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Editorial

Letter from the Editors - Fourth international symposium on naturalistic driving research

The *Journal of Safety Research* is pleased to present this collection of papers that were originally presented at the *Fourth International Symposium on Naturalistic Driving Research*. The symposium, hosted by the National Surface Transportation Safety Center for Excellence (NSTSCE) at Virginia Tech, was held in August 2014. From over 40 papers and posters exploring a wide range of naturalistic driving topics, these studies have been selected through our peer-reviewed process to be presented in this special issue.

Although all of the studies included in this special issue use naturalistic driving research methods, the topics explored and analysis methods used vary widely. Studies in this collection can be roughly categorized into three broad groups:

Novice driving:

- Naturalistic teenage driving study — Findings and lessons learn
- Using naturalistic driving data to examine drivers' seatbelt use behavior, comparison between teens and adults
- Personality and crash risk
- Conducting in-depth naturalistic riding study: examples from beginner motorcyclists

Distracted driving:

- Creation of the NEST distracted driving dataset
- Are cellular phone blocking applications effective for novice teen drivers?
- Drivers' visual behavior when using handheld and hands-free cell phones
- Examination of drivers' cell phone use behavior at intersections by using naturalistic driving data

Methodological papers exploring innovative techniques in data extraction and analysis:

- Population distributions of time to collision at brake application during car following from naturalistic driving data
- Evaluation of a video-based measurement of driver heart rate
- Drunk driving detection based on classification of multivariate time series
- Naturalistic drive cycle synthesis for pickup trucks
- Older driver fitness-to-drive evaluation using naturalistic driving data

We hope you find this collection of naturalistic driving research valuable. Through programs like SHRP 2 (see accompanying letter and articles in this issue) naturalistic driving research will become more prevalent in the years to come with the potential of revolutionizing our understanding of motor vehicle safety. However, all research methodologies have limitations, and no single methodology can fully explain the complex causal nature of crashes. The Journal invites all researchers conducting rigorous evidence-based investigations, regardless of the methods used or conclusions made, to consider submitting their studies. These studies add to the understanding of us all. Only through the publishing of findings in peer-reviewed journals and through the subsequent debate on the merits of the research can the field of motor vehicle safety research advance. In this light, the Journal invites thoughtful commentary on this collection of studies.

Thomas W. Planek
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Editorial

The 4th International Symposium on Naturalistic Driving Research

The Virginia Tech Transportation Institute is proud to have hosted the 4th International Symposium on Naturalistic Driving Research in August of 2014. The papers presented in this special issue are expanded versions of the papers and posters presented at that symposium, and they represent the first dedicated collection of papers in this new area of research. In the past 20 years, we have seen the field of naturalistic driving research expand in incredible fashion. Advances have occurred in all aspects: from vehicles with car trunks and truck cabs filled with analog recording equipment to state-of-the-art miniaturized data collection systems, from a few participants to thousands of participants per study, from manual coding of data using video tape players and spreadsheets to sophisticated data coding and extraction software, and from simple parametric statistical analysis to advanced statistical modeling techniques. Most importantly, naturalistic driving has progressed to the point that the methods, equipment, and data are now available to a wide variety of researchers.

This is what made the 4th Symposium so special: for the first time there were enough researchers doing work in the field that we were able to have a call for papers. By contrast, the three previous symposia were introductory in nature — introducing the methods, equipment, and analysis techniques to a new generation of researchers, with invited papers from those known to be working in the field.

We hope that you find the papers presented in this issue to be useful in your own research, and that you will consider adding the naturalistic driving techniques and data to your research portfolio. Most importantly, we hope that the research highlighted in this issue will provide the impetus to help save lives and improve transportation efficiency worldwide.

