traffic safety despite not being addictive.

Drivers exhibiting PDU interact with electronic devices while driving in ways that elevate their crash risk above that of drivers with normal or occasional device use behavior. All distracted driving can be dangerous because it removes drivers' minds, hands, and, perhaps most importantly, eyes, from the driving task (see Chapter 1). Problematic device use compromises safe driving even more than typical device use behaviors because of the three main ways that PDU interactions differ from typical device use interactions while driving. Relative to drivers with normal device use behaviors, drivers exhibiting PDU may engage in device tasks and interactions that are:

- More frequent,
- Longer in duration, and
- Precipitated by factors external to the driving context (e.g., the driver uses the device because they received an auditory push notification from their device).

Problematic device use drivers also contribute to poor road safety beyond their distracted driving behavior; they are more likely to engage in other risky driving behaviors (Atwood et al., 2018; Oxtoby et al., 2019; Zhao et al., 2013) and report having more near crashes than less device-dependent, more occasional device use drivers (Berenbaum et al., 2019; Terry & Terry, 2015).

One hypothesis is that PDU drivers exhibit some of the same device use behaviors as PDUrs generally, but this has not been evaluated in the driving context. Problem device users within the everyday, non-driving context tend to:

- Check their cellphones more frequently,
- Be more likely to browse social media and interact with other apps that have addictive

design[7] features,
- Respond to incoming communications as much as typical users, but are more likely to initiate them, and
- Be more cognitively absorbed in activities on their devices than typical users.

Although data has been collected on the applications and device functions that are used frequently by the distracted driver population, the applications favored by different types of distracted drivers have not been evaluated. Table 9 illustrates how much researchers do not know about how different types of PDURs are using their devices in and outside of the driving context.

Table 9. Favored apps among device users

	Drivers	**General device users (not in the driving context)**
Device-dependent versus not dependent	Favored apps not identified	Apps with more addictive design features (Montag et al., 2019; Neyman, 2017) Social media apps (Busch et al., 2021; Roberts et al., 2014; Salehan et al., 2013)
High frequency and device-dependent versus high frequency only versus dependent only	Favored apps not identified	Favored apps not identified
High frequency versus low frequency	Favored apps not identified	Social media apps (Elhai et al., 2016)

The types of device applications and functions that are favored by PDU drivers have yet to be studied. It is still unknown if their use patterns differ from occasional device use drivers and PDURs generally.

Forming an understanding of PDU separate from the concept of addictive behavior is valuable for classifying it and developing countermeasures to address this issue. Standard countermeasures for distracted driving may not achieve their intended results among the approximate 2-4 percent of drivers who are PDURs. The extent to which typical and PDURs' responses to countermeasures differ is unclear because PDU and distracted driving have not been reviewed in combination prior to this report. Assuming that PDU is equivalent to typical device use, as well as assuming that this behavior is addictive, are each likely to lead to countermeasures that imperfectly address the safety threat of drivers whose device use places themselves and others at elevated levels of risk.

One example of how people who frequently use devices while driving differ from those who use devices while driving at typical levels comes from a 2015 study by Burton and colleagues wherein participants who self-reported frequent texting while driving had significantly more favorable opinions of a public safety announcement that framed its anti-texting while driving message with positive emotions (appeals to personal responsibility) relative to participants with typical device use habits. Understanding how people who problematically use devices while driving react to countermeasures, allows for the creation of economical, targeted interventions that will be maximally effective.

[7] Discussed later in the *Psychological Mechanisms* section of this chapter, "addictive design" refers to software design principles that use human psychology to create a sense of craving and obligation in users. One example is the "infinite scroll" aspect of Facebook and Instagram, in which users can explore an endless stream of content that is frequently refreshed (Neyman, 2017).

In this report, to compensate for the lack of targeted research on PDU while driving, the authors explored related research on frequent device use while driving and on drivers' self-reported device dependency. Although not all drivers who report device dependency also report frequent device use while driving, (O'Connor et al., 2017; Struckman-Johnson et al., 2015), studies have found a significant relationship between drivers' self-reported device dependency and frequent device use while driving (e.g., Gauld et al., 2014; Kita & Luria, 2018; Mirman et al., 2017; Musicant et al., 2015; O'Connor et al., 2013; Oviedo-Trespalacios et al., 2019; Regan et al., 2020; Struckman-Johnson et al., 2015).

This report examines an emerging research area and parts of the resulting synthesis are preliminary and inconclusive. Although some on-road studies were identified, the bulk of the literature used self-report data from domains with a variety of research objectives, resulting in an eclectic mix of measurement criteria for similar psychological constructs and device use frequency measures. Even with these caveats, this report offers some clarity into the psychological mechanisms underlying PDU while driving and the findings from this report have implications for the treatment and future research of PDU behind the wheel.

A Need for On-Road and Representative Studies in the United States

As the study of PDU while driving is a nascent research area, it involves bringing together disparate research methodologies. On-road and self-report studies of driving behavior are useful for understanding distracted driving, and psychological questionnaires have been applied to understand problematic cellphone use. Although the diversity of methods limits the researchers' ability to integrate empirical data, these different perspectives can supplement each other.

On-road studies have not fully captured device use while driving behavior. The methods of measuring distracted driving activity are imprecise because they are often based on incomplete information (e.g., measures of distraction such as the number of times a phone was unlocked or the number of times a user tapped on the phone do not indicate what kind of activity a driver is performing) or visual information that does not capture why a driver is using their device while driving.

Self-report studies are subject to inaccuracy for a different reason—respondents' cognitive biases. Survey participants frequently under- or over-report their own behaviors to conform with their perceptions of the experimenters' expectations (a phenomenon called social desirability bias; White et al., 2010). In addition, because many of the survey studies reviewed in Chapters 6 and 7 were not designed for the purpose of practical traffic safety research, some of these surveys asked respondents to self-report their frequency of device use while driving without screening their participants for drivers, potentially resulting in biased or diluted findings. Five of the reviewed studies analyzed on-road device use behavior (Atwood et al., 2018; Christoph et al., 2019; Creaser et al., 2015; Delgado et al., 2018; Kita & Luria, 2018). These found that frequent device use while driving was associated with younger driver age, more driving experience for young drivers, more everyday device use, higher self-reported impulsivity, and higher self-reported sensation-seeking.

The amount of device use was significantly lower in the presence of a passenger (Christoph et al., 2019) and none of these studies found a significant gender effect for frequent device use while driving. In addition, drivers with high texting rates (per hour and per day) had significantly higher crash rates, but drivers with high calling rates did not (Atwood et al., 2018). Only one on-road study looked at both device use while driving frequency and device dependency (Kita & Luria, 2018). This Israeli study found that more frequent device use was related to more device dependency, less openness to experience, more extraversion, and more neuroticism. Only the relationship between neuroticism and increased device use while driving was mediated by device dependency. Survey studies corroborate the driver characteristics and personality trait findings from on-road studies, linking these same traits to self-reported frequent and dependent device use while driving.

Self-report studies also raise the possibility that other driver characteristics may be involved in PDU while driving, which should be tested in observational studies. For example, repeating trends from survey findings (see Chapter 7) suggest that frequent device use is related to greater automatic behaviors developed from device habits; greater perceived behavioral control; stronger supportive moral norms; and stronger subjective and descriptive norms (the latter especially for younger drivers). These traits have not been looked at with respect to measures of device dependency nor in the context of on-road behavior. Future high-value self-report data may be estimates of the percentage of PDU drivers (using frequency and dependency measures) in the U.S. population from a representative sample and an estimate of the potential impact of these drivers on traffic safety.

Repeated cross-sectional representative studies could help identify whether the trend toward PDU drivers tending to be younger drivers is an effect of youth and inexperience, a cohort effect of drivers who grew up with mobile devices as a ubiquitous part of their lives, or if this is a sustained trend and we will see high prevalence across age groups in the future. Additionally, future studies assessing PDU while driving would benefit from measuring device use frequency and device use dependency in the same experiment. Only one on-road study has used both of these measures (Kita & Luria, 2018). As more studies are able to identify drivers with PDU, researchers will be able to better identify PDUrs' unique behaviors and assess the effectiveness of potential distracted driving mitigation strategies on this high-risk group.

A Need for Consistent Measures

Characterizing PDU while driving involved sifting through the conflicting and inconsistent measurement criteria established for device dependency and device-use frequency to determine which constructs were empirically validated and relevant for the driving context.

Measuring PDU in the driving context is particularly difficult with existing scales of device use. The most apparent difference among scales of PDU is whether the metric categorizes this behavior as an addiction. While some scales are styled as measures of "addiction," the material reviewed for Chapters 4 and 5 of this report, including the DSM-5, demonstrates that this is currently an incorrect use of the term for excessive and dependent device use, within and outside of the driving context.

The overabundance of device dependency scales also reduces the ability of researchers to compare findings across studies. Furthermore, some measures of PDU from the psychology domain are inappropriate for use in traffic safety. These scales often use frequency of device use while driving as an item on their device dependency assessment scale, creating confounding or circular logic issues with using these scales in traffic safety research.

In the observational studies reviewed for this report, high frequency device users were categorized relative to the sample mean from a sample that was not representative of a State or

National population. For self-report studies, the subjective measures of device use frequency naturally suffer from driver recall inaccuracies and cognitive biases, but many current surveys do not anchor their scales with a quantified value of device engagement (e.g., duration, number of texts, etc.), leading to inconsistent self-assessments between drivers.

As research on PDU while driving matures, it would be ideal if a few established measures of PDU became standard. Selecting and validating a subset of standard scales for use in traffic safety research would help with identifying erroneous results, allow for easier comparison of results across studies. Validated survey tools could be used to identify the actual prevalence of PDUrs within the U.S. driving population. Future research may also benefit from using measures of device use frequency based on a quantified value within a reasonable recall window (e.g., 30 days) to help specifically recruit and study drivers with frequent device use while driving behaviors. By using relevant scales informed by an understanding of the personality factors and behaviors that relate to PDU, it will be possible to continue forming a more accurate understanding of this behavior, rather than merely labelling it an "addiction."

Psychological Mechanisms

While "device addiction" is not empirically validated as a behavioral addiction, it is associated with psychological dysfunction. Problematic device use while driving goes beyond typical distracted driving. As described in Chapter 7, the most consistent and notable traits for PDU while driving are more everyday device use, PDU habits developed outside the vehicle, higher perceived behavioral control self-efficacy, high impulsivity, and greater ADHD symptoms. Many of the psychological mechanisms of PDU while driving are similar to those of typical distracted driving (see Chapter 3). One main difference is that the traits within the excessive reassurance pathway: anxious attachment styles, neuroticism, and poor self-esteem tend to emerge as predictors of high frequency device use and device dependency in the driving context, but not for typical distracted driving.

Pinpointing psychological mechanisms that differentiate PDUrs from typical device users within the driving context is difficult due to the inconsistent and highly specific measures used to address this question. For example, perceived behavioral control (e.g., Brown et al., 2019; Gauld et al., 2014; Rowe et al., 2016; Zhou et al., 2012) and positive attitudes (e.g., Nemme & White, 2010; Prat et al., 2015; Sullman et al., 2018; Walsh et al., 2007) toward distracted driving tend to consistently predict typical distracted driving. However, these are not consistent predictors of PDU while driving. Attitudes tend to not predict PDU in extended TPB models when these models include a moral norms construct (e.g., Bayer & Campbell, 2012; Berenbaum et al., 2019). This example illustrates an issue with some of the personality trait research, where, in the effort to understand driver behavior, traits are reduced into smaller and smaller constructs that are not necessarily distinct and may overlap conceptually (e.g., self-reported moral norms may not be independent from self-reported attitudes). This type of study design can affect the significance of these individual predictors (i.e., due to multicollinearity).

Problematic device use in all contexts arises from a complex array of psychological mechanisms; people do not simply engage in this behavior because of an irresistible craving. The behavior has biological, psychological, and sociocultural components.

Biologically, PDU behavior can create increased connectivity between regions of the brain associated with impulsivity, such as the anterior cingulate cortex, nucleus accumbens, and amygdala-striata system (Di Chira et al., 1999; Meshi et al., 2015; Noël, et al., 2013; Turel et al., 2014). These feedback loops—stronger neural connections—are associated with increased impulsivity and increased experiences of reward from using devices, while inhibitory brain areas such as the prefrontal cortex exert less input on device use behavior over time. Continued PDU over time can create habits that a user may be unaware of, by altering the cues and rewards for the behavior in their brains (Kuss, Pontes, & Griffiths, 2018; Volkow et al., 2016).

Psychologically, smartphone applications encourage continued and intensive use through addictive design strategies. Addictive design is a concept from software development referring to when software design principles use human psychology to create a sense of craving and obligation in users (Neyman, 2017; Montag et al., 2019). It is often present in apps related to social media, video streaming, and gaming. More details about and examples of addictive design are presented in Chapters 2 and 5 of this report. In short, addictive design encompasses the highly curated, mentally rewarding content, often delivered at unpredictable times, that keeps users wanting to check their phone "just for a second" or watch "just one more video." It is not currently clear if PDUrs are more vulnerable to addictive design strategies than normal device users, but this could be explored further.

Socially, certain environments, cultures, and social norms encourage or cue problematic cellphone use. Some contexts appear to be especially motivating for PDUrs (e.g., young drivers communicating with peers) possibly because they are very socially rewarding. Billieux and colleagues' (2015) pathway of "excessive reassurance" often leads to use described as "addictive." Seeking constant connectivity can create and perpetuate problematic smartphone use, even in the driving context.

When drivers frequently check devices and initiate communication (i.e., send text messages or make calls), they may not adjust their device interactions to the driving context, either due to negligence (see Chapters 3 and 7) or undervaluing the risk of their interaction (Bayer & Campbell, 2012; Berenbaum et al., 2019; Hansma et al., 2020; Murphy et al., 2020; Struckman-Johnson et al., 2015) or the complexity of the driving scenario (Atchley et al., 2011). As previously discussed, for PDUrs, strong device use habits developed outside the vehicle carry over into the driving context and may contribute to their increased risk for crashes.

For categorizing device use while driving, Billieux and colleagues' (2015) pathway model is a solid starting point. Its three pathways: the excessive reassurance pathway, the impulsive pathway, and the extraversion pathway, can each describe the underlying factors and characteristics of PDU for some people. This model would require further refinement to create a typology that has device use while driving as a central variable of interest rather than a behavioral symptom mentioned in two of three pathways (excessive reassurance seeking and extraversion). Although truly evaluating the pathway model would require a longitudinal study (since it predicts that these traits are causes rather than effects), current studies focus on traits that characterize the existing population.

A 2019 study conducted to validate the pathway model through survey testing found that high neuroticism and high impulsivity were moderately strong predictors of addictive smartphone use within a convenience sample of 511 respondents in the UK (Pivettta et al., 2019). Representative studies conducted in the United States at points in time with the same subject cohort would provide applicable insight into the underlying personal factors predicting PDU and how these change over time. Although the pathway model is a good starting point, to create economical and targeted mitigation strategies, researchers and practitioners would benefit from a practical understanding of the current distracted driver groups in the United States. Only one additional study, apart from Billieux and colleagues' work, to date has worked toward a distracted driver typology (Maier et al., 2020). Maier and colleagues' survey results suggested that drivers who use devices fall into three groups: non-neurotic drivers, open-extraverted drivers, and conscientious drivers.

Although this research does demonstrate that personality variables influence the frequency of drivers' smartphone use, a future study could develop a typology of distracted drivers in the United States based on underlying traits, device use while driving frequency, and device dependency. Problematic device use while driving is consistently related to greater device habits (related to automatic behaviors often developed outside of the vehicle; e.g., Bayer & Campbell, 2012; Briskin et al., 2018; Hansma et al., 2020; Moore & Brown, 2019; Murphy et al., 2020; Oxtoby et al., 2019) and higher impulsivity in drivers (e.g., Delgado et al., 2018; Lantz & Loeb, 2013; Pivetta et al., 2019; Struckman-Johnson et al., 2015). However, these concepts have not yet been studied together on a driver population and habits have not been integrated into any PDU framework. Given that ongoing PDU in general affects the areas of the brain that mediate impulsivity, it may be useful to directly examine how habits may interact with impulsivity to contribute to PDU while driving behavior. It may follow that impulsive drivers who engage in PDU may be reinforcing and exacerbating their impulsive tendencies as they relate to device use behavior.

Implications

There is a need for focused research on U.S. drivers examining actual PDUrs and their device use behavior while driving. Such research has the potential to inform distracted driving mitigation strategies and help tailor them for PDUrs. With these countermeasures in place, the traffic safety risk posed by high risk distracted drivers could be reduced. This report's overall implications for countermeasure development are as follows:

- Complexity in the behavior needs to be better understood to develop economical and targeted countermeasures. Relevant variables include:
    - Types of problematic users.
    - Situational and social factors associated with problematic use.
- Phone app developers may need to be part of the solution, especially if PDUrs have more trouble inhibiting device use when motivated by addictive design.
    - What types of applications (e.g., minimal risk, high risk, applications incorporating addictive design strategies) are favored by drivers who exhibit PDU behaviors?
    - How do applications favored by PDU drivers differ from the applications favored by occasional device use drivers?

Chapter 8 of this report describes specific countermeasures for device use while driving and how they may be modifiable to focus on problematic device users. Because of the complex array of psychological mechanisms underlying PDU while driving, treatments are not one-size-fits-all.

Strategies typically applied to treating PDU in daily life can be adapted to focus on device use while driving.

Promising techniques include providing information to drivers about the risks of their behavior, limiting their access to device functionality during driving, and addressing the underlying factors that lead to PDU while promoting healthy habits as an alternative. Programs that incorporate one of these strategies include media campaigns, in-vehicle technologies, and behavioral interventions. Most countermeasures for PDU while driving are very feasible to implement, but user buy-in—which is essential—is lacking.

