IDENTIFY MIND-WANDERING BEHIND THE WHEEL

BY

JIBO HE

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Arts in Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2010

Urbana, Illinois

Master’s Committee:

Associate Professor Jason S. McCarley, Chair
Professor Arthur F. Kramer
ABSTRACT

Driver distraction is a significant risk factor for traffic crashes. Distraction from secondary tasks has been the basis of much research and legislation. However, the influence of cognitive distraction, or mind wandering (Smallwood & Schooler, 2006), on driver performance has not been as closely studied. The current study used a self-report method to capture the moment-to-moment off-task thoughts, and investigated the influence of mind wandering on behavior and performance in a simulated driving task. Participants performed a car-following task in a simulated low-traffic driving environment, and were asked to press a button mounted on the steering wheel any time they found themselves “zoning out”. Driving performance metrics and oculomotor scanning data were analyzed to compare driving behaviors and performance under attentive versus inattentive mental states. The results showed that mind wandering caused horizontal narrowing of drivers’ visual scanning, shifts of lane position, and a decrease in the variability of vehicle velocity. Mind wandering influences driver performance in a way similar to distraction from secondary tasks (e.g., Recarte & Nunes, 2000, 2003).
Dedicated to loved ones in my heart, my parents, wife, and professor.
ACKNOWLEDGEMENTS

I am heartily thankful to my supervisor, Jason S. McCarley, whose encouragement, guidance and support from the initial to the final. Under the guidance of Dr. McCarley, I developed an understanding of driver distraction and mind wandering, more importantly scientific research methods and thinking in human factors.

Lastly, I offer my regards and appreciation to all of those who supported me in any respect during the completion of the project, including Chun Wang, Yi-Ching Lee, Ensar Beric, Ron Carbonari, Kelly Steelman, Seth Redenbo, and John Gaspar.
# TABLE OF CONTENTS

LIST OF FIGURES ........................................................................................................ vii

INTRODUCTION ........................................................................................................... 1

  What’s mind wandering? .......................................................................................... 2
  Mind wandering depends on central executive resources ........................................ 3
  Factors influencing mind wandering ....................................................................... 5
  Mind wandering and task performance .................................................................... 6
  The effect of mind wandering depends on meta-awareness ....................................... 7
  Mind wandering may impair driving performance .................................................. 8
  Measuring mind wandering ..................................................................................... 11
  Experiment goals ..................................................................................................... 14

METHODS .................................................................................................................. 16

  Participants .............................................................................................................. 16
  Apparatus ................................................................................................................ 16
  Experiment design .................................................................................................. 17
  Driving environment and task ................................................................................. 17
  Procedure ............................................................................................................... 18

RESULTS ................................................................................................................... 20

  Lane position and variability ................................................................................ 21
  Car following performance ..................................................................................... 22
  Vertical and horizontal deviation of gaze position ............................................... 24
  Percent dwell time in the side mirrors ................................................................... 25
DISCUSSION .......................................................................................................................... 26

FIGURES .................................................................................................................................. 31

REFERENCES .......................................................................................................................... 36
LIST OF FIGURES

Figure 1. Rural driving environment used in the experiment.

Figure 2. Mean of lane position as a function of mental states and wind turbulence. Error bars in all figures indicate within-subject standard errors (Loftus & Masson, 1994) based on the interaction term.

Figure 3. Top: Coherence of the speed of the subject and lead vehicles; Middle: Phase shift of the speed of the subject and lead vehicles, baseline set at 100%; Bottom: Modulus of the speed of the subject and lead vehicles.

Figure 4. Standard deviation of horizontal gaze position as a function of mental state and wind turbulence.

Figure 5. The percent dwell time in the side mirrors.
INTRODUCTION

Drivers contend with various sources of distraction (Hanowski, Perez, & Dingus, 2005), including distractions from secondary tasks, such as telephone conversations, radio tuning, and navigation system interactions. Driver distraction is involved in an estimated 25 to 37 percent of traffic accidents (Sussman, Bishop, Madnick, & Walter, 1985; Wang, Knipling, & Goodman, 1996; Robertson, 2003), and causes approximately $50 billion social and economic costs annually (Stutts, Reinfurt, Staplin, & Rodgman, 2001).

Accordingly, the effects of secondary-task on driving performance have been the focus of intense research. For example, Strayer and Johnston (2001) reported that a word-generation task compromised simulated driving performance, increasing error in a manual tracking task. In a set of on-road studies, Recarte and Nunes found that a verbal and spatial-imagery task caused spatial gaze concentration (Recarte & Nunes, 2000, 2003) and reduced the frequency of glances to the rear-view mirror and speedometer (Recarte & Nunes, 2000).

However, driver distraction does not arise exclusively from secondary tasks. Emerging epidemiological and related laboratory research suggests that mind wandering, a form of purely mental distraction that does not require any manual or visual interaction with the external environment, might also compromise driver performance. In the Indiana Tri-Level Study of the Causes of Traffic Accidents (Treat et al., 1979), recognition failure was found to be involved in 56% of all crash cases analyzed. Among these cases, preoccupation with competing thoughts
accounted for 15% of recognition failure. Other work has found that drivers with poor performance (measured by tickets, accident citations, hospitalizations, injured in fall, and composite mishaps) scored higher in the Cognitive Failure Questionnaire, which measures the tendency of everyday cognitive failure (Larson, Alderton, Neideffer, & Underhill, 1997; Larson & Merritt, 1991). Another epidemiological study using a case-control design also found that drivers with higher accident risk tended to engage in cognitive activities, such as daydreaming or thinking about personal problems while driving (Violanti & Marshall, 1996). These findings imply that cognitive distraction independent of an explicit secondary task may have effects similar to secondary-task distraction.

What’s mind wandering?