Jon Hankey
Senior Associate Director Virginia Tech Transportation Institute, USA

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Drivers' visual behavior when using handheld and hands-free cell phones

Gregory M. Fitch *, Paul R. Bartholomew, Richard J. Hanowski, Miguel A. Perez

Virginia Tech Transportation Institute, USA

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ABSTRACT

Objective: This study investigated driver distraction and how the use of handheld (HH), portable hands-free (PHF), and integrated hands-free (IHF) cell phones affected the visual behavior of motor vehicle drivers. *Method:* A naturalistic driving study recorded 204 participating drivers using video cameras and vehicle sensors for an average of 31 days. A total of 1564 cell phone calls made and 844 text messages sent while driving were sampled and underwent a video review. Baselines were established by recording epochs prior to the cell phone interactions. Total eyes-off-road time (TEORT) was examined to assess the visual demands of cell phone subtasks while driving. Percent TEORT was reported and compared against the baseline. *Results:* Visual-manual subtasks performed on HH, PHF, and IHF cell phones were found to significantly increase drivers' mean percent TEORT. In contrast, conversing on an HH cell phone was found to significantly decrease drivers' mean percent TEORT, indicating that drivers looked at the forward roadway more often. No significant differences in percent TEORT were found for drivers conversing using PHF or IHF cell phones. The mean TEORT durations for visual-manual subtasks performed on an HH cell phone were significantly longer than the mean TEORT durations on either IHF or PHF cell phones. *Practical applications:* This research helps to further reinforce the distinction made between handheld and hands-free cell phone use in transportation distraction policy.

1. Introduction

As of November 2014, 14 states (as well as the District of Columbia, Puerto Rico, Guam, and the Virgin Islands) have banned all handheld (HH) cell phone use while driving (National Highway Traffic Safety Administration, 2014). In part due to this legislation, the use of hands-free devices has risen. Hands-free cell phones comprise both (a) portable hands-free (PHF) devices, which include headsets (wired or wireless) or other aftermarket Bluetooth® devices that are not integrated into the vehicle by the manufacturer, and (b) integrated hands-free (IHF) devices, which consist of speakers, microphones, and controls built into the vehicle by the manufacturer to support voice dialing and hands-free talking.

Previous research has shown that both handheld and hands-free cell phones alter drivers' visual behavior (Harbluk, Noy, Trbovich, & EizenmanHarbluk, Noy, Trbovich, & Eizenman, 2007; Maples, DeRosier, Hoenes, Bendure, & MooreMaples, DeRosier, Hoenes, Bendure, & Moore, 2008; Olson, Hanowski, Hickman, & BocanegraOlson, Hanowski, Hickman, & Bocanegra, 2009). Liang and Lee (2010) found that visual distraction interferes with driving performance more than cognitive distraction and dominates distraction-related decrements to driving performance when the driver is both cognitively and visually distracted. In multiple experimental studies using driving simulators and controlled procedures, just conversing on a cell phone has been shown to degrade performance. This degradation leads to missed signals, slower reaction times, poor speed and headway maintenance, reduction in area of the road scanned, and failure to remember seeing objects (Atchley & Dressel, 2004; Caird, Willness, Steel, & Scialfa, 2008; Drews, Pasupathi, & Strayer, 2004; Horrey & Wickens, 2006; Maples et al., 2008; Rakauskas, Gugerty, & Ward, 2004; Recarte & Nunes, 2003; Strayer & Johnston, 2001). However, naturalistic driving studies have not found conversation on a cell phone to be associated with an increased safety-critical event risk. This discrepancy could be due to the nature of naturalistic studies, and the ability for drivers to select how to drive and use a cellphone (Fitch, Hanowski, & Guo, 2015).