Drivers need to be willing to adopt interventions against PDU while driving in order for these strategies to be effective. For example, many apps that block incoming communications to a driver's smartphone while their vehicle is in motion are available, but these apps have very low numbers of people downloading and regularly using them (Oviedo-Trespalacios et al., 2019; Reagan & Cicchino, 2018).

Problematic device users are predicted to have stronger beliefs that discourage them from reducing their device activity while driving. These beliefs include the perception that it is essential for them to use devices while driving for work or personal reasons as well as optimism bias, the perception that they are more skilled at driving than other people and can therefore use devices with minimal risk. These beliefs can be swayed using information-enhancing, behavior-reinforcement, and capacity-building strategies that can help persuade drivers to change their behavior. Indeed, the vast majority of drivers are aware that using devices while driving is dangerous and express support of legislation against this behavior.

The challenge for typical users and, especially, for problematic device users, is to convince them that their perceived driving skills and the current driving environment do not make their device use behavior while driving acceptable. Such an effort will involve countermeasures of types, including traffic safety programs that resemble typical efforts against distracted driving, strategies for reducing people's device use in daily life, and, perhaps, a reduction in the prevalence and power of "addictive design" technologies designed to grab and hold users' attention without regard for whether or not the user is driving.

References

AAA Foundation for Traffic Safety (2013). *2012 traffic safety culture index*. https://aaafoundation.org/2012-traffic-safety-culture-index/

AAA Foundation for Traffic Safety (2014). *2013 traffic safety culture index*. https://aaafoundation.org/2013-traffic-safety-culture-index/

AAA Foundation for Traffic Safety (2015). *2014 traffic safety culture index*. https://aaafoundation.org/2014-traffic-safety-culture-index/

AAA Foundation for Traffic Safety (2016). *2015 traffic safety culture index*. https://aaafoundation.org/2015-traffic-safety-culture-index/

AAA Foundation for Traffic Safety (2017). *2016 traffic safety culture index*. https://aaafoundation.org/2016-traffic-safety-culture-index/

AAA Foundation for Traffic Safety (2018). *2017 traffic safety culture index*. https://aaafoundation.org/2017-traffic-safety-culture-index/

AAA Foundation for Traffic Safety (2019). *2018 traffic safety culture index*. https://aaafoundation.org/2018-traffic-safety-culture-index/

AAA Foundation for Traffic Safety (2020). *2019 traffic safety culture index*. https://aaafoundation.org/2019-traffic-safety-culture-index/

Abouk, R., & Adams, S. (2013). Texting bans and fatal accidents on roadways: Do they work? Or do drivers just react to announcements of bans? *American Economic Journal: Applied Economics, 5*(2), 179-199. https://doi.org/10.1257/app.5.2.179

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179-211. https://doi.org/10.1016/0749-5978(91)90020-T

Alavi, S. S., Ferdosi, M., Jannatifard, F., Eslami, M., Alaghemandan, H., & Setare, M. (2012). Behavioral addiction versus substance addiction: Correspondence of psychiatric and psychological views. *International Journal of Preventive Medicine, 3*(4), 290-294. http://europepmc.org/abstract/MED/22624087

Albert, G., & Lotan, T. (2019). Exploring the impact of "soft blocking" on smartphone usage of young drivers. *Accident Analysis & Prevention, 125*, 56-62. http://dx.doi.org/10.1016/j.aap.2019.01.031

Albert, G., Musicant, O., Oppenheim, I., & Lotan, T. (2016). Which smartphone's apps may contribute to road safety? An AHP model to evaluate experts' opinions. *Transport Policy, 50*, 54-62. https://doi.org/10.1016/j.tranpol.2016.06.004

Alghnam, S., Towhari, J., Alkelya, M., Alsaif, A., Alrowaily, M., Alrabeeah, F., & Albabtain, I. (2019). The association between mobile phone use and severe traffic injuries: a case-control study from Saudi Arabia. *International Journal of Environmental Research and Public Health, 16*(15), 2-8. https://doi.org/10.3390/ijerph16152706

Alter, A. (2017). *Irresistible: The rise of addictive technology and the business of keeping us hooked*. Penguin. American Addiction Centers. (2020). *Addiction as maladaptive behavior*. Alcoholrehab.com. https://alcoholrehab.com/alcohol-recovery/addiction-as-maladaptive-behavior/

American Driver and Traffic Safety Education Association. (2017). *American Driver and Traffic Safety Education Association novice driver education curriculum standards: Classroom and in-car for segment I and segment II*. http://anstse.info/Resources%20PDF's/Feb%202017/002%20Attachment%20A%20ADTSEA%20Standards.pdf

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.).

Anderson, M., & Perrin, A. (2017). *Tech adoption climbs among older adults*. Pew Research Center. www.pewresearch.org/internet/2017/05/17/tech-adoption-climbs-among-older-adults

Antrobus, V., Burnett, G., Krehl, C., Skrypchuk, L., & Mouzakitis, A. (2015). Human-machine interface design for vehicle navigation systems: the need to balance short-term versus long-term distraction effects. In *Proceedings of the 4th International Driver Distraction and Inattention Conference*. ARRB Group, Ltd. https://trid.trb.org/View/1402267

Apple Inc. (2020). *App Store*. www.apple.com/. www.apple.com/app-store/

Arnold, L. S., Benson, A. J., Tefft, B. C., Barragan, D., Jin, L., Kolek, S., & Horrey, W. J. (2019). *Effectiveness of distracted driving countermeasures: A review of the literature*.

AAA Foundation for Traffic Safety. https://aaafoundation.org/effectiveness-of-distracted-driving-countermeasures-a-review-of-the-literature/

Arnsten, A. F. T., & Li, B. M. (2005). Neurobiology of executive functions: Catecholamine influences on prefrontal cortical functions. *Biological Psychiatry, 57*(11), 1377-1384. https://doi.org/10.1016/j.biopsych.2004.08.019

Ascher, M. S. (2015). Preface. In M. S. Ascher & P. Levounis (Eds.), *The behavioral addictions* (pp. xi–xii). American Psychiatric Publishing Inc.

Atchley, P., Atwood, S., & Boulton, A. (2011). The choice to text and drive in younger drivers: Behavior may shape attitude. *Accident Analysis & Prevention*, *43*(1), 134–142. https://doi.org/10.1016/j.aap.2010.08.003

Atchley, P., Hadlock, C., & Lane, S. (2012). Stuck in the 70s: The role of social norms in distracted driving. *Accident Analysis & Prevention, 48*, 279-284. https://doi.org/10.1016/j.aap.2012.01.026

Atwood, J., Guo, F., Fitch, G., & Dingus, T. A. (2018). The driver-level crash risk associated with daily cellphone use and cellphone use while driving. *Accident Analysis & Prevention*, *119*, 149–154. https://doi.org/10.1016/j.aap.2018.07.007

Bailey, T. J., & Wundersitz, L. N. (2019). *The relationship between self-reported and actual driving-related behaviours: a literature review*. University of Adelaide, Center for Automotive Safety Research. http://casr.adelaide.edu.au/publications/list/?id=1820

Bálint, A., Flannagan, C. A. C., Leslie, A., Klauer, S., Guo, F., & Dozza, M. (2020). Multitasking additional-to-driving: Prevalence, structure, and associated risk in SHRP2 naturalistic driving data. *Accident Analysis & Prevention, 137*, 105455. https://doi.org/10.1016/j.aap.2020.105455

Barnes, S. J., Pressey, A. D., & Scornavacca, E. (2019). Mobile ubiquity: Understanding the relationship between cognitive absorption, smartphone addiction and social network services. *Computers in Human Behavior, 90*, 246-258. https://doi.org/10.1016/j.chb.2018.09.013

Barr, G. C., Jr., Kane, K. E., Barraco, R. D., Rayburg, T., Demers, L., Kraus, C. K., Greenberg, M. R., Rupp, V. A., Hamilton, K. M., & Kane, B. G. (2015). Gender differences in perceptions and self-reported driving behaviors among teenagers. *Journal of Emergency Medicine, 48*(3), 366-370. https://doi.org/10.1016/j.jemermed.2014.09.055

Barratt, E. S. (1959). Anxiety and impulsiveness related to psychomotor efficiency. *Perceptual and Motor Skills, 9*(3), 191-198. https://doi.org/10.2466/pms.1959.9.3.191

Barry, K. (2019). *Car infotainment systems that free you from your phone*. Consumer Reports. www.consumerreports.org/automotive-technology/car-infotainment-systems-that-free-you-from-your-phone/

Bayer, J. B., & Campbell, S. W. (2012). Texting while driving on automatic: Considering the frequency-independent side of habit. *Computers in Human Behavior*, *28*(6), 2083–2090. https://doi.org/10.1016/j.chb.2012.06.012

Beck, H., McManus & B., Stavrinos, D. (2019). Adolescent distracted driving attitudes influenced by experience and individual differences. In *Proceedings of the Transportation Research Board, 98th Annual Meeting*. https://trid.trb.org/view/1572734

Becoña, E. (2018). Brain disease or biopsychosocial model in addiction? Remembering the Vietnam Veteran Study. *Psicothema, 30*(3), 270–275. https://doi.org/10.7334/psicothema2017.303

Begg, D., Brookland, R., & Connor, J. (2017). Associations of repeated high alcohol use with unsafe driving behaviors, traffic offenses, and traffic crashes among young drivers: Findings from the New Zealand Drivers Study. *Traffic Injury Prevention, 18*(2), 111-117. https://doi.org/10.1080/15389588.2016.1224345

Bell, J. L., Taylor, M. A., Chen, G. X., Kirk, R. D., & Leatherman, E. R. (2017). Evaluation of an in-vehicle monitoring system (IVMS) to reduce risky driving behaviors in commercial drivers: Comparison of in-cab warning lights and supervisory coaching with videos of driving behavior. *Journal of Safety Research, 60*, 125-136. https://doi.org/10.1016/j.jsr.2016.12.008

Benson, T., McLaughlin, M., & Giles, M. (2015). The factors underlying the decision to text while driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 35*, 85-100. http://dx.doi.org/10.1016/j.trf.2015.10.013

Berenbaum, E., Harrington, D., Keller-Olaman, S., & Manson, H. (2019). Y TXT N DRIVE? Predictors of texting while driving among a sample of Ontario youth and young adults. *Accident; Analysis and Prevention*, *122*, 301–307. https://doi.org/10.1016/j.aap.2018.10.021

Berlyne, D. E. (1960). Toward a theory of exploratory behavior: II. Arousal potential, perceptual curiosity, and learning. In *Conflict, Arousal, and Curiosity*. (pp. 193–194). McGraw-Hill Book Company.

Berthon, P., Pitt, L., & Campbell, C. (2019). Addictive de-vices: A public policy analysis of sources and solutions to digital addiction. *Journal of Public Policy & Marketing, 38*(4), 451-468. https://doi.org/10.1177/0743915619859852

Bhardwaj, M., & Ashok, M. S. J. (2015). Mobile phone addiction and loneliness among teenagers. *International Journal of Indian Psychology, 2*(3), 27-34.

Bianchi, A., & Phillips, J. G. (2005). Psychological predictors of problem mobile phone use. *CyberPsychology & Behavior, 8*(1), 39-51. https://doi.org/10.1089/cpb.2005.8.39

Bickel, W. K., Miller, M. L., Yi, R., Kowal, B. P., Lindquist, D. M., & Pitcock, J. A. (2007). Behavioral and neuroeconomics of drug addiction: Competing neural systems and temporal discounting processes. *Drug and Alcohol Dependence, 90*, S85-S91. https://doi.org/10.1016/j.drugalcdep.2006.09.016

Billieux, J., Maurage, P., Lopez-Fernandez, O., Kuss, D. J., & Griffiths, M. D. (2015). Can disordered mobile phone use be considered a behavioral addiction? An update on current evidence and a comprehensive model for future research. *Current Addiction Reports, 2*(2), 156-162. https://doi.org/10.1007/s40429-015-0054-y

Billieux, J., Van der Linden, M., & Rochat, L. (2008). The role of impulsivity in actual and problematic use of the cellphone. *Applied Cognitive Psychology, 22*(9), 1195-1210. https://doi.org/10.1002/acp.1429

Bingham, C. R., Bao, S., Flannagan, C., & Pradhan, A. K. (2016). *Using naturalistic driving performance data to develop an empirically defined model of distracted driving*. U.S. Department of Transportation Region V University Transportation Center. https://rosap.ntl.bts.gov/view/dot/35528

Biondi, F. N., Getty, D., Cooper, J. M., & Strayer, D. L. (2019). Examining the effect of infotainment auditory-vocal systems' design components on workload and usability. *Transportation Research Part F: Traffic Psychology and Behaviour, 62*, 520-528. https://doi.org/10.1016/j.trf.2019.02.006

Blau, J. (2015). Apple and Google hope to slide into the driver's seat. *Research Technology Management, 58*(4), 5-8. https://search.proquest.com/docview/1701140138?accountid=193063

Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015). *The economic and societal impact of motor vehicle crashes, 2010* (Revised)(Report No. DOT HS 812 013). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013

Bloch, S. (2020). *Traffic safety review: State focus on distracted driving*. National Conference of State Legislatures. www.ncsl.org/research/transportation/traffic-safety-review-states-focus-on-distracted-driving.aspx

Bodford, J. E., Kwan, V. S. Y., & Sobota, D. S. (2017). Fatal attractions: Attachment to smartphones predicts anthropomorphic beliefs and dangerous behaviors. *Cyberpsychology, Behavior, and Social Networking, 20*(5), 320–326. https://doi.org/10.1089/cyber.2016.0500

Bosler, M., Jud, C., & Herzwurm, G. (2017). *Platforms and ecosystems for connected car services*. In Proceedings of the 9th International Workshop on Software Ecosystems (IWESCO). http://ceur-ws.org/Vol-2053/paper02.pdf

Bradish, T., Wilson, J. H., & Locker, L. J. (2019). Hands-free law in Georgia: Predictors of post-law cellphone use among college drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 66*, 226–233. https://doi.org/10.1016/j.trf.2019.09.007

Bragazzi, N. L., & Del Puente, G. (2014). A proposal for including nomophobia in the new DSM-V. *Psychology Research and Behavior Management, 7*, 155-160. https://doi.org/10.2147/PRBM.S41386

Braitman, K. A., & Braitman, A. L. (2017). Patterns of distracted driving behaviors among young adult drivers: Exploring relationships with personality variables. *Transportation Research Part F: Traffic Psychology and Behaviour, 46,* 169–176. https://www.sciencedirect.com/science/article/abs/pii/S1369847817301134

Brennan, T. M., Jesson, J. E., & Furlanetto, P. G. A. (2019). Quantifying driver cellphone use at signalized intersections using software-defined radio. *Traffic Injury Prevention, 20*(4), 359-364. https://doi.org/10.1080/15389588.2019.1592167

Breslin, S., Shareck, M., & Fuller, D. (2019). Research ethics for mobile sensing device use by vulnerable populations. *Social Science & Medicine, 232*, 50-57. https://doi.org/10.1016/j.socscimed.2019.04.035

Briskin, J. L., Bogg, T., & Haddad, J. (2018). Lower trait stability, stronger normative beliefs, habitual phone use, and unimpeded phone access predict distracted college student messaging in social, academic, and driving contexts. *Frontiers in Psychology, 9*, 2633. https://doi.org/10.3389/fpsyg.2018.02633

Brown, P. M., George, A. M., & Rickwood, D. (2019). Perceived risk and anticipated regret as factors predicting intentions to text while driving among young adults. *Transportation Research Part F: Traffic Psychology and Behaviour, 62*, 339-348. https://doi.org/10.1016/j.trf.2019.01.014

Brown, P. M., George, A. M., & Rickwood, D. J. (2020). Rash impulsivity, reward seeking and fear of missing out as predictors of texting while driving: Indirect effects via cellphone involvement. *Personality and Individual Differences*, in press, 1-4. https://doi.org/10.1016/j.paid.2020.110492

Burton, J. L., Hill, D. J., & Bakir, A. (2015). Influencing light versus heavy engagers of harmful behavior to curb their habits through positive and negative ad imagery. *Journal of Consumer Behaviour, 14*(4), 237–247. https://doi.org/10.1002/cb.1514

Busch, P. A., & McCarthy, S. (2021). Antecedents and consequences of problematic smartphone use: A systematic literature review of an emerging research area. *Computers in Human Behavior*, *114*, 106414. https://doi.org/10.1016/j.chb.2020.106414

Business of Apps (2019). *Push notifications statistics (2019).* http://www.businessofapps.com/marketplace/push-notifications/research/push-notifications-statistics/?source=post_page

Caird, J. K., Simmons, S. M., Wiley, K., Johnston, K. A., & Horrey, W. J. (2018). Does talking on a cellphone, with a passenger, or dialing affect driving performance? An updated systematic review and meta-analysis of experimental studies. *Human Factors, 60*(1), 101-133. https://doi.org/10.1177/0018720817748145

Cambridge University Press. (n.d.). *Smartphone*. In Cambridge Dictionary. https://dictionary.cambridge.org/dictionary/english/smartphone

Carter, P. M., Bingham, C. R., Zakrajsek, J. S., Shope, J. T., & Sayer, T. B. (2014). Social norms and risk perception: Predictors of distracted driving behavior among novice adolescent drivers. *Journal of Adolescent Health, 54*(5), S32-S41. https://doi.org/10.1016/j.jadohealth.2014.01.008

Casey, B. J., Getz, S., & Galvan, A. (2008). The adolescent brain. *Developmental Review, 28*(1), 62-77. https://doi.org/10.1196/annals.1440.010