Mind wandering (Mason et al., 2007; Smallwood, McSpadden, & Schooler, 2007; Smallwood & Schooler, 2006), is also referred to as an attention lapse (Carriere, Cheyne, Smilek, 2008), an absent-minded lapse (Schacter, 2001), a spontaneous cognitive event, daydreaming, stimulus-independent thought, intrusive thought (Antrobus, Singer & Greenberg, 1966; Gold & Reilly, 1985,1986; Klinger, 1977; Klos & Singer, 1981), task unrelated thought (Smallwood, O'Connor, Sudberry, Haskell, & Ballantyn, 2004; Smallwood, Baracaia, Lowe, & Obonsawin, 2003), or spontaneous thought (Christoff, Ream, & Gabrieli, 2004).

Mind wandering, is a spontaneous mental state, in which executive attention is decoupled from current task and context (Smallwood & Schooler, 2006; Smallwood, McSpadden, & Schooler, 2008; Antrobus, Singer, Goldstein, & Fortgang, 1970).
and instead focuses on self-relevant concerns (Klinger, 1999, 2009). During mind wandering, analysis of events in the external environment was reduced (Smallwood, Beach, Schooler, & Handy, 2008), causing “failures in task performance and superficial representations of the external environment” (Smallwood & Schooler, 2006).

Mind wandering depends on central executive resources.

Antrobus (1968) explained the production of mind wandering within the framework of an information processing model of cognition. A shared capacity-limited central cognitive operator is in charge of processing information from external (visual, auditory, tactile etc. sensory modality) and internal (long-term memory) sources (Antrobus, 1968). Because all the concurrent tasks share a common and limited central cognitive operator, if the resources consumed by the primary external task decrease, an increased portion of cognitive resources would be devoted to the generation of mind wandering, allowing more frequent off-task thoughts (Antrobus, 1968; Antrobus, Singer, Goldstein, & Fortgang, 1970; Teasdale, et al., 1995). As a test of this model, Antrobus (1968) measured the production of mind-wandering as a function of information presentation rate in a tone detection task. Results showed that the frequency of mind wandering was a negative linear function of signal presentation rate, supporting the hypothesis of a common central cognitive resource for sensory events and stimulus-independent thoughts.

Baddeley’s working memory model (Baddeley, 1986; Baddeley & Hitch, 1974) provided a more clear depiction of the cognitive mechanism of mind wandering. The
working memory model includes three modular components: a central executive, which supervises attentional control of actions, coordinates multiple tasks, and integrates information in the memory or sensory input; a visuospatial sketchpad, which stores visual images; and an articulatory and phonological loop, which stores sounds. The central executive corresponds to the common and limited central cognitive operator proposed by (Antrobus, 1968). Primary tasks and mind wandering compete for the central executive resources. If more resources are allocated to mind wandering, fewer resources are available for the primary tasks, resulting in performance decrements.

Teasdale and colleagues investigated the role of working memory in generating stimulus independent thoughts, and found evidence that mind wandering depends on central executive resources (Teasdale, et al., 1995). Their study measured the frequency of mind wandering on unpracticed and practiced tasks, and found that practice in a dual verbal memory task and a perceptual motor skill task increased the frequency of mind wandering, an effect that could be explained by the reduction in central resource demands of the dual task after practice. Using a random number generation task, Teasdale and colleagues also found that the randomness of generated numbers decreased during periods of stimulus-independent thoughts, suggesting that the random number generation task and production of mind wandering compete for the central executive resource. They concluded that the production of mind wandering depended on central executive resources (Teasdale, et al., 1995).
Recent findings in neuroscience have also provided evidence that the central executive contributes to mind wandering. An fMRI study found that both the prefrontal default network and executive network regions were associated with subjective self-reports of mind wandering (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009). Activation of default and executive network regions was even stronger when subjects were unaware of their off-task thinking. The involvement of executive network regions when mind wandering, including dorsal anterior cingulate cortex and lateral prefrontal cortex, supplemented behavioral evidence for off-task thinking, and provided further support for the argument that the production of mind wandering requires central executive resources.

Factors influencing mind wandering

As noted above, task demand influences mind wandering frequency by modulating the allocation of central executive resources to external tasks (Forster & Lavie, 2009; Giambra, 1995; Smallwood, Obonsawin, & Heim, 2003). Giambra (1995) varied task demand by manipulating stimulus presentation rate and target probability in a vigilance task. Higher target probability and shorter inter-stimulus intervals, both of which increase processing demand in the vigilance task, reduced mind wandering frequency. Similarly, Forster and Lavie (2009) found that high perceptual load in a visual-search task reduced the frequency of mind wandering. Based on experimental evidence that high signal presentation rate decreased mind wandering, Antrobus (1968) speculated that heavy highway traffic would reduce fantasy and task-irrelevant thought.
Besides, task skills and demand, other factors that may influence the generation of mind wandering are age (Giambra, 1989, 1993; Singer & Antrobus, 1963, 1972), stress (e.g., Antrobus et al., 1967), circadian rhythm (Giambra, et al., 1988–1989), and mood (Smallwood, Fitzgerald, Miles, & Phillips, 2009).

Mind wandering and task performance

Studies have demonstrated mind wandering induced performance losses in a variety of laboratory tasks, including signal detection (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), reading comprehension (Schooler, Reichle, & Halpern, 2005), vigilance (Giambra, 1995), and memory (Carriere, Cheyne, & Smilek, 2008). For example, in the Sustained Attention to Response Task (SART), Robertson et al. (1997) found that mind wandering was accompanied by an increase in response errors. Smallwood and colleagues later found that the amplitude of the P300 component of the event related potential was reduced prior to the occurrence of behavioral (error on SART) and subjective (self-report of mental state) indicators of off-task thinking, further supporting the suggestion that processing in the SART is impaired during mind wandering (Smallwood, et al., 2008).

