TEXTING ON A SMARTWATCH VERSUS A SMARTPHONE: A COMPARISON OF THEIR EFFECTS ON DRIVING PERFORMANCE

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Joel Persinger

Master of Arts, Wichita State University, 2014

Bachelor of Science, Eastern Kentucky University, 2005

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The following faculty members have examined the final copy of this dissertation for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Doctor of Philosophy, with a major in Psychology.

____
Rui Ni, Committee Chair

____
Alex Chaparro, Committee Member

____
Barbara Chaparro, Committee Member

____
Jibo He, Committee Member

____
Jeremy Patterson, Committee Member

Accepted for the College of Liberal Arts and Sciences

____
Ron Matson, Dean

Accepted for the Graduate School

____
Dennis Livesay, Dean

DEDICATION

To my beautiful wife, who has pushed me to go further than I ever thought I could. She has truly carried me though graduate school with love and encouragement.

ABSTRACT

The National Safety Council reports that 6 percent or more car crashes involved text messaging from a smartphone. In addition, many studies have found that cell phone while driving increases crash risk by 2.8–5 times (Klauer et al. 2006; Redelmeier and Tibshirani 1997; Violanti 1998; Violanti and Marshall 1996). With the inevitable prevalence of using portable devices during driving, it is probable that smartwatch usage behind the wheel may rise above smartphone usage. Unfortunately, previous literature seems to confirm the danger of smartwatch over smartphone usage while driving (Giang et al., 2014, 2015). However, these literatures unfairly assigned different notification settings (ringtone versus vibration) to each mobile device. This study compares simulator driving performance between smartphone and smartwatch at varying drive loads. Participants read text messages delivered either on a smartphone or smartwatch with notifications set to auditory only, vibration only or both (multimodal). Driving and texting performance was analyzed for each condition (phone vs. watch and auditory vs. tactile vs. multimodal and high vs. low drive load) to determine which device is more detrimental to driving performance. Interactions were observed between device and notification type for time to engage. Messages were answered faster on the watch with tactile and multimodal settings. Interactions between notification type and driving workload were detected for gain and coherence. More variability of gain was observed for the watch compared to the phone. In addition, tactile notifications had different levels of gain between drive load conditions compared to any other notification type. Both gain and coherence had higher levels in the high drive load compared to the load drive load conditions, indicating a possible underestimation of the driving environment.

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CHAPTER 1

INTRODUCTION

1.1 Driving, distraction and new technology

Distracted driving compromises the safety for the individual driver as well as those around them. In a recent study, distraction was observed to be a contributing factor in 68% of the crashes analyzed (Dingus et al., 2016). Distracted driving is the act of diverting attention away from the critical activities that facilitate safe driving (Lee, Young, & Regan, 2008). Unfortunately, there are many sources of driver distraction, given the many in-vehicle technologies within modern cars (e.g. navigational, entertainment, communication devices). In addition to these, drivers may also be distracted by mobile devices (i.e. tablets, smartphones, smartwatches). For example, 45% of high school teenagers reported they engage in texting while driving (Olsen, Shults, & Eaton, 2013). Unfortunately teens are more prone to automobile accidents when distracted (Klauer et al., 2014). Also consider a recent government report specifying that 6 percent or more crashes (minimum of 341,000) in 2013 involved text messaging from a smartphone (National Safety Council, 2013). These overwhelming numbers have motivated researchers to try to understand the distractible nature of using communicating technology while driving. If we understand the dangers of using a given technology behind the wheel, we can raise public awareness to the danger. There is evidence that if a driver perceives a particular behavior as dangerous behind the wheel, it could actually deter them (Feng, Marulanda, & Donmez, 2014).

Many studies have identified the great risks associated with manipulating mobile devices while driving (Brookhuis, de Vries, & de Waard, 1991; Burge & Chaparro, 2012; Burnett, Summerskill, & Porter, 2004; Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009; He et al., 2014; Tractinsky, Ram, & Shinar, 2013). However, few have analyzed the level of distraction smartwatches create (Giang, Hoekstra-Atwood, & Donmez, 2014; Giang, Shanti, Chen, Zhou, & Donmez, 2015). As smartwatches become part of our society, the use of these devices while driving is inevitable. Their popularity is climbing among consumers with 33 million units shipped in 2015 and 145 million units predicted by 2019 (Danova, 2015). Within the following, two preliminary articles attempted to quantify the impact of receiving notifications with a smartwatch while driving (Giang et al., 2014; Giang et al., 2015).

Two preliminary studies, Giang et al. (2014) and Giang et al. (2015) were the first to compare the levels of driver distraction as result of smartwatch or smartphone usage. Giang et al. (2014) had participants simply drive (baseline) or read messages from a smartwatch or a smartphone while performing a simple car following task within a driving simulator. As they drove, a number of events (lead vehicle braking, surrounding cars turning into vehicle path, bicyclists entering the roadway) occurred that required the driver to react. Message alerts were received on the watch via tactile vibration while the phone alerts were an auditory tone. Giang et al. (2014) analyzed the amount of time each participant took to start to read the message after receiving the notification (time to engage), the amount of time participants needed to read the text message (time to complete), glance duration to the device and the percent of time eyes spent not looking at the road (percent of eyes off road). They found that the time to engage was significantly shorter for the smartwatch compared to the smartphone. Glances were about 0.18 seconds longer for the smartwatch compared to the smartphone, thus increasing the percent of eyes off road in the smartwatch condition by 4.24%.

Next, Giang et al. (2015) replicated the previous study but added an additional driving performance measure. This time they analyzed vehicle braking response time. Again, message alerts were received on the watch via tactile vibration and an auditory tone was used for the phone. Their data confirmed the findings from their earlier experiment. In addition, they observed slower braking response in the smartwatch conditions compared to the baseline (no distraction) and smartphone conditions.

Taken together, the previous evidence suggests that using smartwatches while driving is significantly more dangerous than using a smartphone (Giang et al., 2014; Giang et al., 2015). Interactions on smartwatches take significantly longer to complete compared to smartphones while driving (Giang et al., 2014; Giang et al., 2015). In addition, drivers are faster to interact with the smartwatch compared to smartphones (Giang et al., 2014; Giang et al., 2015). Consequently, driving performance is further compromised when using smartwatches compared to smartphones (Giang et al., 2015). This is very concerning given their convenience and availability (being attached to the body), drivers may be more likely to use them compared to smartphones. Therefore, more investigations are needed to further understand the potential dangers smartwatches pose to drivers. Specifically, there has yet to be an investigation to quantify the level of driving distraction each device (smartwatch or smartphone) creates with each method of notification delivery (audio, tactile or both). Each mobile device can emit either an audible beep, a tactile vibration, or both simultaneously, to notify their users of a message. Previous literature has failed to make this comparison between the smartwatch and smartphone. In fact, Giang et al. (2014) and Giang et al. (2015) has failed to keep notification mediums constant. In their series of experiments, they have assigned the smartwatch tactile alerts and the smartphone audible notifications. One could argue that their results could be due to this inconsistency. For example, many laboratory and driving studies have found that tactile alerts direct spatial attention more so than audible alerts (Fitch, Kiefer, Hankey, & Kleiner, 2007; Huang, Tsai, Kuo, & Wu, 2011; Murata, Kanbayashi, & Hayami, 2013; Scott & Gray, 2008). Further, investigations evaluating which modality (audio, tactile or both) driving assisted system (DAS) warning systems should utilize, has consistently demonstrated that multimodal (both audio and tactile simultaneously) more effectively direct a driver's visual spatial attention (Ho, Reed, & Spence, 2007; Lewis, Penaranda, Roberts, & Baldwin, 2013b; Murata et al., 2013; Politis, Brewster, & Pollick, 2014). Multimodal signals (both audio and tactile) seem more likely to capture the attention of a driver compared to unimodal signals (singularly audio or tactile)(Ho et al., 2007; Lewis, Penaranda, Roberts, & Baldwin, 2013a; Murata et al., 2013; Politis et al., 2014). Considering the DAS literatures within the context of smart devices, it seems there are still unanswered questions regarding the distractible nature of each mobile device.

1.2 Research Question

To date, no literature has investigated the level of driving distraction that notifications of different modalities (auditory, tactile, or both) provide between the smartwatch and smartphone. Consider that some designers, such as Apple, have incorporated strong vibrations to deliver information to the user (they refer to it as a flick on the wrist), it is important to see how these design choices could impact driving distraction. Therefore, this dissertation will quantify driving performance for each device (smartwatch and smartphone) at each notification setting (audio, tactile or both), in order to understand their impact on driving.

For this investigation, previous literature will aid in the design of the experiment. Although many have examined smartphone usage and driving distraction since their beginning, there are no investigations comparing the level of driving distraction acquired from notification settings. Literature evaluating driving assisting systems offer important insight on notification settings. Driving assisting systems (DAS) are in-vehicle technologies that warn drivers of potential dangers such as traffic signal violations, lane deviation and possible collisions with other vehicles or pedestrians (Vehicle Safety Consortium, 2005). In order for these systems to work, the signal from the system must obtain the driver's attention. Consequently, researchers have heavily investigated which method of notification (auditory, tactile, or both) can direct the attention of the driver. Thus this literature is important in understanding how the notification settings from mobile devices capture attention and cause driving distraction. However, it can be argued that notifications from a DAS differ from mobile notifications because unlike mobile device notifications, drivers know that the DAS communicates important information regarding the task of driving. With that in mind, DAS notifications are more likely to be attended to, while mobile notifications could be more easily ignored. However, laboratory studies have indicated that attention is still automatically shifted by a signal (i.e. auditory or tactile) that has nothing to do with the primary task and even still when participants are told to ignore the signal (Kennett, Spence, & Driver, 2002; Mazza, Turatto, Rossi, & Umiltà, 2007; Spence, Nicholls, Gillespie, & Driver, 1998; van der Lubbe & Postma, 2005).

Therefore, the following section will first explore laboratory experiments as well as simulator and on-road driving experiments investigating DAS. Given mobile notification settings include auditory, tactile or both, DAS literature that compare only these modalities as warning signals will be reviewed. Several questions will be addressed by reviewing these literatures. First, it will be explored to what degree crossmodal signals (i.e. involving two or more interactions between different sensory modalities) can shift attention. Second, it will be determined if there are occasions when crossmodal signals might be ignored, and why this might occur. Understanding how attention is shifted for each modality and under what circumstances will help to shape the experiment. Last, the review will address which signal (auditory, tactile or both) is more likely to capture the attention of a driver.

CHAPTER 2

2.1 Unimodal signals and spatial attention

Driving a motor vehicle is a multimodal activity. A driver uses vision for navigation and to monitor for potential hazards. At the same time audition is used to enhance awareness for hazards as well as traffic directions from traffic signals, navigation equipment, in car warning systems, emergency sirens, surrounding car horns, etc. Tactile is also utilized by the driver to receive signals from the road such as speed bumps or road side rumble strips. Unfortunately, among the driving environment these informative signals (pertaining to the driving task) are intermixed with uninformative signals. These are signals that do not pertain to the driving task and merely act as a distraction, such as receiving a notification on a smartwatch while driving. Both the informative and uninformative signals compete for the driver's attention. To better understand driving distraction, it is therefore important to understand how these uninformative signals capture attention. For example, even though we know a signal from a smartwatch is uninformative, do we attend to them automatically? Therefore, the studies reviewed below explored how uninformative unimodal signals shift attention.

Early laboratory studies have created the widespread belief that crossmodal attentional capture is automatic. This has been demonstrated using a spatial cueing task, in which an uninformative cue is presented in a peripheral location followed by a target stimulus that could appear ipsilateral or contralateral relative to the uninformative cue. The initial cue is considered uninformative because it does not predict the actual location the target will appear. van der Lubbe and Postma (2005) observed crossmodal attentional capture by presenting an uninformative alert (auditory or visual) in between an informative cue and a visual target.