Casey, B., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. *Biological Psychology, 54*(1-3), 241-257. https://doi.org/10.1016/S0301-0511(00)00058-2

Centre for Road Safety. (2020). *Mobile phone detection cameras*. Transport for NSW. https://roadsafety.transport.nsw.gov.au/stayingsafe/mobilephones/technology.html

Chambers, R. A., & Potenza, M. N. (2003). Neurodevelopment, impulsivity, and adolescent gambling. *Journal of Gambling Studies, 19*(1), 53-84. https://doi.org/10.1023/a:1021275130071

Charlton, S. G. (2009). Driving while conversing: Cellphones that distract and passengers who react. *Accident Analysis & Prevention, 41*(1), 160-173. https://doi.org/10.1016/j.aap.2008.10.006

Chaudhary, N. K., Casanova-Powell, T. D., Cosgrove, L., Reagan, I., & Williams, A. (2014, March). *Evaluation of NHTSA distracted driving demonstration projects in Connecticut and New York* (Report No. DOT HS 811 635). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.gov/files/811635_eval_nhtsa_distracted_driving_demo_proj_comm_ct_and_ny.pdf

Chen, H. Y. W., & Donmez, B. (2016). What drives technology-based distractions? A structural equation model on social-psychological factors of technology-based driver distraction engagement. *Accident Analysis and Prevention, 91*, 166–174. https://doi.org/10.1016/j.aap.2015.08.015

Chen, H. Y. W., Hoekstra-Atwood, L., & Donmez, B. (2018). Voluntary- and involuntary-distraction engagement: An exploratory study of individual differences. *Human Factors, 60*(4), 575–588. https://doi.org/10.1177/0018720818761293

Chen, H.-Y. W., Donmez, B., Hoekstra-Atwood, L., & Marulanda, S. (2016). Self-reported engagement in driver distraction: An application of the theory of planned behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour, 38*, 151-163. https://doi.org/10.1016/j.trf.2016.02.003

Chen, H.-Y. W., Hoekstra-Atwood, L., & Donmez, B. (2018). Voluntary- and involuntary-distraction engagement: An exploratory study of individual differences. *Human Factors, 60*(4), 575-588. https://doi.org/10.1177/0018720818761293

Christoph, M., Wesseling, S., & van Nes, N. (2019). Self-regulation of drivers' mobile phone use: The influence of driving context. *Transportation Research Part F: Traffic Psychology and Behaviour*, *66*, 262–272. https://doi.org/10.1016/j.trf.2019.09.012

Chung, Y., & Recker, W. W. (2013). Spatiotemporal analysis of traffic congestion caused by rubbernecking at freeway accidents. *IEEE Transactions on Intelligent Transportation Systems, 14*(3), 1416-1422. http://dx.doi.org/10.1109/TITS.2013.2261987

Classen, S., & Monahan, M. (2013). Evidence-based review on interventions and determinants of driving performance in teens with attention deficit hyperactivity disorder or autism spectrum disorder. *Traffic Injury Prevention, 14*(2), 188-193. https://doi.org/10.1080/15389588.2012.700747

Classen, S., Winter, S. M., Brown, C., Morgan-Daniel, J., Medhizadah, S., & Agarwal, N. (2019). An integrative review on teen distracted driving for model program development. *Frontiers in Public Health, 7*, 1-11. https://doi.org/10.3389/fpubh.2019.00111

Clements, J. A., & Boyle, R. (2018). Compulsive technology use: Compulsive use of mobile applications. *Computers in Human Behavior, 87*, 34-48. https://doi.org/10.1016/j.chb.2018.05.018

Coogan, M. A., Campbell, M., Adler, T. J., & Forward, S. (2014). Examining behavioral and attitudinal differences among groups in their traffic safety culture. *Transportation Research Part F: Traffic Psychology and Behaviour, 26*, Part B, 303-316. http://dx.doi.org/10.1016/j.trf.2014.03.005

Cook, S., Boak, A., Hamilton, H. A., Mann, R. E., Manson, H. E., & Wickens, C. M. (2018). The prevalence and correlates of texting while driving among a population-based sample of Ontario students. *Traffic Injury Prevention*, *19*(7), 722–727. https://doi.org/10.1080/15389588.2018.1491038

Cook, S., Boak, A., Hamilton, H. A., Mann, R. E., Manson, H. E., & Wickens, C. M. (2018). The prevalence and correlates of texting while driving among a population-based sample of Ontario students. *Traffic Injury Prevention, 19*(7), 722–727. https://doi.org/10.1080/15389588.2018.1491038

Cooper, J. M., Vladisavljevic, I., Medeiros-Ward, N., Martin, P. T., & Strayer, D. L. (2009). An investigation of driver distraction near the tipping point of traffic flow stability. *Human Factors, 51*(2), 261-268. http://dx.doi.org/10.1177/0018720809337503

Cosgrove, L., Chaudhary, N., & Reagan, I. (2011). *Four high-visibility enforcement demonstration waves in Connecticut and New York reduce hand-held phone use* (Report No. DOT HS 811 845). US. National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1937

Coyne, S. M., Stockdale, L., & Summers, K. (2019). Problematic cellphone use, depression, anxiety, and self-regulation: Evidence from a three-year longitudinal study from adolescence to emerging adulthood. *Computers in Human Behavior, 96*, 78-84. https://doi.org/10.1016/j.chb.2019.02.014

Creaser, J. I., Edwards, C. J., Morris, N. L., & Donath, M. (2015). Are cellular phone blocking applications effective for novice teen drivers? *Journal of Safety Research, 54*, pp 75.e29-78. http://dx.doi.org/10.1016/j.jsr.2015.06.014

D'Addario, P., & Donmez, B. (2019). The effect of cognitive distraction on perception-response time to unexpected abrupt and gradually onset roadway hazards. *Accident Analysis & Prevention, 127*, 177-185. https://doi.org/10.1016/j.aap.2019.03.003

D'Angelo, J. D. (2020). Chapter 16 - Problematic and addictive technology use. In M. A. Moreno & A. J. Hoopes (Eds.), *Technology and adolescent health* (pp. 347-364). Academic Press. https://doi.org/10.1016/B978-0-12-817319-0.00016-5

Dakwar, E. (2015). Problematic exercise: A case of alien feet. In M. S. Ascher & P. Levounis (Eds.), *The Behavioral Addictions* (pp. 29–42). American Psychiatric Publishing Inc.

Day, M. R., Thompson, A. R., Poulter, D. R., Stride, C. B., & Rowe, R. (2018). Why do drivers become safer over the first three months of driving? A longitudinal qualitative study. *Accident Analysis & Prevention, 117*, 225-231. https://doi.org/10.1016/j.aap.2018.04.007

de Waard, D. (1996). *The measurement of drivers' mental workload*. [Thesis, University of Groningen.]

Delgado, M. K., McDonald, C. C., Winston, F. K., Halpern, S. D., Buttenheim, A. M., Setubal, C., Huang, Y., Saulsgiver, K. A., & Lee, Y.-C. (2018). Attitudes on technological, social, and behavioral economic strategies to reduce cellphone use among teens while driving. *Traffic Injury Prevention, 19*(6), 569-576. https://doi.org/10.1080/15389588.2018.1458100

Delgado, M. K., Romer, D., Halpern, S., Huang, Y., Saulsgiver, K., Winston, F., & McDonald, C. C. (2018). *Association between personality traits and phone unlock rates while driving among teen drivers*. In Proceedings of the Transportation Research Board, 97th Annual Meeting. https://trid.trb.org/view/1497078

Delgado, M. K., Wanner, K. J., & McDonald, C. C. (2016). Adolescent cellphone use while driving: An overview of the literature and promising future directions for prevention. *Media and Communication, 4*(3), pp 79-89. https://doi.org/10.17645/mac.v4i3.536

De-Sola Gutiérrez, J., Rodríguez de Fonseca, F., & Rubio, G. (2016). Cell-phone addiction: A review. *Frontiers in Psychiatry, 7*(175). https://doi.org/10.3389/fpsyt.2016.00175

Di Chiara, G., Tanda, G., Bassareo, V., Pontieri, F., Acquas, E., Fenu, S., Cadoni, C., & Carboni, E. (1999). Drug addiction as a disorder of associative learning: role of nucleus accumbens shell/extended amygdala dopamine. *Annals of the New York Academy of Sciences, 877*(1), 461-485.

Dijksterhuis, C., Lewis-Evans, B., Jelijs, B., Tucha, O., de Waard, D., & Brookhuis, K. (2016). In-car usage-based insurance feedback strategies. A comparative driving simulator study. *Ergonomics, 59*(9), 1158-1170. https://doi.org/10.1080/00140139.2015.1127428

Dingus, T. A., Guo, F., Lee, S., Antin, J. F., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. *Proceedings of the National Academy of Sciences, 113*(10), 2636-2641. https://doi.org/10.1073/pnas.1513271113

Dingus, T. A., Owens, J. M., Guo, F., Fang, Y., Perez, M., McClafferty, J., Buchanan-King, M., & Fitch, G. M. (2019). The prevalence of and crash risk associated with primarily cognitive secondary tasks. *Safety Science, 119*, 98-105. https://doi.org/10.1016/j.ssci.2019.01.005

DMV.ORG. (2018b). *Three types of driving distractions*. www.dmv.org/distracted-driving/three-types-of-distractions.php [Note that DMV.ORG is a privately owned website that is not owned or operated by any government agency.]

Donmez, B., Boyle, L. N., & Lee, J. D. (2007). Safety implications of providing real-time feedback to distracted drivers. *Accident Analysis & Prevention, 39*(3), 581-590. https://doi.org/10.1016/j.aap.2006.10.003

Donmez, B., Boyle, L. N., & Lee, J. D. (2008). Mitigating driver distraction with retrospective and concurrent feedback. *Accident Analysis & Prevention, 40*(2), 776-786. https://doi.org/10.1016/j.aap.2007.09.023

Donmez, B., Merrikhpour, M., & Nooshabadi, M. H. (2019). Mitigating teen driver distraction: in-vehicle feedback based on peer social norms. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. https://doi.org/10.1177/0018720819891285

Donovan, D. M., & Marlatt, G. A. (Eds.) (2005). *Assessment of Addictive Behaviors* (2nd ed.). Guilford Press. Driving School Association of the Americas (2017). *Beginner driver education and training: Curriculum content standards*. www.adtsea.org/webfiles/fnitools/documents/dsaa-curriculum-standards.pdf

Ebadi, Y., Fisher, D. L., & Roberts, S. C. (2019). Impact of cognitive distractions on drivers' hazard anticipation behavior in complex scenarios. Transportation Research Record: *Journal of the Transportation Research Board, 2673*(9), 440-451. https://doi.org/10.1177/0361198119846463

Edwards, S. A., & Wundersitz, L. N. (2019). *Distracted driving: Prevalence and motivations*. Centre for Automotive Safety Research, University of Adelaide. http://casr.adelaide.edu.au/publications/list/?id=1818

Ehsani, J., Simons-Morton, B. G., Perlus, J. G., Xie, Y., Albert, P. S. (2015). *Association between cellphone restrictions and teens' self-reported cellphone use while driving.* In Proceedings of the Eighth International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design. https://pubs.lib.uiowa.edu/driving/article/28581/galley/136873/view/

Elhai, J. D., Levine, J. C., & Hall, B. J. (2019). The relationship between anxiety symptom severity and problematic smartphone use: A review of the literature and conceptual frameworks. *Journal of Anxiety Disorders, 62*, 45-52. https://doi.org/10.1016/j.janxdis.2018.11.005

Elhai, J. D., Levine, J. C., Dvorak, R. D., & Hall, B. J. (2016). Fear of missing out, need for touch, anxiety and depression are related to problematic smartphone use. *Computers in Human Behavior, 63*, 509-516. https://doi.org/10.1016/j.chb.2016.05.079

Engelberg, J. K., Hill, L. L., Rybar, J., & Styer, T. (2015). Distracted driving behaviors related to cellphone use among middle-aged adults. *Journal of Transport & Health, 2*(3), 434-440. https://doi.org/10.1016/j.jth.2015.05.002

Falk, E. B., Cascio, C. N., Brook O'Donnell, M., Carp, J., Tinney, F. J., Bingham, C. R., Shope, J. T., Ouimet, M. C., Pradhan, A. K., & Simons-Morton, B. G. (2014). Neural responses to exclusion predict susceptibility to social influence. *Journal of Adolescent Health, 54*(5, Supplement), S22-S31. https://doi.org/10.1016/j.jadohealth.2013.12.035

Farah, H., Musicant, O., Shimshoni, Y., Toledo, T., Grimberg, E., Omer, H., & Lotan, T. (2014). Can providing feedback on driving behavior and training on parental vigilant care affect male teen drivers and their parents? *Accident Analysis & Prevention, 69*, 62-70. https://doi.org/10.1016/j.aap.2013.11.005

Farmer, C. M., Klauer, S. G., McClafferty, J. A., & Guo, F. (2015). Relationship of near-crash/crash risk to time spent on a cellphone while driving. *Traffic Injury Prevention, 16*(8), 792-800. https://doi.org/10.1080/15389588.2015.1019614

Faulks, I.J. (2019). *Caught red-handed: Automatic cameras will spot motor-using motorists, but at what cost?* The Conversation. https://theconversation.com/caught-red-handed-automatic-cameras-will-spot-mobile-using-motorists-but-at-what-cost-125638

Favarò, F. M. (2020). *Impact of smart phones' interaction modality on driving performance for conventional and autonomous vehicles*. Mineta Transportation Institute, San Jose University. https://transweb.sjsu.edu/sites/default/files/1813-Favaro-Impact-Smart-Phones-Driving-Performance-AVs.pdf

Feldman, G., Greeson, J., Renna, M., & Robbins-Monteith, K. (2011). Mindfulness predicts less texting while driving among young adults: Examining attention- and emotion-regulation motives as potential mediators. *Personality and Individual Differences, 51*(7), 856–861. https://doi.org/10.1016/j.paid.2011.07.020

Ferdinand, A. O., & Menachemi, N. (2014). *Associations between driving performance and engaging in secondary tasks: A systematic review*. American Journal of Public Health, 104(3), 39-48. https://doi.org/10.2105/AJPH.2013.301750

Fernandez, D. P., Kuss, D. J., & Griffiths, M. D. (2020). Short-term abstinence effects across potential behavioral addictions: A systematic review. *Clinical Psychology Review, 76*, 1-22. https://doi.org/10.1016/j.cpr.2020.101828

Fernandez, D. P., Kuss, D. J., & Griffiths, M. D. (2020). Short-term abstinence effects across potential behavioral addictions: A systematic review. *Clinical Psychology Review, 76*. https://doi.org/10.1016/j.cpr.2020.101828

Fischer, P. (2015). *Distracted & dangerous: Helping States keep teens focused on the road*. Governors Highway Safety Association. www.ghsa.org/sites/default/files/2016-11/TeenDistractedDriving%20Final%205.pdf

Fisher, D. L, Caird, J. K., Horrey, W. L., & Trick, L. M. (Eds.). (2017). *Handbook of teen and novice drivers: Research, practice, policy, and directions.* CRC Press LLC. www.routledge.com/Handbook-of-Teen-and-Novice-Drivers-Research-Practice-Policy-and-Directions/Fisher-Caird-Horrey-Trick/p/book/9780367868154

Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A. (2015). Drivers' visual behavior when using handheld and hands-free cellphones. *Journal of Safety Research 54*, 105-108. http://dx.doi.org/10.1016/j.jsr.2015.06.008

Flaherty, M. R., Kim, A. M., Salt, M. D., & Lee, L. K. (2020). Distracted driving laws and motor vehicle crash fatalities. *Pediatrics, 145*(6). https://doi.org/10.1542/peds.2019-3621

Foreman, A. M., Hayashi, Y., Friedel, J. E., & Wirth, O. (2019). Social distance and texting while driving: A behavioral economic analysis of social discounting. *Traffic Injury Prevention, 20*(7), 702–707. https://doi.org/10.1080/15389588.2019.1636233

Foss, R. D., & Goodwin, A. H. (2014). Distracted driver behaviors and distracting conditions among adolescent drivers: Findings from a naturalistic driving study. *Journal of Adolescent Health, 54*(5, Supplement), S50-S60. https://doi.org/10.1016/j.jadohealth.2014.01.005

Foss, R. D., Goodwin, A. H., McCartt, A. T., & Hellinga, L. A. (2009). Short-term effects of a teenage driver cellphone restriction. *Accident Analysis & Prevention, 41*(3), 419-424. https://doi.org/10.1016/j.aap.2009.01.004

Freeman, J., Kaye, S.-A., Truelove, V., & Davey, J. (2017). Age, gender and deterrability: Are younger male drivers more likely to discount the future? *Accident Analysis & Prevention, 104*, 1–9. https://doi.org/10.1016/j.aap.2017.03.022

Friedman Naomi, P. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General, 133*(1), 101-135. https://doi.org/10.1037/0096-3445.133.1.101

Fuller, R. (2011). Chapter 2 - Driver control theory: From task difficulty homeostasis to risk allostasis. In B. E. Porter (Ed.), *Handbook of traffic psychology*, (pp. 13-26). Academic Press. https://doi.org/10.1016/B978-0-12-381984-0.10002-5

Galandra, C., Basso, G., Cappa, S., & Canessa, N. (2018). The alcoholic brain: neural bases of impaired reward-based decision-making in alcohol use disorders. *Neurological Sciences, 39(*3), 423-435. https://doi.org/10.1007/s10072-017-3205-1

Gallina, A. (2020). *Vlogging: Just another unecessary distraction*. EndDD.org. www.enddd.org/end-distracted-driving/distracted-driving-updates/vlogging-just-another-unnecessary-distraction/

