Title

Distraction 'Hangover': Characterization of the Delayed Return to Baseline Driving Risk After Distracting Behaviors

Permalink

https://escholarship.org/uc/item/5139392p

Authors

Hill, Linda, MD, MPH
Townsend, Jeanne, PhD
Snider, Joseph, PhD
et al.

Publication Date

2020-07-01

DOI

10.7922/G2377706

RESEARCH REPORT

Institute of
Transportation
Studies

UNIVERSITY
OF
CALIFORNIA

Distraction ‘Hangover’: Characterization of the Delayed Return to Baseline Driving Risk After Distracting Behaviors

Linda Hill, MD, MPH; Jeanne Townsend, PhD; Joseph Snider, PhD;
Ryan Spence; Anne-Marie Engler; Ryan Moran;
Sarah Hacker; and Leanne Chukoskie

University of California, San Diego

July 2020

UC San Diego
School of Medicine

Report No.: UC-ITS-2019-27 | DOI: 10.7922/G2377706

Technical Report Documentation Page

1. Report No.
UC-ITS-2019-27

2. Government Accession No.
N/A

3. Recipient's Catalog No.
N/A

4. Title and Subtitle
Distraction 'Hangover': Characterization of the Delayed Return to Baseline Driving Risk After Distracting Behaviors

5. Report Date
May 2020

6. Performing Organization Code
UC San Diego

7. Author(s)
Linda Hill, MD, MPH. orcid.org/0000-0002-1249-1826; Jeanne Townsend, PhD; Joseph Snider, PhD. orcid.org/0000-0002-0176-5107; Ryan Spence; Anne-Marie Engler; Ryan Moran, MD, MPH orcid.org/0000-0002-2219-5502; Sarah Hacker; and Leanne Chukoskie, PhD. orcid.org/0000-0003-4041-3646

8. Performing Organization Report No.
N/A

9. Performing Organization Name and Address
Department of Family Medicine and Public Health
9500 Gilman Dr., 0811
La Jolla, CA 92037

10. Work Unit No.
N/A

11. Contract or Grant No.
UC-ITS-2019-27

12. Sponsoring Agency Name and Address
The University of California Institute of Transportation Studies
www.ucits.org

13. Type of Report and Period Covered
Final Report (September 2018 - June 2020)

14. Sponsoring Agency Code
UC ITS

15. Supplementary Notes
DOI:10.7922/G2377706

16. Abstract

Drivers can use handsfree devices to limit distraction. However, the cognitive cost of switching between tasks adds an underappreciated, potentially long period to the total distraction time. This project measured the effects of handsfree smartphones on driving behaviors by engaging ninety-seven 21- to 78-year-old individuals who self-identified as active drivers and smartphone users in a simulated driving scenario that included smartphone distractions. Peripheral-cue and car-following tasks were used to assess driving behavior, along with synchronized eye tracking. This research found that simulated driving performance drops to dangerous levels after smartphone distraction for all ages and for both voice and texting. The participants swerved for 15.1 seconds after a voice distraction and for a longer 20.6 seconds after a text distraction. Participants from the 71+ age group missed seeing about 50% of peripheral cues within 4 seconds of the distraction. Coherence with the lead car during following task dropped from 0.54 to 0.045 during distraction, and seven participants rear-ended the lead car.

17. Key Words
Driving, distraction, behaviors, smartphones, driving simulators, eye fixations, text messages, voice communication, high risk drivers, car following

18. Distribution Statement
No restrictions.

19. Security Classification (of this report)
Unclassified

20. Security Classification (of this page)
Unclassified

21. No. of Pages
35

22. Price
N/A

Form Dot F 1700.7 (8-72)

Reproduction of completed page authorized

About the UC Institute of Transportation Studies

The University of California Institute of Transportation Studies (UC ITS) is a network of faculty, research and administrative staff, and students dedicated to advancing the state of the art in transportation engineering, planning, and policy for the people of California. Established by the Legislature in 1947, ITS has branches at UC Berkeley, UC Davis, UC Irvine, and UCLA.

Acknowledgments

This study was made possible through funding received by the University of California Institute of Transportation Studies from the State of California through the Public Transportation Account and the Road Repair and Accountability Act of 2017 (Senate Bill 1). The authors would like to thank the State of California for its support of university-based research, and especially for the funding received for this project. The authors would also like to thank the San Diego Association of Governments (SANDAG) and Dr. David Strayer for their helpful reviews.

Disclaimer

Table of Contents

List of Tables

List of Figures

Executive Summary

In 2017, there were 37,473 deaths and an estimated 3.7 million ER visits for non-fatal injuries related to motor-vehicle use (Insurance Information Institute, 2020). Since 2010, both total and age-adjusted mortality rates have increased. Around 94 percent of all traffic accidents are attributed to driver behavior, particularly distracted driving (Singh, 2015) which has been a factor in an estimated 2.4 million injuries and approximately 3000 crash-related fatalities each year (National Highway Traffic Safety Administration, 2019). The sources of distracted driving can be visual, manual, or cognitive, such as eating, drinking, talking with passengers, adjusting equipment in the car (e.g. radio), or using smartphones.

Studies have shown that smartphone use, regardless of whether handsfree or handheld, is distracting (Just et al., 2008; Strayer et al., 2006) and that the risk of a crash is four to six times greater when they are used (McEvoy et al., 2005; Redelmeier & Tibshirani, 1997). Despite public warnings, smartphone tasks that require devoted attention, such as texting, emailing, or web browsing, remain common while driving (Schroeder et al., 2018; Tison et al., 2011).

While efforts have been made to limit visual distractions from smartphone use, such as Bluetooth integration, these have not really reduced cognitive distraction, when drivers stop paying attention to road conditions. Additionally, there is growing evidence that the effects associated with phone use linger beyond the initial loss of attention (known as a "hangover" effect) and are associated with hazardous driving behavior (Borowsky et al., 2015, 2016; Savage et al., 2020). Despite increased legislation over the last several years limiting cell phone use while driving (Governors Highway Safety Association, 2020), crash rates have increased over the last decade (Insurance Information Institute, 2020). There is a great need to further understand the dangers of smartphone use while driving, and to better understand the persistent "hangover" effects of cognitive distraction.

The purpose of this study was to determine the effects of smartphone distraction on the driving performance of active adult drivers faced with responding to a hands-free call or a short text in a live driving simulation, and how long the effects on their driving behavior lasted. We tested various driver reactions including speed, amount of swerving, and drifting outside one's lane. We also used an eye tracker to locate where drivers looked during the tests, and how much of the view ahead they focused on after being distracted since research shows that as their attention returns to the road, their eyes focus on a narrower area, and they may miss important driving events, like oncoming traffic.

We asked 97 participants who drive daily and regularly use smartphones to perform two simulated driving tasks. In the first test they were asked to respond to a seeing a signal in their left or right peripheral vision, as might appear in an outside rear view mirror, by pressing a corresponding level on the steering wheel. In the second test they were asked to match their speed to a lead car that was alternatingly slowing down and speeding up. In both situations, a smart phone mounted just to the right of the steering wheel would periodically ring, indicating a handsfree call or a text message. After the ring, participants tended to speed up a little, stiffen their foot on the accelerator, swerve dramatically, and exhibit tunnel vision. These behavioral changes were still detectable as long as 20-25 seconds after the distraction occurred, with longer recovery times for texting, enough time to travel nearly half a mile at highway speeds. The distraction hangover extended so long that in some cases the next smartphone distraction came before the participants were able to recover. Worse, seven drivers in the second simulation actually ended up colliding (virtually) with the lead car. Of the remaining 90 drivers who managed to avoid a collision, their ability to match the lead car's speed, or "coherence," dropped almost to zero.

Age Effects

Age was also a factor in the tests. In the first simulation, when drivers could choose their own speed, older drivers tended to drive more slowly than younger ones, by about two mph for each decade of life. Driving slower did not help with the first driving simulation, though, and the oldest individuals missed 50 percent of the peripheral cues that came within four seconds of a text message. This means that in a real driving situation older drivers might have failed to detect nearly half of the salient information in their visual periphery while driving. However, older drivers performed as well as the youngest during the car-following portion of the test, and even did a bit better than younger drivers when distracted. The youngest individuals also took the longest time to stabilize their lane position after a distraction, and they were almost four seconds slower than the next oldest age group.