Regardless of the spatial origin of the uninformative cue (28.3° or 19.3° from fixation), it’s location (ipsilateral or contralateral) relative to the target still moderated participants’ response time to visually discriminate the target. Mazza et al. (2007) had participants spatially locate a visual or auditory target following a visual or auditory uninformative cue. The uninformative cue could also appear ipsilateral or contralateral relative to the target. It is important to note that participants were told to ignore the cue, that it was unrelated to target location. They found that ipsilateral trials had shorter response times than contralateral trials. Indicating that attention was spatially shifted by the cue, even though participants were told to ignore it.

Thus far it would appear that crossmodal signals, specifically visual and auditory, can shift attention automatically. These attentional shifts have also been observed for the tactile modality. For example, Spence et al. (1998) demonstrated that spatially uninformative tactile cues could orient attention while performing visual and auditory elevation discrimination judgements. An auditory or visual target was presented following the uninformative tactile cue. Much like the previous paradigm, the tactile cue could appear ipsilateral or contralateral relative to the target. Again it was observed that elevation discrimination responses were significantly faster and more accurate for the targets that were presented shortly after an ipsilateral uninformative tactile cue. Similarly Kennett et al. (2002) had an elevation discrimination task using two foam cubes (mounted to each hand) that had both a pair of LED lights and vibrators mounted to the top and bottom. One condition presented uninformative visual cues (via LED) followed by a vibration target from one of the vibration motors. The other condition was exactly the same except the vibration was the uninformative cue and the visual stimulus was the target. Participants only needed to specify the target locations (higher or lower set of LEDs or vibrators), regardless of which hand was stimulated. For both the visual and tactile conditions, their results demonstrated that responses were faster when the uninformative cue were presented ipsilateral compared to contralateral. Again this is consistent with previous literature that indicates that spatial attention is moved to the location even though the cue is uninformative. As attention is automatically shifted, participants are unable to prevent allocating attention to the uninformative cue.

The previous literature indicates that uninformative signals automatically shift attention for the auditory and tactile modality, suggesting that a driver could be automatically distracted by an auditory or tactile notification from a mobile device. However, driving is a complex task and these previous studies only used simple detection tasks to demonstrate automatic attentional shifts for these modalities. Next, literature that evaluates attentional shifts while performing more complex tasks are reviewed.

2.2 Unimodal signals and Sensory blindness

Thus far the literature seems to suggest that even if attention is focused on a primary task, remaining attentional capacity is still allocated to surrounding stimulus quickly and automatically. The cross modal attentional capture also seems unpreventable. Even when participants are told to ignore the cue or that it is uninformative, spatial attention will still be allocated to it (Kennett, Eimer, Spence, & Driver, 2001; Mazza et al., 2007; Spence et al., 1998; van der Lubbe & Postma, 2005). Given the previous literature, it was surprising when Santangelo, Olivetti Belardinelli, and Spence (2007) demonstrated that there may be instances when signals from other modalities go unnoticed. Apparently when attention is focused on a task with a high attentional workload, leaving no spare resource, inputs from other modalities can go unnoticed (Santangelo et al., 2007). Santangelo et al. (2007) demonstrated this using three different conditions, single task, dual task and no-stream. The dual task condition contained a rapid serial visual or auditory presentation (RSVP or RSAP) task, which consisted of a continuous stream of 11 items presented one at a time on a screen for 96 ms. The stream of items had letters (distractors) and numbers (target). The target numbers could appear either the 3rd, 6th, or 9th position in the stream. The other task that was performed during the RSVP or RSAP task was a discrimination task (left or right side). There were visual or auditory targets consisting of lights and speakers at various elevations on the monitor. These targets could simultaneously appear either on the 3rd or 6th position in the RSVP or RSAP stream. The visual or auditory targets were cued 224 ms before the event. The cue would occur on either the same side as the target (cued condition), or opposite (uncued condition). Participants had to track either which position (out of 11) the visual or auditory target digit occurred (digit target trial) or which side the target (spatial target trial) occurred. Participants speedily indicated if they saw the digit target or the spatial target. The single task conditions also contained the RSVP, however participants were only asked to pay attention to it (no information was drawn from it). The only task was to distinguish the spatial target. In the no-stream condition, the RSVP was replaced by a central fixation cross.

The authors' results within the no-stream conditions (when RSVP or RSAP was not present) seemed to replicate the previous literature findings. That is, the uninformative auditory or visual cues aided discrimination when the target was ipsilateral rather than contralateral. However, the novel finding resides within the other two conditions that employed the RSVP or the RSAP. Contrary to previous findings, the uninformative auditory or visual cues actually had no affect on the discrimination task within both the dual task and single task conditions. These results are interesting because it directly contradicts the previous literature that demonstrated uninformative signals capture and orient attention quickly, efficiently and automatically (Kennett et al., 2001; Mazza et al., 2007; Spence et al., 1998; van der Lubbe & Postma, 2005). Uninformative cues failed to orient attention when the RSVP or RSAP was present (dual and single task conditions) compared to when it was absent (no-stream condition). Consider that with the no-stream condition and the single task condition participants were only performing the single detection task. The only difference between them are that participants viewed either a fixation cross or the stream of letters and numbers (RSVP or RSAP). If the workload was the same for both conditions, why was there a difference in response time? The authors' interpretation suggested that when participants focused their attention on the RSVP, it utilized perceptual resources automatically until it was depleted. Even though no task was performed using the RSVP information, just attending to it still used perceptual resource. The RSVP was not providing relevant information in the single task condition and therefore should have been ignored, yet it was still using attentional resource.

Even though the previous results were considered controversial, upon further reflection, the results actually converge with previous publications. Originally, it seemed the literature suggested when attention is focused on a primary task, the remaining attentional capacity is still allocated to surrounding stimuli quickly and automatically, (Kennett et al., 2001; Mazza et al., 2007; Spence et al., 1998; van der Lubbe & Postma, 2005). Santangelo et al. (2007) and Santangelo and Spence (2007a) actually provided us with a series of experiments that explain what would happen if while performing a primary task, no attentional resource remains. It would seem that attentional resource is initially given to the primary task, which will use as much resource as it needs to perform the task. If all the resource is used, then all attentional capacity will remain on the primary task. Signals from other modalities will be unable to interrupt or divert attention away. On the other hand, if the primary task does not require all attentional capacity, other modalities will be free to shift attention with their input.

Thus far the literatures discussed have helped to explain how unimodal signals capture attention in a dual task setting. When performing a task such as driving, crossmodal signals from a mobile device could draw attention automatically. However, this would happen only when the task does not saturate all available attentional capacity. This is an important consideration when forming an experiment that will compare unimodal to multimodal signals. In order to assess how the mobile devices capture attention with different modality signals, driving workload must be considered. Next a theoretical model is introduced that could potentially explain Santangelo et al. (2007) and Santangelo and Spence (2007a) results.

2.3 Load theory of attention: an explanation of sensory blindness

Researchers were surprised by the outcome of Santangelo et al. (2007) and Santangelo and Spence (2007a). Since that time, however, many have used load theory to bridge the gap between previous literatures and these recent experiments (Lavie, 1995, 2005; Lavie, Hirst, De Fockert, & Viding, 2004; Lavie & Tsal, 1994). According to load theory, our limited attention is distributed in an automatic manner to stimuli within proximity. Further, the process of allocating attention is beyond our control. Therefore, distractions are not voluntarily withheld. For example, when performing a task that has a lower perceptual load, spare attentional capacity can involuntarily spill over to irrelevant distractions. Inversely, distractions are prevented within activities requiring a high perceptual load given the task will use all available attentional capacity.

Evidence for load theory has been demonstrated in behavioral studies such as those previously discussed as well as neurological methods. In line with the major premise of load theory, various neuroimaging studies have exhibited high perceptual load significantly reduces brain response. For example, as perceptual load increases, the activity in the ventral visual cortex which is activated by task irrelevant stimuli will decrease (Handy, Soltani, & Mangun, 2001; Pinsk, Doniger, & Kastner, 2004). In addition, the level of activity in the visual cortex invoked by complex stimuli (e.g. moving dot displays, flickering checkboards) is determined by the perceptual load required by the primary task (Parks, Beck, & Kramer, 2013; Parks, Hilimire, & Corballis, 2011).

Load theory provides a model that explains previous literature investigating unimodal detection in dual task situations. It should certainly be taken into consideration within the experimental design of this dissertation. For example, with a more challenging driving scenario, the unimodal signals from the mobile devices could be ignored regardless of modality (i.e. tactile or auditory). Therefore, when comparing unimodal signals, driving workload must be accounted for.

Thus far the discussed literature has focused on how unimodal signals capture attention in dual task scenarios. The previous literatures have aided in the understanding of how and when these attentional shifts occur. However, the studies that have aided in this understanding have all occurred within the laboratory. Consider that this dissertation seeks to investigate how mobile devices and notification settings cause driving distraction. Thus, it is important to consider literature that investigates how signals from different modalities capture attention within the driving environment. Therefore, the reviewed literature within the following section evaluates how unimodal signals from a DAS capture attention to aid driving. These researchers actually compare the degree to which each unimodal signal (auditory versus tactile) can obtain a driver's attention and aid driving. This direct comparison is a small glimpse of how each mobile notification signal might capture the attention of a driver and cause distraction.

2.4 Unimodal warning signals and driving research

The most applicable research to this dissertation is driving research that investigates the usage of auditory or tactile signals in DAS. These literatures offer essential insight for a couple reasons. First they directly compare the degree to which auditory and tactile signals can capture attention. Secondly, these comparisons are made within the context of driving. Thus, these direct comparisons between auditory and tactile signals should indicate which of the two is more effective at shifting attention behind the wheel.

Notably, authors have suggested several reasons why they think tactile signals might be more effective at shifting attention than auditory signals within the context of driving (Santangelo & Spence, 2007a). For example, spatial coding for tactile stimuli is completely different from auditory stimuli. Unlike auditory connections, the somatosensory cortical areas have direct fiber connections with the motor cortex (Jones & Powell, 1979). It has also been suggested that touch requires less processing capacity compared to audition because touch was an early or primitive modality within human evolution (Gregory, 1967). This was observed when Baldock, Mathias, McLean, and Berndt (2007) found that a tactile warning system did not increase the workload of the drivers in their study. The authors successfully utilized tactile warnings to signify lane departure to assist snow plow drivers with a higher workload due to harsh conditions.

Scott and Gray (2008) were among the first to test collision warning systems of different modalities against one another within the context of driving. They used a car following task generated within a simulator. Response time to braking events of the lead car along with crashes were tracked. The tactile (0.332 s and 5.1% respectively) warning system had the lowest response time and percentage of crashes compared to audio (0.338 s and 7.8% respectively) warning systems.

Using pre-programed driving animations, Huang et al. (2011) constructed different crash scenarios participants would have to apply the brakes when a collision was detected. They compared braking response time between collision warnings from three modalities (i.e. visual, audio and tactile). Consistent with Scott and Gray (2008) reaction times were lower for tactile (428 ms) followed by audio (540 ms) and visual (848 ms) collision warnings.

Fitch et al. (2007) tested auditory warnings against tactile in vehicle collision warnings outside the simulator. Their participants drove on an 8-mile stretch of public highway, while receiving direction specific warnings (even though no collision was occurring) either via auditory or tactile. Participants were required to specify the direction the collision warning indicated. The authors kept track of the participant's response time and accuracy. They reported that compared to the auditory warnings, the tactile warnings reduced response time by 257 ms and increased the percentage localization from 32% to 84%.