Despite the well-documented evidence for performance decrements, mind wanders may also promote task performance to some extent. According to Antrobus, people may intentionally engage in off-task thinking for various purposes, for example, to plan for future events, to relieve boredom, to entertain themselves, and to maintain arousal level when working in a monotonous environment, such as long drives and train voyage (Antrobus, Singer, Goldsein, & Fortgang, 1970). Antrobus
(1968) argued that “daydreaming and similar transformations on memory do not interrupt the response to sensory input, e.g. when driving a car”, and off-task thought, as undeliberate planning, is likely to be rewarded in improved performance in subsequent overt behaviors.

The effect of mind wandering depends on meta-awareness

The extent of performance decrement caused by mind wandering also depends on the mind wanderer’s awareness of his or her mental state (Smallwood, et al., 2007; Smallwood, McSpadden, & Schooler, 2008). Explicit awareness of mental contents, termed as meta-awareness, waxes and wanes from unawareness to direct monitoring of the wandering mind (Schooler, 2002; Schooler & Schreiber, 2004; Smallwood, et al., 2007). Using a thought-sampling technique, Smallwood, McSpadden and Schooler (2007) distinguished two types of mind wandering: tuning out, or mind wandering with meta-awareness of immediate mental contents, and zoning out, or mind wandering without meta-awareness of mental contents. In their study of target detection (detecting a target stimulus “XXXXX” among words) (Smallwood, et al., 2007), mind wandering without awareness was associated with brief reaction times and poor response inhibition, while mind wandering with awareness was associated with long reaction times, suggesting that meta-awareness of mind wandering mediates the consequences off-task thought. This conclusion was affirmed by a reading comprehension task (Smallwood, McSpadden, et al., 2008).
Mind wandering may impair driving performance

Ubiquitous as mind wandering is in our daily driving, whether mind wandering impairs driving performance is seldom studied and largely unknown. Except for several epidemiological and survey studies (Violanti & Marshall, 1996; Larson, Alderton, Neideffer, & Underhill, 1997; Larson & Merritt, 1991), as far as we know, little empirical research has examined the mechanisms by which mind wandering interferes with driving performance. Nevertheless, the central executive explanation of mind wandering suggests that off-task thoughts would impair the performance of the driving-related tasks. Research in closely related areas may also shed light on mechanisms of driving performance impairment during mind wandering.

First, driving involves cognitive functions, such as, signal detection (e.g., detect turning traffic signals, watch out for darting pedestrians across the road) and vigilance (e.g., monitor dashboard). Existing studies have documented that task performance is degraded during mind wandering (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Manly, Robertson, Galloway, & Hawkins, 1999; Giambra, 1995). With worse signal detection ability and unsustainable attention focus, absent-minded drivers should drive poorer than when they were attentive.

Secondly, various secondary-task distractions analogous to mind wandering---for example, working memory task (Alm & Nilsson, 1995; Briem & Hedman, 1995), mental arithmetic task (McKnight & McKnight, 1993), reasoning task (Brown, Tickner, & Simmonds, 1969), word generation task (Strayer & Johnston, 2001), visual and spatial imaginary task (Recarte & Nunes, 2000)---are known to impair driving performance. For example, Recarte and Nunes (2000) found that secondary
verbal and spatial-imagery tasks while driving caused the visual inspection window to shrink both horizontally and vertically, and increased the fixation duration in the spatial-imagery task. These tasks all load on central executive resources, as mind wandering does, suggesting that mind wandering may also impair driving performance and change eye scanning patterns because of its demand for central executive resources.

Thirdly, mind wandering is accompanied with changes in eye scanning patterns. Antrobus and colleagues found that the frequency of eye movements was positively associated with the rate of changes of cognitive content. Their study found that eye movements and blinks were more frequent under the instruction to engage in active than passive thinking, to suppress than to generate a wish, and to imagine moving than static visual imagery (Antrobus, Antrobus, & Singer, 1964). In the study of the effects of mind wandering on reading performance, eye movement behaviors were found to be impaired, with more blinks (Smilek, Carriere, & Cheyne, 2010), longer fixation duration, and more erratic eye scanning patterns (Reichle, Reineberg, & Schooler, 2010). Proper eye scanning pattern is critical for driving safety. However, there has been no empirical effort to identify the link of eye movements when driving under mind wandering states versus attentive states.

Moreover, studies of cognitive failures provide additional support for the idea that mind wandering will hinder driving. The frequency of cognitive failure, incidents in which people fail to maintain attention on ongoing activity (Cognitive Failure Questionnaire, CFQ, Broadbent, Cooper, FitzGerald & Parkes, 1982), is predictable of traffic accidents mishaps and hospital admissions (Larson, Anderton,
Neideffer, & Underhill, 1997; Larson & Merritt, 1991; Wickens, Toplak, & Wiesenthal, 2008; Allahyari et al., 2008). The CFQ scale is often used as a measurement of the propensity to mind wandering. CFQ scores are predictive of both the self-reported frequency of mind wandering (McVay & Kane, 2009), and performance in Sustained Attention Response Task (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Manly, Robertson, Galloway, & Hawkins, 1999). Similar to cognitive failure, when mind wandering, attention is diverted away from the primary tasks (Smallwood & Schooler, 2006). Analogously, mind wandering would also predict accident rate as CFQ does, because of less attention devoted to driving. The study of Violanti and Marshall confirmed this speculation, by providing the evidence that drivers with higher accident risk are more likely to daydream or think about personal problems while driving (Violanti & Marshall, 1996)