The precise differences between the various types of cell phones in terms of their subtask visual attention demands are still relatively unknown. Hands-free cell phones reduce some of the physical demands associated with handheld devices (e.g., holding the phone), but not all. Some of the inherent subtasks, such as initiating and terminating a call, still require visual and manual interactions. Moreover, they may lead to drivers engaging in other activities given that hands-free cell phones relinquish the driver from having to hold a cell phone. A study by the Insurance Institute for Highway Safety (IIHS) concluded that when drivers were not using a phone, they tended to engage in other distracting behaviors, such as eating or drinking (Karush, 2014). This idea can be extended to hands-free cell phone use: unconstrained by the demands of operating an HH cell phone drivers may engage in

* Corresponding author at: 3500 Transportation Research Dr, Blacksburg, VA 24061, USA.
E-mail addresses: gfitch@vtti.vt.edu (G.M. Fitch), pbartholomew@vtti.vt.edu (P.R. Bartholomew), rhanowski@vtti.vt.edu (R.J. Hanowski), miperez@vtti.vt.edu (M.A. Perez).

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other visually and manually demanding tasks. For example, although the difference was less than 0.5%, Soccolich, Fitch, Perez, and Hanowski (2014) found that drinking and eating occur significantly more often in IHF subtasks than in HH subtasks (0.58% and 0.15%, respectively).

To better gauge the effects of HH and hands-free cell phones on driver distraction, this study investigates cell phone use by analyzing several smaller subtasks that impose their own demands on the driver. By measuring and comparing these subtasks, we can better determine the primary contributors to cognitive and visual distraction in driving. Specifically, this study examines visual attention to the forward roadway as manifest in the effect that selected subtasks have on eye-glance behavior for HH, PHF, and IHF cell phones and considers the impact on driver safety policy.

2. Method

The data analyzed in this study were collected using a naturalistic driving study (NDS) previously performed by the Virginia Tech Transportation Institute (VTTI) and Westat (NHTSA contract DTNH22-05-D-1002). In this NDS, 204 drivers were continuously recorded for an average of 31 days. The average age of the drivers was 41 years, and the gender distribution was 63% female and 37% male. Only participants who, upon screening, reported that they drive and talk using a cell phone at least once per day were admitted into the study. Drivers were from Virginia and North Carolina, states that do not ban handheld cell phone use while driving. Participants used their own cell phones and interfaces, and were not provided other phones or interfaces to use. Participants who operated vehicles with hands-free interfaces may have made both handheld and hands-free calls.

Naturalistic data collection began when the vehicle ignition was started and consisted of video and kinematic data. The video data included five camera angles, one of which recorded the driver's actions. These data were used in conjunction with the cell phone records released by the participants to identify calls and text messages exchanged while the vehicle was in motion. Only epochs that occurred while the vehicle was traveling at least 8 km/h were considered in the analysis. A total of 1564 calls and 844 text messages were identified, for a total of 2408 cell phone use samples.

Trained video data reductionist recorded the precise beginning and end frames of the observed cell phone subtasks. Each individual subtask was given a specific and unique cell phone interaction ID. Table 1 presents the subtasks that were identified in the analysis. It is important to note that some PHF and IHF interactions may have included use of the HH phone interface. For example, a participant could receive a call and answer with the handheld phone but proceed to converse and end the conversation using the IHF system in the car.

Once the different subtasks were identified, the reductionists reduced the drivers' eye-glance locations for the sampled subtasks. Due to the oftentimes lengthy nature of cell phone calls, a random 6-s interval of the conversation was sampled for the eye-glance reduction. A 6-s sampling period has been used in similar studies of safety-critical events and is the established standard practice at VTTI for the reduction of eye-glance behavior (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Six seconds represents a long enough duration to accurately measure eye-glance behavior while ensuring only one subtask is being performed.

Table 1
Subtasks reduced for sampled calls.