This situation has the potential to worsen as both the population over 65 increases along with increasing numbers of older adults who cross the so-called digital-divide. According to Pew Research in the four years preceding 2017, smartphone use by seniors increased from 18 to 42 percent (PEW, 2017). As those accustomed to using smartphones age this may exacerbate problems in a population with documented driving-related visual attention challenges (Owsley et al., 1991).

Handsfree versus Texting

Handsfree devices are generally assumed to have less impact on driving performance than hand-held ones (Ishigami & Klein, 2009), though there is evidence to the contrary (McEvoy et al., 2005). While, at about 15 seconds, the recovery time may be faster during handsfree phone use, that is still enough time to drive a quarter mile at highway speeds.

For most of the driving measures, we detected no difference between the handsfree and text distractions, including speed, lane drift, and swerving. Both handsfree and text distractions increased swerve speeds about the same, and the longer recovery time for texting may be a result of participants touching the phone a second time to respond to the text. Also, while participants looked at the phone for about half as long as when distracted by handsfree rings versus texts, the portion of the display screen their eyes returned to shrunk in both cases by about the same amounts.

Policy Implications

From a safety perspective, our study highlights the risks of driving while using smartphones, and from a public health standpoint, our study showcases the burden created by distractions on drivers' cognitive functions and the length of time it takes them to recover. The ongoing effects of distraction on driving safety have serious implications for common driving habits, like checking emails and texts at traffic lights or in heavily congested and stopped traffic. Surveys reveal that up to 50 percent of drivers check their phones at traffic lights (Hill et al., 2015).

Most importantly, while our study did indicate some mitigation of these risks with handsfree phone use over texting, these differences are of little public health significance or practical importance. Drivers, policy makers, pedestrians, and the public alike should be informed of the true risks of distracted driving, including hangover effects. The marked changes in driving performance demonstrated in this study may explain the worrisome upward trends in crash risk. Traffic laws should reflect the science of driving safety, including the risks of handsfree phone use while driving and distraction hangover, in addition to the current bans on handheld phone use. As technology continues to become engrained through our daily tasks, including increasingly sophisticated automobiles and cell phones, policy makers should better align available evidence regarding in-vehicle technology and the science of distraction. We need effective public education programs to increase appreciation of the dangers of distraction, including handsfree phone use, and the risks of even short distractions that nonetheless are associated with hangover effects.

Key Points

- A 20-25 second distraction hangover after a smartphone distraction.
- Similar results for handsfree talking and texting.
- Drivers’ field of view shrank nearly 50 percent after distraction.

Introduction

In 2017, there were 37,473 deaths and an estimated 3.7 million ER visits for non-fatal injuries related to motor-vehicle use (Insurance Information Institute, 2020). Since 2010, both crude and age-adjusted mortality rates have increased, numbering an additional almost 5,000 individuals who died in this time frame. In addition, pedestrian mortality rates have also increased, accounting for 17 percent of these deaths (IIHS-HLDI, 2020).

Around 94 percent of all traffic accidents are attributed to driver-related circumstances (as opposed to environment or vehicle issues); of these, distraction is a major contributor (Singh, 2015), and distracted driving has been implicated in an estimated 2.4 million injuries and approximately 3000 crash-related fatalities, each year (National Highway Traffic Safety Administration, 2019). Sources of distracted driving can be visual, manual, or cognitive, such as eating, drinking, talking with passengers, adjusting equipment in the car (e.g. radio), or using smartphones.

Smartphones have become increasingly ubiquitous and sophisticated (Smith, 2017), and their use is a well-recognized cause of distraction during driving that has been studied extensively. Studies have shown that smartphone use, regardless of whether handsfree or handheld, is a source of distraction (Just et al., 2008; Strayer et al., 2006) and that increases crash risk by an estimated four to six times over baseline (McEvoy et al., 2005; Redelmeier & Tibshirani, 1997). Smartphone tasks that require devoted attention, such as texting, emailing, or web browsing, remain common while driving (Schroeder et al., 2018; Tison et al., 2011). Thus, with smartphone use, distractions can be visual, cognitive, or auditory. Of concern are common misperceptions of the risk of multitasking while driving. Ninety-three percent of respondents to the *National Survey of Distracted Driving* reported safety concerns if they were a passenger in a car of someone who was driving and sending texts, and 86 percent were concerned if the driver was reading texts. However, texting while driving is prevalent and increased between 2012 and 2015 (Schroeder et al., 2018; Tison et al., 2011).

Much attention has been paid to the importance of limiting visual disruption with the use of technology (such as with Bluetooth integration); however, these adaptations do not reduce cognitive distraction. Additionally, there is growing evidence that the cognitive loads associated with phone use persist beyond the point of distraction (known as a “hangover” effect) and are associated with hazardous driving behavior (Borowsky et al., 2015, 2016; Savage et al., 2020). Despite the growing body of legislation over the last several years limiting cell phone use while driving (Governors Highway Safety Association, 2020), crash rates have increased over the last decade (Insurance Information Institute, 2020). There is a great need to further understand the dangers of smartphone use while driving, and to better understand the persistent “hangover” effects of cognitive distraction.

The purpose of this study was to determine the effects of smartphone distraction on the driving performance of active adult drivers, and measure (1) demographics and self-reported driving behaviors, (2) the immediate behavioral consequences of distraction (hands-free call or responding to a short text) in a live driving simulation, and (3) the “hangover time” or how long the behavioral consequences of distraction persist.

Methods

Participant Recruitment and Eligibility

Participants were recruited from existing contacts and flyers in the local university community and screened for eligibility. Inclusion criteria were: active CA driver's license, at least 20 years old, drive at least once a week, own and use a smartphone, text at least once a week, and fluent in English. Participants were excluded if they had a caregiver, or if they reported a diagnosis of cognitive impairment, dementia, or Alzheimer's disease. Informed consent was gathered from all participants. This study was approved by the IRB at UC San Diego.

Survey Development

Prior to the driving test, participants were asked to complete a 60-item survey about their demographics, driving habits, and distracted driving. Participants were asked: "On average, how many days a week do you drive?" and "On the days you drive, approximately how many hours do you spend driving?"; as well as "How much time do you spend talking on a HANDHELD (HANDS-FREE) cell phone while driving?".

Driving Tasks

In a single testing visit, participants completed two 30-minute simulated driving sessions (one with handsfree and one with texting smartphone distractions) in front of a computer screen. Each session consisted of two approximately 15-minute segments: 1) a dual task that required divided attention with responses to visual cues in the left and right periphery while driving, and 2) a car following task in which the lead car used a variable sinusoidal acceleration and braking pattern. Each task segment had an initial period with no distraction (baseline), lasting approximately 2.5 minutes, followed by a period of distraction.

In the divided attention task, red diamond symbols were displayed at the edges of the screen. Participants were asked to respond to a change in the symbol, from diamond to triangle, by pressing a paddle on the steering wheel corresponding to the side of the screen on which the symbol changed (Figure 1). The paddles were located on the back of the steering wheel and pulled with the fingers. The changed symbol remained on the screen for 5 seconds or until the participant responded. Where space is limited, we refer to the divided attention task as the 'dual' task.

In the car following task, participants were asked to match their speed as closely as possible to a police vehicle moving ahead of them that was altering its speed variably, so as not to be predictable.