Gauld, C. S., Lewis, I. M., White, K. M., Fleiter, J. J., & Watson, B. (2019). Public education messages aimed at smartphone use among young drivers: A mixed methods exploration of their effectiveness. *Transportation Research Part F: Traffic Psychology and Behaviour, 60*, 311-326. https://doi.org/10.1016/j.trf.2018.10.027

Gauld, C. S., Lewis, I., & White, K. M. (2014). Concealing their communication: Exploring psychosocial predictors of young drivers' intentions and engagement in concealed texting. *Accident Analysis & Prevention, 62*, 285-293. http://dx.doi.org/10.1016/j.aap.2013.10.016

Gauld, C. S., Lewis, I., White, K. M., Fleiter, J. J., & Watson, B. (2017). Smartphone use while driving: What factors predict young drivers' intentions to initiate, read, and respond to social interactive technology? *Computers in Human Behavior, 76*, 174-183. https://doi.org/10.1016/j.chb.2017.07.023

George, A. M., Brown, P. M., Scholz, B., Scott-Parker, B., & Rickwood, D. (2018). "I need to skip a song because it sucks": Exploring cellphone use while driving among young adults. *Transportation Research Part F: Traffic Psychology and Behaviour*, *58*, 382–391. https://doi.org/10.1016/j.trf.2018.06.014

Gerte, R., Enam, A., Konduri, K. C., Ramachandran, N., Dalal, D. (2018). *Understanding the psychological factors underlying smartphone related distracted driving: Exploratory analysis using a nationwide survey.* New England University Transportation Center. https://trid.trb.org/view/1593386

Gibson, J. J., & Crooks, L. E. (1938). A theoretical field-analysis of automobile-driving. *The American Journal of Psychology, 51*(3), 453-471. https://doi.org/10.2307/1416145

Glendon, A. I., Clarke, S., & McKenna, E. F. (2006). *Human safety and risk management*. CRC Press LLC. www.routledge.com/Human-Safety-and-Risk-Management-A-Psychological-Perspective-Third-Edition/Glendon-Clarke/p/book/9781138747340

Gliklich, E., Guo, R., & Bergmark, R. W. (2016). Texting while driving: A study of 1211 U.S. adults with the Distracted Driving Survey. *Preventive Medicine Reports, 4*, 486–489. https://doi.org/10.1016/j.pmedr.2016.09.003

Gonçalves, S., Dias, P., & Correia, A.-P. (2020). Nomophobia and lifestyle: Smartphone use and its relationship to psychopathologies. *Computers in Human Behavior Reports, 2*, 1-8. https://doi.org/10.1016/j.chbr.2020.100025

Goodwin, A. H., O'Brien, N. P., & Foss, R. D. (2012). Effect of North Carolina's restriction on teenage driver cellphone use two years after implementation. *Accident Analysis & Prevention, 48*, 363-367. https://doi.org/10.1016/j.aap.2012.02.006

Governors Highway Safety Association. (2020, July). *Distracted driving laws by State*. Governors Highway Safety Association. www.ghsa.org/index.php/state-laws/issues/distracted%20driving%20%20

Grant, J. E., Potenza, M. N., Weinstein, A., & Gorelick, D. A. (2010). Introduction to behavioral addictions. *The American Journal of Drug and Alcohol Abuse, 36*(5), 233-241. https://doi.org/10.3109/00952990.2010.491884

Gray, C. (2015). Texting while driving: A test of self-control theory. *Sociology & Criminal Justice Theses & Dissertations*. https://doi.org/10.25777/pt6w-dk65

Griffiths, M. (1996). Behavioural addictions. *Psychology Review, 3*(2), 9-12. Griffiths, M. (2005). A 'components' model of addiction within a biopsychosocial framework. *Journal of Substance Use, 10*(4), 191-197. https://doi.org/10.1080/14659890500114359

Groom, M., van Loon, E., Daley, D., Chapman, P., & Hollis, C. (2015). Driving behaviour in adults with attention deficit/hyperactivity disorder. *BMC Psychiatry, 15*(175), 1-11. http://dx.doi.org/10.1186/s12888-015-0566-y

Guo, F., & Fang, Y. (2013). Individual driver risk assessment using naturalistic driving data. *Accident Analysis & Prevention, 61*, 3-9. https://doi.org/10.1016/j.aap.2012.06.014

Guttman, N., & Gesser-Edelsburg, A. (2011). "The little squealer" or "the virtual guardian angel"? Young drivers' and their parents' perspective on using a driver monitoring technology and its implications for parent-young driver communication. *Journal of Safety Research, 42*(1), 51-59. https://doi.org/10.1016/j.jsr.2010.11.001

Güzeller, C. O., & Coşguner, T. (2012). Development of a problematic cellphone use scale for Turkish adolescents. *Cyberpsychology, Behavior and Social Networking, 15*(4), 205–211. https://doi.org/10.1089/cyber.2011.0210

Gwyther, H., & Holland, C. (2012). The effect of age, gender and attitudes on self-regulation in driving. *Accident Analysis & Prevention, 45*, 19-28. https://doi.org/10.1016/j.aap.2011.11.022

Ha, J. H., Chin, B., Park, D.-H., Ryu, S.-H., & Yu, J. (2008). Characteristics of excessive cellular phone use in Korean adolescents. *CyberPsychology & Behavior, 11*(6), 783-784. https://doi.org/10.1089/cpb.2008.0096

Hamari, J., Malik, A., Koski, J., & Johri, A. (2019). Uses and gratifications of Pokémon Go: Why do people play mobile location-based augmented reality games? *International Journal of Human–Computer Interaction, 35*(9), 804-819. https://doi.org/10.1080/10447318.2018.1497115

Hansma, B. J., Marulanda, S., Chen, H.-Y. W., & Donmez, B. (2020). Role of habits in cell phone-related driver distractions. *Transportation Research Record, 264*(12), 254-262 https://doi.org/10.1177/0361198120953157

Harkin, L. J., & Kuss, D. (2020). "My smartphone is an extension of myself": A holistic qualitative exploration of the impact of using a smartphone. *Psychology of Popular Media*, 1-11. https://doi.org/10.1037/ppm0000278

Harris, B., Regan, T., Schueler, J., & Fields, S. A. (2020). Problematic cellphone and smartphone use scales: A Systematic Review. *Frontiers in Psychology, 11*, 1-24. https://doi.org/10.3389/fpsyg.2020.00672

Hartney, E. (2020). *The difference between an addiction and a compulsion.* Very Well Mind. www.verywellmind.com/the-difference-between-an-addiction-and-a-compulsion-22240

Hayashi, Y., Foreman, A. M., Friedel, J. E., & Wirth, O. (2019). Threat appeals reduce impulsive decision making associated with texting while driving: A behavioral economic approach. *PloS One, 14*(3), 1-19. https://doi.org/10.1371/journal.pone.0213453

Hayashi, Y., Miller, K., Foreman, A. M., & Wirth, O. (2016). A behavioral economic analysis of texting while driving: Delay discounting processes. *Accident Analysis and Prevention, 97*, 132–140. https://doi.org/10.1016/j.aap.2016.08.028

Hayashi, Y., Rivera, E. A., Modico, J. G., Foreman, A. M., & Wirth, O. (2017). Texting while driving, executive function, and impulsivity in college students. *Accident Analysis and Prevention, 102*, 72–80. https://doi.org/10.1016/j.aap.2017.02.016

Hayashi, Y., Russo, C. T., & Wirth, O. (2015). Texting while driving as impulsive choice: A behavioral economic analysis. *Accident Analysis and Prevention, 83*, 182–189. https://doi.org/10.1016/j.aap.2015.07.025

He, J., McCarley, J. S., Crager, K., Jadliwala, M., Hua, L., & Huang, S. T. (2018). Does wearable device bring distraction closer to drivers? Comparing smartphones and Google Glass. *Applied Ergonomics, 70*, 156-166. https://doi.org/10.1016/j.apergo.2018.02.022

Heineman, K. (2012). *Technology can detect driver phone use*. Inside Science. American Institute of Physics. https://www.insidescience.org/video/technology-can-detect-driver-phone-use

Hill, L., Baird, S., Al-wahab, U., Larocca, J., Chukwueke, J., Engelberg, J., Engler, A.-M., Jahns, & J., Rybar, J., (2017). *Distracted driving behaviors and beliefs among older adults: A LongROAD analysis of the Training, Research, and Education for Driving Safety study*. AAA Foundation for Traffic Safety. https://aaafoundation.org/distracted-driving-behaviors-beliefs-among-older-adults-longroad-analysis-training-research-education-driving-safety-study/

Hill, L., Rybar, J., Styer, T., Fram, E., Merchant, G., & Eastman, A. (2015). Prevalence of and attitudes about distracted driving in college students. *Traffic Injury Prevention, 16*(4), 362-367. https://doi.org/10.1080/15389588.2014.949340

Hoekstra-Atwood, L. (2015). *Driving under involuntary and voluntary distraction: Individual differences and effects on driving performance*. [Master's thesis, Department of Mechanical and Industrial Engineering, University of Toronto].

Hoekstra-Atwood, L., Chen, H.-Y. W., & Donmez, B. (2017). Simulator study of involuntary driver distraction under different perceptual loads. *Transportation Research Record, 2663*(1), 12–19. https://doi.org/10.3141/2663-02

Horrey, W. J., Lesch, M. F., & Garabet, A. (2008). Assessing the awareness of performance decrements in distracted drivers. *Accident Analysis & Prevention, 40*(2), 675–682.

Horvath, J., Mundinger, C., Schmitgen, M. M., Wolf, N. D., Sambataro, F., Hirjak, D., Kubera, K. M., Koenig, J., & Wolf, R. C. (2020). Structural and functional correlates of smartphone addiction. *Addictive Behaviors, 105*, 1-7. https://doi.org/10.1016/j.addbeh.2020.106334

Horwood, S., & Anglim, J. (2019). Problematic smartphone usage and subjective and psychological well-being. *Computers in Human Behavior, 97*, 44-50. https://doi.org/10.1016/j.chb.2019.02.028

Hughes, N., & Burke, J. (2018). Sleeping with the frenemy: How restricting 'bedroom use' of smartphones impacts happiness and wellbeing. *Computers in Human Behavior, 85*, 236-244. https://doi.org/10.1016/j.chb.2018.03.047

Ianzito, C. (2019). *Cellphone addiction is fueling distracted driving*. AARP. www.aarp.org/auto/driver-safety/info-2019/texting-increases-distracted-driving.html

Insurance Institute for Highway Safety. (2019). Talking not texting accounts for most phone use, drivers say. (2019). *Status Report, 54*(1), 4. www.iihs.org/iihs/sr/statusreport/article/54/1/2

Insurance Institute for Highway Safety. (2020). *Topic: Distracted driving.* Insurance Institute for Highway Safety – Highway Loss Data Institute. www.iihs.org/topics/distracted-driving

Intini, P., Colonna, P., & Ryeng, E. O. (2019). Route familiarity in road safety: A literature review and an identification proposal. *Transportation Research Part F: Traffic Psychology and Behaviour, 62*, 651-671. http://dx.doi.org/10.1016/j.trf.2018.12.020

Iseland, T., Johansson, E., Skoog, S., & Dåderman, A. M. (2018). An exploratory study of long-haul truck drivers' secondary tasks and reasons for performing them. *Accident Analysis & Prevention, 117*, 154–163. https://doi.org/10.1016/j.aap.2018.04.010

Jang, H. J. (2002). *The psychological characteristics of adolescents addictive using cellular phone*. [Unpublished Master's thesis, Sungshin Women's University, Seoul].

Jenaro, C., Flores, N., Gómez-Vela, M., González-Gil, F., & Caballo, C. (2007). Problematic internet and cell-phone use: Psychological, behavioral, and health correlates, *Addiction Research & Theory, 15*(3), 309-320, https://doi.org/10.1080/16066350701350247

Jentsch, J. D., & Taylor, J. R. (1999). Impulsivity resulting from frontostriatal dysfunction in drug abuse: implications for the control of behavior by reward-related stimuli. *Psychopharmacology, 146*(4), 373-390. https://doi.org/10.1007/PL00005483

Jung, T., Kaß, C., Zapf, D., & Hecht, H. (2019). Effectiveness and user acceptance of infotainment-lockouts: A driving simulator study. *Transportation Research Part F: Traffic Psychology and Behaviour, 60*, 643-656. https://doi.org/10.1016/j.trf.2018.12.001

Kardefelt-Winther, D. (2015). Commentary on: Are we overpathologizing everyday life? A tenable blueprint for behavioral addiction research. *Journal of Behavioral Addictions, 4*(3), 126. https://doi.org/10.1556/2006.4.2015.019

Kaviani, F., Robards, B., Young, K. L., & Koppel, S. (2020). Nomophobia: Is the fear of being without a smartphone associated with problematic use? *International Journal of Environmental Research and Public Health*, *17*(17). https://doi.org/10.3390/ijerph17176024

Kaviani, F., Young, K. L., Robards, B., & Koppel, S. (2020). Nomophobia and self-reported smartphone use while driving: An investigation into whether nomophobia can increase the likelihood of illegal smartphone use while driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 74*, 212-224. https://doi.org/10.1016/j.trf.2020.08.024

Kidd, D. G., & McCartt, A. T. (2015). *The relevance of crash type and severity when estimating crash risk using the SHRP2 naturalistic driving data*. In Proceedings of the 4th International Driver Distraction and Inattention Conference. ARRB Group, Limited. https://trid.trb.org/view/1402259

Kidd, D. G., Dobres, J., Reagan, I., Mehler, B., & Reimer, B. (2017). Considering visual-manual tasks performed during highway driving in the context of two different sets of guidelines for embedded in-vehicle electronic systems. *Transportation Research Part F: Traffic Psychology and Behaviour, 47*, 23-33. https://doi.org/10.1016/j.trf.2017.04.002

Kim, E., & Koh, E. (2018). Avoidant attachment and smartphone addiction in college students: The mediating effects of anxiety and self-esteem. *Computers in Human Behavior, 84*, 264-271. https://doi.org/10.1016/j.chb.2018.02.037

Kim, K., Ghimire, J., Pant, P., & Yamashita, E. (2019). Self-reported handheld device use while driving. *Accident Analysis & Prevention, 125*, 106-115. http://dx.doi.org/10.1016/j.aap.2019.01.032

King, A. L. S., Valença, A. M., Silva, A. C., Sancassiani, F., Machado, S., & Nardi, A. E. (2014). "Nomophobia": Impact of cellphone use interfering with symptoms and emotions of people with panic disorder compared with a control group. *Clinical Practice and Epidemiology in Mental Health, 10*(1), 28-35. https://doi.org/10.2174/1745017901410010028

King, H. (2016). *Snapchat speed filter blamed for 107-MPH highway accident.* CNN Business. https://money.cnn.com/2016/04/26/technology/snapchat-speed-filter/

Kinnear, N., & Stevens, A. (2015). *The battle for attention: Driver distraction—A review of recent research and knowledge.* IAM Roadsmart.http://www.iamroadsmart.com/docs/default-source/research-reports/report---the-battle-for-attention-v3.pdf

Kita, E., & Luria, G. (2018). The mediating role of smartphone addiction on the relationship between personality and young drivers' smartphone use while driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 59*(Part A), 203–211. https://doi.org/10.1016/j.trf.2018.09.001

Klauer, S. G., Sayer, T. B., Baynes, P., & Ankem, G. (2016). Using real-time and post hoc feedback to improve driving safety for novice drivers. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 60*(1), 1936-1940. https://doi.org/10.1177/1541931213601441

Kloker, S. (2020). Non-addictive information systems. *Information Systems Frontiers, 22*(3), 549-562. https://doi.org/10.1007/s10796-020-10011-w

Kneidinger-Müller, B. (2019). When the smartphone goes offline: A factorial survey of smartphone users' experiences of mobile unavailability. *Computers in Human Behavior, 98*, 1-10. https://doi.org/10.1016/j.chb.2019.03.037

Kruger, D. J., & Djerf, J. M. (2017). Bad vibrations? Cellphone dependency predicts phantom communication experiences. Computers in Human Behavior, 70, 360-364. https://doi.org/10.1016/j.chb.2017.01.017

Kuss, D. J., & Billieux, J. (2017). Technological addictions: Conceptualisation, measurement, etiology and treatment. *Addictive Behaviors, 64*, 231-233. https://doi.org/10.1016/j.addbeh.2016.04.005

Kuss, D. J., & Griffiths, M. D. (2017). Social networking sites and addiction: Ten lessons learned. *International Journal of Environmental Research and Public Health, 14*(3), 311.

