Towards understanding mobile device use in Commercial Motor Vehicle Drivers: Do drivers interact as a drowsiness countermeasure?

Laura M. Toole, Richard J. Hanowski, Tonya L. Smith-Jackson,

Woodrow W. Winchester III

Virginia Tech

Abstract

This study examined factors associated with mobile device use (MDU) while driving in commercial motor vehicle operations. Analyses were performed on a naturalistic truck driving data set that involved 100 drivers operating a commercial truck that had been instrumented with data collection equipment, including video cameras. The focus of the analysis reported here was twofold. First, how does the MDU recorded in naturalistic driving video compare to the estimates of MDU from the National Occupant Protection Use Survey (NHTSA 2011)? Second, does MDU vary as a function of time-of-day? Regarding the first issue, based on video inspection, it was determined that participants used a hand-held phone approximately 4.3% of the time and a hands-free phone 4.0% of the time (totaling 8.3% of the driving time). When cell phones, Citizen's Band radios, and dispatching devices were included, it was found participants used devices 10.4% of the time. Considering time of day of MDU, one analysis binned the data to match circadian rhythm high (9 a.m. and 7 p.m.) and low (1 p.m. and 2 a.m.) points. Across the four bins, the highest proportion of MDU (accounting for exposure) occurred in the early morning (2 a.m.) bin. Results of additional analyses similarly provide support for the hypothesis that truckers may use a mobile device as a countermeasure to drowsiness.

Introduction

Driver distraction has become a major focus in the United States and internationally. Much of the focus surrounding secondary tasks, such as dialing a cell phone, has been on negative impacts. As a result of previous research, the Federal Motor Carrier Safety Administration (FMCSA) enacted two regulations that ban several cell phone interactions, including texting, reaching for or dialing a cell phone, and making a call with a hand-held cell phone (U.S. Department of Transportation, FMCSA 2010a; U.S. Department of Transportation, FMCSA 2010b). However, not all communication with cell phones (i.e., hands-free use) has been banned because it may be beneficial to drivers (U.S. Department of Transportation, FMCSA 2010b). Some studies have noted that secondary task engagement may support performance (Olson, Hanowski, Hickman, and Bocanegra 2009, Hickman, Hanowski, and Bocanegra 2010). This is especially true at low arousal levels (Fitch and Hanowski 2011, Curry, Meyer, and Jones 2013). These findings could be framed and explained using the Yerkes-Dodson curve and related research regarding arousal level and performance (Curry et al. 2013).

The Yerkes-Dodson curve illustrates the relationship between performance and arousal; optimal performance occurs with medium levels of arousal. In a vehicle-driving paradigm, asleep-at-the-wheel and overload might be considered end points on an arousal continuum. Much of the research directed at driver engagement in secondary tasks has focused on the negative safety impacts; that is, performing secondary tasks may overload the driver and affect the primary task of safely operating the vehicle. What is less understood is the impact that secondary task involvement might have on supporting (improving) performance at low arousal levels.

The current research examined the relationship between level of arousal and secondary task engagement; specifically, whether the percentage of mobile device use differs as a function of time of day, which has been linked to drowsiness. In addition, the amount of mobile device use found in naturalistic driving data is compared to national estimates. The analyses were achieved using a secondary data analysis, or an analysis of pre-existing data that answers questions that were not examined in the original study. The population of focus was commercial motor vehicle (CMV) drivers. A CMV has been defined as a “vehicle with a gross vehicle weight rating [GVWR] of 26,001 lb or more” (Virginia Department of Motor Vehicles n.d.: 1). The next section will elaborate on key concepts examined in the study: arousal, time of day, and mobile device use.

Level of Arousal

As noted, the Yerkes-Dodson curve could be used to describe why participants might engage in secondary tasks. Through Yerkes and Dodson (1908), it was established that participants’ capabilities to perform a task and the amount of effort required to perform the task were related. Hebb (1955) expanded on the ideas from Yerkes and Dodson and established that there is also a relationship between arousal and performance. Furthermore, Hebb indicated that there is an optimal level of arousal to maximize performance; when arousal is too low or too high, stimuli that restore the optimal level will be repeated. This phenomenon has also been noted by other researchers (Curry et al. 2013, Leuba 1955, Fischer, Langer, Birbaumer, and Brocke 2008).