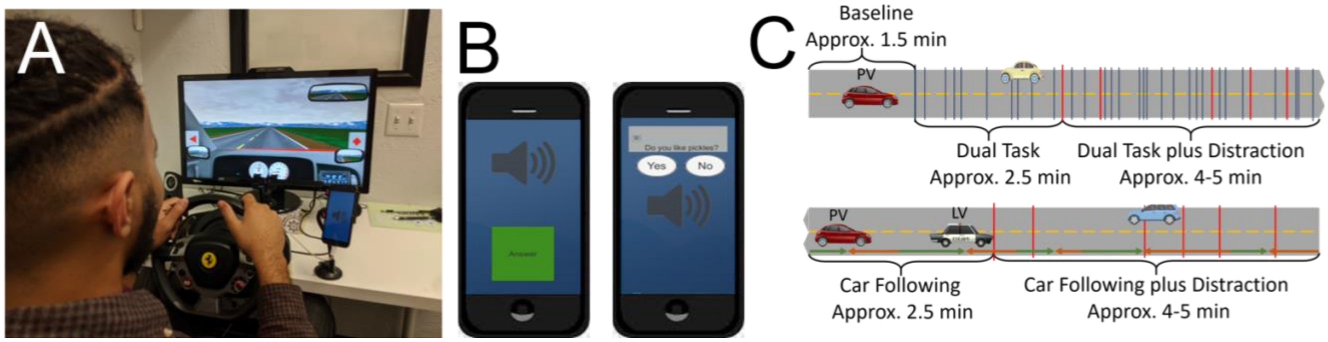

Figure 1. (A) Example setup of a participant seated in front of the driving simulator controls a first-person car view with a steering wheel and pedals (not shown). A small eye tracker is located at the bottom of the screen and the smartphone is placed easily in reach of the right hand. (B) Example display for each of the phone distractions; hands free voice call (left) and text message (right). (C) The drive begins with a short baseline period, where there are no tasks or distraction. Dual task comes before the car following task; PV = participant vehicle, LV = lead vehicle.

Distraction Events

Hands free calls and texting served as distracting events. The phone rang to indicate a handsfree call or chimed to indicate a text (Figure 1). Participants responded to handsfree calls by pressing a large green button on the phone. Upon answering the call, they heard a brief audio message, e.g. “Hello, I am calling from your alma mater doing a survey on graduates, what is your current occupation?” [pause for response] “Thank you. Goodbye.” In the texting distraction, texts appeared on the phone without the need to unlock or touch the phone. Simple questions such as “Do you drink coffee?” were followed by a yes/no response button on the phone that the participant touched. Participants were encouraged to respond to all audio and text messages.

After the initial baseline, distraction events were placed randomly in each task segment to avoid predictability. The driving tasks and the distraction events were randomly timed and independent of each other; some distractions occurred simultaneously with a task event, while others occurred between task events. There were five distraction events during the divided attention task and six during the car following task in the handsfree distraction drive. There were nine distraction events in each segment of the texting distraction drive.

Measures

- *Swerve speed* is the lateral speed of the car in the lane, $|\Delta x/\Delta t|$ where x is the distance of the virtual car from the left side of the road and t is the simulation time. The participant controls lane position with the steering wheel.
- *Lane Excursion* is the number of times the driver crosses either the center or shoulder lane markers, accumulated over the whole drive.
- *Time to recover* is calculated from the swerve speed for each participant averaged over trials by grouping the swerve speed into 100 ms bins, time locked to the event. It is the time to return to 10 percent of the baseline

subtracted peak swerve speed after the distracting event. Starting at the distraction time, we first find the maximum swerve speed, subtract the baseline and calculate 10 percent of that difference. The 10 percent value is considered 'recovered' and we find the first time after the peak when the swerve speed returns to 10 percent.

- *Coherence* is a unitless measure of how well a driver adapts their speed to a lead car that is speeding up and slowing down. If speeds are unrelated, then coherence is zero. If speeds are perfectly matched, coherence is one. Drivers require some time to notice that their distance to the lead car is changing and to respond by speeding up or slowing down. Unlike a simple correlation of speeds, coherence is one even in the presence of a delay, as long as the delay is constant.

- *Central width* is calculated from gaze location on the screen as measured by the Tobii 4C eye tracker. To focus in on the central part of the view, where the participant should look to control the car, we isolate the middle 60 percent of the screen horizontally and the middle 30 percent vertically. In the driving task, eye movements are dominated by left-right scanning (Figure 5), so within the central part of the screen, we ignore vertical movement and look at the horizontal spread of gaze locations. Inter-quartile range is used to estimate the spread. Larger central width indicates a wider scan path, and more potential to notice, e.g., oncoming traffic.

- *Time-on-phone* is calculated from the gaze data as the total time spent looking toward the phone. Since the phone is in a different plane than the screen, it appears anomalously large, and we use range: horizontal between [0.8, 2] and vertical in [-0.7, 0.2] (see Figure 5). Note that this window extends beyond the screen. The time-on-phone value is the sum of the time the gaze is in that window.

Eye Tracking

Gaze point relative to the screen was tracked with a Tobii 4C (Tobii, Inc; licensed for research use). The eye tracker was temporally aligned with the driving data with a custom synchronization pulse (Snider et al., 2013). During the drive, the simulator triggered 8-bit pulses on an external digital-analog device (Measurement Computing USB 200) that was read in by an Arduino compatible analog digital converter (Teensy 3.1) connected with USB to a recording computer. Custom plugins for the LabRecorder software (https://github.com/sccn/labstreaminglayer) recorded the synchronization pulse and the data stream from the Tobii 4C eye tracker. The synchronization pulses were also recorded in the frame-by-frame data from the simulator and then used to align the simulator and eye tracking data, post hoc.

Before starting their drive, participants calibrated with the built-in eye tracker calibration routine: seven points, one central, three equally spaced at the top, and three equally spaced at the bottom. Eye tracking failed in n = 10 participants, but the participant pool with eye tracking was not significantly different from the whole population (t(182) = -0.016, p = .987).

Statistics

For display purposes ages are broken into groups of average age range (e.g. 26.3 is included in the 20-26 age group, but 26.7 is included in the 27-55 age group). For testing statistical significance, we used the age, including fractions of a year, at experiment time in linear mixed models with maximal fixed effects and minimal random effects (Bates et al., 2015). This allowed us to analyze unbalanced groups without dropping data. To estimate significance, we use Satterthwaite's method (Kuznetsova et al., 2017). Where noted, we use alternate tests for simple comparisons between groups, e.g. t-tests. Means and standard errors of measures are reported as M(STD) with the value in parenthesis representing the error in the last digit of the mean. Ninety-five percent confidence intervals are used to visualize spread in plots and are bootstrapped (10,000 iterations) using the HMisc package (Harrell Jr & Harrell Jr, 2015). All statistics and data analysis are done in R (R Core Team, 2014).

Results

In brief, participants controlled a first person view simulated drive with a steering wheel and foot pedals, as in a car. A smart phone within easy reach of the participants' right hands periodically rang a call or indicated a text message at known distances along the drive. The participants responded to the call with their voice and to the text with small yes/no buttons that mimicked auto-respond on a phone. The calls and text conditions were separately blocked over about 15 minutes, including an approximately 1.5-minute baseline condition with no calls or texts. In addition to the behavioral responses, we recorded eye position with respect to the screen on a Tobii 4C eye tracker.

Participant Demographics and Self-reported Driving Characteristics

A total of 101 participants were recruited, and 97 participants completed the study protocol. Of the 4 who did not complete the study, two did not meet eligibility criteria, and two experienced hardware failures. Average participant age was M = 50.8, SD = 21.1, range = 58.60. Participant demographics are summarized in Table 1.

The divided attention segment always preceded the car following segment. Ninety-one of the 97 participants completed both the handsfree and text drives. Of the six participants who completed only one drive, four completed the handsfree drive and two the text drive; where possible single drive participants are included in the analysis. A subset of 71 participants started with the handsfree drive, and 26 with text. The age distributions for participants who started with handsfree (M = 52.74 years, SD = 21.61) and text (M = 45.43 years, SD = 18.54) are not significantly different (t(95) = -1.52; p = .13), but the unbalanced order is a potential confound.

Table 1. Sociodemographic characteristics of participants (n=97)

Baseline Characteristic		Age Group				Total
		20-26	27-55	56-70	71+	
Participants		25	25	24	23	97
Gender	Male	7	9	5	15	36
	Female	18	16	19	8	61
Race	White/Caucasian	9	12	21	22	64
	Black/African American	0	1	1	0	2
	Asian	10	4	0	0	14
	Pacific Islander	0	1	1	0	2
	Other	2	3	0	1	6
Ethnicity	Hispanic	4	4	1	0	9

Table 2 shows the results from a self-report distracted driving questionnaire.

Table 2. Participant self-reported driving characteristics.