Kuss, D. J., Kanjo, E., Crook-Rumsey, M., Kibowski, F., Wang, G. Y., & Sumich, A. (2018). Problematic cellphone use and addiction across generations: The roles of psychopathological symptoms and smartphone use. *Journal of Technology in Behavioral Science, 3*(3), 141-149. https://doi.org/10.1007/s41347-017-0041-3

Kuss, D. J., Pontes, H. M., & Griffiths, M. D. (2018). Neurobiological correlates in internet gaming disorder: A Systematic Literature Review. *Frontiers in Psychiatry, 9*, 166. https://doi.org/10.3389/fpsyt.2018.00166

Kwon, M., Kim, D.J., Cho, H., & Yang, S., (2013). The smartphone addiction scale: Development and validation of a short version for adolescents. *PLOS ONE 8*(12), 1-7. https://doi.org/10.1371/journal.pone.0083558

Lannoy, S., Chatard, A., Selimbegovic, L., Tello, N., Van der Linden, M., Heeren, A., & Billieux, J. (2020). Too good to be cautious: High implicit self-esteem predicts self-reported dangerous cellphone use. *Computers in Human Behavior, 103*, 208–213. https://doi.org/10.1016/j.chb.2019.09.018

Lansdown, T. C. (2012). Individual differences and propensity to engage with in-vehicle distractions – A self-report survey. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(1), 1-8. https://doi.org/10.1016/j.trf.2011.09.001

Lansdown, T. C., Stephens, A. N., & Walker, G. H. (2015). driver distractions: A systemic transport problem. *Accident Analysis & Prevention, 74*, 360-367. https://doi.org/10.1016/j.aap.2014.07.006

Lantz, G., & Loeb, S. (2013). An exploratory study of psychological tendencies related to texting while driving. *International Journal of Sustainable Strategic Management*, *4*(1), 39-49. http://dx.doi.org/10.1504/IJSSM.2013.056384

LaRose, R., & Eastin, M. S. (2004). A social cognitive theory of internet uses and gratifications: Toward a new model of media attendance. *Journal of Broadcasting & Electronic Media, 48*(3), 358-377. https://doi.org/10.1207/s15506878jobem4803_2

LaRose, R., Lin, C. A., & Eastin, M. S. (2003). Unregulated internet usage: Addiction, habit, or deficient self-regulation? *Media Psychology, 5*(3), 225-253. http://dx.doi.org/10.1207/S1532785XMEP0503_01

LaVoie, N., Lee, Y.-C., & Parker, J. (2016). Preliminary research developing a theory of cell phone distraction and social relationships. *Accident Analysis & Prevention, 86*, 155-160. https://doi.org/10.1016/j.aap.2015.10.023

Lerner, N., Singer, J., & Huey, R. (2008). *Driver strategies for engaging in distracting tasks using in-vehicle technologies* (Report No. DOT HS 810 919). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/16514

Leung, L. (2007). Leisure boredom, sensation seeking, self-esteem, and addiction. In E. A. Konijn, S. Utz, M. Tanis, & S. B. Barnes (Eds.), *Mediated Interpersonal Communication* (pp. 359-381).

Leung, L. (2008). Linking psychological attributes to addiction and improper use of the mobile phone among adolescents in Hong Kong. *Journal of Children and Media, 2*(2), 93-113. https://doi.org/10.1080/17482790802078565

Li, L., Zhong, B., Hutmacher, C., Liang, Y., Horrey, W. J., & Xu, X. (2020). Detection of driver manual distraction via image-based hand and ear recognition. *Accident Analysis & Prevention, 137*, 1-10. https://doi.org/10.1016/j.aap.2020.105432

Liese, B. S., Benau, E. M., Atchley, P., Reed, D., Becirevic, A., & Kaplan, B. (2019). The Self-perception of Text-message Dependency Scale (STDS): Psychometric update based on a U.S. sample. *The American Journal of Drug and Alcohol Abuse*, *45*(1), 42–50. https://doi.org/10.1080/00952990.2018.1465572

Linkov, V., Zaoral, A., Řezáč, P., & Pai, C.-W. (2019). Personality and professional drivers' driving behavior. *Transportation Research Part F: Traffic Psychology and Behaviour, 60*, 105-110. https://doi.org/10.1016/j.trf.2018.10.017

Liu, S.-Y., Lee, J. D., Lee, J. Y., & Venkatraman, V. (2018). Glances that matter: Applying quantile regression to assess driver distraction from off-road glances. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 62*(1), 1954-1958. https://doi.org/10.1177/1541931218621443

Lopez-Fernandez, O. (2017). Short version of the Smartphone Addiction Scale adapted to Spanish and French: Towards a cross-cultural research in problematic cellphone use. *Addictive Behaviors, 64*, 275-280. https://doi.org/10.1016/j.addbeh.2015.11.013

Lopez-Fernandez, O., Honrubia-Serrano, L., Freixa-Blanxart, M., & Gibson, W. (2014). Prevalence of problematic cellphone use in British adolescents. *CyberPsychology, Behavior, and Social Networking, 17*(2), 91-98. https://doi.org/10.1089/cyber.2012.0260

Lopez-Fernandez, O., Männikkö, N., Kääriäinen, M., Griffiths, M. D., & Kuss, D. (2018). Mobile gaming and problematic smartphone use: A comparative study between Belgium and Finland*. Journal of Behavioral Addictions, 7*(1), 88-99. https://doi.org/10.1556/2006.6.2017.080

Louie, J. F., & Mouloua, M. (2019). Predicting distracted driving: The role of individual differences in working memory. *Applied Ergonomics, 74*, 154-161. https://doi.org/10.1016/j.apergo.2018.07.004

Lu, X., Katoh, T., Chen, Z., Nagata, T., & Kitamura, T. (2014). Text messaging: Are dependency and excessive use discretely different for Japanese university students? *Psychiatry Research, 216*(2), 255-262. https://doi.org/10.1016/j.psychres.2013.12.024

Macy, M. L., Carter, P. M., Bingham, C. R., Cunningham, R. M., & Freed, G. L. (2014). Potential distractions and unsafe driving behaviors among drivers of 1- to 12-year-old children. *Academic Pediatrics, 14*(3), 279-286. http://dx.doi.org/10.1016/j.acap.2014.02.010

Maier, C., Mattke, J., Pflügner, K., & Weitzel, T. (2020). Smartphone use while driving: A fuzzy-set qualitative comparative analysis of personality profiles influencing frequent high-risk smartphone use while driving in Germany. *International Journal of Information Management, 55*, 1-12. https://doi.org/10.1016/j.ijinfomgt.2020.102207

Marler, W. (2018). Mobile phones and inequality: Findings, trends, and future directions. *New Media & Society, 20*(9), 3498-3520. https://doi.org/10.1177/1461444818765154

Marulanda, S., Chen, H. Y. W., & Donmez, B. (2015). *Capturing voluntary, involuntary, and habitual components of driver distraction in a self-reported questionnaire*. 8th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.

Marulanda, S., Chen, H.-Y. W., Donmez, B., (2015). Capturing voluntary, involuntary, and habitual components of driver distraction in a self-reported questionnaire. In *Proceedings of the 2015 Driving Assessment Conference*. https://pubs.lib.uiowa.edu/driving/article/28543/galley/136835/download/

Mazaheri, M. A., & Najarkolaei, F. R. (2014). Cellphone and internet addiction among students in Isfahan university of medical sciences-Iran. *Journal of Health Policy and Sustainable Health, 1*(3).

McCartt, A. T., Hellinga, L. A., & Braitman, K. A. (2006). Cellphones and driving: Review of research. *Traffic Injury Prevention, 7*(2), 89-106. https://trid.trb.org/view/794323

McDonald, C. C., & Sommers, M. S. (2015). Teen drivers' perceptions of inattention and cell phone use while driving. *Traffic Injury Prevention, 16*(Supplement 2), S52-S58. https://doi.org/10.1080/15389588.2015.1062886

Mehler, B., Kidd, D., Reimer, B., Reagan, I., Dobres, J., & McCartt, A. (2016). Multi-modal assessment of on-road demand of voice and manual phone calling and voice navigation entry across two embedded vehicle systems. *Ergonomics, 59*(3), 344-367. https://doi.org/10.1080/00140139.2015.1081412

Mehrotra, S. K., Zhang, F., & Roberts, S. C. (2018). Evaluation and validation of distraction detection algorithms on data sources. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 62*(1), 1949-1953. https://doi.org/10.1177/1541931218621442

Meldrum, R. C., Boman, J. H., & Back, S. (2018). Low self-control, social learning, and texting while driving. *American Journal of Criminal Justice*. https://doi.org/10.1007/s12103-018-9448-4

Merrikhpour, M., & Donmez, B. (2017). Designing feedback to mitigate teen distracted driving: A social norms approach. *Accident Analysis & Prevention, 104*, 185-194. https://doi.org/10.1016/j.aap.2017.04.016

Merrikpour, M. (2017). *Utilizing social norms theory to mitigate teen driver distraction.* [Doctoral dissertation, University of Toronto]. https://hfast.mie.utoronto.ca/wp-content/uploads/Merrikhpour_Maryam_2017_PhD_Thesis.pdf

Meshi, D., Tamir, D. I., & Heekeren, H. R. (2015). The emerging neuroscience of social media. *Trends in Cognitive Sciences, 19*(12), 771-782. https://doi.org/10.1016/j.tics.2015.09.004

Mikoski, P., Zlupko, G., & Owens, D. A. (2019). Drivers' assessments of the risks of distraction, poor visibility at night, and safety-related behaviors of themselves and other drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 62*, 416-434. https://doi.org/10.1016/j.trf.2019.01.011

Mirman, J. H., Durbin, D. R., Lee, Y.-C., & Seifert, S. J. (2017). Adolescent and adult drivers' cellphone use while driving with different interlocutors. *Accident Analysis & Prevention, 104*, 18-23. http://dx.doi.org/10.1016/j.aap.2017.04.014

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49-100. https://doi.org/10.1006/cogp.1999.0734

Mollenhauer, M., Noble, A. M., & Doerzaph, Z. R. (2016). *Mobile user interface development for the Virginia Connected Corridors*. Virginia Tech Transportation Institute. http://cvi-utc.org/wp-content/uploads/2016/10/Mollenhauer_Mobile-User-Interface-Development-for-the-Virginia-Connected-Corridors_Final.pdf

Montag, C., Lachmann, B., Herrlich, M., & Zweig, K. (2019). Addictive features of social media/messenger platforms and freemium games against the background of psychological and economic theories. *International Journal of Environmental Research and Public Health*, *16*(14), 1-16. https://doi.org/10.3390/ijerph16142612

Moore, M. M., & Brown, P. M. (2019). The association of self-regulation, habit, and mindfulness with texting while driving. *Accident Analysis & Prevention, 123*, 20–28. https://doi.org/10.1016/j.aap.2018.10.013

Morgan, J., & Hancock, P. A. (2009). Estimations in driving. In C. Castro (Ed.), *Human factors of visual and cognitive performance in driving* (pp. 51–62). CRC Press/Taylor and Francis Company. www.taylorfrancis.com/books/9780429136719

Murphy, G., Gauld, C., & Lewis, I. (2020). Predicting the monitoring/reading of communications on a smartphone among young drivers using an extended theory of planned behaviour. *Accident Analysis & Prevention, 136*, 105403. https://doi.org/10.1016/j.aap.2019.105403

Musicant, O., Lotan, T., & Albert, G. (2015). Do we really need to use our smartphones while driving? *Accident Analysis & Prevention*, *85*, 13–21. https://doi.org/10.1016/j.aap.2015.08.023

Nakano, Y., Okamura, K., Kosuge, R., Kihira, M., & Fujita, G. (2019). Effect of visible presence of policing activities on drivers' vigilance and intention to refrain from non-driving activities: A scenario-based survey of general Japanese drivers. *Accident Analysis & Prevention, 133*, 1-9. https://doi.org/10.1016/j.aap.2019.105293

National Center for Statistics and Analysis. (2018). *Distracted driving 2016*. (Traffic Safety Facts Research Note. Report No. DOT HS 812 517). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812517

National Center for Statistics and Analysis. (2019). *Distracted driving in fatal crashes, 2017*. (Traffic Safety Facts Research Note. Report No. DOT HS 812 700). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812700

National Center for Statistics and Analysis. (2019). *Driver electronic device use in 2018* (Traffic Safety Facts Research Note. Report No. DOT HS 812 818). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812818

National Center for Statistics and Analysis. (2019). *2018 fatal motor vehicle crashes: Overview* (Traffic Safety Facts Research Note. Report No. DOT HS 812 826). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812826

National Driver Education Standards (2017). *Novice teen driver education and training administrative standards (NTDETAS) 2017 revision*. http://www.anstse.info/Resources%20PDF's/2019%20Resources/001%20-%202017%20NTDETAS%20FINAL%203-14-19.pdf

National Highway Traffic Safety Administration. (2010). *Overview of the National Highway Traffic Safety Administration's driver distraction program*. www.nhtsa.gov/sites/nhtsa.dot.gov/files/811299.pdf

National Highway Traffic Safety Administration (2014). *Guidelines for reducing visual-manual driver distraction during interactions with integrated, in-vehicle, electronic devices*. www.regulations.gov/document/NHTSA-2014-0088-0002

National Highway Traffic Safety Administration. (2020). *Fatality Analysis Reporting System* (FARS). [Data set]. https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars%20

National Highway Traffic Safety Administration. (2020). *Distracted driving 2018* (Traffic Safety Facts Research Note. Report No. DOT HS 812 926). https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812926

National Highway Traffic Safety Administration. (2020). *Visual-manual distraction guidelines conformance report*. [In press]. Battelle Memorial Institute.

National Traffic Law Center. (2017). *Investigation and prosecution of distracted driving cases* (Report No. DOT HS 812 407). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.gov/files/documents/812407-distracteddrivingreport.pdf

Nelson, E., Atchley, P., & Little, T. D. (2009). The effects of perception of risk and importance of answering and initiating a cellular phone call while driving. *Accident Analysis & Prevention, 41*(3), 438-444. https://doi.org/10.1016/j.aap.2009.01.006

Nemme, H. E., & White, K. M. (2010). Texting while driving: Psychosocial influences on young people's texting intentions and behaviour. *Accident Analysis & Prevention, 42*(4), 1257-1265. https://doi.org/10.1016/j.aap.2010.01.019

Neyens, D. M., & Boyle, L. N. (2007). The effect of distractions on the crash types of teenage drivers. *Accident Analysis & Prevention, 39*(1), 206-212. https://doi.org/10.1016/j.aap.2006.07.004

Neyman, C. J. (2017). A survey of addictive software design. *California Polytechnic State University*. https://digitalcommons.calpoly.edu/cscsp/111

Nichols, J. Q. V. A. (2018). Evaluating the effectiveness of an anti-texting-while-driving training program for young drivers: The role of ADHD symptomatology [ProQuest Information & Learning]. In *Dissertation Abstracts International: Section B: The Sciences and Engineering* (Vol. 78, Issues 12-B(E)). https://scholarworks.uvm.edu/graddis/768/

Niu, J., Wang, X., Liu, X., Wang, D., Qin, H., & Zhang, Y. (2019). Effects of cellphone use on driving performance in a multiresource workload scenario. *Traffic Injury Prevention, 20*(1), 37-44. https://doi.org/10.1080/15389588.2018.1527468

Noël, X., Brevers, D., & Bechara, A. (2013). A neurocognitive approach to understanding the neurobiology of addiction. *Current Opinion in Neurobiology, 23*(4), 632-638. https://doi.org/10.1016/j.conb.2013.01.018

Nowosielski, R. J., & Trick, L. M. (2019). How common in-car distractions affect driving performance in simple and complex road environment. *Accident Reconstruction Journal, 29*(4), 12-15. https://trid.trb.org/view/1663477

O'Connor, S. S., Shain, L. M., Whitehill, J. M., & Ebel, B. E. (2017). Measuring a conceptual model of the relationship between compulsive cellphone use, in-vehicle cellphone use, and motor vehicle crash. *Accident Analysis & Prevention, 99*, Part A, 372-378. https://doi.org/10.1016/j.aap.2016.12.016

O'Connor, S. S., Whitehill, J. M., King, K. M., Kernic, M. A., Boyle, L. N., Bresnahan, B. W., Mack, C. D., & Ebel, B. E. (2013). Compulsive cellphone use and history of motor vehicle crash. *Journal of Adolescent Health*, *53*(4), 512-519. http://dx.doi.org/10.1016/j.jadohealth.2013.05.015

O'Dea, S. (2020). *Daily time spent on mobile devices in the U.S. 2014-2021.* Statista. www.statista.com/statistics/1045353/mobile-device-daily-usage-time-in-the-us/

Ortiz, C., Ortiz-Peregrina, S., Castro, J. J., Casares-López, M., & Salas, C. (2018). Driver distraction by smartphone use (WhatsApp) in different age groups. *Accident Analysis & Prevention, 117*, 239-249. https://doi.org/10.1016/j.aap.2018.04.018

Ortiz, N. C., Ramnarayan, M., & Mizenko, K. (2017). Distraction and road user behavior: An observational pilot study across intersections in Washington, D.C. *Journal of Transport & Health, 7*, Part A, 13-22. https://doi.org/10.1016/j.jth.2017.05.362

Otto, J., Finley, K., Green, K., & Ward, N. (2019). *Understanding law enforcement attitudes and beliefs about traffic safety*. Western Transportation Institute. www.mdt.mt.gov/research/projects/trafficsafety-attitudes.shtml

Ouimet, M. C., Pradhan, A. K., Brooks-Russell, A., Ehsani, J. P., Berbiche, D., & Simons-Morton, B. G. (2015). Young drivers and their passengers: A systematic review of epidemiological studies on crash risk. *Journal of Adolescent Health, 57*(1, Supplement), S24-S35. https://doi.org/10.1016/j.jadohealth.2015.03.010

Oviedo-Trespalacios, O. (2018). Getting away with texting: Behavioural adaptation of drivers engaging in visual-manual tasks while driving. *Transportation Research Part A: Policy and Practice, 116*, 112-121. https://doi.org/10.1016/j.tra.2018.05.006

Oviedo-Trespalacios, O., Haque, M. M., King, M., & Washington, S. (2017). Self-regulation of driving speed among distracted drivers: An application of driver behavioral adaptation theory. *Traffic Injury Prevention, 18*(6), 599-605. https://doi.org/10.1080/15389588.2017.1278628

Oviedo-Trespalacios, O., Haque, M. M., King, M., & Washington, S. (2017). Speed adaptation behaviour of distracted drivers: The role of road infrastructure and traffic complexities. In *Proceedings of the Transportation Research Board, 96th Annual Meeting*. https://doi.org/10.13140/RG.2.2.34343.55207