Taken together, these literatures provide further understanding of how notifications within a given technology obtain the driver's attention. Unimodal warning signals orient driver's attention, which in turn causes a decrease response time to collision events. Support for this derives from the previous reviewed laboratory studies. Recall that crossmodal attentional capture can be automatic in certain circumstances (Kennett et al., 2002; Mazza et al., 2007; Spence et al., 1998; van der Lubbe & Postma, 2005). Further, it would appear between the two unimodal signals, tactile warning systems yield shorter response times along with greater accuracy compared to auditory warning systems (Fitch et al., 2007; Huang et al., 2011; Scott & Gray, 2008). This could indicate that tactile signals are more efficient at capturing attention than auditory signals within the context of driving. Given mobile devices are equipped to generate both auditory and tactile signals, it is important to understand which of these signals have the greater potential for distraction when driving.

An additional consideration is when a mobile device is set to produce a notification signal with both auditory and tactile simultaneously (multimodal signal). This has not been considered thus far but is important given some mobile users and designers utilize this setting. Therefore, to obtain a complete understanding of the distractible nature of mobile devices and notification types, multimodal signals must be included. Thus the following reviewed literature will demonstrate how multimodal signals capture attention in the laboratory as well as within the driving environment.

2.5 Multimodal research

The investigation of multimodal signals will begin by discussing laboratory literature that examines multimodal attentional capture using neurological and behavioral methods. Next, DAS literature that compares the efficiency of attentional capture of unimodal signals to multimodal signals within the driving environment will be reviewed.

2.6 Multimodal signals and spatial attention

Interest in multimodal attentional capture was ignited by Barry Stein, Alex Meredith and colleagues from their investigations of multisensory enhancement (Stein & Meredith, 1993; Stein & Stanford, 2008). Multisensory enhancement is a situation where the response to the crossmodal stimulus is greater than the response to either component stimuli (Stein & Stanford, 2008). For example, the superior colliculus (SC), which controls changes in orientation (i.e. shifts in fixation and attention) (Kustov & Robinson, 1996), has multisensory neurons with excitatory receptive fields, one for each modality (Stein & Stanford, 2008). When a signal stimulates two modalities, and derives from the same temporal (Meredith, Nemitz, & Stein, 1987; Recanzone, 2003) and spatial location (Meredith & Stein, 1986a, 1996) (i.e. sight and sound occurring at the same time from the same place), it can actually increase neural activity (Meredith & Stein, 1986b; Stanford, Quessy, & Stein, 2005; Stanford & Stein, 2007). For example, Meredith and Stein (1986b) measured the activity of a cat superior colliculus neuron in response to a visual stimulus, an auditory stimulus, or both simultaneously. The multimodal stimulus generated more impulses (18 per trial) compared to the combine total of impulses for visual and auditory alone (about two impulses per trial). Santangelo, Van der Lubbe, Belardinelli, and Postma (2008) measured event related brain potentials (ERP) as participants performed a spatial discrimination task with either unimodal or multimodal signals. Their ERP data was significantly enhanced by the multimodal signals. Once again, the multimodal ERP was significantly larger than the sum of the ERP within the two unimodal conditions.

Multimodal signals not only increase neural activity, but can also have a significant positive affect on behavioral performance by increasing the speed and probability of perceiving and locating a stimulus (Bell, Meredith, Van Opstal, & Munoz, 2005; Diederich & Colonius, 2004). For example, Bell et al. (2005) observed a reduced saccadic response time in rhesus monkeys performing a delayed saccade task. This has also been observed in humans as well (Hughes, Reuter-Lorenz, Nozawa, & Fendrich, 1994; Nozawa, Reuter-Lorenz, & Hughes, 1994; Santangelo, Van der Lubbe, et al., 2008). Diederich and Colonius (2004) compared response times of the detection of unimodal and multimodal signals. Their detection task required participants to hit a button when they detected either an auditory signal, visual signal, tactile signal, a combination of the two or all three signals displayed. In addition to superior response times for multimodal over unimodal, they also observed an added benefit of having the trimodal signal beyond the bimodal signal. It should be noted that the degree of multisensory enhancement is moderated by the intensity of the individual stimulus (Bell et al., 2005; Diederich & Colonius, 2004; Frens, Van Opstal, & Van der Willigen, 1995; Stanford et al., 2005). In other words, individual cues that are highly salient are easily detected and so, when presented together, it has a proportionately modest effect on neural activity and behavioral performance.

2.7 Multimodal signals and sensory blindness

Previous literature found unimodal signals fail to capture attention when the perceptual workload is too high (Santangelo et al., 2007; Santangelo & Spence, 2007a). Given the previous discussion of multisensory enhancement, researchers wondered if multimodal signals would also go unnoticed in situations of higher perceptual load. Santangelo and Spence (2007b) performed an experiment similar to their previous experiments (Santangelo et al., 2007; Santangelo & Spence, 2007a), using the RSVP with a dual task, single task and no-stream conditions. Again, participants performed a spatial elevation discrimination task while either attending to targets in the RSVP (dual task), simply observe the RSVP (single task), or observe a fixation cross which replaced the RSVP (no stream). This time Santangelo and Spence (2007b) presented multimodal uninformative cues (rather than unimodal uninformative cues) before the unimodal target (for the elevation discrimination). Unlike their previous work with unimodal uninformative cues (Santangelo et al., 2007; Santangelo & Spence, 2007a), their results indicated that the multimodal uninformative cues shifted spatial attention regardless of condition. In other words, unlike unimodal cues, multimodal cues can capture attention regardless of perceptual load. It is important to note that Santangelo and Spence (2007b) used audiovisual cues as their multimodal uninformative cues, while Santangelo, Ho, and Spence (2008) showed the same affect for audiotactile multisensory cues. This might suggest that mobile devices with multimodal notifications enabled could potentially pose a greater distraction to drivers. This is an important concern that this dissertation hopes to directly address.

To further understand how multimodal signals capture attention within the context of driving, the following reviews DAS literatures that utilizes multimodal signals as warnings. These literatures are extremely helpful because they directly compare performance of each unimodal signal against one another as well as to multimodal signals. This should give some indication of which mobile notification setting (audio, tactile or multimodal) pose as a greater distraction.

2.8 Multimodal and driving research

Researchers began evaluating multimodal signals to see if it's enhancement could be implemented within a DAS. Within the following sections, literatures that directly compare in-vehicle warnings using audio, tactile and combinations of both will be reviewed. Therefore, the following literatures will give some idea of how a unimodal and multimodal notifications from the smartphone and smartwatch could potentially redirect a driver’s spatial attention automatically.

Ho et al. (2007) utilized a driving simulator in order to compare unimodal auditory (a car horn), unimodal tactile (290- Hz vibration), and combined audiotactile or multimodal warning signals that would alert and inform drivers of likely collision events. Participants drove along a rural road as they followed a lead car. From time to time the lead car would slow or apply its brakes, and participants were expected to respond by applying their brake. Their participants had a significantly more rapid braking response following the multimodal warning signals compared to either unimodal conditions. There was also a significant difference between unimodal tactile (M= 1001 ms) and auditory (M= 887 ms) signals. These findings are inconsistent with previous laboratory studies that observed faster response times for tactile warning signals compared to audio warning signals (Fitch et al., 2007; Huang et al., 2011; Scott & Gray, 2008). One possible explanation for this discrepancy is the choice of audio stimuli. Ho et al. (2007) used a car horn for their stimuli while the other literatures used an audio tone (Fitch et al., 2007; Huang et al., 2011; Scott & Gray, 2008). Consider that a car horn has a more intuitive meaning for drivers than the tactile vibration. It could be argued that it is a more conditioned response to tap the brake when a car horn is heard rather than a vibration.

Murata et al. (2013) also compared all combinations of unimodal and multimodal warnings within a driving simulator. As their participants drove they were instructed to monitor for hazards. When a hazard occurred (e.g. collision with another car), reaction times along with warning signal detection percentage (hit percentage) were recorded and evaluated. Aside from tactile warnings (unimodal), multimodal signals had the highest hit rate percentage and the lowest reaction time compared to both unimodal visual and auditory warning signals. Among the various conditions, the best performance arose from tactile warnings (unimodal) and audio-tactile (multimodal). It is important to note that Murata et al. (2013) chose to use a pure tone for their auditory warnings. This could explain the different outcome from Ho et al. (2007).

Some researchers have focused on creating a DAS with varying degrees of urgency. Researchers recognized that not all warnings require immediate attention. For example, a driver might receive a warning about a possible collision, or experience a warning regarding low windshield washing fluid. Both are important for safety but avoiding a crash is urgent, thus requiring immediate action, while washer fluid can be replaced at the next service station. The following literatures explore conveying urgency within the DAS, which is outside of the scope of the dissertation. However, a couple of these literatures make direct comparisons of unimodal and multimodal detection. For example, Lewis et al. (2013b) sought to determine which signal, unimodal or multimodal, are more effective at portraying urgency levels. Of these, they wondered which would be more effective when the driver is engaged in a secondary task requiring working memory. This literature is of particular interest to this dissertation given that it could give some indication of how effective multimodal and unimodal notifications are at capturing attention under higher workloads in the driving environment. Their experiment required participants to drive while responding to unimodal (auditory, visual or tactile) or multimodal (coupled combinations of each) warning signals by pressing on the brake. Braking response times to the warning signals along with the occasions participants failed to apply the brake (misses) were recorded for analysis. Warning signals could be high or low urgency, which was defined by the amount of alerts received in a 2500 ms time span (e.g. 1 pulse every 9 ms versus every 475 ms). Like Ho et al. (2007) and Murata et al. (2013), they also found that multimodal alerts resulted in faster braking response times compared to unimodal. Additionally, participants were more likely to miss warnings when performing the N-back task in the unimodal condition compared to the multimodal condition. In other words, even at high workloads, unlike unimodal, multimodal signals can persistently obtain the attention of drivers. These results could be explained by sensory blindness. Recall that laboratory studies observed that unimodal signals are likely to go undetected when the workload is high (Santangelo et al., 2007; Santangelo & Spence, 2007a). However, this is not the case with multimodal signals (Santangelo & Spence, 2007b). This could mean that multimodal notifications from mobile devices could persistently direct a driver's attention regardless of how challenging their situation. However, further investigation is needed to support this idea.

Politis et al. (2014) also compared all unimodal and multimodal combinations of in vehicle warnings at various urgency levels for their ability to prompt a braking response. Unlike Lewis et al. (2013b), individual comparisons of unimodal conditions were reported. The authors created three circumstances in which participants would apply the brake when performing a car following task. The first circumstance involved the lead car braking with a DAS warning presented at the same time (car & warning). The second was when the lead car would apply its brake with no DAS warning presented (car only). Finally, the third circumstance was when a DAS warning was presented with no lead vehicle braking (warning only). As expected, multimodal (M= 0.71 sec) spurred significantly faster braking responses compared to unimodal

(M= 0.77 sec). Their unimodal comparisons across all conditions showed that braking response for tactile and auditory warning signals were about the same. However, when reviewing the braking response by circumstance and modality of warning, they found faster braking with tactile warnings in the warning only condition and faster braking with auditory warnings in the car & warning conditions.

Taken together these literatures mutually observed that multimodal signals are more efficient at capturing the attention of drivers compared to unimodal signals (Ho et al., 2007; Lewis et al., 2013b; Murata et al., 2013; Politis et al., 2014). Lewis et al. (2013b) was able to demonstrate that even at high workloads, unlike unimodal signals, multimodal signals can still obtain the attention of drivers. If DAS warnings are able to capture attention of drivers with a higher workload, mobile devices might do the same. If so, multimodal notifications from mobile devices could be dangerous if they occur during critical driving situations. During such situations, even minor shifts of attention could result in a car crash.