		Age Group				Total
		20-26	27-55	56-70	71+	
Driving	Frequency					
	Once a Week	2	0	1	0	3
	More than once a week	10	4	7	6	27
	Every day	13	21	16	17	67
	Time per drive					
	30 mins or less	11	6	6	8	31
	1 hour	12	10	12	14	48
	2 hours	1	9	6	1	17
	3 hours	1	0	0	0	1
Phone usage	Handheld					
	1-5 minutes (emergency/911calls)	18	14	9	7	48
	10-30 minutes	0	5	1	1	7
	Not applicable - I do not use a handheld device while driving	7	6	14	15	42
	Handsfree					
	1-5 minutes (emergency/911calls)	10	13	12	10	45
	10-30 minutes	8	8	4	0	20
	30-60 minutes	2	0	2	1	5
	1-2 hours	1	1	0	0	2
	5 hours or more	0	0	2	0	2
	Not applicable - I do not use a hands-free device while driving	4	3	4	12	23

Simulated Driving Measures

There were no statistically significant differences between text and handsfree distraction for the gross, simulated driving measures. During the dual task portion of the drive, speed was freely controlled by the participants, and older participants drove more slowly (-2.2(4) mph per decade of age, F(1, 95.72) = 12.16, p = 7.39e-6) and took longer to complete the trial (7(1) seconds per decade of age, F(1, 90.57) = 15.70, p = 1.48e-4). Participants could maintain a constant speed in the following stage when the lead car set the speed regardless of age group. During following, there is a statistically significant interaction between age and stage, reflecting decreasing average speed with age only during the dual stage (Table 3, age x stage interaction F(1, 657.84) = 78.37, p < 2e-16). Similarly, the total time for the tasks normalized in the following stage (Table 3, age x stage interaction F(1, 652.40) = 61.80, p = 1.57e-14).

Table 3. Simulated driving measures

Measure				Age Group							
				20-26		27-55		56-70		71+	
	Condition	Stage	Dist.	M	SD	M	SD	M	SD	M	SD
Average Times(s)	baseline	dual	HF	176.56	23.50	181.99	28.20	203.91	21.43	210.62	33.38
			text	172.35	22.56	181.30	23.63	199.52	17.56	192.54	19.46
		following	HF	119.99	0.89	119.56	7.53	121.68	5.77	125.15	19.07
			text	120.09	1.00	118.42	9.05	121.84	2.06	120.45	6.93
	distracted	dual	HF	252.80	34.43	262.26	43.33	283.38	24.04	291.88	65.85
			text	253.31	33.36	260.11	42.66	283.79	19.45	271.26	29.88
		following	HF	309.89	3.92	303.90	34.62	319.37	41.17	318.24	37.60
			text	308.84	8.98	303.71	31.76	310.89	13.05	309.00	21.96
Lane excursion (count)	baseline	dual	HF	2.24	2.91	1.20	1.32	2.52	2.78	2.87	3.12
			text	2.36	2.45	1.29	1.40	2.30	2.20	2.19	1.54
		following	HF	1.16	1.93	0.80	1.78	0.87	0.97	1.22	2.02
			text	0.48	0.65	0.79	1.35	1.00	0.90	1.29	1.42
	distracted	dual	HF	2.16	3.35	1.16	1.40	2.00	1.65	2.48	3.88
			text	1.72	2.49	1.50	2.06	2.74	3.05	2.95	2.04
		following	HF	0.96	1.67	1.12	2.13	1.57	1.80	1.83	3.20
			text	1.16	1.80	0.75	1.19	2.17	2.17	1.95	1.99

Measure				Age Group							
				20-26		27-55		56-70		71+	
	Condition	Stage	Dist.	M	SD	M	SD	M	SD	M	SD
Lane variability (m)	baseline	dual	HF	1.14	0.85	1.01	0.24	1.07	0.23	1.14	0.28
			text	1.40	1.77	1.22	0.72	1.15	0.24	1.14	0.30
		following	HF	0.87	0.26	0.95	0.30	0.95	0.16	1.01	0.31
			text	0.89	0.18	0.96	0.28	0.99	0.14	1.09	0.22
	distracted	dual	HF	0.90	0.19	0.90	0.21	0.94	0.18	1.24	1.32
			text	0.90	0.19	0.95	0.27	1.06	0.28	1.05	0.17
		following	HF	0.78	0.16	0.84	0.24	0.94	0.16	1.06	0.52
			text	0.79	0.20	0.85	0.25	0.97	0.17	1.00	0.16
Speed (mph)	baseline	dual	HF	66.05	11.27	64.35	11.50	57.11	6.15	56.24	9.35
			text	67.17	8.80	65.65	10.62	58.11	4.63	60.77	6.49
		following	HF	57.61	0.38	58.38	5.62	56.97	3.01	55.79	5.26
			text	57.42	0.50	58.79	7.01	56.65	1.32	57.83	4.18
	distracted	dual	HF	69.69	11.85	68.20	15.97	61.20	5.62	61.09	10.39
			text	69.26	10.36	68.47	14.30	60.96	4.77	64.05	7.28
		following	HF	57.15	0.74	59.80	14.33	57.72	5.68	57.55	7.51
			text	57.50	1.93	59.54	11.12	57.19	2.94	57.60	5.81
Speed variability (mph)	baseline	dual	HF	7.01	4.27	6.65	4.96	6.38	2.68	7.00	1.79
			text	7.34	3.68	7.11	5.43	5.68	1.78	7.04	2.84
		following	HF	6.61	1.82	7.05	4.59	5.86	2.24	7.48	2.61
			text	6.98	1.84	6.68	2.80	5.98	2.45	7.99	3.01
	distracted	dual	HF	6.27	4.87	5.87	5.94	4.34	2.73	6.94	4.15
			text	5.28	4.29	5.66	6.08	4.46	3.61	6.46	3.28
		following	HF	7.49	2.02	7.35	4.00	6.03	2.05	8.36	7.12
			text	7.79	3.39	6.98	4.46	5.87	2.29	7.34	2.69

With the presence of the lead car and pressing the paddles on the wheel, the two stages are different tasks, so we consider them separately. During the car following stage, the number of lane excursions (drifting outside the lane) increased with distraction 0.18(9) events faster per decade of age (F(1, 265.53) = 4.55, p = .034) and with the text distraction 0.18(9) events faster per decade of age (F(1, 269.09) = 4.46, p = 0.036). Similarly, lane variability increases faster during distraction 0.03(1) m per decade, but, interestingly, in both the dual and following stages of the task, the overall lane variability decreases significantly with distraction (dual: -0.3(2) m, F(1, 257.38) = 1.23, p = 0.0016; following: -0.20(4) m, F(1, 275.04) = 13.52, p = 2.84e-4). In addition to the previously mentioned increase with age, speed also increases 3(2) mph during the distraction interval in the dual stage (F(1, 280.18) = 5.24, p = .023), although speed was 0.8(9) mph less variable during distraction (F(1, 280.73) = 6.57, p = .011).

Swerve Speed

Swerve speed, the lateral speed in the lane, is stable around ~0.3 m/s in the five seconds before the distraction (Figure 2). After the distraction, it rapidly increases to a peak of about 0.5 m/s, before slowly decaying back to the baseline value. The participant rarely recovers all the way to baseline before the next distraction event (vertical gray lines in Figure 2). To characterize this interval across participants, we create a histogram of each participant's swerve speed with respect to the distraction event, then find the time between the first peak in swerve speed and recovery to 10 percent of that value (Figure 2B). Participants take longer to recover during the text condition, 20.6(6) s, versus 15.1(6) s during handsfree (F(1, 374) = 45.7, p = 5.34e-11). Note that there are more text events than handsfree, because of the construction of the drive. The time when participants started swerving varied in the handsfree distraction, so the swerve speed distribution (Figure 2A, top) is spread out. Individual participants' recovery times are faster in handsfree than in texting (Figure 2B), but more variable in when they start.

Interestingly, there is a slight increase in recovery time for the youngest group, and if we compare the youngest and second youngest groups, the 20-26 year-olds take 4(2) seconds longer to recover (F(1, 194) = 4.57, p = .034).