Oviedo-Trespalacios, O., Haque, M. M., King, M., & Washington, S. (2017). Effects of road infrastructure and traffic complexity in speed adaptation behaviour of distracted drivers. *Accident; Analysis & Prevention, 101*, 67–77. https://doi.org/10.1016/j.aap.2017.01.018

Oviedo-Trespalacios, O., King, M., Vaezipour, A., & Truelove, V. (2019). Can our phones keep us safe? A content analysis of smartphone applications to prevent cellphone distracted driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 60*, 657-668. https://doi.org/10.1016/j.trf.2018.11.017

Oviedo-Trespalacios, O., Nandavar, S., & Haworth, N. (2019). How do perceptions of risk and other psychological factors influence the use of in-vehicle information systems (IVIS)? *Transportation Research Part F: Traffic Psychology and Behaviour, 67*, 113-122. https://doi.org/10.1016/j.trf.2019.10.011

Oviedo-Trespalacios, O., Nandavar, S., Newton, J. D. A., Demant, D., & Phillips, J. G. (2019). Problematic use of cellphones in Australia...Is it getting worse? *Frontiers in Psychiatry*, *10*, 105. https://doi.org/10.3389/fpsyt.2019.00105

Oviedo-Trespalacios, O., Williamson, A., & King, M. (2019). User preferences and design recommendations for voluntary smartphone applications to prevent distracted driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 64*, 47-57. https://doi.org/10.1016/j.trf.2019.04.018

Oxtoby, J., Schroeter, R., Johnson, D., & Kaye, S.-A. (2019). Using boredom proneness to predict young adults' cellphone use in the car and risky driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 65*, 457–468. https://doi.org/10.1016/j.trf.2019.08.008

Palat, B., Saint Pierre, G., & Delhomme, P. (2019). Evaluating individual risk proneness with vehicle dynamics and self-report data - Toward the efficient detection of At-risk drivers. *Accident Analysis & Prevention, 123*, 140-149. https://doi.org/10.1016/j.aap.2018.11.016

Panova, T., & Carbonell, X. (2018). Is smartphone addiction really an addiction? *Journal of Behavioral Addictions, 7*(2), 252-259. https://doi.org/10.1556/2006.7.2018.49

Parnell, K. J., Rand, J., & Plant, K. L. (2020). A diary study of distracted driving behaviours. *Transportation Research Part F: Traffic Psychology and Behaviour*, *74*, 1–14. https://doi.org/10.1016/j.trf.2020.08.003

Pavlou, D., Papadimitriou, E., Papantoniou, P., Yannis, G., & Papageorgiou, S. G. (2017). The impact of cognitive impairments on accident risk. *Berichte der Bundesanstalt fuer Strassenwesen. Unterreihe Fahrzeugtechnik* (117), 1-9. www.nrso.ntua.gr/geyannis/wp-content/uploads/geyannis-pc240.pdf

Peer, S., Muermann, A., & Sallinger, K. (2020). App-based feedback on safety to novice drivers: Learning and monetary incentives. *Transportation Research Part F: Traffic Psychology and Behaviour, 71*, 198-219. https://doi.org/10.1016/j.trf.2020.04.005

Pew Research Center (2019). *Mobile fact sheet*. www.pewresearch.org/internet/fact-sheet/mobile/

Pivetta, E., Harkin, L., Billieux, J., Kanjo, E., & Kuss, D. J. (2019). Problematic smartphone use: An empirically validated model. *Computers in Human Behavior, 100*, 105-117. https://doi.org/10.1016/j.chb.2019.06.013

Ponte, G., Baldock, M.R.J., & Thompson, J.P. (2016). *Examination of the effectiveness and acceptability of cellphone blocking technology among driver of corporate fleet vehicles*. Centre for Automotive Safety Research, Adelaide. http://casr.adelaide.edu.au/publications/list/?id=1675

Pope, C. N., Bell, T. R., & Stavrinos, D. (2017). Mechanisms behind distracted driving behavior: The role of age and executive function in the engagement of distracted driving. *Accident Analysis & Prevention, 98*, 123-129. https://doi.org/10.1016/j.aap.2016.09.030

Potenza, M. N. (2015). Helping people behave themselves: Identifying and treating behavioral addictions. In M. S. Ascher & P. Levounis (Eds.), *The behavioral addictions.* (pp. 3–7). American Psychiatric Publishing, Inc. https://doi.org/10.1176/appi.books.9781585625499

Prat, F., Gras, M. E., Planes, M., González-Iglesias, B., & Sullman, M. J. M. (2015). Psychological predictors of texting while driving among university students. *Transportation Research Part F: Traffic Psychology and Behaviour, 34*, 76-85. http://dx.doi.org/10.1016/j.trf.2015.07.023

Precht, L., Keinath, A., & Krems, J. F. (2017). Identifying effects of driving and secondary task demands, passenger presence, and driver characteristics on driving errors and traffic violations – Using naturalistic driving data segments preceding both safety critical events and matched baselines. *Transportation Research Part F: Traffic Psychology and Behaviour, 51*, 103-144. https://doi.org/10.1016/j.trf.2017.09.003

Purucker, C., Naujoks, F., Prill, A., & Neukum, A. (2017). Evaluating distraction of in-vehicle information systems while driving by predicting total eyes-off-road times with keystroke level modeling. *Applied Ergonomics, 58*, 543-554. https://doi.org/10.1016/j.apergo.2016.04.012

Qiao, N., & Bell, T. M. (2015). State all-driver distracted driving laws and high school students' texting while driving behavior. *Traffic Injury Prevention, 17*(1), 5-8. https://doi.org/10.1080/15389588.2015.1041112

Quisenberry, P. N. (2015). Texting and driving: Can it be explained by the general theory of crime? *American Journal of Criminal Justice, 40*(2), 303–316. https://doi.org/10.1007/s12103-014-9249-3

Rahman, M. M., Strawderman, L., Lesch, M. F., Horrey, W. J., Babski-Reeves, K., & Garrison, T. (2018). Modelling driver acceptance of driver support systems. *Accident Analysis and Prevention, 121*, 134-147. https://doi.org/10.1016/j.aap.2018.08.028

Ramnath, R., Kinnear, N., Chowdhury, S., & Hyatt, T. (2020). *Interacting with Android Auto and Apple CarPlay when driving: The effect on driver performance: A simulator study. IAM Roadsmart*. https://iamwebsite.blob.core.windows.net/media/docs/default-source/default-document-library/iam-roadsmart-trl-simulator-study_infotainment.pdf?sfvrsn=d873495c_2

Ranney, T. A. (2008). *Driver distraction: A review of the current state-of-knowledge* (Report No. DOT HS 810 787). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.dot.gov/files/810787_0.pdf

Reagan, I. J. & Cicchino, J. B. (2018). Do Not Disturb While Driving: Use of cellphone blockers among adult drivers. Insurance Institute for Highway Safety. www.iihs.org/topics/bibliography/ref/2179

Regan, M. A., Lee, J. D., & Young, K. L. (2008). *Driver distraction: Theory, effects, and mitigation*. CRC Press LLC. www.routledge.com/Driver-Distraction-Theory-Effects-and-Mitigation/Regan-Lee-Young/p/book/9780849374265

Regan, T., Harris, B., Van Loon, M., Nanavaty, N., Schueler, J., Engler, S., & Fields, S. A. (2020). Does mindfulness reduce the effects of risk factors for problematic smartphone use? Comparing frequency of use versus self-reported addiction. *Addictive Behaviors, 108*, 1-8. https://doi.org/10.1016/j.addbeh.2020.106435

Reimer, B., Mehler, B., D'Ambrosio, L. A., & Fried, R. (2010). The impact of distractions on young adult drivers with attention deficit hyperactivity disorder (ADHD). *Accident Analysis & Prevention, 42*(3), 842–851. https://doi.org/10.1016/j.aap.2009.06.021

Retting, R. (2020). *Pedestrian traffic fatalities by State*. Governors Highway Safety Organization. www.ghsa.org/resources/Pedestrians20

Richard, C. M., Campbell, J. L., Lichty, M. G., Brown, J. L., Chrysler, S., Lee, J. D., Boyle, L., & Reagle, G. (2012). *Motivations for speeding, Volume I: Summary report* (Report No. DOT HS 811 658). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1938

Richard, C. M., Joonbum, L., Brown, J. L., & Landgraf, A. (2020). *Analysis of SHRP2 speeding data* (Report No. DOT HS 812 858). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/44242

Richard, C. M., Magee, K., Bacon-Abdelmoteleb, P., Brown, J. L. (2018). *Countermeasures That Work: A highway safety countermeasure guide for State Highway Safety Offices, ninth edition* (Report No. DOT HS 812 478). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.gov/files/documents/812478_countermeasures-that-work-a-highway-safety-countermeasures-guide-.pdf

Richard, C., Campbell, J., Lichty, M., Brown, J., Chrysler, S., Lee, J., Boyle, L., & Reagle, G. (2013). *Motivations for speeding, volume II: Findings report* (Report No. DOT HS 811 818). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1962

Robbins, T., Cador, M., Taylor, J., & Everitt, B. (1989). Limbic-striatal interactions in reward-related processes. *Neuroscience & Biobehavioral Reviews, 13*(2-3), 155-162.

Roberts, J. A., Pullig, C., & Manolis, C. (2015). I need my smartphone: A hierarchical model of personality and cell-phone addiction. *Personality and Individual Differences, 79*, 13-19. https://doi.org/10.1016/j.paid.2015.01.049

Roberts, J., Yaya, L., & Manolis, C. (2014). The invisible addiction: Cell-phone activities and addiction among male and female college students. *Journal of Behavioral Addictions, 3*(4), 254-265. https://doi.org/10.1556/jba.3.2014.015

Roberts, S. C., Ghazizadeh, M., & Lee, J. D. (2012). Warn me now or inform me later: Drivers' acceptance of real-time and post-drive distraction mitigation systems. *International Journal of Human-Computer Studies, 70*(12), 967-979. https://doi.org/10.1016/j.ijhcs.2012.08.002

Rosenberg, K. P., & Feder, L. C. (Eds.). (2014). *Behavioral addictions: Criteria, evidence, and treatment*. Academic Press. https://doi.org/10.1016/C2012-0-02731-7

Rowe, R., Andrews, E., Harris, P. R., Armitage, C. J., McKenna, F. P., & Norman, P. (2016). Identifying beliefs underlying pre-drivers' intentions to take risks: An application of the theory of planned behaviour. *Accident Analysis & Prevention, 89*, 49-56. https://doi.org/10.1016/j.aap.2015.12.024

Rudisill, T. M., Baus, A. D., & Jarrett, T. (2019). Challenges of enforcing cellphone use while driving laws among police: A qualitative study. *Injury Prevention, 25*(6), 494-500. https://doi.org/10.1136/injuryprev-2018-042931

Sadoff, R. L., Drogin, E. Y., & Gurmu, S. (2015). Forensic implications of behavioral addictions. In M. S. Ascher & P. Levounis (Eds.), *The behavioral addictions* (pp. 9–26). American Psychiatric Publishing Inc.

SAE International. (2015, June). *Navigation and route guidance function accessibility while driving* (STABILIZED Jun 2015) J2364_201506. www.sae.org/standards/content/j2364_201506/

Sahin, S., Ozdemir, K., Unsal, A., & Temiz, N. (2013). Evaluation of cellphone addiction level and sleep quality in university students. *Pakistan Journal of Medical Sciences, 29*(4), 913. https://doi.org/10.12669/pjms.294.3686

Salehan, M., & Negahban, A. (2013). Social networking on smartphones: When cellphones become addictive. *Computers in Human Behavior, 29*(6), 2632-2639. https://doi.org/10.1016/j.chb.2013.07.003

Salmon, P. M., Read, G. J. M., Beanland, V., Thompson, J., Filtness, A. J., Hulme, A., McClure, R., & Johnston, I. (2019). Bad behaviour or societal failure? Perceptions of the factors contributing to drivers' engagement in the fatal five driving behaviours. *Applied Ergonomics, 74*, 162-171. https://doi.org/10.1016/j.apergo.2018.08.008

Sanbonmatsu, D. M., Strayer, D. L., Behrends, A. A., Ward, N., & Watson, J. M. (2016). Why drivers use cellphones and support legislation to restrict this practice. *Accident Analysis & Prevention, 92*, 22-33. https://doi.org/10.1016/j.aap.2016.03.010

Sanbonmatsu, D. M., Strayer, D. L., Biondi, F., Behrends, A. A., & Moore, S. M. (2017). *Cell phone use diminishes self-awareness of the adverse effects of cellphone use on driving.* Mountain-Plains Consortium, University of Utah. http://www.ugpti.org/resources/reports/downloads/mpc17-322.pdf

Sapacz, M., Rockman, G., & Clark, J. (2016). Are we addicted to our cellphones? *Computers in Human Behavior, 57*, 153-159. https://doi.org/10.1016/j.chb.2015.12.004

Schick, A., Vegega, M., & Chaudhary, N. (2014, April). *Distracted driving high-visibility enforcement demonstrations in California and Delaware*. (Traffic Tech. Report No. DOT HS 811 993). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/2022

Schmuck, D., Karsay, K., Matthes, J., & Stevic, A. (2019). "Looking up and feeling down." The influence of mobile social networking site use on upward social comparison, self-esteem, and well-being of adult smartphone users. *Telematics and Informatics, 42*, 1-12. https://doi.org/10.1016/j.tele.2019.101240

Schneider, H., Pfetzer, E., Black, W., Dickey, J., (2017). *Factors influencing seatbelt utilization in Louisiana and strategies to improve usage rate*. Louisiana Transportation Research Center. (FHWA Report No. FHWA/LA.16/572).

Schroeder, P., Meyers, M., & Kostyniuk, L. (2013). *National survey on distracted driving attitudes and behaviors – 2012* (Report No. DOT HS 811 729). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.dot.gov/files/811729.pdf

Schroeder, P., Wilbur, M., & Peña, R. (2018). *National survey on distracted driving attitudes and behaviors - 2015* (Report No. DOT HS 812 461). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.gov/files/documents/13123-2015_natl_survey_distracted_driving_031418_v5_tag.pdf

Scott-Parker, B., & Weston, L. (2017). Sensitivity to reward and risky driving, risky decision making, and risky health behaviour: A literature review. *Transportation Research Part F: Traffic Psychology and Behaviour, 49*, 93-109. https://doi.org/10.1016/j.trf.2017.05.008

Senserrick, T., Scott-Parker, B., Buckley, L., & Watson, B. (2016). Influences on novice drivers' speed selection: A review. In *Proceedings of the Transportation Research Board (TRB) 95th Annual Meeting*, 1-25. https://eprints.qut.edu.au/92409/

Shaw, F. A., Malokin, A., Mokhtarian, P. L., & Circella, G. (2019). It's not all fun and games: An investigation of the reported benefits and disadvantages of conducting activities while commuting. *Travel Behaviour and Society, 17*, 8-25. https://doi.org/10.1016/j.tbs.2019.05.008

Shaw, F. A., Park, S. J., Bae, J., Becerra, Z., Corso, G. M., Rodgers, M. O., & Hunter, M. P. (2019). Effects of roadside distractors on performance of drivers with and without attention deficit tendencies. *Transportation Research Part F: Traffic Psychology and Behaviour, 61*, 141-151. http://dx.doi.org/10.1016/j.trf.2018.02.013

Shevlin, B. R. K., & Goodwin, K. A. (2019). Past behavior and the decision to text while driving among young adults. *Transportation Research Part F: Traffic Psychology and Behaviour, 60*, 58-67. http://dx.doi.org/10.1016/j.trf.2018.09.027

Shinar, D. (2017). *Traffic safety and human behavior* (2nd ed.). Emerald Publishing Limited. https://books.emeraldinsight.com/page/detail/Traffic-Safety-and-Human-Behavior/?k=9781786352224

Simmons, S. M., Caird, J. K., & Steel, P. (2017). A meta-analysis of in-vehicle and nomadic voice-recognition system interaction and driving performance. *Accident Analysis & Prevention, 106*, 31-43. https://doi.org/10.1016/j.aap.2017.05.013

Simmons, S. M., Hicks, A., & Caird, J. K. (2016). Safety-critical event risk associated with cell phone tasks as measured in naturalistic driving studies: A systematic review and meta-analysis. *Accident Analysis & Prevention, 87*, 161-169. https://doi.org/10.1016/j.aap.2015.11.015

Simons-Morton, B. G., Bingham, C. R., Ouimet, M. C., Pradhan, A. K., Chen, R., Barretto, A., & Shope, J. T. (2013). The effect on teenage risky driving of feedback from a safety monitoring system: A randomized controlled trial. *Journal of Adolescent Health, 53*(1), 21-26. https://doi.org/10.1016/j.jadohealth.2012.11.008

Slavin, R. E. (1986). Best-evidence synthesis: An alternative to meta-analytic and traditional reviews. *Educational Researcher, 15*(9), 5-11. https://doi.org/10.3102/0013189X015009005

Slavin, R. E. (1987). Best-evidence synthesis: Why less is more. *Educational Researcher, 16*(4), 15-16. https://doi.org/10.3102/0013189X016004015

Smith, C. (2017). *Someone found a way to hack Pokemon Go's speed restrictions.* BGR. https://bgr.com/2017/03/20/pokemon-go-speed-limit-bypass-trick/

Sprattler, K. (2013). *Distracted driving: Survey of the States*. Governors Highway Safety Association. www.ghsa.org/resources/2013distracted%20

Stanford, M. S., Mathias, C. W., Dougherty, D. M., Lake, S. L., Anderson, N. E., & Patton, J. H. (2009). Fifty years of the Barratt Impulsiveness Scale: An update and review. *Personality and Individual Differences, 47*(5), 385-395. https://doi.org/10.1016/j.paid.2009.04.008