Subtask	Abbreviation
Handheld: locate/reach/answer	HH: locate/answer
Handheld: dialing	HH: dial
Handheld: talk/listen/voice commands	HH: talk/listen
Handheld: texting	HH: text
Handheld: viewing/browsing/reading	HH: browse/read
Handheld: end task	HH: end task
Portable hands-free: locate/put on headset/earpiece	PHF: locate/put on
Portable hands-free: push button to begin/answer	PHF: begin/answer
Portable hands-free: talk/listen/voice commands	PHF: talk/listen
Portable hands-free: push button to end	PHF: end task
Integrated hands-free: press button to begin/answer	IHF: begin/answer
Integrated hands-free: talk/listen/voice commands	IHF: talk/listen
Integrated hands-free: press button to end	IHF: end task

A 20-s epoch was used as the standard baseline period. This 20-s epoch was sampled 30 s prior to the first subtask performed for every cell phone call and text message. Sampling a baseline close in time to the cell phone interaction ensured that a similar driving context was found in both the baseline and the subtask epoch. This allowed for a higher degree of experimental control to be achieved. The 20-s epoch thus provides a long enough period to secure representative data for the driver's eye-glance behavior while also maintaining the continuity of the driving context (Hanowski, Perez, & Dingus, 2005). Additional detail is presented in Fitch et al. (2013).

The visual demands of cell phone subtasks while driving were assessed using Total Eyes-off-road Time (TEORT). Both percent TEORT and TEORT durations were examined. These measures reflect driver inattention to the forward roadway that results from either multiple short off-road glances or one long off-road glance over an interval of interest. Percent TEORT provides a normalized measure that allows for the comparison of visual behavior across the different subtasks. TEORT duration has been correlated with a decrease in driver performance, and thus is considered a tenable basis to compare subtask risk in the context of visual distraction (Klauer, Guo, Sudweeks, & Dingus, 2010; Liang & Lee, 2010; Olson et al., 2009).

Percent TEORT was computed as the total number of samples, measured in video frames, where the driver's eyes were off the forward roadway divided by the total number of samples in the subtask or baseline sample. The operational definition for TEORT that was used included glances made to mirrors and side windows. As an example, a driver who takes his/her eyes off the road for a total of 7.8 s when performing a dialing subtask over 12.4 s would have a percent TEORT of 63%.

The interval of analysis spanned the duration of the individual subtask, or for conversation subtasks the randomly selected 6-s interval. Inferential statistics were only performed in instances where eye-glance data were available for the subtask and corresponding baseline. This allowed for a controlled comparison of percent TEORT. For each separate subtask, a one-way within-subject analysis of variance (ANOVA) was performed to investigate whether the mean percent TEORT when performing the subtask differed from the mean percent TEORT during its matched baseline sample. The cell phone interaction ID was used as the within-subject variable. To expand on the example above, only baseline epochs that took place in the interactions where dialing occurred would be considered in the within-subject analysis. Table 2 presents the ANOVA summary results.

3. Results

3.1. Percent teort

With respect to HH cell phone use, locating the cell phone, dialing, browsing, text messaging, simultaneously browsing and conversing, and ending cell phone use were all found to significantly increase the percentage of time drivers took their eyes off the forward roadway. Conversing on an HH cell phone, however, was found to significantly lower drivers' mean percent TEORT from 14.6% to 9.5%.

With respect to PHF cell phone use, locating the HH cell phone, dialing on an HH cell phone, and simultaneously browsing and conversing on the PHF cell phone were all found to significantly increase the percentage of time drivers took their eyes off the forward roadway. Conversing on a PHF cell phone did not have a significant effect on mean percent TEORT.

With respect to IHF cell phone use, locating the HH cell phone, pressing a button to begin/answer an IHF call, dialing on an HH cell

Table 2
ANOVA results for within-subject comparisons of mean percent TEORT between each subtask and its matched baseline.