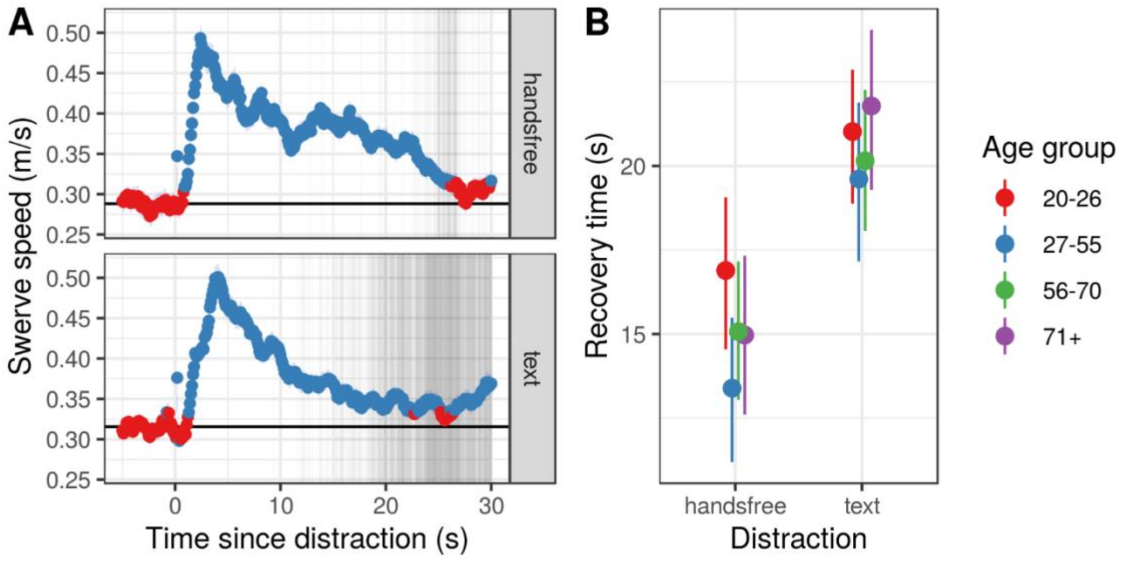

Figure 2. (A) Swerve speed is the left-right speed of the car on the virtual road, averaged over all participants. Just before the distraction, participants swerve at a steady ~0.3 m/s, but after the distraction there is a sudden jump in swerve speed. Blue (red) indicates the swerve speed is (not) significantly different from baseline (t-test). Vertical gray lines are at the time of the next event for all participants. (B) The time to recover to 10% of the maximum swerve speed is longer with text distractions, 20.6(6)s, than hands free, 15.5(7)s, and there is no detectable difference between age groups.

Dual Task

Participants responded to peripheral cues located near their left/right side view mirrors by pressing corresponding paddles on the back of their steering wheel. The peripheral cue remained on the screen for up to five seconds before signaling a timeout when the participants failed to notice the cue. The long duration of the cue and simplicity of the task lead to very few mistakes with only 28 errors out of 4639 total chances for all participants. There are, however, 500 instances where a participant timed out on the task, and failed to respond within five seconds, and the overall success rate, including timeouts, decreased with age (1.7(7)% drop per decade, F(1, 94.4) = 12.78, p = 5.55e−4, Figure 3A). Success rate remained the same with or without the phone adding to the distraction (F(1, 281.11) = 0.67, p = .41). Similarly, reaction time slowed 120(30) ms per decade of age (F(1, 95.49) = 26.91, p = 1.19e−6), but reaction time did not change when the phone distracted the driver (F(1, 281.76) = 1.24, p = .27).

There are 119 text distractions within four seconds before a peripheral cue appeared across all participants. Averaged within age groups, the oldest age group missed approximately half of the peripheral cues that occurred within the first four seconds after the text (M = 0.50, CI = [0.33, 0.70], n = 30, Figure 3B), and there was a significant drop in correct response to the peripheral cue of 5(2)% per decade of age (F(1, 79.77) = 5.72, p = .019).

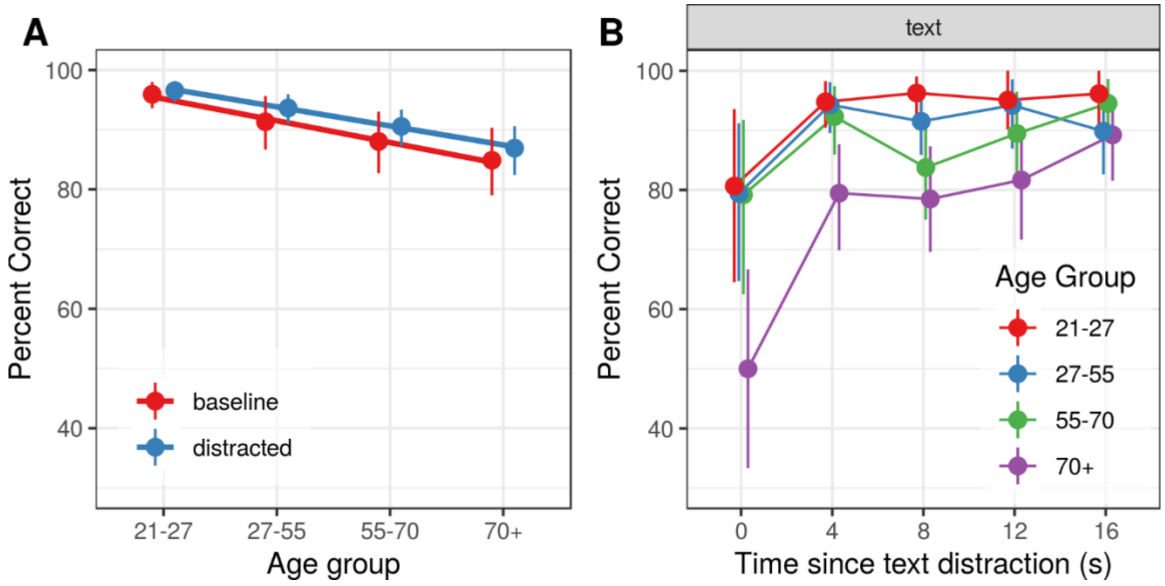

Figure 3. (A) Percent correct on the dual task for each age group. Performance drops with age, and almost all the mistakes are timeouts, where the cue went unnoticed for 5 seconds. Points are participant means and 95% confidence interval; the line is a best fit. (B) Percent correct for the peripheral task time locked to the distraction. Timeout rate is high in the first few seconds after the distraction then drops back toward baseline. Only the text condition is shown. Points are the means across individual trials within each time bin, and error bars are 95% confidence intervals.

Car Following Task

Participants followed a lead car whose speed oscillated sinusoidally between 47 and 67 mph (Figure 2). For the first approximately 1.2 miles of travel, the phone was inactive, then it rang/signaled a text repeatedly for about 3 more miles of travel, on the same schedule as the dual task probe events. Of the N = 97 participants, n = 7 went through the virtual lead car, effectively passing it without noticing they had. In real driving these would have been rear-end collisions with the lead car.

Coherence is a commonly used measure of how well the driver matches the speed of the lead car, taking into account a phase difference due to reaction time of the follower: a coherence of one indicated perfect performance, and zero perfect failure (Porges et al., 1980). Participants who passed the lead car (n = 7) no longer saw the cue and were removed for this analysis (no significant change in age distribution, t(185) = 0.0331, p = .97). For the undistracted part of the drive, the participants averaged a reasonably high 0.56(2) coherence, but that dropped precipitously to a very low 0.045(4) coherence after the first phone event (F(1, 253.87) = 227.64, p < 2.2e-16). This decorrelation with the lead car is readily apparent in Figure 4 where for the part of the travel that the phone is inactive, the participant accurately matches the lead car, but as soon as the phone rings, the participant's speed is unrelated to the lead car.