While the previous literature has converging conclusions regarding multimodal signals, they have diverging conclusions regarding unimodal signals (Ho et al., 2007; Lewis et al., 2013b; Murata et al., 2013; Politis et al., 2014). Specifically, which unimodal signal, auditory or tactile, is more likely to capture the attention of a driver. Murata et al. (2013) indicates that tactile signals capture attention more efficiently than auditory signals, while Ho et al. (2007) reports the opposite. Politis et al. (2014) observed that depending on the situation either could capture attention more efficiently. Within the context of this dissertation, such an understanding is important for driving safety. Thus further investigation is needed to determine which unimodal notification signal is more likely to cause greater distraction while driving. Such an investigation could help with designing accommodations in mobile devices to increase driving safety.

2.9 Summary

To date, no literature has investigated the level of driving distraction notifications of different modalities (auditory, tactile, or multimodal) provided between the smartwatch and smartphone. Therefore, this dissertation will quantify driving performance for each device at each notification setting in order to understand the impact they have on driving. Given the lack of literature on this topic, this dissertation has relied on laboratory studies and investigations evaluating driving assisted systems (DAS). Early laboratory studies have indicated that attention is automatically shifted by unimodal signals even when the signal has nothing to do with the primary task (Kennett et al., 2002; Mazza et al., 2007; Spence et al., 1998; van der Lubbe & Postma, 2005). This could mean that even though unimodal signals from a mobile device do not pertain to driving they could still shift attention automatically. Compared to auditory signals, tactile signals seem more likely to capture attention (Fitch et al., 2007; Huang et al., 2011; Murata et al., 2013; Scott & Gray, 2008). Meaning, tactile notifications could be more disruptive to driving than auditory notifications. However, sensory blindness can occur regardless of modality (Santangelo et al., 2007; Santangelo & Spence, 2007a). Sensory blindness occurs when a primary task is so taxing to attention, that a crossmodal signal is not detected. According to load theory, sensory blindness occurs when the primary task is challenging and requires more attentional resource, which in turn leaves little to no spare attentional capacity for distractions (Lavie, 1995, 2005; Lavie et al., 2004; Lavie & Tsal, 1994). This has been observed in the laboratory (Santangelo et al., 2007; Santangelo & Spence, 2007a), and within a driving study (Lewis et al., 2013b). Conceivably this could mean that when driving conditions are more challenging, unimodal signals from mobile devices are not as distracting. Interestingly multimodal signals are not susceptible to sensory blindness (Santangelo, Ho, et al., 2008; Santangelo & Spence, 2007b). Furthermore, compared to unimodal signals, multimodal signals can capture and shift attention faster and more efficiently (Ho et al., 2007; Lewis et al., 2013a; Murata et al., 2013; Politis et al., 2014). This could mean that multimodal signals could be more distracting while driving compared to unimodal signals. Hence, regardless of driving conditions, multimodal signals could persistently obtain a driver's attention. If so, multimodal notifications from mobile devices could be dangerous if they occur during critical driving situations. During such situations, even minor shifts of attention could result in a car crash. However, more investigations are needed to confirm these conclusions.

When comparing the level of driving distraction between smartphones and smartwatches, previous literature has either failed to hold notification settings consistent or to compare them (Giang et al., 2014; Giang et al., 2015). Therefore, this dissertation will attempt to discover the true level of driving distraction each mobile device and notification setting provides. Using a driving simulator, a car following task similar to the previously reviewed literatures will be used to compare each mobile device at various notification settings (Giang et al., 2014; Giang et al., 2015). Like the previous literatures the task will involve reading text messages from a smartphone or smartwatch while maintaining a safe distance from the lead car. Since previous DAS literature has demonstrated that workload is important (i.e. sensory blindness), there will be two driving conditions, a high and low drive load condition (see experimental design below for explanation). Notification settings will include two unimodal conditions (auditory or tactile) and a multimodal condition (both auditory and tactile simultaneously). Driving and texting performance will be tracked and analyzed. Additionally, glances toward the device will also be recorded and analyzed.

Below are the specific predictions based on observations from the previously reviewed literature.

H1: Driving and texting performance will be worse for smartwatch conditions compared to smartphone conditions (Giang et al., 2014; Giang et al., 2015).

H2: Drive load and notification types will affect driving and texting performance (Lavie, 1995, 2005; Lavie et al., 2004; Lavie & Tsal, 1994; Lewis et al., 2013a).

H3: Specifically, multimodal notifications will have worse driving performance but best texting performance compared to unimodal conditions (Ho et al., 2007; Lewis et al., 2013a; Murata et al., 2013; Politis et al., 2014), especially in the high workload driving conditions (Lewis et al., 2013a; Santangelo et al., 2007; Santangelo & Spence, 2007a).

H4: Because of the attentional capturing properties of multimodal notifications, (Lewis et al., 2013a; Santangelo et al., 2007; Santangelo & Spence, 2007a) less glances will occur in the multimodal conditions compared to unimodal conditions especially in the high workload driving conditions (Lewis et al., 2013a; Santangelo et al., 2007; Santangelo & Spence, 2007a).

CHAPTER 3

METHOD

3.1 Participants

A total of 40 college students (M= 21.7 years old, SD= 4.5 years), 17 male and 23 female were recruited from a mid-west university. Participants received class credit in exchange for their participation. They were screened to ensure that they had at least two year's experience operating a smartphone and a motor vehicle. The average miles participants drove was 76 miles per day with a standard deviation of 105 miles. The average number of texts messages participants wrote per day was 30 with a standard deviation of 20 messages. All participants had normal or corrected-to-normal visual acuity.

3.2 Equipment

Driving simulator: The driving simulator is a modified version from Kang, Ni, and Andersen (2008). It was written in C++ and Open Graphics Library (OpenGL) and was run within a Dell 7500 PC using Windows XP Professional. The scene was controlled using a Logitech Driving Force GT steering wheel and petals connected to a racing seat. The driving scene was viewed from a 46" Sony LCD television, set to 1920 x 1080 screen resolution at 60 hz (a visual angle of 25 deg by 15 deg). The driving environment was seen from a first-person viewpoint from within the car. Driving sessions lasted about 45 seconds. Therefore each condition had 12 driving sessions.

A Point 2 View camera, model number CDVU-03IP was connected to the computer. This camera faced the participant and capture glances to the mobile device during dual task driving conditions. Additionally, it recorded audio as participants read text messages out loud.

Mobile devices: Two mobile devices were used for the secondary reading task. For the smartphone condition, a Samsung Volt LS740P phone running Android 4.4 was used. It has a quad-core 1.2 GHz Snapdragon^{TM} processor. It also has a 4.7'' display with a screen resolution of 540 x 960 pixels. The second device was a Samsung Galaxy Gear Smartwatch running Android 4.2. It has a 1.63'' display with a screen resolution of 320 X 320 pixels.

3.3 Experimental design

The present study used a mixed design with device (smartwatch versus smartphone) as a between-subjects variable and drive load (high versus low), and notification type medium (tactile versus auditory versus tactile and auditory) as within-subjects variables. There will be two additional driving baseline conditions capturing both high and low drive load without a secondary task, thus creating a total of 14 conditions. The only difference between the two driving conditions is that the high drive load conditions have more speed variability from the lead car (twice the amount) compared to the low load conditions (see below). Synonymous with previously mentioned studies' manipulations of perceptual load and working memory (Lewis et al., 2013a; Santangelo et al., 2007; Santangelo & Spence, 2007a), this dissertation will use velocity changes to increase or decrease the attentional load on the driver. Thus, the name high and low drive load indicates the load on attention. High drive load (with greater speed variation) requires the driver to allocate more attention to monitor continual speed changes while low drive load requires less monitoring. This manipulation mimics driving conditions in high and low traffic complexity (Paxion, Galy, & Berthelon, 2014). High traffic complexity has been defined as areas that require more frequent speed changes such as driving situations with a high density of cars, or residential neighborhoods (Paxion et al., 2014). Inversely, low traffic complexity has been defined as areas that require less frequent speed changes such as freeway driving (Paxion et al., 2014). Traffic complexity has been shown to manipulate peripheral detection and response times (Lee & Triggs, 1976; Miura, 1990) as well as detection for other modalities behind the wheel (Brown & Poulton, 1961; Harms, 1991; Recarte & Nunes, 2003; Verwey, 2000).

The dependent variables include driving performance, texting performance, and glances. The driving simulator performance was assessed using distance headway, root-mean-square (RMS) velocity error, control gain, phase angle, and squared coherence (explained in the results section). These data points are automatically gathered from within the driving simulator itself.

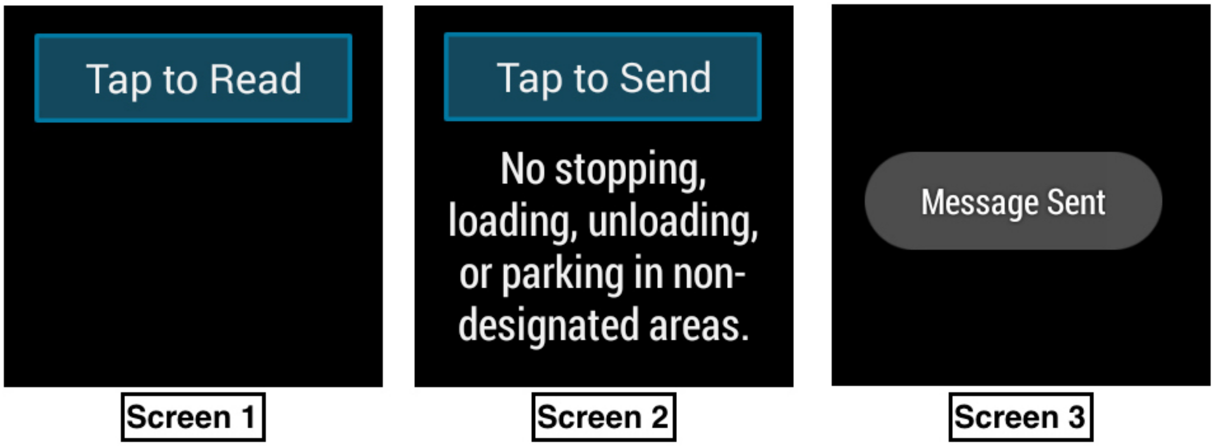
Glances to the mobile device were captured using a camera (CDVU-03IP Point 2 View) pointed directly at the driver's face. Video was recorded by the driving simulator computer, which creates a standard video file. It was analyzed by viewing and counting the glances to the mobile device manually. Glances were averaged across conditions and should provide some evidence of how distracting each device and notification medium is while driving.

Lastly, the custom applications created for the mobile device also track data from within the application itself. For this dissertation, the focus will be on the average time to engage and time to complete. The time to engage is how quickly drivers were able to begin the secondary task in following the notification. This is defined as the time between the notification and when they push the tap to read button (see Figure 1). Time to engage should help reflect how well a device and notification medium can capture attention. The time to complete is how long it takes a driver to finish reading the text message from the mobile device. It is defined as time between when a driver presses the tap to read button and the tap to send button (see Figure 1). This should give an indication of how challenging a device is to use while driving and how well the device or notification medium diverts attention. For example, A shorter time to engage indicates that attention was immediately diverted to the texting task before the driver could check the environment to ensure it was safe to begin texting. Additionally, a longer time to complete in comparison to other devices, will reflect that it was challenging to use behind the wheel.