Despite evidence implying driving decrements when mind wandering, there is no direct verification of the effect of mind wandering on driving performance. Moreover, positive effects of mind wandering on driving, such as arousal maintenance during boring driving, were expected by some researchers (Antrobus, Singer, Goldsein, & Fortgang, 1970). Would mind wandering’s functions of planning and arousal maintenance make up for its demand on limited-capacity central executive resources? How and to what extent would mind wandering influence driving safety? This research is devoted to study the effects of mind wandering on driving behaviors and performance, in a high-fidelity driving simulator.
Measuring mind wandering

In studies of physical or cognitive driver distraction, the researcher usually asks the participants to engage in a loading task, for example, using a cell phone or doing simple arithmetic calculations while driving. By comparing driver performance under dual task and the single-task conditions, the researcher can then evaluate the influence of distracting task. Mind wandering, as a self-activated thought, is more difficult to manipulate and measure in a controlled experiment. An experimenter cannot ask participants to mind wander naturally in the experiment, but can at best create conditions that encourage mind wandering prone task scenarios, for example, by asking participants to engage in simple, boring, and well-practiced tasks. There are two general methods that can be used to measure mind wandering, thought-sampling and retrospective questioning (Smallwood & Schooler, 2006).

The thought sampling technique has two broad categories, probe-caught mind wandering and self-caught mind wandering (Smallwood & Schooler, 2006; Schooler & Schreiber, 2004), differing in the way of sampling methods. The probe-caught method is modeled after the experience-sampling procedure (e.g., Hurlburt, 1993). Participants are given a probe at either random or quasi-random intervals, and are then asked to report their immediate mental content. The mental content can be classified as mind wandering or not by either the participant or by the experimenter. For example, Kane, Brown, McVay et al. (2007) used the probe-caught mind wandering paradigm to investigate the relationship between working memory capacity and mind wandering propensity in daily life. In their experiment, a personal
digital assistant signaled participants eight times daily to record their immediate thoughts, and their psychological and physical context.

In the self-caught technique for detecting mind wandering, participants are asked to monitor and report their mental states whenever they find their thoughts wandering off the current task (e.g., Cunningham, Scerbo, & Freeman, 2000). The probe-caught and self-caught mind wandering techniques differ in the level of meta-awareness they demand; the self-caught technique can only detect episodes of mind wandering that spontaneously enter meta-awareness, while the probe-caught mind wandering often catches off task thought before participants become meta-aware of them (Smallwood, et al., 2007).

Some evidence suggested that people have little or no direct introspective access to higher order cognitive processes (Nisbett & Wilson, 1977). Recent research also suggests frequent mind wandering without awareness. If the participants were not probed, these instances of mind wandering would go without being noticed by participants. Therefore, it is necessary to test the validity of thought-sampling technique to study mind wandering. Nevertheless, an accumulating body of empirical research has substantiated the validity of self-reports of mind wandering. Self-report of mind wandering is associated with decrements in behavioral performance in a variety of tasks, for example, memory retrieval (Smallwood et al., 2003), reading comprehension (Schooler, Reichle, & Halpern, 2004), Sustained Attention to Response Task (SART; Robertson, Andrade, Baddeley, & Yiend, 1997). Self-report of mind wandering also shows accompanying physiological changes, as revealed by neuroscience research, using EEG (Cunningham et al., 2000) and fMRI
(Mason, et al., 2007), and measures of heart rate and galvanic skin response (Smallwood et al., 2004). Mason and colleagues (2007), using the thought sampling technique and brain imaging, found that mind wandering is associated with activity in a default mode network of cortical regions. Importantly, self-report of mind wandering tendency was correlated with activity in the default network, which provides a direct neural signature of mind wandering, supporting the validity of the thought-sampling technique.

Kane and colleagues used the thought-sampling technique to study how working memory influences mind wandering frequency in an executive control task (SART; a go/no-go task) in the laboratory (McVay & Kane, 2009). Afterwards, they studied the frequency of mind wandering in everyday life using the same group of subjects (McVay, Kane, & Kwapil, 2009). They found that participants whose mind wandered more frequently in the controlled laboratory study were more likely to report off-task thinking in daily life, supporting the ecological validity to study mind wandering using thought-sampling technique in the laboratory.

Retrospective questionnaires, measure the frequency or contents of mind wandering during a recently completed task. Specific techniques include thought listing (Seibert & Ellis, 1991), the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), the Thinking Content component of the Dundee Stress State Questionnaire (Matthews, Joyner, Gililand, Campbell, & Faulconner, 1999), and the Imaginal Processes Inventory (Singer & Antrobus, 1970). The retrospective approach does not require subjects’ response during the ongoing primary task, and therefore, is less intrusive than either the probe-caught and self-caught thought-
sampling technique. However, retrospective questionnaires have inherent limitations, and may confound with meta-cognition, memory and task performance. To track the frequency of mind wandering accurately, subjects need to monitor the allocation of attention consistently. Consider that attention may drift away from primary task without awareness; the retrospective approach may overlook these instances of mind wandering without awareness. Moreover, people are poor at memorizing detailed information about the past mental events, even for recent events (Nisbett & Wilson, 1977). Most importantly, questionnaires can measure the overall frequency of mind wandering, but cannot evaluate the influence of mind wandering on immediate task performance.

Experiment goals

The awareness of distraction may determine how and to what extent mind wandering impairs driving performance. In the commonly studied visual and cognitive distraction, for example, GPS, cell-phone use, and conversation with a passenger while driving, drivers are usually aware that they are multi-tasking, and these distracting tasks may impair their performance. To maintain driving safety, drivers could choose to engage in these distracting tasks when they are capable of doing, such as, before starting the car, or when the velocity is low. With awareness of ongoing distracting task, drivers could also make a compensatory adjustment, or be more alerted to a possible hazard. However, for mind wandering, which is a self-activated and purely internal cognitive distraction; people are usually distracted by it without awareness (Schooler, Reichle, & Halpern, 2004). Therefore, for driving, it
would be hard for drivers to choose a proper time to engage in this distracting task, and take necessary precautions.