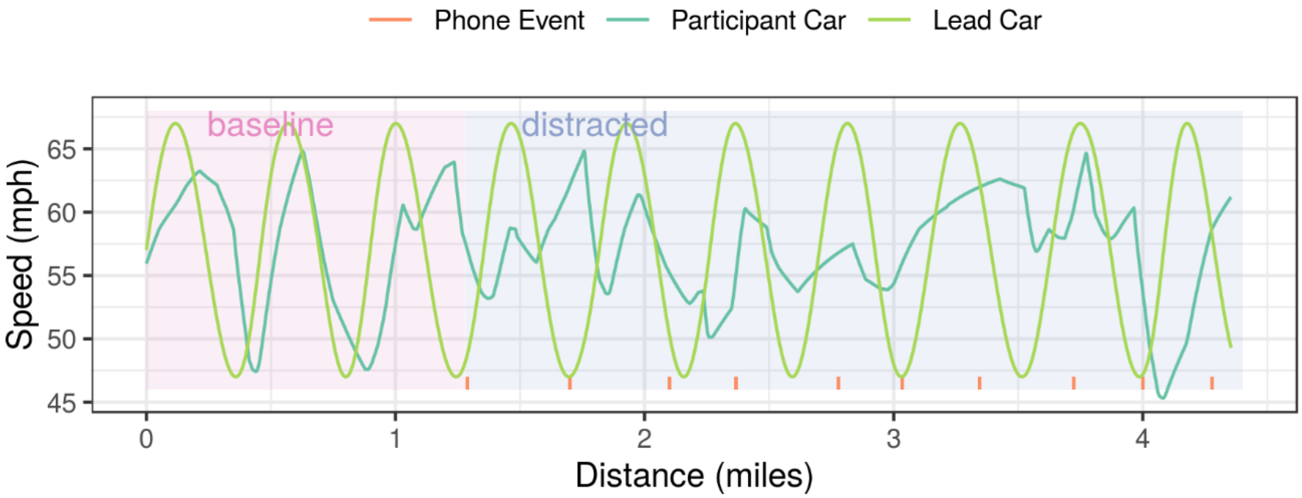

Figure 4. Raw car following data from a single trial. The lead car's speed is indicated in light blue, and the participant's speed in dark blue. The red tick marks indicate text events. During the first 1.3 miles of the drive, the participant matched the lead car speed (coherence = 0.77), but as soon as the phone distracted the participant (red vertical lines), their speed decohered with the lead car (coherence = 0.009).

Overall, there was a significant drop in coherence of 0.04(1) units per decade of age (F(1, 85.98) = 9.47, p = .0028). Also, there was a significant interaction between age and baseline/distracted condition (F (1, 253.87) = 29.69, p = 1.20e-7). For the baseline condition, participants showed a decrease in performance with age of 0.04(1) units of coherence per decade of age (F (1, 86.65) = 13.36, p = 4.40e-4), but coherence increased 0.008(2) units per decade of age (F (1, 171) = 14.26, p = 2.19e-4). Also five of the 70+ year old group and a single 41-year-old, maintained a reasonable 0.2 coherence during the distracted part of the drive.

Eye Movements

Gaze position of the participants was recorded with a Tobii 4C mounted at the bottom of the screen. Participants received no feedback about their eye position, and it was intended as a post-hoc observation tool of where the participants looked. The eye tracker calibration includes some distance beyond the screen and covers the phone at the lower right (Figure 5). Participants spent most of their time looking at the center of the screen, their rearview mirrors to the left, right, and above right, and their speedometer console.

Participants looked at the phone only briefly during the baseline: Mhandsfree = 0.55 s, SDhandsfree = 0.75 s; Mtext = 1.08 s, SDtext = 1.29 s. Participants spent more time looking at the phone during the distraction condition: Mhandsfree = 7.94 s, SDhandsfree = 4.52 s; Mtext = 39.36 s, SDtext = 16.38 s. The baseline condition was of shorter overall duration, so we eliminate it from the statistical comparison, but the total time available to look at the phone was approximately the same across the two types of distraction, so we can compare the total time as a proxy for phone looks. Participants spent 27(3) s more looking at their phone during the about 9-minute text distraction than the handsfree distraction (F (1, 85.23) = 35.86, p = 4.88e−8).

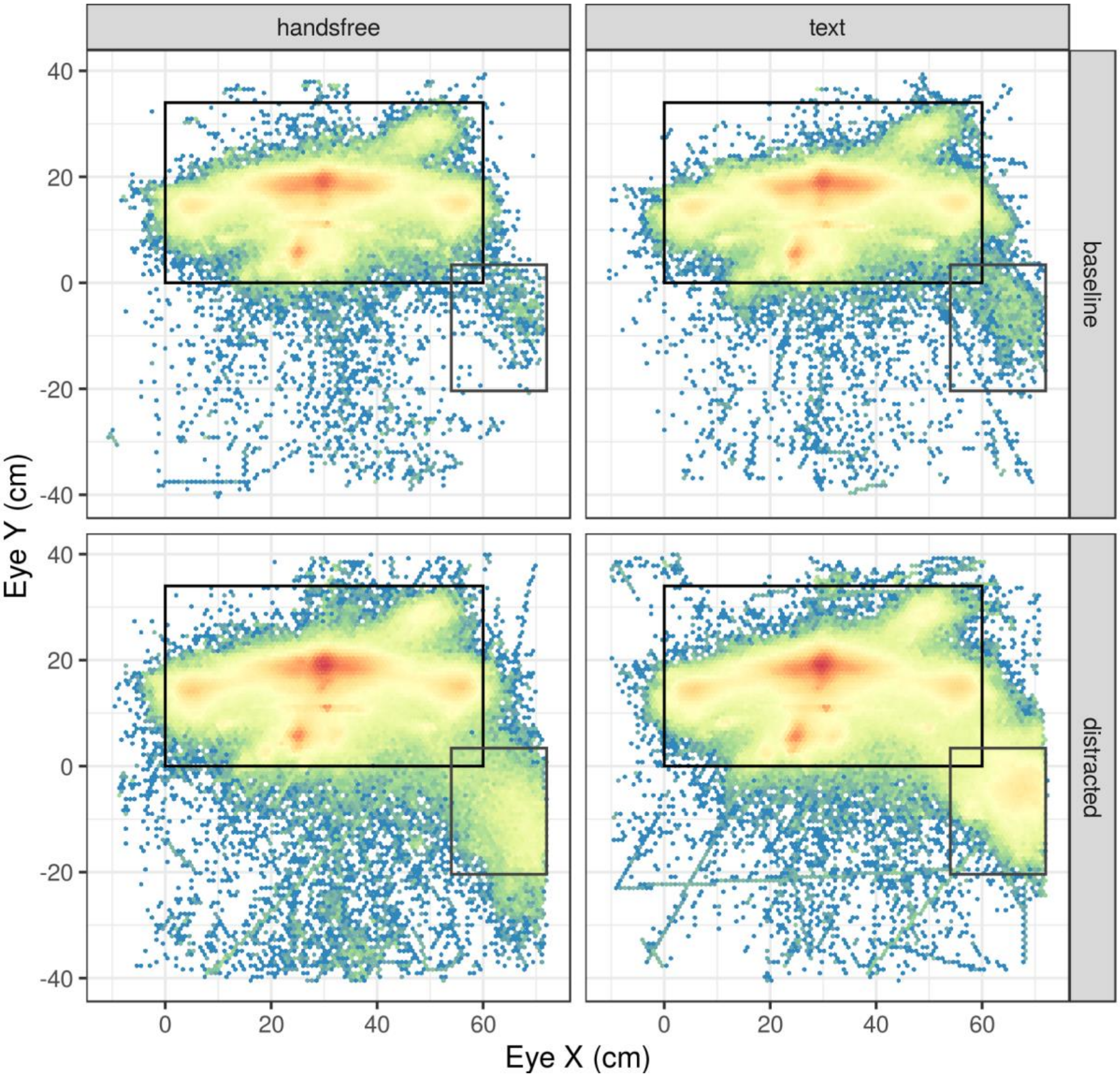

Figure 5. A heatmap of the eye position during the entire baseline, handsfree, and text drives. The black square is the screen, and the smaller gray square is the phone to the lower right of the screen. Participants mostly look in the center of the screen at the road, and at their mirrors and speedometer. The phone events pull the eyes off the driving task to the phone. Note that the phone appears falsely large because it is closer to the participant than the screen.

The central part of the screen had most of the task related stimuli, including oncoming traffic, lane markers, and so on. In addition to pulling gaze away from the central part of the screen, distraction may cause a form of tunnel vision, where the scan path of the central region shrinks. To isolate the tunnel vision effect, we only look at the central region visible in the heatmap (Figure 5, horizontal range [0.2, 0.8], vertical range [0.4, 0.7]), and exclude the mirror, speedometer, and phone regions. The width is the calculated as the interquartile range of the horizontal eye position, conditioned on being in the central region. Over the six decade range in the ages of the participants, fixation variability increases with age, and to compensate for that increase, we measure the percent change in field of view within each subject between baseline and distracted conditions. There is an overall significant drop on the screen from 5.9(6) cm to 3.8(6) cm, or 50(20)% (F(1, 558.49) = 688.67, p < 2.2e-16).