State Farm Mutual Automobile Insurance Company (2016). *Smartphones while driving: We know it's risky. So why do we do it?* State Farm. https://newsroom.statefarm.com/8th-state-farm-distracted-driving-survey

Stavrinos, D., Jones, J. L., Garner, A. A., Griffin, R., Franklin, C. A., Ball, D., Welburn, S. C., Ball, K. K., Sisiopiku, V. P., & Fine, P. R. (2013). Impact of distracted driving on safety and traffic flow. *Accident Analysis & Prevention, 61*, 63-70. http://dx.doi.org/10.1016/j.aap.2013.02.003

Stavrinos, D., Pope, C. N., Shen, J., & Schwebel, D. C. (2018). Distracted walking, bicycling, and driving: Systematic review and meta-analysis of mobile technology and youth crash risk. *Child Development, 90*(3), 118-128. https://doi.org/10.1111/cdev.12827

Steadman, M., Chao, M. S., Strong, J. T., Maxwell, M., & West, J. H. (2014). CU L8ter: YouTube distracted driving PSAs use of behavior change theory. *American Journal of Health Behavior, 38*(1), 3-12. https://doi.org/10.5993/ajhb.38.1.1

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review, 28*(1), 78-106. https://doi.org/10.1016/j.dr.2007.08.002

Steinberger, F., Moeller, A., & Schroeter, R. (2016). The antecedents, experience, and coping strategies of driver boredom in young adult males. *Journal of Safety Research, 59*, 69–82. https://doi.org/10.1016/j.jsr.2016.10.007

Strayer, D. L., Cooper, J. M., McCarty, M. M., Getty, D. J., Wheatley, C. L., Motzkus, C. J., Goethe, R. M., Biondi, F., & Horrey, W. J. (2019). Visual and cognitive demands of CarPlay, Android Auto, and five native infotainment systems. *Human Factors, 61*(8), 1371-1386. https://doi.org/10.1177/0018720819836575

Struckman-Johnson, C., Gaster, S., Struckman-Johnson, D., Johnson, M., & May-Shinagle, G. (2015). Gender differences in psychosocial predictors of texting while driving. *Accident; Analysis and Prevention*, *74*, 218–228. https://doi.org/10.1016/j.aap.2014.10.001

Suckling, J., & Nestor, L. J. (2017). The neurobiology of addiction: the perspective from magnetic resonance imaging present and future. *Addiction, 112*(2). https://doi.org/10.1111/add.13474

Sullman, M. J. M., Hill, T., & Stephens, A. N. (2018). Predicting intentions to text and call while driving using the theory of planned behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour, 58*, 405-413. https://dx.doi.org/10.1016/j.trf.2018.05.002

Sullman, M. J. M., Przepiorka, A. M., Prat, F., & Blachnio, A. P. (2018). The role of beliefs in the use of hands-free and handheld cellphones while driving. *Journal of Transport & Health, 9*, 187-194. https://doi.org/10.1016/j.jth.2018.04.001

Takao, M., Takahashi, S., & Kitamura, M. (2009). Addictive personality and problematic mobile phone use. *CyberPsychology & Behavior, 12*(5), 501-507. https://doi.org/10.1089/cpb.2009.0022

Tanis, M., Beukeboom, C. J., Hartmann, T., & Vermeulen, I. E. (2015). Phantom phone signals: An investigation into the prevalence and predictors of imagined cellphone signals. *Computers in Human Behavior, 51*, 356-362. https://doi.org/10.1016/j.chb.2015.04.039

Tannenbaum, C., Greaves, L., & Graham, I. D. (2016). Why sex and gender matter in implementation research. *BMC Medical Research Methodology, 16*(1), 145. https://doi.org/10.1186/s12874-016-0247-7

Tarabay, R., & Abou-Zeid, M. (2018). Assessing the effects of auditory-vocal distraction on driving performance and physiological measures using a driving simulator. *Transportation Research Part F: Traffic Psychology and Behaviour, 58*, 351-364. https://doi.org/10.1016/j.trf.2018.06.026

Tavakolizadeh, J., Atarodi, A., Ahmadpour, S., & Pourgheisar, A. (2014). The prevalence of excessive cellphone use and its relation with mental health status and demographic factors among the students of Gonabad University of Medical Sciences in 2011-2012. *Razavi International Journal of Medicine, 2*(1), 15-27.

Tay, R., & Knowles, D. (2004). Driver inattention: Drivers' perception of risks and compensating behaviours. *IATSS Research, 28*(1), 89-94. https://doi.org/10.1016/S0386-1112(14)60095-9

Terry, C. P., & Terry, D. L. (2015). Cellphone-related near accidents among young drivers: Associations with mindfulness. *The Journal of Psychology: Interdisciplinary and Applied*, *149*(7), 665–683. https://doi.org/10.1080/00223980.2014.964166

Thege, B. K., Woodin, E. M., Hodgins, D. C., & Williams, R. J. (2015). Natural course of behavioral addictions: A 5-year longitudinal study. *BMC Psychiatry, 15*(1), 4. https://bmcpsychiatry.biomedcentral.com/articles/10.1186/s12888-015-0383-3

Thomée, S., Härenstam, A., & Hagberg, M. (2011). Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults-a prospective cohort study. *BMC Public Health, 11*(1), 66. https://doi.org/10.1186/1471-2458-11-66

Tippey, K. G., Sivaraj, E., & Ferris, T. K. (2017). Driving while interacting with Google Glass: investigating the combined effect of head-up display and hands-free input on driving safety and multitask performance. *Human Factors, 59*(4), 671-688. https://doi.org/10.1177/0018720817691406

Tison, J., Chaudhary, N., & Cosgrove, L. (2011). *National phone survey on distracted driving attitudes and behaviors* (Report No. DOT HS 811 555). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1928/dot_1928_DS1.pdf?

Toda, M., Monden, K., Kubo, K., & Morimoto, K. (2006). Mobile phone dependence and health-related lifestyle of university students. *Social Behavior and Personality: An International Journal, 34*(10), 1277-1284. https://doi.org/10.2224/sbp.2006.34.10.1277

Truelove, V., Freeman, J., & Davey, J. (2019). "I Snapchat and Drive!" A mixed methods approach examining Snapchat use while driving and deterrent perceptions among young adults. *Accident Analysis & Prevention, 131*, 146-156. https://doi.org/10.1016/j.aap.2019.06.008

Truelove, V., Freeman, J., & Davey, J. (2019). "You can't be deterred by stuff you don't know about": Identifying factors that influence graduated driver licensing rule compliance. *Safety Science, 111*, 313-323. https://doi.org/10.1016/j.ssci.2018.09.007

Truelove, V., Freeman, J., Szogi, E., Kaye, S., Davey, J., & Armstrong, K. (2017). Beyond the threat of legal sanctions: What deters speeding behaviours? *Transportation Research Part F: Traffic Psychology and Behaviour, 50*, 128-136. https://doi.org/10.1016/j.trf.2017.08.008

Tselentis, D. I., Yannis, G., & Vlahogianni, E. I. (2017). Innovative motor insurance schemes: A review of current practices and emerging challenges. *Accident Analysis & Prevention, 98*, 139-148. https://doi.org/10.1016/j.aap.2016.10.006

Turel, O., & Bechara, A. (2016). Social networking site use while driving: ADHD and the mediating roles of stress, self-esteem and craving. *Frontiers in Psychology, 7*, 455. https://doi.org/10.3389/fpsyg.2016.00455

Turel, O., He, Q., Xue, G., Xiao, L., & Bechara, A. (2014). Examination of neural systems sub-serving Facebook "addiction." *Psychological Reports, 115*(3), 675-695. https://doi.org/10.2466%2F18.PR0.115c31z8

van Deursen, A. J. A. M., Bolle, C. L., Hegner, S. M., & Kommers, P. A. M. (2015). Modeling habitual and addictive smartphone behavior: The role of smartphone usage types, emotional intelligence, social stress, self-regulation, age, and gender. *Computers in Human Behavior, 45*, 411-420. https://doi.org/10.1016/j.chb.2014.12.039

Van Rooij, A., & Prause, N. (2014). A critical review of “internet addiction” criteria with suggestions for the future. *Journal of Behavioral Addictions, 3*(4), 203-213. https://doi.org/10.1556/JBA.3.2014.4.1

Vegega, M., Jones, B., & Monk, C. (2013, December). *Understanding the effects of distracted driving and developing strategies to reduce resulting deaths and injuries: A report to Congress (Report N*o. DOT HS 812 053). National Highway Traffic Safety Administration. www.nhtsa.gov/document/understanding-effects-distracted-driving

Verplanken, B., & Wood, W. (2006). Interventions to break and create consumer habits. *Journal of Public Policy & Marketing, 25*(1), 90–103.

Vogel, E. A., Rose, J. P., Roberts, L. R., & Eckles, K. (2014). Social comparison, social media, and self-esteem. *Psychology of Popular Media Culture, 3*(4), 206-222. https://doi.org/10.1037/ppm0000047

Voinea, G. D., Postelnicu, C. C., Duguleana, M., Mogan, G. L., & Socianu, R. (2020). Driving performance and technology acceptance evaluation in real traffic of a smartphone-based driver assistance system. *International Journal of Environmental Research and Public Health, 17*(19), 1-20. https://doi.org/10.3390/ijerph17197098

Volkow, N. D., & Fowler, J. S. (2000). Addiction, a disease of compulsion and drive: involvement of the orbitofrontal cortex. *Cerebral Cortex, 10*(3), 318-325. https://doi.org/10.1093/cercor/10.3.318

Volkow, N. D., Fowler, J. S., & Wang, G.-J. (2003). The addicted human brain: insights from imaging studies. *The Journal of Clinical Investigation, 111*(10), 1444-1451. https://doi.org/10.1172/JCI18533

Volkow, N. D., Koob, G. F., & McLellan, A. T. (2016). Neurobiologic advances from the brain disease model of addiction. *New England Journal of Medicine, 374*(4), 363-371. https://doi.org/10.1056/NEJMra1511480

Volkow, N. D., Wang, G.-J., Fowler, J. S., & Tomasi, D. (2012). Addiction circuitry in the human brain. *Annual review of pharmacology and toxicology, 52*, 321-336. https://doi.org/10.1146/annurev-pharmtox-010611-134625

Vollrath, M., Meilinger, T., & Krüger, H.-P. (2002). How the presence of passengers influences the risk of a collision with another vehicle. *Accident Analysis & Prevention, 34*(5), 649-654. https://doi.org//10.1016/S0001-4575(01)00064-1

von Meduna, M., Steinmetz, F., Ante, L., Reynolds, J., & Fiedler, I. (2020). Loot boxes are gambling-like elements in video games with harmful potential: Results from a large-scale population survey. *Technology in Society, 63*, 1-12. https://doi.org/10.1016/j.techsoc.2020.101395

Waddell, L. P., & Wiener, K. K. (2014). What’s driving illegal cellphone use? Psychosocial influences on drivers’ intentions to use hand-held cellphones. *Transportation Research Part F: Traffic Psychology and Behaviour, 22*, 1-11. https://doi.org/10.1016/j.trf.2013.10.008

Walsh, S. P., White, K. M., & Young, R. M. (2010). Needing to connect: The effect of self and others on young people's involvement with their mobile phones. *Australian Journal of Psychology, 62*(4), 194-203. https://doi.org/10.1080/00049530903567229

Walsh, S. P., White, K. M., Hyde, M. K., & Watson, B. (2008). Dialling and driving: Factors influencing intentions to use a mobile phone while driving. *Accident Analysis & Prevention, 40*(6), 1893-1900. https://doi.org/10.1016/j.aap.2008.07.005

Walsh, S. P., White, K. M., Watson, B., & Hyde, M. K. (2007). *Psychosocial factors influencing mobile phone use while driving* (RSRG 2007-06).

Wang, H., Jin, C., Yuan, K., Shakir, T. M., Mao, C., Niu, X., Niu, C., Guo, L., & Zhang, M. (2015). The alteration of gray matter volume and cognitive control in adolescents with internet gaming disorder. *Frontiers in Behavioral Neuroscience, 9*, 64. https://doi.org/10.3389/fnbeh.2015.00064

Wang, H.-Y., Sigerson, L., & Cheng, C. (2019). Digital nativity and information technology addiction: Age cohort versus individual difference approaches. *Computers in Human Behavior, 90*, 1-9. https://doi.org/10.1016/j.chb.2018.08.031

Warren, I., Meads, A., Whittaker, R., Dobson, R., & Ameratunga, S. (2018). Behavior change for youth drivers: Design and development of a smartphone-based app (BackPocketDriver). *JMIR Formative Research, 2*(2), 1-19. https://doi.org/10.2196/formative.9660

Weber, B., Dangelmaier, M., Diederichs, F., & Spath, D. (2020). User rating and acceptance of attention-adaptive driver safety systems. *European Transport Research Review, 12*(1), 1-12. https://doi.org/10.1186/s12544-020-00414-w

White, K. M., Hyde, M. K., Walsh, S. P., & Watson, B. (2010). Mobile phone use while driving: An investigation of the beliefs influencing drivers' hands-free and hand-held mobile phone use. *Transportation Research Part F: Traffic Psychology and Behaviour, 13*(1), 9-20. https://doi.org/10.1016/j.trf.2009.09.004

White, M., Eiser, J., & Harris, P. (2004). Risk perceptions of mobile phone use while driving. *Risk Analysis, 24*(2), 323-334. https://doi.org/10.1111/j.0272-4332.2004.00434.x

Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors, 50*(3), 449-455. https://doi.org/10.1518/001872008X288394

Wilbur, M. (2019). *Young driver survey* (Report No. DOT HS 812 761). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/42691/Email

Wilcockson, T. D. W., Osborne, A. M., & Ellis, D. A. (2019). Digital detox: The effect of smartphone abstinence on mood, anxiety, and craving. *Addictive Behaviors, 99*, 1-4. https://doi.org/10.1016/j.addbeh.2019.06.002

Winkler, A., Jeromin, F., Doering, B. K., & Barke, A. (2020). Problematic smartphone use has detrimental effects on mental health and somatic symptoms in a heterogeneous sample of German adults. *Computers in Human Behavior, 113*, 1-10. https://doi.org/10.1016/j.chb.2020.106500

Wise, R. A., & Rompre, P.-P. (1989). Brain dopamine and reward. *Annual Review of Psychology, 40*(1), 191-225. https://doi.org/10.1146/annurev.ps.40.020189.001203

Wohleber, R. W., & Matthews, G. (2016). Multiple facets of overconfidence: Implications for driving safety. *Transportation Research Part F: Traffic Psychology and Behaviour, 43*, 265-278. https://doi.org/10.1016/j.trf.2016.09.011

Wood, W., & Neal, D. T. (2007). A new look at habits and the habit-goal interface. *Psychological Review, 114*(4), 843. https://doi.org/10.1037/0033-295X.114.4.843

World Health Organization (2001). *International Classification of Functioning, Disability, and Health: ICF.* https://apps.who.int/iris/handle/10665/42407

Wu, J., & Xu, H. (2018). The influence of road familiarity on distracted driving activities and driving operation using naturalistic driving study data. *Transportation Research Part F: Traffic Psychology and Behaviour, 52*, 75-85. https://doi.org/10.1016/j.trf.2017.11.018

Xiao, Y., & Shi, J. (2015). Analyzing the influence of mobile phone use of drivers on traffic flow based on an improved cellular automaton model. *Discrete Dynamics in Nature and Society, 2015*, 1-9. https://doi.org/10.1155/2015/573090

Xie, J. Y., Chen, H.-Y. W., & Donmez, B. (2016). Gaming to safety. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 60*(1), 1884-1888. https://doi.org/10.1177/1541931213601429

Young, K. L. (2008). *Driver distraction: Theory, effects, and mitigation* (M. A. Regan, J.D., Lee, K.L. Young, Eds.). CRC Press LLC. www.routledge.com/Driver-Distraction-Theory-Effects-and-Mitigation/Regan-Lee-Young/p/book/9780849374265

Young, R. A. (2016). Evaluation of the total eyes-off-road time glance criterion in the NHTSA visual-manual guidelines. *Transportation Research Record: Journal of the Transportation Research Board, 2602*(1), 1–9. https://doi.org/10.3141/2602-01

Zaman, T., & Lache, D. (2015). Texting and e-mail problem use. In M. S. Ascher & P. Levounis (Eds.), *The behavioral addictions* (pp. 101–112). American Psychiatric Publishing Inc.