More recently Fischer and colleagues (2008) examined (i) whether the brain compensates for low stimulation and (ii) the level of stimulation found when participants chose their settings in a driving simulator. Participants drove in a simulator at three different task demand levels: low, self-chosen, and high. These levels differed in the maximum speed participants could drive, the number of other cars on the road, and the type of environment they were driving in (e.g., the low level involved participants driving a racing circuit with no other cars at a maximum of 30 km/hr). In addition, participants performed a secondary, choice reaction time task. The measures used to capture stimulation were physiological (i.e., electroencephalograph [EEG], vertical electrooculogram [EOG], and electrocardiogram [ECG]) and questionnaires (i.e., NASA-Task Load Index [NASA-TLX] and Short Questionnaire for Current Strain [KAB]).

The results revealed that the self-selected task demand level had the highest level of brain stimulation (Fischer et al. 2008). This indicates that participants chose routes in a hilly, rural environment and speeds (i.e., 59.08 km/hr [*SD* = 14.40]) that produced an "optimal" level of arousal to facilitate attention (Fischer et al. 2008: 1449). The highest level of compensation as indicated by the EEG was found during the low task demand level; thus participants may have worked to increase their level of arousal when task demand was low.

Time of Day

In the current research, time of day was defined as the time a baseline epoch of interest, (explained later) occurred based on the 24-hour clock (Hanowski, Wierwille, Garness, and Dingus 2000). Time of day can effect humans' arousal and other characteristics, such as temperature, through the ebb and flow of the circadian rhythm (Aschoff 1965). Low periods during the circadian rhythm have been linked to decreased levels of alertness (Caldwell, Caldwell, and Schmidt 2008). In addition, Stutts, Wilkins, and Vaughn (1999), Johns (2000), and Desai and Haque (2006) have indicated that time of day and the circadian rhythm may cause drowsiness. For this study, drowsiness was defined as the desire to sleep (Stutts et al. 1999, Johns 2000). Drowsiness can decrease an individual's ability to perform a task continuously unless effort is exerted to compensate for the decreased alertness (Kahneman 1973). It has been suggested that as a driver becomes drowsy his/her attentional capacity for a specific task decreases (Gugerty and Brooks 2002).

Past findings related to time of day provide insight into the effects of circadian rhythm, arousal, and performance. The primary goal of Wylie, Shultz, Miller, Mitler, and Mackie (1996) was to examine the effects of time of day, among other factors, on driving performance as it related to safety for CMV drivers. The researchers believed driver drowsiness, as well as a decrease in driving performance and alertness, could stem from the factors they were examining. Physiological measures, such as EEG and body temperature, and driving performance measures, such as lane position and speed, were recorded during an on-road study. The results indicated that a higher level of drowsiness could be seen at night (i.e., midnight to dawn) versus day, particularly from late evening to dawn. In addition, performance decrements were found during this high drowsiness period.

Mobile Device Use

The secondary task examined in the current research was mobile device use. Within "mobile device use" the three specific devices of interest were cell phones, Citizen's Band (CB) radios, and dispatching devices. In addition, cell phone use was further divided into subtasks. The definition of each device and cell phone subtask can be found in Table 1 and are based on Olson et al. (2009).