Cell phone type	Subtask	Baseline mean (%)	SE (%)	Subtask mean (%)	SE (%)	N	df_1	df_2	F stat	*p*-Value
HH	HH: locate/answer	15.2	1.0	33.1	1.6	201	1	87	105.18	<.0001
	HH: dial	16.1	1.4	59.5	1.4	131	1	64	498.36	<.0001
	HH: talk/listen	14.6	0.9	9.5	0.9	207	1	91	14.80	.0002
	HH: browse/read HH: talk/listen	12.3	1.7	71.5	2.7	56	1	34	357.38	<.0001
	HH: end task	14.8	1.0	44.1	2.0	179	1	84	120.07	<.0001
PHF	PHF: locate/put on	14.6	8.8	25.5	3.8	4	–	–	–	–
	PHF: begin/answer	13.6	1.8	24.1	12.1	8	1	5	0.90	.3852
	HH: locate/answer	16.7	3.1	46.3	5.9	23	1	12	19.71	.0008
	HH: dial	19.3	3.4	63.3	3.2	13	1	7	50.11	.0002
	PHF: talk/listen	16.4	1.9	16.0	2.1	49	1	22	0.02	.8776
	PHF: end task	13.0	5.3	21.6	9.1	9	1	6	0.44	.5316
	HH: browse/read PHF: talk/listen	15.9	3.3	72.8	6.3	15	1	11	117.34	<.0001
IHF	IHF: begin/answer	11.7	1.2	52.7	2.9	69	1	36	117.58	<.0001
	HH: locate/answer	15.0	2.2	43.4	4.3	39	1	25	32.13	<.0001
	HH: dial	15.9	2.6	64.5	2.7	31	1	21	189.12	<.0001
	IHF: talk/listen	12.4	1.0	15.6	1.7	108	1	49	1.32	.2560
	IHF: end task	11.7	1.1	45.4	3.4	74	1	42	64.62	<.0001
	HH: browse/read IHF: talk/listen	14.6	2.6	58.1	5.3	14	1	11	56.51	<.0001
Text/browse	HH: locate/answer	15.5	0.9	33.2	1.6	192	1	55	28.42	<.0001
	HH: browse/read	16.0	1.0	62.9	1.3	157	1	47	294.37	<.0001
	HH: text	16.1	1.3	67.6	1.2	112	1	26	263.32	<.0001
	HH: end task	15.8	0.9	29.6	1.9	178	1	49	19.69	<.0001

phone, simultaneously browsing and conversing on the IHF cell phone, and pressing a button to end an IHF call were all found to significantly increase the percentage of time drivers took their eyes off the forward roadway. Conversing on an IHF cell phone did not have a significant effect on mean percent TEORT.

3.2. Teort duration

TEORT duration represents the total amount of time the participant's visual attention was away from the roadway during the span of the individual subtask. Table 3 presents the mean TEORT durations for cell phone subtasks. Differences were investigated using a one-way between-subject ANOVA. A significant effect was found, $F(9, 651) = 48.99$, $p < .0001$. A Tukey–Kramer test revealed where the significant differences existed. Text messaging ($M = 23.3$ s), browsing ($M = 8.2$ s), and dialing ($M = 7.8$ s) all led to substantially longer TEORT durations than when drivers performed PHF and IHF cell phone subtasks. To compare HH and hands-free subtasks, the largest mean TEORT for a hands-free subtask was observed when locating a PHF device (TEORT duration of 2.7 s). Note that TEORT durations are not presented for talk/listen subtasks because an eye-glance reduction was not performed beyond the sampled 6-s talk/listen subtask interval.

Table 3
Mean TEORT durations collapsed across cell phone types.

Subtask	Mean TEORT (s)	Standard error	N
HH: text	23.3^{A}	1.7	207
HH: browse/read	$8.2^{B, D}$	0.5	286
HH: dial	7.8^{B}	0.3	405
PHF: locate/put on	$2.7^{B, C, D}$	0.9	15
IHF: begin/answer	$2.5^{C, D}$	0.4	120
HH: locate/answer	$1.3^{C, D}$	0.1	746
HH: end task	$1.3^{C, D}$	0.1	813
IHF: end task	$1.3^{C, D}$	0.1	154
PHF: end task	$0.5^{C, D}$	0.1	33
PHF: begin/answer	$0.5^{C, D}$	0.2	13

Tukey–Kramer significant differences denoted by capital letters. If two subtasks have different superscript letters, they were found to be significantly different.