There are complex sets of interactions for fixed effects in the width data, but over the participant ages, from 20-79 years, fixation variability increases and that confounds the measurement of width. To compensate, we calculate the percent change in width during the distraction (Figure 6), and then there is only a fixed effect of stage where the width during the following condition is 47(5)% more compressed than during the dual task (F(1, 230.10) = 130.49, p < 2e-16).

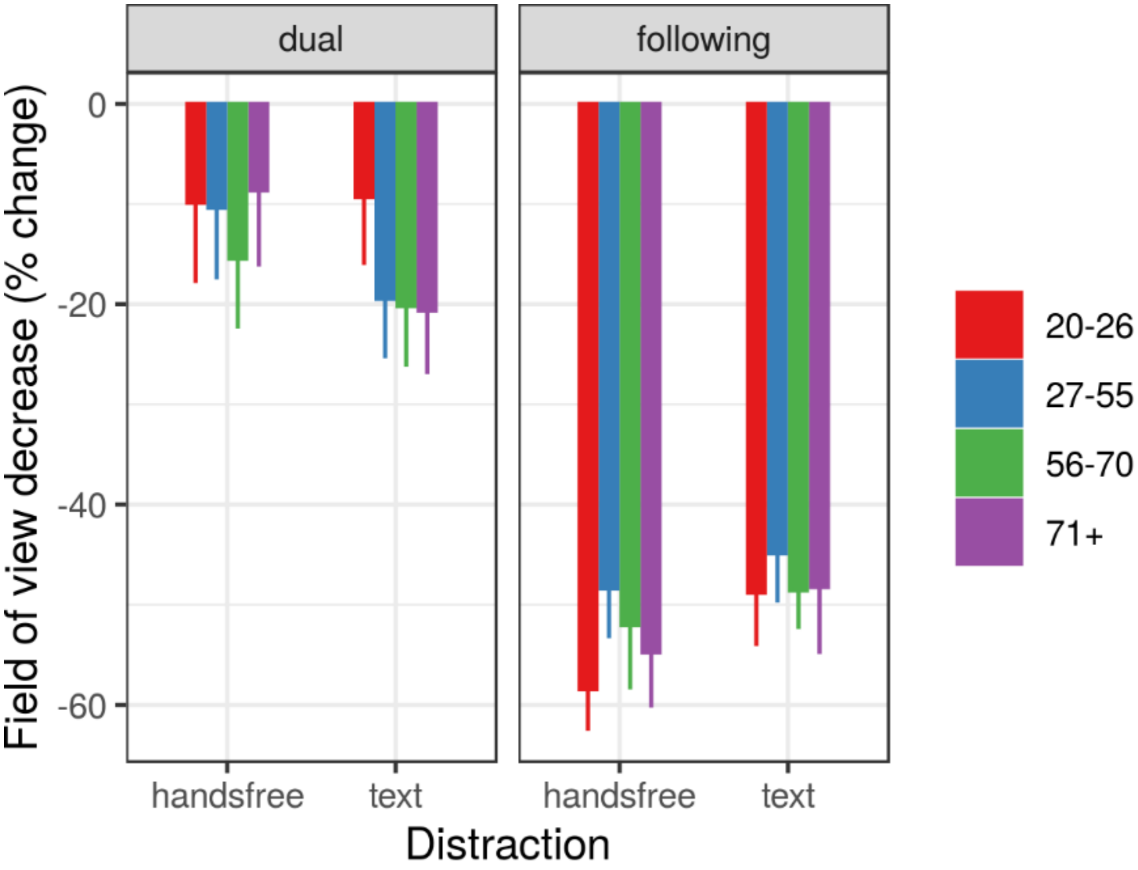

Figure 6. Percent decrease in the field of view, the interquartile range of the central part of the screen. Distraction type, age, and stage are all represented, but only stage is a significant difference. Bars are the percent change from baseline, and the errors are 95% confidence intervals across participants.

Discussion

We asked 97 participants who drive daily and regularly use smartphones to perform two simulated driving tasks: dual, responding to a peripheral cue; and following, matching a variable speed lead car. During both conditions, a smart phone mounted just to the right of the steering wheel would periodically ring, indicating a handsfree call or a text message. After the ring, participants tended to speed up a little, stiffen their foot on the accelerator, swerve dramatically, and exhibit tunnel vision. These behavioral changes were still detectable as long as 20-25 seconds after the distraction event, enough time to travel nearly half a mile at highway speeds.

Distraction Hangover

This study demonstrated a distraction hangover effect up to 25 seconds for swerve speed for both hands-free and texting, but with a longer recovery time for texting. The recovery after distraction for dual tasks was up to 16 seconds. These findings are compatible with those of Strayer et al in a 2015 study showing residual effects up to 27 seconds from distraction (Strayer et al., 2015). The ongoing effects of distraction on driving safety has implications for the habits of driving, checking emails and texts at traffic lights or in heavily congested and stopped traffic. Surveys of drivers have revealed that up to 50 percent of drivers check their phones at traffic lights (Hill et al., 2015).

The distraction hangover extended so long that in some cases the next smartphone distraction came before the participants were able to recover all the way to baseline. This appeared most impressively with seven drivers (about seven percent of the total) colliding with the lead car. Of the remaining 90 drivers who managed to avoid colliding with the lead car, a measure of how well they match the lead car's speed, coherence, dropped almost to zero. To put that in context, normal driving has a coherence of approximately 0.5-0.7, as our participants had without the phone distraction. Baseline coherence is known to drop with age, but only a few percent as we observe (Doroudgar et al., 2017). Moderate alcohol levels have limited effect on coherence (Jongen et al., 2016). Chronic marijuana users on THC have a measured coherence in a similar paradigm of about 0.44 (Doroudgar et al., 2018). The drop in coherence to nearly zero that we observed in all groups indicates that the distraction events not only interfered with the car following task but devastated it.

Age Effects

Driving behavior in the simulator was similar across age as has been observed in previous studies (Doroudgar et al., 2017). During the dual task, when speed was self-selected, the most consistent age-related change in driving was a general slowing of about two mph per decade of life: when given the choice, the oldest individuals in their seventh decade drove nearly 15 mph slower than the youngest, in their second decade. However, the oldest individuals performed as well as the youngest, in terms of lane excursions and lane and speed variability, even during the car-following portion of the task, when average speeds were controlled by the lead car and were the same across age groups. Driving slower did not help their dual task performance that worsened with age, and the oldest individuals missed approximately half of the peripheral cues that came within four seconds of a text message. This means the oldest group failed to detect 50 percent of the salient information in their visual periphery while driving.

While peripheral cue and baseline car following performance worsened with age, car-following ability during distraction improved slightly, although not all the way to baseline performance. The score for car following bottomed out for the youngest groups, indicating increased age provides some protection to following ability. This is surprising since younger individuals are almost always better at the driving tasks, with their faster reaction times and steadier movements (Doroudgar et al., 2017). Another indication of the protective effect of age is that the youngest individuals take the longest time to stabilize their lane position after a distraction event, and they are almost four seconds slower than the next oldest age group.

This situation has the potential to worsen as both the US population over 65 increases along with increasing numbers of older adults who cross the so-called digital-divide. According to Pew Research in the four years preceding 2017, smartphone use in seniors increased from 18 to 42 percent, while internet use overall increased from 43 percent in 2010 to 73 percent in 2019 (PEW, 2017). Smartphone use is anti-correlated with age; as current 60-year-olds age into the 65+ range, they bring with them greater facility and experience with cell phone use. The concern is that this may exacerbate problems in a population with documented driving-related visual attention challenges (Owsley et al., 1991).