Table 1 Description of Mobile Device Use Subtasks

Subtask	Definition
Dial Cell Phone	The participant dials cell phone, which may include answering or hanging up phone. It is assumed the participant is looking at/may reach for the cell phone.
Text Message on Cell Phone	The participant seems to be text messaging on cell phone. This may include the

	participant focusing on a cell phone for a period of time and continuously pressing keys. It is assumed the participant is looking at/may reach for the cell phone.
Talk/Listen to Hand-Held Phone	The participant holds a hand-held phone to his/her ear. In addition, he/she seems to be talking/listening.
Talk/Listen to Hands-Free Phone	The participant has an earpiece in his/her ear and seems to be talking /listening.
Talk/Listen to Citizen's Band (CB) Radio	The participant talks/listens to a CB radio. It is assumed the participant is looking at/may reach for the CB radio.
Interact with/Look at Dispatching Devices	The participant interacts with/looks at dispatching device. This may include holding the device on his/her lap/steering wheel while using the device. It is typically kept on the passenger seat/floor between the driver and passenger seat. It is assumed the participant is looking at/may reach for the device.
Mobile Device Use (Including All Devices and Subtasks)	The participant is performing any of the subtasks defined above. They are all grouped into a general use category.

Research has thoroughly assessed the risk of interacting with these devices, including analyses at the subtask level (Fitch et al. 2013, Hickman, Hanowski and Bocanegra 2010, Olson et al. 2009). The results of these studies provided insight for the current research in regard to mobile device use and driving performance. Recently, Fitch and colleagues (2013) examined distraction that stemmed from the use of hand-held, portable hands-free (e.g., Bluetooth headset), and integrated hands-free (e.g., sync system in vehicle) cell phones for 204 passenger car drivers. The researchers were granted access to the personal cell phone records of participants; this allowed the researchers to verify exactly when the drivers were using their cell phones and under what conditions (i.e., by cross referencing the cell phone record with the video). Through a naturalistic study, the researchers examined how engagement with these types of cell phones influenced driving performance. Analyses indicated when drivers were talking on a hand-held cell phone that there was a significant *decrease* in the mean amount of time they spent with their eyes off the road. In addition, talking on a hand-held cell phone was found to significantly *decrease* the number of times drivers unintentionally left their lane. In addition to mobile device use related to performance, researchers examined the percentage of cell phone use by the participants. Of the 8,240 total hours of driving, 871 were spent talking on cell phones; that is, participants were talking on a cell phone, hand-held or hands-free, for 10.6% of the driving time.

Baker, Bowman, Nakata, and Hanowski (2008) used focus groups with various types of CMV drivers to gain insight into CMV driver drowsiness and potential countermeasures. The questions posed during the sessions were based on the gaps in the literature. One particular question asked the drivers about countermeasures they used or strategies they had to remain alert when drowsy. Participants indicated that one technique they used was to converse on their CB radio to keep themselves alert.

Jellentrup, Metz, and Rothe (2011) investigated if conversing on a cell phone was related to participant alertness. Researchers collected a physiological measure (EEG) and eye-closure rates (through metal coils on the eyelids of one eye). The participants drove on a test track for two 3-hour blocks, one in the morning and one in the afternoon. During these periods the drivers received three phone calls (i.e., after 1, 2, and 2.5 hours). In regard to blink duration, a driver is more alert if he/she experiences a decrease in blink duration. Such a decrease was found during and 10 minutes after the first and second phone calls in the morning as compared to 20 minutes before the call. However, in the afternoon block only the first phone call was associated with a significant decrease, which also occurred during and 10 minutes after the call versus 20 minutes before. The difference in the alertness of drivers in the morning and afternoon could indicate an influence of time of day and circadian rhythm.

Method

The aim of the current research was to examine if mobile device use varies as a function of time of day. In addition, the amount of mobile device use recorded in the naturalistic driving video used in the current research was compared to the estimates from the 2010 National Occupant Protection Use Survey (NOPUS). As noted, a secondary data analysis was performed using data that were collected through the Naturalistic Truck Driving Study (NTDS) (Blanco et al. in press).

The Data Used

In the NTDS, there were 95 males and 5 females whose age ranged from 21 to 73 years old with a mean of 44.50 (SD = 12.20). Their years of CMV driving experience ranged from 0.1 to 54 with a mean of 9.10 (SD = 10.46). Each of the 100 participants drove a CMV for an average of four work weeks. All of the CMVs were instrumented with various types of data collection equipment, including video cameras that captured five views (e.g., the driver and the external environment). In addition, participants recorded their work/rest schedules in driver logbooks.