Considering the unconsciousness of some mind wandering and the prevalence of off-task thinking, mind wandering may incur more damage to driving safety than other external distraction. However, there is almost no research on how mind wandering influences driving in the scientific literature. The lack of research in this area is a result of the difficulty to track internal thoughts, and measure driving performance in real-time without endangering the drivers. In this study reported here, we utilized the self-caught thought-sampling technique to measure mind wandering, and examined the relationship between mind wandering and driving behaviors in a high-fidelity driving simulator.
METHODS

Participants

Nineteen participants (11 female and 8 male) were recruited through online advertisements and campus posters. The first subject was excluded from data analysis because of the technical failure to collect eye movement data. The ages of the participants ranged from 19 to 30 years, with a mean of 22 and standard deviation of 2.81. The mean self-reported driving distance per year of the participants was 6600 miles (range = 100 to 15000 miles). All participants had normal or corrected-to-normal visual acuity. Participants were each paid $8 per hour for a two-and-a-half hour experimental session.

Apparatus

Data were collected in a fully immersive fixed-base driving simulator, consisting of a 1998 Saturn SL positioned in a wrap-around environment with 135° forward and rear visual fields. Eight Epson Powerlite 703C projectors (1024 × 768 pixels of resolution) projected the driving scenes onto separate screens. Road and traffic information is visible through the interior and exterior rear view mirrors.

The simulator control dynamics were modeled after a typical four-door Saturn sedan. Drive Safety’s Vection Simulation Software™ Version 1.6.1 (DriveSafety, 2004) was used to display the virtual driving scenarios. The driving environments and traffic scenarios were created using HyperDrive Authoring Suite™ Version 1.6.1. The wind turbulence, button and brake press events, and other environmental
features were coordinated through TCL programming scripts. Measures of real-time driving performance, including time stamp, velocity, headway distance, time to collision, trigger events, brake inputs, and accelerator pedal position etc., were sampled at 30 Hz and auto-recorded for later analysis during the execution of a simulated drive.

Eye and head movements were collected with a Smart Eye Pro 3.0 system (SmartEye AB, 2004). This system consisted of three Sony XC HR50 monochrome cameras, which were equipped with two IR-illuminators and mounted on the dashboard of the car. The cameras feed information into software that locates predefined characteristic points on the participant’s face, and in this way determines where the participant’s foveae are pointing. Data were analyzed with customized software.

Experiment design

The research used a 2 (no vs. high wind turbulence) × 2 (mental state: mind wandering vs. attentive) within-subject design. Each session included five blocks, with the first block for practice driving, and the following four blocks for test-driving. No wind and high wind conditions were mixed within blocks, with sequence counter balanced across participants.

Driving environment and task

As is shown in Figure 1, the simulated driving environment consisted of a straight, two-lane rural road about 12.4 miles in length with small hills on one side
and pasture, cattle, and houses on the other side of the road. There was no traffic in
the opposing lane. The route included a 55 m/h speed limit which participants were
required to obey. The driving environment was purposefully created to be dull in
order to increase the number of mind wandering episodes (Kane, Brown, McVay,
Silvia, Myin-Germey, & Kwapi, 2007). The road was divided into two parts, one
part without lateral wind, and the other part with heavy lateral wind. The sequence
of the no and heavy wind segments was counter-balanced across drives. The
participants did not know the sequence of the wind conditions, or the exact location
where the wind turbulence would change.

The participant’s task was to maintain safe vehicle control, and follow the lead
vehicle ahead (blue Grand Prix), and keep ahead of the following vehicle (red Grand
Prix) in the same right-hand lane of the rural road. Participants were asked to keep a
safe headway distance between their car and the lead car. During the drive,
participants were told to keep their attention on the driving task as much as possible.
However, if they found themselves zoning out, they were required to press a button
on the steering wheel to report the mental states. To help them better understand the
concept of “zone out”, the experimenter gave participants examples to help them
differentiate “zone out” from normal driving.

Procedure

Screening. Upon arriving at the lab, drivers completed an informed consent form, a
screening questionnaire inquiring their driving experience and propensity for
simulator sickness, along with a demographic questionnaire. Drivers with at least
four years of driving experience, normal or corrected-to-normal vision ability, and no prior simulator sickness experience were allowed to participate in this experiment.  

**Practice drive.** Following camera calibration, participants were provided with a brief description of the experimental task. An example and definition of “zone-out” was also given to the participants to explain the concept. Participants then completed a practice drive to get used to the simulator and the driving environment. They were free to ask questions during the 10-minute practice drive session.

**Test drives.** Main experimental blocks began after participants fully understood the task and were comfortable to drive in the simulator. During the test drives, participants need to drive while self-monitoring their mental states, and press a button on the steering wheel if they caught themselves mind wandering. Each participant completed four drive sessions, each lasting about fifteen minutes. Each drive session include both no wind and heavy wind conditions. Participants were given a chance to rest between blocks.
RESULTS

Participants self-reported more episodes of mind wandering per 15-minute drive in no wind ($M = 5.69$) than in heavy wind ($M = 3.72$), $t (17) = 3.668$, $p = 0.002$. Thus, as expected, driving conditions that placed heavier demands on attention appeared to produce fewer episodes of mind wandering.