3.4 Experimental tasks

The driving scenario consisted of a 3-lane road with the driver and the lead vehicle in the center lane. The lead vehicle was a white sports utility vehicle, which leads the driver through the scene with no other cars on the road at an average speed of 40 miles per hour. The task required the drivers to sit in the driving simulator seat to operate the gas and brake pedals in order to maintain a safe distance from the lead vehicle. Consistent with other literatures, road noise could be heard in the background at 75 dB (Ho et al., 2007; Huang et al., 2011; Murata et al., 2013; Politis et al., 2014; Scott & Gray, 2008). At the beginning of each trial, drivers had about 5 seconds of automated driving to demonstrate the desired distance to maintain from the lead vehicle. After the 5 seconds had expired a tone would sound signifying that the driver had control. Drivers were told after hearing the chime, the lead vehicle’s speed would change from time to time. Thus, the lead vehicle would apply it’s brakes randomly, there was about four or five braking events every driving session (45 seconds). Given there are 12 driving sessions for every condition, there was a total drive time of 8 minutes with 60 total braking events per condition. During higher drive load conditions, the speed profile of the lead car would experience larger changes in speed compared to the low drive load conditions. Drivers were not notified about the high and low workload conditions.

The text-reading task was modeled after Peng, Boyle, and Lee (2014). The text reading application created for the smartphone and smartwatch is preloaded with news headlines adapted from Yahoo news. These headlines were randomly picked from the internet but screened for word length and complexity. The character lengths of the reading materials range from 60 to 80 characters (M= 68.57, SD= 5.52). They were carefully picked so that they did not exceed the smartwatches screen size. In other words, no scrolling was needed on either device when reading these passages. When using the text message application, participants would wait an intermittent amount of time until receiving a notification from the device. The notification was either tactile, audible or multimodal. The tactile signal used the device’s native vibration motor and lasts about 400 milliseconds. The audible signal used the device’s native setting for an audible notification prompt, which was a 98-decibel beep for about 100 milliseconds for both devices. Once a notification is received, a button would appear labeled “Tap to Read”. Once pressed, the passage would be displayed and the label on the button would then change to “Tap to Send” (see Figure 1). After reading the passage out loud, the participant would push the button, then “message sent” would briefly appear before the entire screen would go blank once again



No stopping, loading, unloading, or parking in non-designated areas.

Screen 1 Screen 2 Screen 3

Figure 1. Depicts three screen shots of the text reading application taken from within the watch. Once a notification is received, a button would appear labeled "Tap to Read" (screen 1). Once pressed, the passage would be displayed and the label on the button would then change to "Tap to Send" (screen 2). After reading the passage out loud, the participant would push the button again, and then a pop up would appear with the passage "message sent" (screen 3). Afterward, the entire screen would go blank.

3.5 Procedure

Before being included in the study, participants took an online survey (see appendix a). The survey merely determined their eligibility (i.e. own and operated a car and smartphone for 2 years). If eligible, the survey would generate a code that would allow them to sign up for the study. Participants completed the experiment in the lab at a scheduled time in about 2 hours (14 conditions lasting about 6 minutes along with a 10-minute break). Upon arriving, participants would first sign an informed consent form (see appendix b), then perform the Snellen visual acuity test. After confirming the participant had normal visual acuity they would receive a brief written description of the driving and reading text messages tasks (see appendix c). After demonstrating the text messaging application, the participants would be asked to practice the application using the watch or phone. Participants would practice until they felt comfortable with the mobile device. Next participants practiced driving using the simulator for at least 6 driving sessions. Once the participant felt comfortable and it was clear they understood the task, the experiment proceeded. Participants were instructed to drive in the simulator with both hands on the wheel (or whatever hand configuration they do naturally). Each condition consisted of 12 driving sessions. The sessions were approximately 45 seconds long. In that time, participants would randomly receive one text message between 25 to 30 seconds into the drive. During phone conditions, participants would retrieve and return the phone from their lap around the front pocket area. After the first 8 conditions were completed, participants were given a 10-minute break. Afterward the remaining 9 trials were completed. Additional breaks were taken if the participant requested. The order of the 14 tasks were counter balanced between the participants. Following the conclusion of the experiment, a post survey was completed that inquired about their perceived level of difficulty and distraction for each condition (see appendix d and e). In addition, it inquired about the perceived speed of texting task engagement for each condition.

CHAPTER 4

RESULTS

The outcome of the data analysis of the texting and driving performance is explained below, along with the manual count of glances. The data analysis was completed in SPSS version 21.

4.1 Driving data

Similar to previous literatures, two types of driving performance were assessed, global and local performance measures (Andersen & Sauer, 2007; Brackstone & McDonald, 2007; Brookhuis, Waard, & Mulder, 1994; Kang et al., 2008). The global measures include the following distance from the lead vehicle and the RMS speed error (i.e. the overall difference between driver's speed relative to that of the lead vehicle). The local measures of driving performance are derived from comparing driver's speed to the lead vehicle's speed using a fast Fourier transform (FFT). By using FFT, the average values for control gain, phase angle, and squared coherence are derived for each driver for each condition at three varying frequencies. The frequencies represent high (0.03 hz), medium (0.08 hz) and low (0.12 hz) speed changes of the lead vehicle. For example, the high frequency change represents fast speed changes from the lead car, while low frequency changes represent slower speed changes. The main effect of frequency was added to the analysis of gain, phase and coherence (i.e. Frequency, Notification Type, Drive Load, and Device). Given that the local measures include frequency and global measures do not, global measures have one less main effect (i.e. Notification Type, Drive Load, and Device).

These calculations were performed within a specific window of time within the driving sim session. The window of time, which we refer to as the dual task window, is based on the period in which participants are actively engaged in the texting task. It was constructed on the bases of two considerations. First, the mobile texting software will send a text message around 25 seconds at the earliest and 30 seconds at the latest after the session is initiated. Therefore, the dual task window would begin at 24 seconds including a 1 second buffer in case the mobile app was initiated early. Second, the longest time to engage and time to complete were also considered. The longest time to engage was within the watch auditory condition with a high drive load (M= 933.38 ms, SD= 670.38 ms). Additionally, the longest time to complete was within the watch auditory condition with a lower drive load (M= 403.33 ms, SD= 195.95 ms). Given it should only take about 3 seconds to begin and complete the texting task, the latter end of the dual task window was 33 seconds. Therefore, only the driving data collected between 24 seconds and 33 seconds were included in the analysis.

4.1.1 Control gain

Control gain is considered a local measurement because it is one of the measures used to access the sensitivity and level of response to the lead car's speed changes. Specifically, gain is a measure of the amplitude of the driver's response relative to the changes in speed of the lead car. For example, a larger gain (1 or more) indicates the driver is responding with more force than necessary. Inversely lower gain (less than one) indicates the driver's response is insufficient in relation to the change in speed from the lead car.

The average gain scores were derived for each driver and analyzed with a mixed-design ANOVA with device (phone versus watch) as a between-subjects factor and notification type (auditory versus tactile versus multimodal), drive load (high versus low) and frequency (high vs. medium vs. low) as within-subjects factors. The results of the analysis can be reviewed in Table 1. Mauchly's test indicated that assumption of sphericity had been violated for the three-way interaction between frequency, notification type and drive load. Therefore, the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity. This correction was also used for the two interactions between notification type and drive load and for the interaction between frequency and notification type.

A significant two-way interaction was observed between notification type and drive load, $F(1.4,53.5) = 47.97$ $p < .001$ $\eta^2 = .56$. This interaction accounted for the highest amount of variance (56 percent). As shown in Figure 2, when drive load increases, gain for auditory and multimodal notifications increases as well. While gain for tactile stays persistently the same.

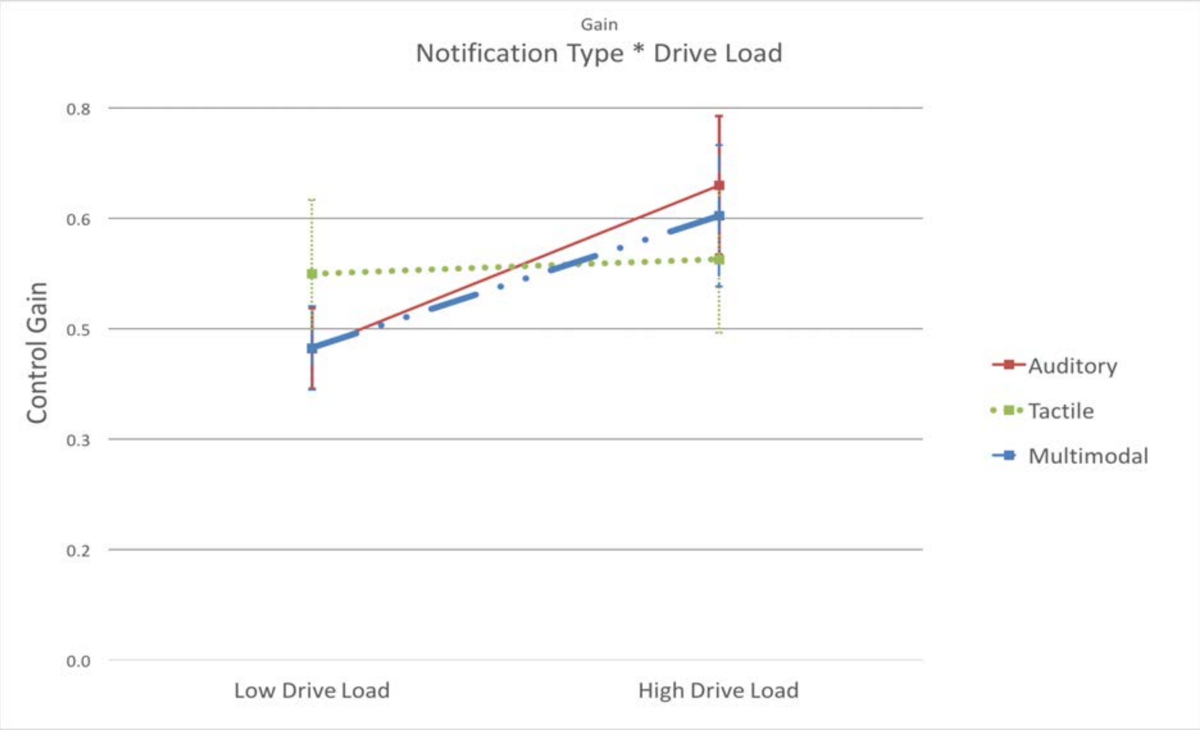


Figure 2. Depicts gain as a function of notification type and drive load condition. The error bars depicted represent standard error.