Zhang, H., Qian, D., Yang, X., & Shao, C. (2019). The impact of speech-based texting on drivers' braking reaction and deceleration duration in the car-following scenario. *Journal of Transportation Safety & Security, 11*(5), 520-543. https://doi.org/10.1080/19439962.2018.1436106

Zhang, Y., Lin, X., Zhou, H., Xu, J., Du, X., & Dong, G. (2016). Brain activity toward gaming-related cues in internet gaming disorder during an addiction stroop task. *Frontiers in Psychology, 7*, 714. https://doi.org/10.3389/fpsyg.2016.00714

Zhao, N., Reimer, B., Mehler, B., D'Ambrosio, L. A., & Coughlin, J. F. (2013). Self-reported and observed risky driving behaviors among frequent and infrequent cell phone users. *Accident Analysis & Prevention*, *61*, 71–77. https://pubmed.ncbi.nlm.nih.gov/22878144/

Zhitomirsky-Geffet, M., & Blau, M. (2016). Cross-generational analysis of predictive factors of addictive behavior in smartphone usage. *Computers in Human Behavior, 64*, 682-693. https://doi.org/10.1016/j.chb.2016.07.061

Zhou, R., Rau, P.-L. P., Zhang, W., & Zhuang, D. (2012). Mobile phone use while driving: Predicting drivers' answering intentions and compensatory decisions. *Safety Science, 50*(1), 138-149. https://doi.org/10.1016/j.ssci.2011.07.013

Zhou, R., Wu, C., Rau, P.-L. P., & Zhang, W. (2009). Young driving learners' intention to use a handheld or hands-free mobile phone when driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*(3), 208-217. https://doi.org/10.1016/j.trf.2008.11.003

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., & Yannis, G. (2019). A meta-analysis of the impacts of operating in-vehicle information systems on road safety. *IATSS Research, 43*(3), 185-194. https://doi.org/10.1016/j.iatssr.2019.01.003

Appendix A: Summary of Study Methods and Measures From Chapter 6 Problematic Device Use Literature

Topic	Citation	Measure of Device Dependency (if Applicable)	Main Method and Sample	Country
Device dependency and driving risk	(Liese et al., 2019)	Self-perception of Text-message Dependency Scale (STDS)	Survey; Drivers	United States
Device dependency and driving risk	(O'Connor et al., 2013)	Cellphone Overuse Scale (CPOS)	Survey; Drivers	United States
Device dependency and prevalence	(Struckman-Johnson et al., 2015)	Cellphone dependency scale (CPD)	Survey	United States
Device dependency, frequent use, and driving risk	(O'Connor et al., 2017)	Cellphone Overuse Scale (CPOS)	Survey; Drivers	United States
Different device use activities	(Atchley et al., 2011)	--	Survey; Drivers	United States
Different device use activities	(Gray, 2015)	--	Survey	United States
Different device use while driving activities	(Kaviani et al., 2020)	--	Survey; All ages community sample; Drivers	Australia
Different device use while driving activities	(Parnell et al., 2020)	--	On-road diary; Survey	United Kingdom
Frequency; Different device use while driving activities	(Christoph et al., 2019)	--	On-road	Netherlands
Frequent use and driving risk	(Lantz & Loeb, 2013)	--	Survey	United States
Frequent use and driving risk	(Musicant et al., 2015)	--	Survey; All ages community sample; Drivers	Israel
Frequent use and driving risk	(Oxtoby et al., 2019)	--	Survey; Drivers	Australia
Frequent use and driving risk	(Terry & Terry, 2015)	--	Survey; Drivers	United States
Frequent use and driving risk	(Zhao et al., 2013)	--	Survey; Drivers	United States
Prevalence; Different device use while driving activities	(AAA, 2016-2020).	--	Survey; Representative population; Drivers	United States
Prevalence	(Cook et al., 2018)	--	Survey; Representative population; Drivers	Canada
Prevalence	(Ianzito, 2019)	--	Mobile phone data from drivers and driver survey	United States
Prevalence; Frequent use and driving risk	(Atwood et al., 2018)	--	On-road	United States

Appendix B: Summary of Problematic Device Use While Driving and Driver Traits Relationships From Chapter 7

Trait	Direction	Associated Problematic Device Dimension	Measure of Device Dependency (if Applicable)	Citation	Study and Sample	Country
ADHD symptoms	More ADHD symptoms	Behavioral intention to use a device while driving	--	(Nichols, 2018)	Survey	United States
ADHD symptoms	More ADHD symptoms	Device cravings leading to frequent device use while driving	--	(Turel & Bechara, 2016)	Survey; Drivers	United States
Age	Younger	Device dependency	MPPUS (Mobile Phone Problematic Use Scale)	(Oviedo-Trespalacios et al., 2019)	Survey; All ages community sample	Australia
Age	Younger	Device dependency	Addictive Mobile Phone Tendencies Scale	(Walsh et al., 2007)	Survey; Drivers	Australia
Age	Younger	Frequent device use while driving	--	(Atwood et al., 2018)	On-road	United States
Age	Younger	Frequent device use while driving	--	(Walsh et al., 2007)	Survey; Drivers	Australia
Agreeableness	Not related	Frequent device use while driving	--	(Kita & Luria, 2018)	On-road and survey	Israel
Agreeableness	More agreeableness (3/3 driver types)	Frequent device use while driving	--	(Maier et al., 2020)	Survey; All ages community sample; Drivers	Germany
Anxiety	More anxiety	Behavioral intention to use a device while driving	--	(Bradish et al., 2019)	Survey	United States
Anxiety	More nomophobia (only for subscale related to being unable to access information without one's phone)	Frequent device use while driving	--	(Kaviani et al., 2020)	Survey; All ages community sample; Drivers	Australia
Attitudes	More positive attitudes	Behavioral intention to use a device while driving	--	(Murphy et al., 2020)	Survey; Drivers	Australia
Attitudes	Not related	Frequent device use while driving	--	(Bayer & Campbell, 2012)	Survey	United States

Attitudes	More positive attitudes	Frequent device use while driving	--	(Hansma et al., 2020)	Survey; All ages community sample	Canada
Attitudes	More positive attitudes	Frequent device use while driving	--	(Chen & Donmez, 2016)	Survey; All ages community sample; Drivers	Canada
Attitudes	Not related	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representativ e population; Drivers	Canada
Boredom proneness	More boredom proneness (males only)	Frequent device use while driving	--	(Oxtoby et al., 2019)	Survey; Drivers	Australia
Cognitive capture	More cognitive capture	Behavioral intention to use a device while driving	--	(Murphy et al., 2020)	Survey; Drivers	Australia
Conscientiousness	Not related	Frequent device use while driving	--	(Kita & Luria, 2018)	On-road and survey	Israel
Conscientiousness	Less conscientious ness (2/3 driver types); More conscientious ness (1/3 driver types)	Frequent device use while driving	--	(Maier et al., 2020)	Survey; All ages community sample; Drivers	Germany
Device dependency	More dependency	Behavioral intention to use a device while driving	Mobile Phone Involvement Questionnaire (MPIQ)	(White et al., 2012)	Survey; Drivers	Australia
Device dependency	Not related	Behavioral intention to use a device while driving	Mobile Phone Involvement Questionnaire (MPIQ)	(Gauld et al., 2017)	Survey; Drivers	Australia
Device dependency	More dependency	Frequent concealed device use while driving	Mobile Phone Involvement Questionnaire (MPIQ)	(Gauld et al., 2014)	Survey; Drivers	Australia
Device dependency	More dependency	Frequent device use while driving	Smartphone Addiction Scale	(Kita & Luria, 2018)	On-road and survey	Israel
Device dependency	More dependency	Frequent device use while driving	Cellphone dependency scale (CPD)	(Struckman-Johnson et al., 2015)	Survey	United States
Device dependency	More dependency	Frequent device use while driving	Mobile Phone Problematic Use Scale (MPPUS)	(Oviedo-Trespalacios et al., 2019)	Survey; All ages community sample	Australia
Device dependency	More dependency	Frequent device use while driving	Perceived need (how much the absence of a device would be felt while driving)	(Musicant et al., 2015)	Survey; All ages community sample; Drivers	Israel
Device	More	Frequent	Mobile Phone	(Mirman et	Survey;	United

dependency	dependency	device use while driving	Problematic Use Scale (MPPUS)	al., 2017)	Drivers	States
Device dependency	More dependency	More near crashes	Cellphone Intrusive Thoughts Scale	(Terry & Terry, 2015)	Survey; Drivers	United States
Driving experience	More driving experience (for teen drivers)	Frequent device use while driving	--	(Creaser et al., 2015)	On-road	United States
Driving experience	More frequent driving	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representativ e population; Drivers	Canada
Driving experience	Not related (taking a driver education course)	Frequent device use while driving	--	(Cook et al., 2018)	Survey; Representativ e population; Drivers	Canada
Education and socioeconomic status	More education	Device dependency	Mobile Phone Problematic Use Scale (MPPUS)	(Oviedo-Trespalacios et al., 2019)	Survey; All ages community sample	Australia
Everyday device use	More everyday device use	Device dependency	NMP-Q (nomophobia)	(Kaviani et al., 2020)	Survey; All ages community sample; Drivers	Australia
Everyday device use	More everyday device use	Frequent device use while driving	--	(Atwood et al., 2018)	On-road	United States
Everyday device use	More everyday device use	Frequent device use while driving	--	(Kaviani et al., 2020)	Survey; All ages community sample; Drivers	Australia
Everyday device use	More everyday device use	Frequent device use while driving	--	(Oxtoby et al., 2019)	Survey; Drivers	Australia
Everyday device use	More everyday device use	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representativ e population; Drivers	Canada
Everyday device use	More social media use	Frequent device use while driving	--	(Cook et al., 2018)	Survey; Representativ e population; Drivers	Canada
Extraversion	More extraversion	Frequent device use while driving	--	(Kita & Luria, 2018)	On-road and survey	Israel
Extraversion	More extraversion	Frequent device use while driving	--	(Briskin et al., 2018)	Survey	United States
Extraversion	More extraversion (for 2/3 driver types)	Frequent device use while driving	--	(Maier et al., 2020)	Survey; All ages community sample; Drivers	Germany
Extraversion	More extraversion	Frequent device use while driving	--	(Braitman & Braitman, 2017)	Survey; Drivers	United States

Gender	More female	Device dependency	Cellphone Dependency Scale (CPD)	(Struckman-Johnson et al., 2015)	Survey	United States
Gender	No gender effect	Device dependency	Mobile Phone Problematic Use Scale (MPPUS)	(Oviedo-Trespalacios et al., 2019)	Survey; All ages community sample	Australia
Gender	More female	Device dependency	NMP-Q (nomophobia)	(Kaviani et al., 2020)	Survey; All ages community sample; Drivers	Australia
Gender	More female (marginal effect)	Frequent device use while driving	--	(Creaser et al., 2015)	On-road	United States
Gender	No gender effect	Frequent device use while driving	--	(Atwood et al., 2018)	On-road	United States
Gender	No gender effect	Frequent device use while driving	--	(Struckman-Johnson et al., 2015)	Survey	United States
Gender	No gender effect	Frequent device use while driving	--	(Cook et al., 2018)	Survey; Representativ e population; Drivers	Canada
Geography	Urban	Frequent device use while driving	--	(Cook et al., 2018)	Survey; Representativ e population; Drivers	Canada
Habit (automaticity)	More habits	Frequent device use while driving	--	(Bayer & Campbell, 2012)	Survey	United States
Habit (automaticity)	More habits	Frequent device use while driving	--	(Bayer & Campbell, 2012)	Survey	United States
Habit (automaticity)	More habits	Frequent device use while driving	--	(Briskin et al., 2018)	Survey	United States
Habit (automaticity)	More habits	Frequent device use while driving	--	(Hansma et al., 2020)	Survey; All ages community sample	Canada
Habit (automaticity)	More habits (only at low levels of mindfulness)	Frequent device use while driving	--	(Moore & Brown, 2019b)	Survey; All ages community sample; Drivers	Australia
Habit (automaticity)	More habits	Frequent device use while driving	--	(Murphy et al., 2020)	Survey; Drivers	Australia
Habit (automaticity)	More habits (only for males)	Frequent device use while driving	--	(Oxtoby et al., 2019)	Survey; Drivers	Australia
Impulsivity	More impulsiveness (planning impulsivity only)	Device dependency (scale also measures frequent device use while driving)	Problematic Mobile Phone Use Questionnaire (PMPUQ)	(Pivetta et al., 2019)	Survey; All ages community sample	United Kingdom

Impulsivity	More impulsiveness (delay discounting task)	Frequent device use while driving	--	(Hayashi et al., 2015)	Laboratory	United States
Impulsivity	Not related (delay discounting task)	Frequent device use while driving	--	(Hayashi et al., 2016)	Laboratory	United States
Impulsivity	Not related (delay discounting task)	Frequent device use while driving	--	(Hayashi et al., 2017)	Laboratory	United States
Impulsivity	More impulsiveness (BIS survey scale)	Frequent device use while driving	--	(Delgado et al., 2018)	On-road	United States
Impulsivity	Not related (delay discounting task)	Frequent device use while driving	--	(Delgado et al., 2018)	On-road	United States
Impulsivity	More impulsiveness	Frequent device use while driving	--	(Lantz & Loeb, 2013)	Survey	United States
Impulsivity	More impulsiveness	Frequent device use while driving	--	(Struckman-Johnson et al., 2015)	Survey	United States
Mindfulness	Less mindfulness	Behavioral intention to use a device while driving	--	(Murphy et al., 2020)	Survey; Drivers	Australia
Mindfulness	Less mindfulness	Frequent device use while driving	--	(Feldman et al., 2011)	Survey; Drivers	United States
More near collisions	More near collisions	Device dependency	Cellphone Intrusive Thoughts Scale	(Terry & Terry, 2015)	Survey; Drivers	United States
More near collisions	More near collisions	Frequent device use while driving	--	(Terry & Terry, 2015)	Survey; Drivers	United States
More near collisions	More near collisions	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representative population; Drivers	Canada
Neuroticism	More neuroticism (mediated by device dependency symptoms)	Frequent device use while driving	Smartphone Addiction Scale	(Kita & Luria, 2018)	On-road and survey	Israel
Neuroticism	More neuroticism	Frequent device use while driving	--	(Briskin et al., 2018)	Survey	United States
Neuroticism	Less neuroticism (1/3 driver types); More neuroticism (1/3 driver types)	Frequent device use while driving	--	(Maier et al., 2020)	Survey; All ages community sample; Drivers	Germany

Norms	Not related (subjective norms)	Behavioral intention to use a device while driving	--	(Murphy et al., 2020)	Survey; Drivers	Australia
Norms	Stronger supportive subjective norms and descriptive norms	Frequent device use while driving	--	(Meldrum et al., 2018)	Survey	United States
Norms	Stronger supportive moral norms and subjective norms	Frequent device use while driving	--	(Briskin et al., 2018)	Survey	United States
Norms	Stronger supportive moral norms and subjective norms	Frequent device use while driving	--	(Bayer & Campbell, 2012)	Survey	United States
Norms	Not related to subjective and descriptive norms	Frequent device use while driving	--	(Hansma et al., 2020)	Survey; All ages community sample	Canada
Norms	Stronger supportive subjective norms; Marginally significant stronger descriptive norms (only for drivers 30 and under)	Frequent device use while driving	--	(Chen & Donmez, 2016)	Survey; All ages community sample; Drivers	Canada
Norms	Stronger supportive moral norms; Not related to subjective norms; Stronger supportive descriptive norms (for sending messages, but not reading);	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representative population; Drivers	Canada
Openness to experience	Less openness to experience	Frequent device use while driving	--	(Kita & Luria, 2018)	On-road and survey	Israel
Openness to experience	More openness to experience	Frequent device use while driving	--	(Briskin et al., 2018)	Survey	United States
Openness to experience	More openness to experience (2/3 driver types); Less openness to experience	Frequent device use while driving	--	(Maier et al., 2020)	Survey; All ages community sample; Drivers	Germany

	(1/3 driver types)					
Perceived behavioral control	Poorer perceived control to resist	Behavioral intention to use a device while driving	--	(Bradish et al., 2019)	Survey	United States
Perceived behavioral control	Less perceived control	Behavioral intention to use a device while driving	--	(Murphy et al., 2020)	Survey; Drivers	Australia
Perceived behavioral control	Not related	Frequent device use while driving	--	(Bayer & Campbell, 2012)	Survey	United States
Perceived behavioral control	More perceived control	Frequent device use while driving	--	(Hansma et al., 2020)	Survey; All ages community sample	Canada
Perceived behavioral control	More for reading; Not significant for sending	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representativ e population; Drivers	Canada
Perceived behavioral control efficacy	More	Behavioral intention to use a device while driving	--	(Murphy et al., 2020)	Survey; Drivers	Australia
Perceived behavioral control efficacy	More	Frequent device use while driving	--	(Bayer & Campbell, 2012)	Survey	United States
Perceived behavioral control efficacy	More	Frequent device use while driving	--	(Struckman-Johnson et al., 2015)	Survey	United States
Perceived behavioral control efficacy	More	Frequent device use while driving	--	(Hansma et al., 2020)	Survey; All ages community sample	Canada
Perceived behavioral control efficacy	More	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representativ e population; Drivers	Canada
Race	White	Frequent device use while driving	--	(Cook et al., 2018)	Survey; Representativ e population; Drivers	Canada
Risk perceptions	Lower risk perceptions	Frequent device use while driving	--	(Mirman et al., 2017)	Survey; Drivers	United States
Risk perceptions	Greater risk perceptions (for reading messages, but not sending)	Frequent device use while driving	--	(Berenbaum et al., 2019)	Survey; Representativ e population; Drivers	Canada
Self-control	Less self-control	Frequent device use while driving	--	(Quisenberry , 2015)	Survey	United States
Self-control	Less self-control (if supportive descriptive norms)	Frequent device use while driving	--	(Meldrum et al., 2018)	Survey	United States

Self-esteem	Poor self-esteem	Device cravings leading to frequent device use while driving	--	(Turel & Bechara, 2016)	Survey; Drivers	United States
Self-esteem	Poor self-esteem	Device dependency (scale also measures frequent device use while driving)	Problematic Mobile Phone Use Questionnaire (PMPUQ)	(Lannoy et al., 2020)	Survey	France
Sensation-seeking	Stronger sensation-seeking	Frequent device use while driving	--	(Delgado et al., 2018)	On-road	United States
Sensation-seeking	Stronger sensation-seeking (only for drivers over 30)	Frequent device use while driving	--	(Chen & Donmez, 2016)	Survey; All ages community sample; Drivers	Canada
Social skills	Maladaptive social skills (male only)	Frequent device use while driving	--	(Oxtoby et al., 2019)	Survey; Drivers	Australia
Social skills	More anxious attachment; Less avoidant attachment	Urge to respond to a smartphone while driving	--	(Bodford et al., 2017)	Survey	United States

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