Klinger (1978) estimated the median duration of each mind wandering episode to be 5s, and the mean duration to be 14s. Smallwood, Beach, Schooler, & Handy (2008) adopted a 15 second time window for mind wandering in their study using the SART task. Therefore, the ten-second time window from -13 s to -4 s prior to each button press was designated as a mind wandering interval, and the window from 20 s to 29 s after the button press as an attentive interval. Intervals were limited to ten seconds duration to minimize the risk that analysis would extend beyond the onset of each mind wandering episode, and the window from -3 s to 0 s was excluded from analysis to avoid possible contamination from the demand to execute a button press when reporting a mind wandering episode. The window from 20 s to 29 s post-report was chosen as the interval of attentive driving to eliminate the influence of potential corrective over-adjustments to their driving behavior that participants might make immediately upon emerging from mind wandering. This therefore represented a conservative test of the potential changes that occurred during mind wandering. Analyses using the interval from 4 s to 13 s post-report produced a pattern of results similar to that reported below. Analysis of data for a
pair of larger time windows (-30s to -4s for the mind wandering interval; 4s to 30s for the attentive intervals) also produced results similar to those reported.

Driving performance measurements and eye scanning data were analyzed using a 2 × 2 within-subject ANOVA with mental state (mind wandering vs. attentive) and wind turbulence (no wind vs. heavy wind) as within-subject factors. Measures chosen for preliminary analysis were the mean and standard deviation of lane deviation, the mean and standard deviation of velocity, and the horizontal and vertical standard deviation of gaze position. Measures of lane position and velocity gauged the participants’ ability to monitor and control the vehicle laterally and longitudinally, while the horizontal and vertical standard deviation of the eye position measured how broadly participants distributed their visual attention.

Lane position and variability

Analyses of average lane position and lane position variability gauged the influence of mind wandering on lateral vehicle control. The lane position is the offset, in meters, of the vehicle’s center from the center of the lane. Positive values indicate offset to the right of the lane, and negative values indicate offset to the left. Figure 2 shows mean lane position values. On average, offset values were positive, indicating that participants generally drove to the right of their lane. However, analysis revealed a highly reliable main effect of wind turbulence, \( M = .013 \text{ m} \) vs. .09 m) \( [F(1, 15) = 5.91, p = .028, \eta^2_{\text{partial}} = .28] \), and a marginally reliable effect of mental states, \( M = .04 \text{ m} \) during mind wandering intervals vs. .07 m during attentive intervals) \( [F(1, 15) = 3.14, p = .097, \eta^2_{\text{partial}} = .17] \), indicating that
participants drove farther to the right under heavy wind conditions than under no wind, and tended to drive further to the right when attentive than when mind wandering. Interaction effect was not significant, \( F(1, 15) = 0.397, p = .538, \eta^2_{\text{partial}} = .026 \).

Analysis of the variability of lane position produced a reliable main effect of wind turbulence, \( F(1, 15) = 111.293, p < .001, \eta^2_{\text{partial}} = .881 \), but no reliable main effect of mental state, \( F(1, 15) = .002, p = .967, \eta^2_{\text{partial}} = .000 \), and no reliable interaction, \( F(1, 15) = .049, p = .828, \eta^2_{\text{partial}} = .003 \).

Car following performance

Analyses of the mean and variability of velocity assessed the influence of mind wandering on longitudinal vehicle control. Analysis of mean velocity distance revealed no significant main effect of both wind turbulence, \( F(1, 15) = .577, p = .459, \eta^2_{\text{partial}} = .037 \), and mental state, \( F(1, 15) = .025, p = .876, \eta^2_{\text{partial}} = .002 \), and no significant interaction\( F(1, 15) = .028, p = .869, \eta^2_{\text{partial}} = .002 \). The standard deviation of velocity showed a significant main effect of wind turbulence, \( F(1, 15) = 17.696, p = .001, \eta^2_{\text{partial}} = .541 \), and also reliable main effect of mental states, \( F(1, 15) = 6.725, p = .020, \eta^2_{\text{partial}} = .310 \), but no interaction effect, \( F(1, 15) = 1.032, p = .326, \eta^2_{\text{partial}} = .064 \). Analysis of accelerater position produced a similar pattern of effects.

To better understand the changes of the standard deviation of velocity, a spectral analysis of the velocity of the lead and subject vehicles (Brookhuis, De Waard, & Mulder, 1994) was carried out to compare drivers’ car following performance under attentive versus inattentive mental states. Spectral analysis
provides a fine-grained evaluation of drivers’ ability to adapt to the speed variation of the vehicle in the front, offering three independent measurements, including the coherence, the phase shift, and the modulus. Coherence, defined as the squared cross-correlation of subject and lead vehicle speed, measures the accuracy of drivers’ speed adaption. The score of coherence ranges from zero to one, with zero indicating no coherence between leading and subject vehicle speed, and one indicating perfect coherence. The phase shift measures the time delay of drivers to respond to the speed change of lead vehicle. A smaller phase shift value indicates better driving performance. Modulus, defined as the ratio of the speed gain of subject vehicle over the leading vehicle, measures the response amplification of drivers. A modulus value larger than one indicates drivers overreacted to the speed change of lead vehicle, and a decimal value indicates under-reaction. Coherence, phase shift, and modulus measure the accuracy, time delay, and intensity of speed adjustment in response to lead vehicle variation, respectively.

Coherence, phase shift, and modulus were analyzed using separate ANOVAs, with mental state (mind wandering vs. attentive) and wind turbulence (no wind vs. heavy wind) as within-subject factors. See Figure 3 for the graph.

Analysis of coherence revealed a significant main effect of mental state, \(M = .907\) for wandering mind vs. .941 for attentive mind) \([F(1, 15) =1304.739, p < .001, \eta^2_{partial} = .989]\), suggesting more accurate speed adjustment in response to lead vehicle speed change when the drivers were attentive. However, the main effect of wind turbulence, \([F(1, 15) =2.110, p = .167, \eta^2_{partial} = .123]\), and the interaction effect, \([F(1, 15) =1.217, p = .287, \eta^2_{partial} = .075]\), were not significant.
Analysis of phase shift did not yield any significant effects, all Fs < 1.0, ps > .10.