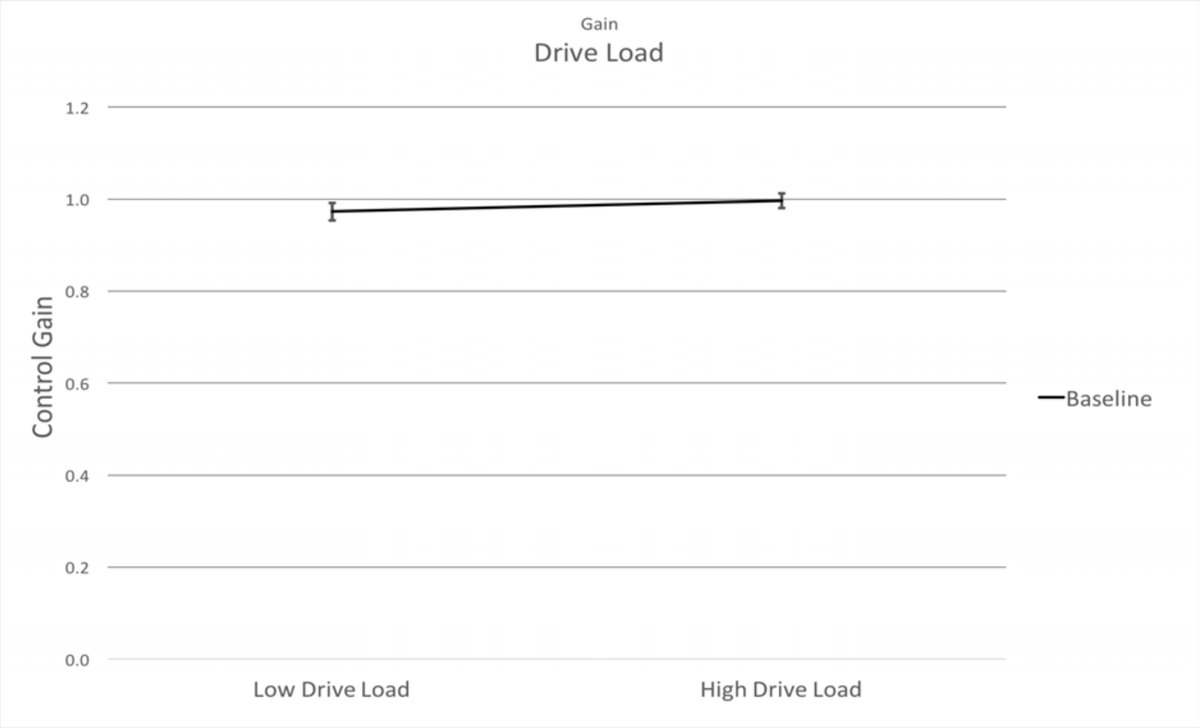


Figure 3. Depicts the baseline performance for gain as a function of drive load condition. Given the baseline resides at highest end of performance, the baseline is presented in a separate graph so it does not distort graphs depicting experimental conditions. The error bars depicted represent standard error.

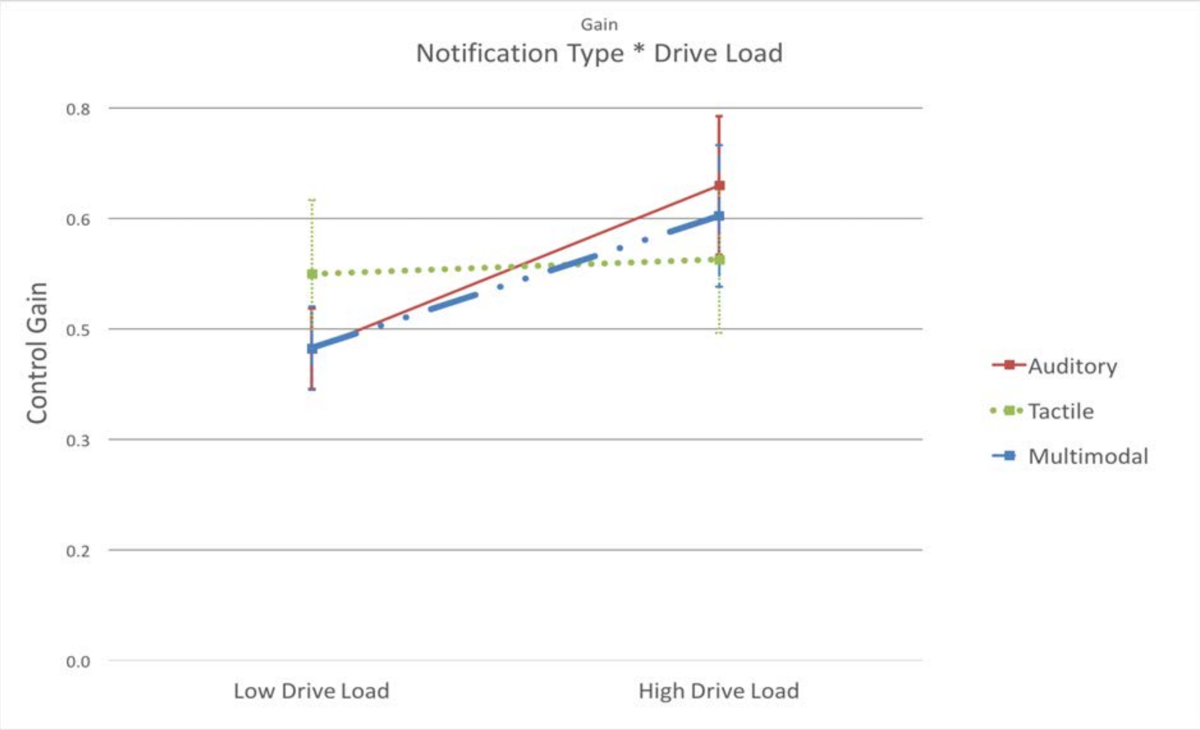


Figure 4. Depicts the gain for the phone as a function notification type and drive load condition. The error bars depicted represent standard error.

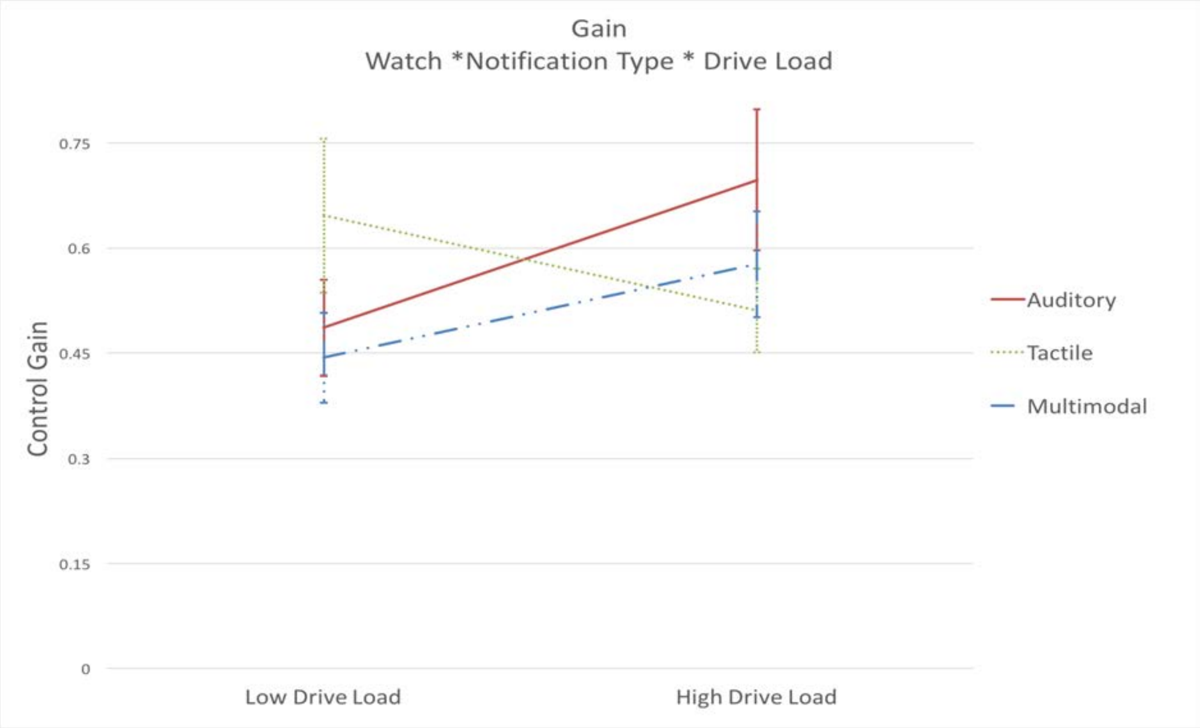


Figure 5. Depicts the gain for the watch as a function notification type and drive load condition. The error bars depicted represent standard error.

A post hoc Tukey HSD (honestly significant difference) test was performed to compare all linear combinations of notification type by drive load. The results of the Tukey HSD can be seen in Table 2. According to the Table, tactile notifications were not significantly different in the amount of gain between the two drive load conditions. However, the amount of gain observed for auditory and multimodal notifications changed between the different drive load conditions. Specifically, when the drive load is low, tactile notifications have significantly (*p* <.01) more gain than both auditory and multimodal conditions. When the drive load is high, tactile has significantly less (*p* <.01) gain than both auditory and multimodal notifications. Auditory notifications were not significantly different from multimodal at either drive load conditions. Given they are not different from one another, it would appear we did not observe multimodal enhancement. In addition, It would appear that something is different regarding tactile notification with respect of the other notification types. Lastly it would appear more gain resides in the high drive load condition (M= 0.60, SD= 0.08) compared to the low drive load conditions (M= 0.46, SD= 0.06), suggesting there was better performance in the high drive load condition compared to the lower drive load condition.

Next, a significant two-way interaction was observed between notification type and device, *F*(2,76) = 3.55 $p < .05$ $\eta^2 = .09$. This interaction carried the second highest amount of variance at 9 percent. As shown in Figure 6, it appears different notifications produce different amounts of gain for each device. However, a post hoc analyses using the Tukey HSD test failed to reveal any significant difference between the various combinations of conditions (see Table 3).

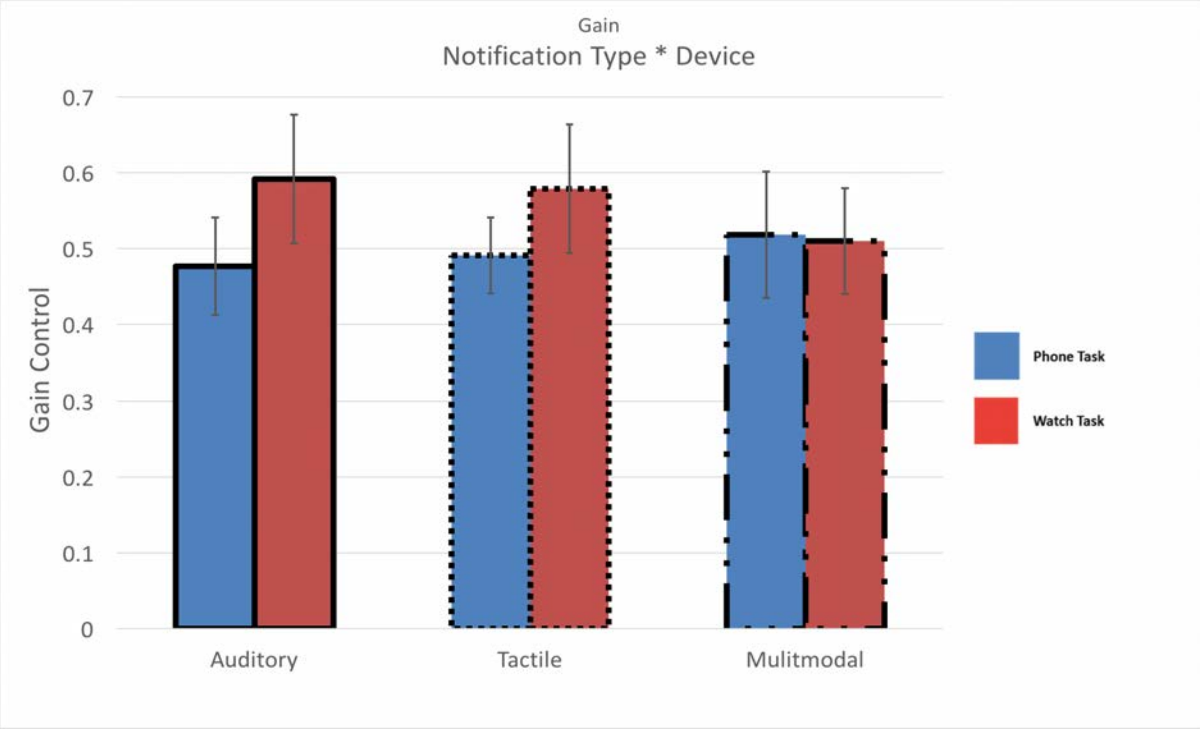


Figure 6. Depicts the observed gain for each notification type and device. The error bars depicted represent standard error.