Handsfree versus Texting

Handsfree devices are generally assumed to degrade driving performance less than hand-held ones (Ishigami & Klein, 2009), though there is evidence to the contrary (McEvoy et al., 2005), and texting, and increased availability of connected-car technology makes handsfree phones ever more appealing (Drews et al., 2009; Hosking et al., 2009; Libby et al., 2013). Shorter recovery times for handsfree than text distractions as well as less time spent looking at the phone would seem to bear this out. However, at about 15 seconds, the recovery time may be faster when driving during handsfree phone use, but that is still enough time to drive a quarter mile at highway speeds.

For most of the driving measures, we measured no difference between the handsfree and text distraction, including speed, lane excursions, and lane variability. Handsfree and text distractions increase swerve speed to almost the same peak value, and the longer recovery time for texting may be an artifact of the participants touching the phone a second time to respond to the text. Also, while participants place their gaze on the phone for about half the time when distracted by handsfree rings versus texts, the fraction of the screen they return to shrinks in both cases by indistinguishable amounts. After the phone distracts the driver, they must focus some of their limited attention on the phone, either to read a text or listen to a message. As they dedicate that attention away from the road, their eyes focus on a narrower area, and they miss important driving events, like oncoming traffic.

Policy Implications

From a safety perspective, our study highlights the risks of using smartphones on driving behaviors, and from a public health standpoint, our study showcases the burden of the degree of cognitive load on drivers with distractions. Most importantly, while our study did indicate some mitigation of these risks with handsfree over texting behaviors, these differences are of little public health significance or practical importance. Stakeholders of road safety, including drivers, policy makers, pedestrians, and the public alike should be informed of the true risks of distraction while driving, including the concern of the hangover effects of cognitive loads. The marked changes in driving performance during distraction demonstrated in this study may explain the worrisome upward trends in crash risk. Traffic laws should reflect the science of driving safety, reflecting the risks of handsfree phone use while driving, including distraction hangover, in addition to the current bans on handheld phone use. As technology continues to become engrained through our daily tasks, including increasingly sophisticated automobiles and cell phones, policy makers should better align available evidence regarding in-vehicle technology and the science of distraction. We need effective public education programs to increase appreciation of the dangers of distraction, including handsfree phone use, and the risks of even short distractions that nonetheless are associated with hangover effects.

Key Points

- 20-25 second distraction hangover after a smartphone event.
- Similar results for handsfree talking and texting.
- Field of view shrank nearly 50% after distraction.

References

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Borowsky, A., Horrey, W. J., Liang, Y., Garabet, A., Simmons, L., & Fisher, D. L. (2015). The effects of momentary visual disruption on hazard anticipation and awareness in driving. Traffic Injury Prevention, 16(2), 133–139.

Borowsky, A., Horrey, W. J., Liang, Y., Garabet, A., Simmons, L., & Fisher, D. L. (2016). The effects of brief visual interruption tasks on drivers' ability to resume their visual search for a pre-cued hazard. Accident Analysis & Prevention, 93, 207–216.

Doroudgar, S., Chuang, H. M., Bohnert, K., Canedo, J., Burrowes, S., & Perry, P. J. (2018). Effects of chronic marijuana use on driving performance. Traffic Injury Prevention, 19(7), 680–686. https://doi.org/10.1080/15389588.2018.1501800

Doroudgar, S., Chuang, H. M., Perry, P. J., Thomas, K., Bohnert, K., & Canedo, J. (2017). Driving performance comparing older versus younger drivers. Traffic Injury Prevention, 18(1), 41–46. https://doi.org/10.1080/15389588.2016.1194980

Drews, F. A., Yazdani, H., Godfrey, C. N., Cooper, J. M., & Strayer, D. L. (2009). Text Messaging During Simulated Driving. Human Factors, 51(5), 762–770. https://doi.org/10.1177/0018720809353319

Governors Highway Safety Association (2020). Distracted Driving. https://www.ghsa.org/issues/distracted-driving

Harrell Jr, F. E., & Harrell Jr, M. F. E. (2015). Package 'Hmisc.' CRAN2018, 235–6.

Hill, L., Rybar, J., Styer, T., Fram, E., Merchant, G., & Eastman, A. (2015). Prevalence of and attitudes about distracted driving in college students. Traffic Injury Prevention, 16(4), 362–367.

Hosking, S. G., Young, K. L., & Regan, M. A. (2009). The effects of text messaging on young drivers. Human Factors, 51(4), 582–592.

IIHS-HLDI (2020). Fatality Facts 2018: Pedestrians. IIHS-HLDI Crash Testing and Highway Safety. https://www.iihs.org/topics/fatality-statistics/detail/pedestrians

Insurance Information Institute (2020). Facts + Statistics: Highway safety. https://www.iii.org/fact-statistic/facts-statistics-highway-safety#Traffic%20Deaths,%202009-2018

Ishigami, Y., & Klein, R. M. (2009). Is a hands-free phone safer than a handheld phone? Journal of Safety Research, 40(2), 157–164. https://doi.org/10.1016/j.jsr.2009.02.006

Jongen, S., Vuurman, E. F. P. M., Ramaekers, J. G., & Vermeeren, A. (2016). The sensitivity of laboratory tests assessing driving related skills to dose-related impairment of alcohol: A literature review. Accident Analysis & Prevention, 89, 31–48. https://doi.org/10.1016/j.aap.2016.01.001

Just, M. A., Keller, T. A., & Cynkar, J. (2008). A decrease in brain activation associated with driving when listening to someone speak. Brain Research, 1205, 70–80.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. Journal of Statistical Software, 82(13).

Libby, D., Chaparro, A., & He, J. (2013). Distracted while driving: A comparison of the effects of texting and talking on a cell phone. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 57(1), 1874–1878.

McEvoy, S. P., Stevenson, M. R., McCartt, A. T., Woodward, M., Haworth, C., Palamara, P., & Cercarelli, R. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: A case-crossover study. Bmj, 331(7514), 428.

National Highway Traffic Safety Administration (2019). Distracted driving in fatal crashes, 2017 (Traffic Safety Facts Research Note DOT HS 812 700).

Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1991). Visual/cognitive correlates of vehicle accidents in older drivers. Psychology and Aging, 6(3), 403.

PEW (2017). Technology use among seniors. Pew Research Center: Internet, Science & Tech. https://www.pewresearch.org/internet/2017/05/17/technology-use-among-seniors/

Porges, S. W., Bohrer, R. E., Cheung, M. N., Drasgow, F., McCabe, P. M., & Keren, G. (1980). New time-series statistic for detecting rhythmic co-occurrence in the frequency domain: The weighted coherence and its application to psychophysiological research. Psychological Bulletin, 88(3), 580–587. https://doi.org/10.1037/0033-2909.88.3.580

R Core Team (2014). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. http://www.R-project.org/

Redelmeier, D. A., & Tibshirani, R. J. (1997). Association between cellular-telephone calls and motor vehicle collisions. New England Journal of Medicine, 336(7), 453–458.

Savage, S. W., Potter, D. D., & Tatler, B. W. (2020). The effects of cognitive distraction on behavioural, oculomotor and electrophysiological metrics during a driving hazard perception task. Accident Analysis & Prevention, 138, 105469.

Schroeder, P., Wilbur, M., & Peña, R. (2018). National Survey on Distracted Driving Attitudes and Behaviors—2015 (DOT HS 812 461). National Highway Traffic Safety Administration.

Singh, S. (2015). Critical reasons for crashes investigated in the national motor vehicle crash causation survey.

Smith, A. (2017). Record shares of Americans now own smartphones, have home broadband. Pew Research Center, 12, 1–2.

Snider, J., Plank, M., Lee, D., & Poizner, H. (2013). Simultaneous neural and movement recording in large-scale immersive virtual environments. Biomedical Circuits and Systems, IEEE Transactions On, 7(5), 713–721.

Strayer, D. L., Cooper, J. M., Turrill, J., Coleman, J. R., & Hopman, R. J. (2015). Measuring cognitive distraction in the automobile III: A comparison of ten 2015 in-vehicle information systems.

Strayer, D. L., Drews, F. A., & Crouch, D. J. (2006). A Comparison of the Cell Phone Driver and the Drunk Driver. Human Factors, 48(2), 381–391. https://doi.org/10.1518/001872006777724471

Tison, J., Chaudhary, N., & Cosgrove, L. (2011). National phone survey on distracted driving attitudes and behaviors (DOT HS 811 555). National Highway Traffic Safety Administration.