Modulus values under four conditions were all smaller than one, suggesting that drivers were conservative in adjusting vehicle speed. Analysis of modulus revealed a significant main effect of mental state, (M = .909 for wandering mind vs. .938 for attentive mind) [F (1, 15) =22.948, p < .001, η² partial = .605], suggesting that drivers adapted speed to a better extent of the lead vehicle speed change when attentive. However, the main effect of wind turbulence, [F (1, 15) =.276, p =.607, η² partial = .018], and interact effect were not significant, [F (1, 15) =.945, p =.346, η² partial = .059].

Comparison of the intervals -13 to -4 seconds and 13 to 4 seconds produced no reliable effects in any measure, potentially suggesting that car following performance requires several seconds to recover following the end of a mind wandering interval.

Vertical and horizontal deviation of gaze position

Horizontal and vertical standard deviations of gaze position within the forward view of the scenario served as measures of participants’ spatial attentional allocation while driving. Horizontal and vertical deviation data were submitted to separate ANOVAs. Figure 4 shows the mean values of the standard deviation of horizontal eye positions. The main effect of wind turbulence was not significant, [F (1, 15) =.882, p =.362, η² partial = .056], nor was the interaction, [F (1, 15) =2.938, p =.107, η² partial = .164]. However, data showed a reliable main effect of mental state, (M
=.048 m for mind wandering vs. .058 m for attentive) \([F (1, 15) =14.187, p =.002, \eta^2_{\text{partial}} = .486]\), indicating that the dispersion of the participants’ gaze was smaller during mind wandering than during attentive driving.

Analysis of the vertical eye position revealed a significant main effect of wind turbulence, \((M = .10 \text{ m for heavy wind vs.} .08 \text{ m for no wind}) \quad [F (1, 15) =7.158, p =.017, \eta^2_{\text{partial}} = .323]\). But neither the main effect of mental state, \([F (1, 15) =.642, p =.435, \eta^2_{\text{partial}} = .041]\), nor the interaction effect was significant, \([F (1, 15) =1.419, p =.352, \eta^2_{\text{partial}} = .086]\).

The results above indicate that the horizontal distribution of visual attention narrowed during mind wandering. To examine this effect more closely, a further analysis assessed the frequency of the side mirror checks.

Percent dwell time in the side mirrors

Percent dwell time in the side mirrors is calculated as the percent of time during which the eyes fixate on the side mirrors. The percent dwell time in the side mirrors provides a measure of participants’ efforts to seek rear-view information. Left- and right-side checks were combined for analysis. Figure 5 shows the percent dwell time in the side mirrors per interval. ANOVA analysis shows no significant interaction effect of mental state by wind turbulence, \([F (1, 15) =.085, p =.775, \eta^2_{\text{partial}} = .006]\), and no main effect of wind turbulence, \([F (1, 15) =.747, p =.401, \eta^2_{\text{partial}} = .047]\), but does reveal a significant main effect of mental state \((M = 6.46 \text{ vs.} 8.03) \quad [F (1, 15) = 8.416, p = 0.011, \eta^2_{\text{partial}} = .359]\).
DISCUSSION

In this study, subjects drove in a simulated driving scenario, while self-monitoring episodes of mind wandering. Mind wandering was accompanied by at least three changes in participants’ driving performance. Firstly, mindless drivers followed the velocity changes of the lead vehicle less carefully and under-compensated the velocity change. Secondly, participants drove nearer to the center of their lane, and therefore nearer to the edge of the opposite lane. Thirdly, participants narrowed their visual attention, making fewer saccades among the forward view, the left and right mirrors, and rearview mirror and reducing the standard deviation of horizontal eye position by almost 10 percent. These data indicated higher driving risks when mind wandering. In the current experiment, the opposing lane was always free of traffic and the leading vehicle never braked suddenly, meaning that these changes were of no consequence to driver safety. Under normal circumstances, however, a leftward shift in lane position would bring the driver’s vehicle nearer to oncoming vehicles in the adjacent lane, reducing the driver’s margin of safety and potentially increasing the risk of collision. The leading vehicle may also brake or slow down unexpectedly, the under-compensation of leading vehicle velocity change would lead to longer braking time, possibly causing rear-end crash.

Mind wandering appears to have effects similar to other forms of secondary task distraction, in terms of the eye scanning patterns. The dispersion of horizontal attention narrows, with the standard deviation of horizontal eye position shrinking
almost 10 percent when mind wandering. This result is similar to, though smaller than, an effect reported by Recarte and Nunes (2000). Such a narrowing of attention implies a potentially inflated risk of failure to detect road hazards while mind-wandering, and thus an inflated accident risk. Moreover, when the mind wanders, participants made fewer saccades among the forward view, the left and right mirror, and rearview mirror. This result corresponds to the effect of cognitive demanding task on driving. Similar to the effect of mind wandering, past work has found that cognitive distraction from a secondary task narrows drivers’ visual scanning (Brookhuis, de Vries, & de Waard, 1991; Recarte & Nunes, 2000, 2003; Victor, Harbluk, & Engström, 2005), reducing the horizontal dispersion of visual fixations and the frequency of mirror checks just as was observed during mind wandering in the current study.