In the Driver Distraction in Commercial Vehicle Operations (CVO) study (Olson et al. 2009), researchers sought to determine if the driver was performing a secondary task just before or during a safety-critical event or baseline epoch of interest. Trained data reductionists viewed the video of each event or epoch of interest, identified if the driver was engaging in a secondary task, and recorded details about the type of secondary task. The recorded information included the mobile device use.

Safety-critical Event and Baseline Epoch

Generally, a safety-critical event is a driver error that was marked by the data collection system and verified by a trained data reductionist (Olson et al. 2009). This driver error could stem from a secondary task that took the driver's attention away from the forward roadway. A baseline epoch is normal, uneventful driving representative of the participants. Baseline epochs are randomly sampled from an entire database based on certain criteria, such as how long a driver participated in the study. They provide a general picture of normative driving and secondary task engagement.

Time-of-day Bins

In the current research, the data were divided into four 2-hour bins in order to gain more specific information about the relationship between mobile device use and time of day. The bins were determined based on previous literature regarding driving performance and circadian rhythm (Lenné, Triggs, and Redman 1997, Moller, Kayumov, and Shapiro 2003, Wylie at al. 1996). The bins are defined in Table 2.

Table 2 Division of data into bins

Bin	Time of Day	Will be referred to as
Low Circadian Rhythm Bin	2:00 a.m. – 3:59 a.m.	Low Morning Bin
High Circadian Rhythm Bin	9:00 a.m. – 10:59 a.m.	High Morning Bin
Low Circadian Rhythm Bin	1:00 p.m. – 2:59 p.m.	Low Afternoon Bin
High Circadian Rhythm Bin	7:00 p.m. – 8:59 p.m.	High Evening Bin

The figure below depicts the circadian rhythm with the bins marked by red squares.

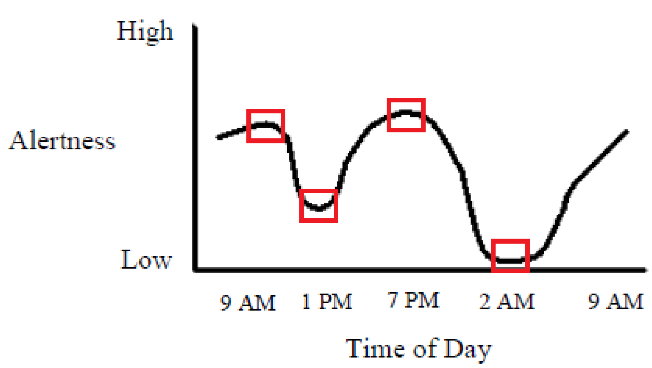

Figure 1 Source: Reproduced from Toole, in press. Crash risk and mobile device use based on fatigue and drowsiness factors in truck drivers. Virginia Tech, Blacksburg, VA. With permission.

Analysis

In order to determine if the percentage of mobile device use (including all devices and subtasks) changed across these bins, a chi-square test was conducted. If the result was significant, additional chi-square tests were conducted to determine which bins had significantly different percentages. In addition, a generalized linear mixed model (GLMM) with logit link function was used to predict the odds as a function of the presence of mobile device use during a baseline epoch as a function of time of day.

To compare the amount of mobile device use recorded in the current research to that estimated by NOPUS 2010, the data were separated based on the presence or absence of mobile device use and what type of subtask the driver was engaging in. The number of each of the mobile device and cell phone subtasks were divided by the total number of baseline epochs with and without mobile device use (i.e., 3,956) and multiplied by 100. Only baselines were used in order to compare the results of these analyses to the results of the chi-square test. The percentage of "mobile device use (including all devices and subtasks)," "talking/listening on hands-free cell phones," "talking/listening on hand-held cell phones," and "dialing a cell phone" were calculated.

As noted, baseline epochs provide a good picture of general device use as opposed to safety-critical events. For this reason, safety-critical events were not included in the chi-square test, GLMM, or comparison to previous estimates. However, it is important to realize that this method does thus not include all occurrences of mobile device use, but rather presents an estimate based on the randomly selected baselines. An alpha level of .05 was used to determine significance.