Finally, a significant two-way interaction was observed between drive load and frequency, *F*(2,76) = 3.18 $p < .05$ $\eta^2 = .08$. This interaction accounted for eight percent of the variance. As shown in Figure 7, the function of frequency by drive load appears to be similar in shape between the two levels of drive load. As drive load increases, gain for the various levels of frequency shift upward. Just like the interaction between notification type and drive load, better performance was observed in the high drive load condition compared to the low drive load condition at each frequency.

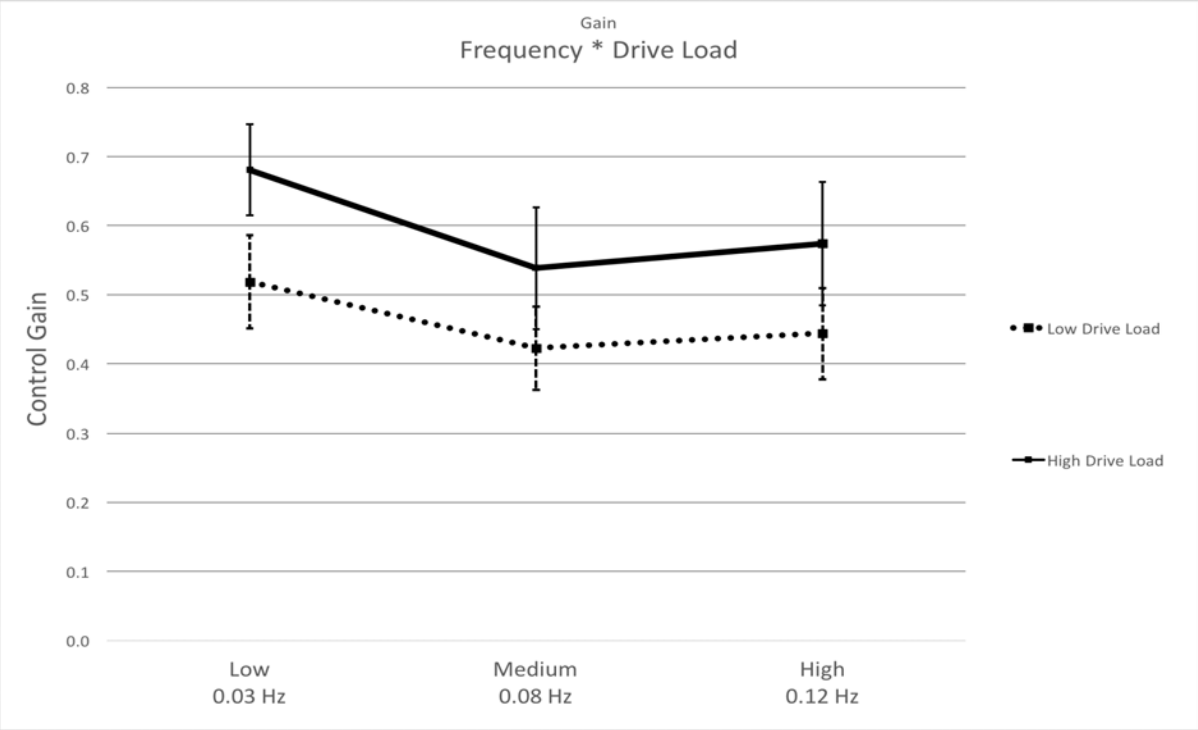


Figure 7. Depicts gain as a function of frequency and drive load. The error bars depicted represent standard error.

A post hoc Tukey HSD test was performed to compare all combinations of drive load by frequency. The results (see Table 4) indicated significant differences of low, medium and high frequencies between high and low drive load settings, confirming that there was a significant increase of gain from low to high drive load for all three frequencies. This is a very interesting but counter intuitive result, as one might expect worse performance as the drive load increases. However, the shift upward in gain can be interpreted as more attention or perhaps effort was dedicated to the driving task. This also helps to confirm that the high drive load manipulation was significantly more difficult for the participants.

Table 1. *NOVA Source Table (Gain)*

Source	SS	df	MS	F	*p*	partial .η2
Device	0.76	1	0.76	1.36	.250	.04
Subjects Within Groups	21.21	38	0.56			
Frequency	0.07	2	0.03	0.17	.844	.00
Frequency * Device	0.50	2	0.25	1.27	.286	.03
Frequency x Subjects Within Groups	14.92	76	0.20			
Notification Type (corrected with Greenhouse-Geisser)	1.44	1.27	1.14	4.98	.023	.12
Notification Type * Device	1.03	2	0.51	3.55	.034	.09
Notification Type x Subjects Within Groups	11.03	76	0.15			
Greenhouse-Geisser	11.03	48.31	0.23			
Drive Load	0.54	1	0.54	16.99	.001	.31
Drive Load * Device	0.00	1	0.00	0.01	.919	.00
Drive Load x Subjects Within Groups	1.21	38	0.03			
Frequency * Notification Type (corrected with Greenhouse-Geisser)	0.99	2.35	0.42	1.64	.195	.04
Frequency * Notification Type * P1_or_W2	0.40	4	0.10	0.67	.612	.02
Frequency * Notification Type x Subjects Within Groups	22.82	152	0.15			
Greenhouse-Geisser	22.82	89.17	0.26			
Frequency * Drive Load	0.23	2	0.11	3.18	.047	.08
Frequency * Drive Load * Device	0.17	2	0.09	2.41	.096	.06
Frequency * Drive Load x Subjects Within Groups	2.70	76	0.04			
Notification Type * Drive Load (corrected with Greenhouse-Geisser)	3.60	1.41	2.56	47.97	.001	.56
Notification Type * Drive Load * Device	0.18	2	0.09	2.43	.095	.06
Notification Type * Drive Load x Subjects Within Groups	2.85	76	0.04			
Greenhouse-Geisser	2.85	53.49	0.05			
Frequency * Notification Type * Drive Load	0.36	4	0.09	1.82	.128	.05
Frequency * Notification Type * Drive Load * Device	0.48	4	0.12	2.42	.065	.06
Frequency * Notification Type * Drive Load x Subjects Within Groups	7.46	152	0.05			

Table 2. *Tukey HSD comparison of gain for the interaction between notification type and driving workload*

A	B	Mean Diff	Cohen's *d*
Auditory with High Drive Load	Auditory with Low Drive Load	0.22**	0.66
	Tactile with Low Drive Load	0.12**	0.31
	Tactile with High Drive Load	0.10**	0.30
	Multimodal with Low Drive Load	0.22**	0.65
	Multimodal with High Drive Load	0.04	--
Tactile with Low Drive Load	Auditory with Low Drive Load	0.10**	0.33
	Multimodal with Low Drive Load	0.10**	0.33
Tactile with High Drive Load	Auditory with Low Drive Load	0.12**	0.52
	Tactile with Low Drive Load	0.01	--
	Multimodal with Low Drive Load	0.12**	0.50
Multimodal with Low Drive Load	Auditory with Low Drive Load	0	--
Multimodal with High Drive Load	Auditory with Low Drive Load	0.18**	0.53
	Tactile with Low Drive Load	0.07*	0.20
	Tactile with High Drive Load	0.05	--
	Multimodal with Low Drive Load	0.17**	0.52

* *p* <.05 ** *p* <.01

Table 3. *Tukey HSD comparison of gain for the interaction between notification type and device*

A	B	Mean Diff	Cohen's *d*
Phone with Auditory	Phone with Tactile	0.01	--
	Phone with Multimodal	0.04	--
	Watch with Auditory	0.12	--
	Watch with Tactile	0.10	--
	Watch with Multimodal	0.03	--
Phone with Tactile	Phone with Multimodal	0.03	--
	Watch with Auditory	0.10	--
	Watch with Tactile	0.09	--
	Watch with Multimodal	0.02	--
Phone with Multimodal	Watch with Auditory	0.07	--
	Watch with Tactile	0.06	--
Watch with Tactile	Watch with Auditory	0.01	--
Watch with Multimodal	Phone with Multimodal	0.01	--
	Watch with Auditory	0.08	--
	Watch with Tactile	0.07	--

* *p* <.05 ** *p* <.01

Table 4. *Tukey HSD comparison of gain for the interaction between drive load and frequency*

A	B	Mean Diff	Cohen's *d*
Low Drive Load with Low Frequency	High Drive Load with Low Frequency	0.16**	0.58
	High Drive Load with Medium Frequency	0.02	--
	High Drive Load with High Frequency	0.06	--
Low Drive Load with Medium Frequency	Low Drive Load with Low Frequency	0.10**	0.33
	Low Drive Load with High Frequency	0.02	--
	High Drive Load with Low Frequency	0.26**	0.94
	High Drive Load with Medium Frequency	0.12**	0.40
	High Drive Load with High Frequency	0.15**	0.44
Low Drive Load with High Frequency	Low Drive Load with Low Frequency	0.07*	0.22
	High Drive Load with Low Frequency	0.24**	0.72
	High Drive Load with Medium Frequency	0.09**	0.28
	High Drive Load with High Frequency	0.13**	0.34
High Drive Load with Medium Frequency	High Drive Load with Low Frequency	0.14**	0.52
	High Drive Load with High Frequency	0.04	--
High Drive Load with High Frequency	High Drive Load with Low Frequency	0.11**	0.32

* *p* <.05 ** *p* <.01

4.1.2 Control phase angle

Control phase angle is also considered a local measurement that provides information about the time lag between the lead car's speed change and the driver's response using the controls. The averaged control phase scores were derived for each driver under each condition and were analyzed with a four-way ANOVA with the varying conditions of device (phone versus watch), notification type (auditory versus tactile versus multimodal) and drive load (high versus low) and frequency (high vs. medium vs. low) as within-subject factors. The analysis did not yield any significant results (see Table 5), suggesting that no differences in delay of response were observed among the various conditions.

Table 5. *ANOVA Source Table (Phase)*

Source	SS	df	MS	F	*p*	partial .η2
Device	30543.93	1	30543.93	0.53	.47	.01
Subjects Within Groups	2179482.55	38	57354.80			
Frequency	347521.75	2	173760.87	3.21	.06	.08
Frequency * Device	26777.50	2	13388.75	0.25	.78	.01
Frequency x Subjects Within Groups	4114854.32	76	54142.82			
Notification Type	10867.95	2	5433.98	0.57	.57	.02
Notification Type * Device	243.71	2	121.85	0.01	.99	.00
Notification x Subjects Within Groups	729543.98	76	9599.26			
Drive Load	3089.66	1	3089.66	0.87	.36	.02
Drive Load * Device	1716.54	1	1716.54	0.48	.49	.01
Drive Load x Subjects Within Groups	135080.90	38	3554.76			
Frequency * Notification Type	70338.43	4	17584.61	1.03	.39	.03
Frequency * Notification Type * Device	42167.50	4	10541.87	0.62	.65	.02
Frequency * Notification Type x Subjects Within Groups	2583802.35	152	16998.70			
Frequency * Drive Load	5598.14	2	2799.07	0.42	.66	.01
Frequency * Drive Load * Device	3336.57	2	1668.29	0.25	.78	.01
Frequency * Drive Load x Subjects Within Groups	510068.39	76	6711.43			
Notification Type * Drive Load	4049.02	2	2024.51	0.52	.60	.01
Notification Type * Drive Load * Device	4333.12	2	2166.56	0.56	.58	.01
Notification Type * Drive Load x Subjects Within Groups	295473.65	76	3887.81			
Frequency * Notification Type * Drive Load	8059.30	4	2014.83	0.37	.83	.01
Frequency * Notification Type * Drive Load * Device	19705.87	4	4926.47	0.90	.47	.02
Frequency * Notification Type * Drive Load x Subjects Within Groups	831668.54	152	5471.50			

4.1.3 Squared coherence

Lastly, squared coherence is also considered a local measurement that measures the squared correlation between the lead vehicles speed changes and the driver's response. The squared coherence is an indication of the variance of the driver's speed tracking performance. Higher scores mean that the driver's speed profile is highly correlated with the speed profile of the lead vehicle. Inversely as scores approach zero, or no correlation, it is an indication of random responding.