4. Discussion

Driving performance depends on how well drivers visually attend to the road and perceive events as they occur (Fitch, Grove, Hanowski, & PerezFitch, Grove, Hanowski, & Perez, 2014; Klauer et al. Klauer, Guo, Sudweeks, & Dingus, 2010). Drivers' visual attention to the forward roadway was substantially affected by visual-manual subtasks performed on an HH cell phone. Locating, dialing, text messaging, browsing, and ending an HH call all increased the percentage of TEORT compared to the baseline. Furthermore, the TEORT durations of the text messaging, browsing, and dialing activities were all considerably longer than subtasks performed with PHF and IHF cell phone interfaces. The long TEORT durations observed when using an HH cell phone are a concern and justify the distinctions made between HH and hands-free cell phones in driver distraction policies and legislation.

Similar to previous findings on cognitively distracted drivers (Atchley & DresselAtchley & Dressel, 2004; Maples et al., 2008; Olson et al., 2009; Maples et al., 2008; Olson et al., 2009), drivers' visual attention to the forward roadway was found to significantly increase when conversing on an HH cell phone. Interestingly, no changes were found when drivers were involved in hands-free conversations. Perhaps drivers conversing on a hands-free cell phone continued to visually sample their surroundings because their head's mobility was not restricted by their hand. It is also possible that drivers conversing on an HH cell phone became less likely to simultaneously perform other visually demanding secondary tasks (e.g., eating food or drinking a beverage; Soccolich et al., 2014). Further research is required to investigate why these findings exist.

5. Summary

This study investigated drivers' visual behavior when using HH and hands-free cell phones. It was found that drivers decreased their visual attention to the forward roadway when performing visual-manual cell phone subtasks. The amount of time drivers looked away from the road was significantly longer when performing HH visual-manual subtasks compared to hands-free visual-manual subtasks. This study shows that drivers' interactions with hands-free cell phones differ from their interactions with HH cell phones. These differences, as well as the differences in safety-critical event risk that have been found, support the distinctions made between cell phone types in transportation policy.

6. Practical applications

Transportation policy and legislation rely on research to make educated decisions that affect a wide constituency. The findings from this study support the distinctions between HH and hands-free cell phones that are made in cell phone bans. The amount of time drivers looked away from the forward roadway when using hands-free cell phones was substantially shorter than when using HH cell phones. This significant difference has major impacts on driving performance. As we have seen in the studies mentioned above, visual distraction is more deleterious to driver performance and more difficult to compensate for. The finding of this study indicates that hands-free cell phones mitigate driver distraction and thus offer a compelling alternative to HH cell phones.

In order for hands-free devices to effectively mitigate driver distraction, the technology must be designed with this goal in mind. More research should be performed to investigate how hands-free devices could impact behavior behind the wheel, such as leading to increased engagement in secondary tasks. The results of such studies should then be used to inform the design of the user interfaces employed in the context of hands-free devices, ideally with the objective of reducing drivers' visual engagement with the interface.

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Gregory M. Fitch is a research scientist and leads the User Experience Group for the Center for Automated Vehicle Systems at the Virginia Tech Transportation Institute. He received his Ph.D. from the Grado Department of Industrial and Systems Engineering at Virginia Tech in 2009.

Paul R. Bartholomew is a research assistant in the Center for Automated Vehicle Systems at VTTI. He is currently pursuing a Ph.D. in the Grado Department of Industrial and Systems Engineering at Virginia Tech.

Richard J. Hanowski is the director of the Center for Truck and Bus Safety (CTBS) at the Virginia Tech Transportation Institute (VTTI). He received his Ph.D. from the Grado Department of Industrial and Systems Engineering at Virginia Tech in 2000.

Miguel A. Perez is the director of the Center for Data Reduction and Analysis Support (CDRAS) at the Virginia Tech Transportation Institute (VTTI). He received his Ph.D. from the Grado Department of Industrial and Systems Engineering at Virginia Tech in 2005 and is a Certified Professional Ergonomist.