Results and Discussion

As noted, the amount of mobile device use present in the videos for the current research was compared to the estimates of cell phone use provided by NOPUS during 2010. The NOPUS data included drivers using a hand-held or hands-free cell phone (National Highway Traffic Safety Administration 2011). A total of 5% of drivers used a hand-held cell phone and 4% used a hands-free cell phone.

The table below provides the number of baseline epochs of interest that included each device or cell phone use subtask in the current research. Please note that multiple subtasks could have occurred during a baseline epoch, so simply adding the number of epochs in each subtask will not produce the correct total.

Table 3 Number of baseline epochs of interest for each category and subtask

Category/Subtask	Number of Epochs
Total Number of Baseline Epochs	3,956
Mobile Device Use (Including All Devices and Subtasks)	413
No Mobile Device Use	3,543
Dial Cell Phone	30
Text Message on Cell Phone	3

Talk/Listen to Hand-Held Cell Phone	169
Talk/Listen to Hands-Free Cell Phone	157
Talk/Listen to CB Radio	40
Interact with/Look at Dispatching Device	26

Participants conversed on a hand-held cell phone approximately 4.3% of the time and a hands-free cell phone approximately 4.0% of the time. These results were similar to the estimates from NOPUS (i.e., 8.3% in the current study vs. 9% in NOPUS); however, they were slightly lower than the 10.6% usage found by Fitch et al. (2013). The slight difference in the percentage conversing could be explained by the fact that the Fitch et al. (2013) data were collected more recently; there were approximately 80 million more cell phone subscribers in the United States between when the data for the current research were collected in 2004 and NOPUS in 2010 (History of Wireless Communication 2011). It is important to realize that the study population is also different between the NOPUS and Fitch et al. data, which used light vehicle drivers, and the current research, which used CMV drivers. Given these caveats, the findings regarding MDU are quite similar between these three studies. Also, when all baseline epochs for MDU (including all devices and subtasks) were included, participants engaged 10.4% of the time in the current research (comparable to Fitch et al. 2013). To clarify, when all subtasks related to cell phones, talking/listening to a CB radio, and interacting with/looking at a dispatching device were combined, the results indicated participants engaged in MDU 10.4% of the time.

It was also important to determine the percentage of mobile device use in each 2-hour time bin and whether or not there was a significant difference between bins. The results could point to whether or not drivers attempt to regulate their arousal when drowsy. First, the GLMM with logit link function was conducted to predict the odds as a function of the presence of MDU during a baseline epoch as a function of time of day. The result was significant ($p < .001$). This indicates that time of day was a good predictor of the presence of mobile device use.

As noted, a chi-square test was conducted to determine if the percentage of mobile device use (including all devices and subtasks) was different across bins. The table below represents the contingency table used; it is important to realize that although the data is presented in a contingency table, the test analyzes proportions.

Table 4 Contingency table for chi-square test

Bin	Mobile Device Use	No Mobile Device Use	Total
Low Morning	41	189	230
High Morning	11	238	249
Low Afternoon	27	318	345
High Evening	39	404	443

The result of the chi-square test for all of the baseline epochs was significant $\chi^2(3, N = 1{,}267) = 27.84$, $p < .001$. This indicates that there was a significant difference in percentage between at least two of the bins. The percentage of mobile device use (including all devices and subtasks) found for each bin was as follows: low morning bin was 17.83%, high morning bin was 4.42%, low afternoon bin was 7.83%, and the high evening bin was 8.80%. Additional chi-square tests were conducted to compare each of the bins to one another. It can be seen from the table below that the low morning bin had a significantly higher percentage of mobile device use (including all devices and subtasks) than all other bins. In addition, the percentage for the high evening bin was significantly greater than the percentage for the high morning bin.