Despite similar effect on eye scanning patterns, mind wandering has different effects on lateral and longitudinal vehicle control from secondary-task distraction. Secondary-task distraction have often seems to have little effect on lateral vehicle control (Alm & Nilsson, 1995; Horrey & Wickens, 2006), and sometimes seems to engender safer control, reducing the variability of lateral position (Becic et al., 2010; Brookhuis et al., 1991; Kubose, et al., 2006) and shifting mean vehicle position away from oncoming traffic (Alm & Nilsson, 1994). Mind wandering, in contrast, was accompanied by a shift toward the oncoming lane. Conversely, secondary-task distraction can degrade longitudinal vehicle control (Kubose et al., 2006) and reduce headway margins (Alm & Nilsson, 1995). Mind wandering did incur changes in longitudinal vehicle control. Coherence analysis
showed that mindless drivers followed the leading vehicle less carefully, and tended to under-react to the velocity change of the leading vehicle, which may lead to lengthened response time to hazardous events. However, mind wandering appeared to entail little change in the mean or variability of headway distance between subject vehicle and a lead vehicle in this study. Was this result because mindless drivers did not compensate for cognitive distraction by increasing headway distance, or the limitation of current study? The presence of a trailing vehicle and fixed distance between the leading and trailing vehicle might have prevented the drivers’ compensation strategy. It is therefore interesting and important to validate the effects of mind wandering in the future, using a standard car following paradigm, by removing the trailing vehicle and sudden brake or slow-down of the leading vehicle.

These effects suggest that mind wandering and secondary-task distractions may influence driver performance through mechanisms that are only partially overlapping. This conclusion accords with the observation, described above, that mind wandering and secondary-task distraction entails different forms of thought content (Smallwood et al., 2003), as well as the findings that mind wandering (Smallwood et al., 2008) and secondary-task driver distraction (Strayer & Drews, 2007) affect the P300 in slightly different ways. Mind wandering was found to involve in both medial prefrontal default network regions and executive network (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009), while distraction from a sentence listening task only caused less activity for the parietal and superior extrastriate (Just, Keller, & Cynkar, 2008).
Mind wandering and secondary-task distraction might also differ in the level of meta-cognitive awareness. Although drivers tend to underestimate the detrimental effects of secondary-task distraction on their behind-the-wheel performance (Horrey, Lesch, & Garrabet, 2008, 2009; Lesch & Hancock, 2004; White, Eiser, & Harris, 2004), they are clearly aware that they are engaging in a secondary-task when conversing on a cell phone or interacting with an in-vehicle information system. In contrast, a person may mind-wander for an extended time before noticing that his attention has drifted from the primary task (Smallwood, McSpadden, & Schooler, 2008). Secondary-task distraction may therefore allow compensatory behaviors or changes in task prioritization (Alm & Nilsson, 1994; Haigney, Taylor, & Westerman, 2000). In contrast, for mind wandering without awareness, people lose supervisory control of the primary task, but during mind wandering with awareness, people still reserve some extent of task supervision (Smallwood, McSpadden & Schooler, 2007).

In this study, subjects were asked to report their mental states as soon as they found themselves mind wandering. Therefore, the mind wandering instances captured in this study should be largely mind wandering without awareness, suggesting little likelihood of intentional compensatory behaviors to internal driving distraction. It is important to explore whether the availability of meta-cognitive awareness plays a role in the extent of driving decrement caused by cognitive distraction. A possible approach is to compare the influence of mind wandering with or without awareness on driving performance, using probe-caught mind wandering technique.
In summary, this study indicates that mind wandering can alter driver performance in ways that are potentially dangerous. Mind wandering, as a kind of internal cognitive distraction, demonstrated to have similar effect on eye scanning patterns as other cognitive distraction, which was caused by secondary task (Recarte & Nunes, 2000, 2003). At the same time, however, results suggest that performance data and oculomotor scanning behavior may allow the detection of drivers’ mind wandering episodes before they are recognized by the driver him/herself, potentially providing interventions to detect inattentiveness and alert drivers (Liang et al., 2007). Further research will be necessary to test this possibility.
FIGURES

Figure 1

(a). Perspective view

(b). Orthographic view
Figure 2

The graph illustrates the mean lane position in meters under different wind conditions for individuals in mind-wandering and attentive states. The x-axis represents wind conditions, with categories for 'no wind' and 'high wind.' The y-axis shows the mean lane position, with values ranging from 0.00 to 0.16. The data indicates a significant increase in lane deviation under high wind conditions compared to no wind conditions, with greater variability in the mind-wandering state.
Figure 3

- **Coherence**
  - No Wind: 0.90
  - Heavy Wind: 0.92

- **Phase shift**
  - No Wind: 60
  - Heavy Wind: 90

- **Modulus**
  - No Wind: 0.90
  - Heavy Wind: 0.92
Figure 4

![Bar chart showing standard deviation of horizontal eye position in mind-wandering vs. attentive conditions under no wind and heavy wind conditions.](chart.png)
Figure 5

![Bar chart showing percent dwell time in the side mirrors for mind-wandering and attentive conditions under no wind and heavy wind conditions. The chart indicates a higher percent dwell time under no wind for both conditions, with a notable difference between mind-wandering and attentive states.](image)

- **X-axis**: Wind condition (No wind, Heavy wind)
- **Y-axis**: Percent dwell time in the side mirrors
- **Legend**:
  - Mind-wandering
  - Attentive
REFERENCES


driver and the drunk driver. *Human Factors, 48*(2), 381-391.

distraction in traffic. AAA Foundation for Traffic Safety crashes. Retrieved

Sussman, E. D., Bishop, H., Madnick, B., & Walter, R. (1985). Driver inattention and


Treat, J. R., Tumbas, N. S., McDonald, S. T., Shinar, D., Hume, R. D., Mayer, R. E.,
accidents: Final report Volume I: Causal factor tabulations and assessments.
Institute for Research in Public Safety, Indiana University, DOT HS-805 085.

measures to in-vehicle task difficulty. *Transportation Research: Part F, 8*(2),
167-190.

epidemiological approach. *Accident Analysis and Prevention, 28*(2), 265-270.

in crashes: New statistics from the 1995 Crashworthiness Data System. *40th
Annual Proceedings of the Association for the Advancement of Automotive
Medicine, 377–392.*