Table 5 Chi-square results when comparing all bins to one another

Bins	Results
Low Morning and High Morning	$\chi^2(1, N = 479) = 22.21$, $p < .001$*
Low Morning and Low Afternoon	$\chi^2(1, N = 575) = 13.23$, $p < .001$*
Low Morning and High Evening	$\chi^2(1, N = 673) = 11.76$, $p < .001$*
High Morning and Low Afternoon	$\chi^2(1, N = 594) = 2.81$, $p = .09$
High Morning and High Evening	$\chi^2(1, N = 692) = 4.57$, $p = .03$*
Low Afternoon and High Evening	$\chi^2(1, N = 788) = 0.24$, $p = .62$

*Refers to statistically significant results.

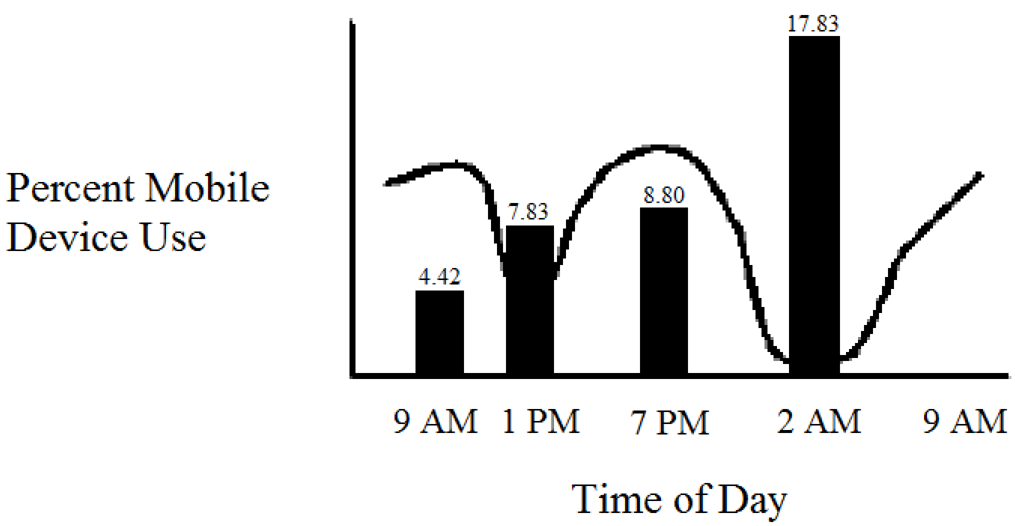

Figure 2 Percentage of mobile device use for each bin overlaid on circadian rhythm highs and lows

The findings that mobile device use in the low morning bin was significantly higher, as seen in Figure 2, may indicate that participants used the mobile devices to counter drowsiness and regulate their level of arousal. Wylie et al. (1996) lends support that participants were most likely drowsy during the low morning period. The findings that the high evening bin had a higher percentage of mobile device use than the high morning are also supported by the finding that there was a high level of drowsiness in the late evening (Wylie et al. 1996). The possibility that participants were moderating their level of arousal is consistent with Fischer et al. (2008).

Summary and Conclusions

Overall, in the current research, the percentage of conversing on a cell phone was 8.3% and the percentage of mobile device use (including all devices and subtasks) was approximately 10.4%. When the data were divided into bins, the low morning bin had a significantly higher percentage of mobile device use (including all devices and subtasks) (i.e., 17.8%) than all other bins. This percentage is also approximately 70% greater than the 10.4% of mobile device use (including all devices and subtasks) found with all baseline epochs (normative behavior).

As noted, time of day is associated with the circadian rhythm and drowsiness (Stutts et al. 1999, Johns 2000, Desai and Haque 2006); thus, it might be assumed that drivers were drowsy during the low morning period for the current research. In addition, individuals are likely to repeat a task that increases arousal (Hebb 1955). This was reported by drivers in the focus groups conducted by Baker et al. (2008). In the current research, one explanation for the findings is that drivers may have increased their mobile device use in the early morning hours to increase their arousal from a low to a more moderate level, which could be seen as a countermeasure to drowsiness. As seen in the Yerkes-Dodson curve, a moderate level of arousal is associated with improved performance.

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