The average coherence scores were derived for each driver and analyzed with a mixed-design ANOVA with device (phone versus watch) as a between-subjects factor and notification type (auditory versus tactile versus multimodal), drive load (high versus low) and frequency (high vs. medium vs. low) as within-subjects factors. The results of the analysis can be reviewed in Table 6. A Mauchly's test indicated that assumption of sphericity had been violated for the two-way interaction between notification type and drive load. Therefore, the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity. A significant two-way interaction was observed between notification type and drive load, $F(1.2,44.4) = 97.74$ $p < .001$ $\eta^2 = .72$. This interaction accounted for a considerably high amount of variance (72 percent). Figure 8 shows the levels of coherence as a function of notification type and drive load.

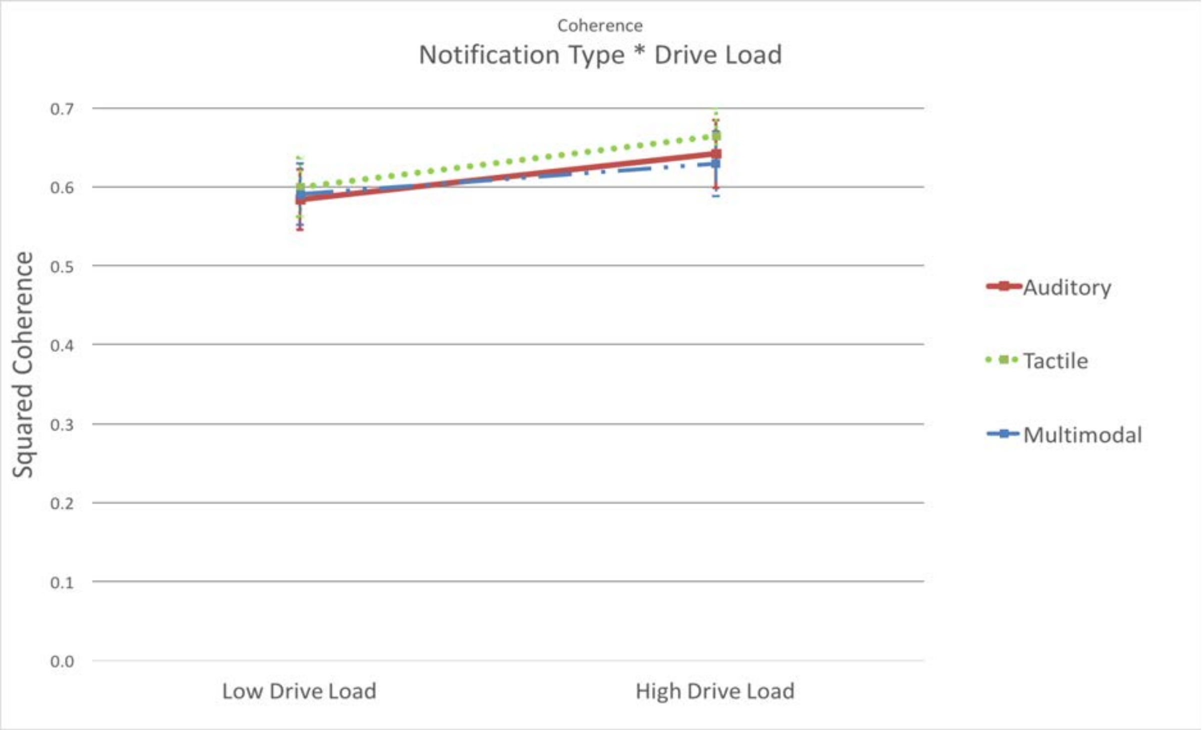


Figure 8. Depicts coherence as a function of notification type and drive load. The error bars depicted represent standard error.

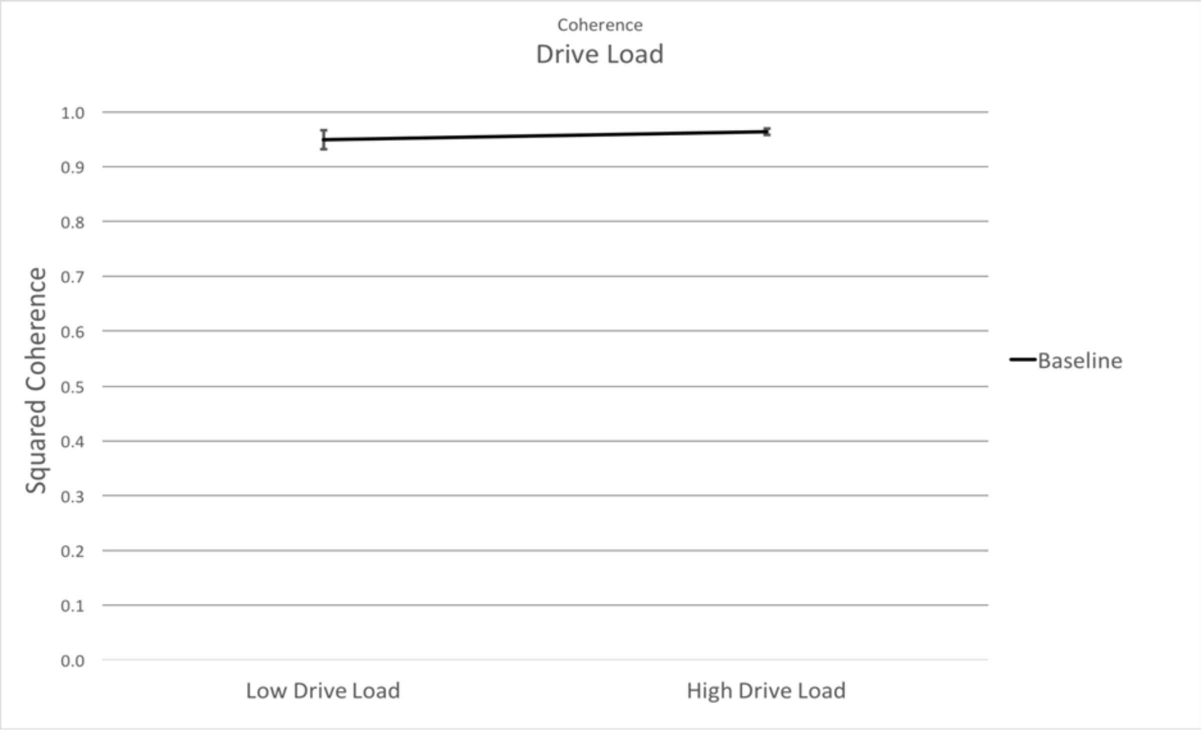


Figure 9. Depicts the baseline performance for coherence as a function of drive load condition. Given the baseline resides at highest end of performance, the baseline is presented in a separate graph so it does not distort graphs depicting experimental conditions. The error bars depicted represent standard error

A post hoc Tukey HSD test was performed to compare all combinations of notification type by drive load for coherence. The results of the Tukey HSD can be seen in Table 7. According to the Table, notification types were not different from one another within the low or high driving conditions. The majority of variance for coherence occurred between low and high drive load. In other words, coherence varied more so by drive load rather than notification type. Just as we observed within the interactions for gain, better driving performance was observed in the high drive load conditions compared to low drive load conditions.

Table 6. *ANOVA Source Table (Coherence)*

Source	SS	df	MS	F	*p*	partial .η2
Device	0.24	1	0.24	1.27	.268	.03
Subjects Within Groups	7.06	38	0.19			
Frequency	0.07	2	0.03	0.68	.508	.02
Frequency * Device	0.03	2	0.02	0.33	.717	.01
Frequency x Subjects Within Groups	3.81	76	0.05			
Notification Type (corrected with Greenhouse-Geisser)	0.48	1.42	0.34	9.16	.001	.19
Notification Type * Device	0.02	2.00	0.01	0.33	.717	.01
Notification x Subjects Within Groups	2.00	76.00	0.03			
Greenhouse-Geisser	2.00	54.12	0.04			
Drive Load	0.05	1.00	0.05	6.65	.014	.15
Drive Load * Device	0.01	1.00	0.01	0.80	.378	.02
Drive Load x Subjects Within Groups	0.26	38.00	0.01			
Frequency * Notification Type	0.05	4.00	0.01	0.46	.765	.01
Frequency * Notification Type * Device	0.13	4.00	0.03	1.12	.349	.03
Frequency * Notification Type x Subjects Within Groups	4.27	152.00	0.03			
Frequency * Drive Load	0.01	2.00	0.01	1.32	.274	.03
Frequency * Drive Load * Device	0.00	2.00	0.00	0.18	.834	.01
Frequency * Drive Load x Subjects Within Groups	0.41	76.00	0.01			
Notification Type * Drive Load	4.37	1.17	3.74	97.74	.001	.72
Notification Type * Drive Load * Device	0.01	2.00	0.00	0.19	.826	.01
Notification Type * Drive Load x Subjects Within Groups	1.70	76.00	0.02			
Greenhouse-Geisser	1.70	44.36	0.04			
Frequency * Notification Type * Drive Load	0.01	4.00	0.00	0.17	.952	.01
Frequency * Notification Type * Drive Load * Device	0.03	4.00	0.01	0.54	.707	.01
Frequency * Notification Type * Drive Load x Subjects Within Groups	2.16	152.00	0.01			

Table 7. *Tukey HSD Comparison of Coherence for Notification type by Drive Load*

A	B	Mean Diff	Cohen's *d*
Auditory with Low Drive Load	Multimodal with Low Drive Load	0.01	--
Auditory with High Drive Load	Auditory with Low Drive Load	0.06	--
	Tactile with Low Drive Load	0.04	--
	Multimodal with Low Drive Load	0.05	--
	Multimodal with High Drive Load	0.01	--
Tactile with Low Drive Load	Auditory with Low Drive Load	0.02	--
	Multimodal with Low Drive Load	0.01	--
Tactile with High Drive Load	Auditory with Low Drive Load	0.08*	0.50
	Auditory with High Drive Load	0.02	--
	Tactile with Low Drive Load	0.06	--
	Multimodal with Low Drive Load	0.07*	0.45
	Multimodal with High Drive Load	0.04	--
Multimodal with High Drive Load	Auditory with Low Drive Load	0.05	--
	Tactile with Low Drive Load	0.03	--
	Multimodal with Low Drive Load	0.04	--

* $p < .05$ ** $p < .01$

4.1.4 Root mean square

Root-mean-square (RMS) velocity errors were defined as occasions when the driver fails to accurately adjust their speed to the changes of the lead vehicle's speed. Root mean square velocity error was calculated for each driver for each of the varying conditions of device type, drive load and notification type. A mixed-design ANOVA with device (phone versus watch) as a between-subjects factor and notification type (auditory versus tactile versus multimodal), and drive load (high versus low) as within-subjects factors. The results of the analysis can be seen in Table 8. According to the analysis, only the main effect of drive load was significant, $F(1,38) = 9.14$ $p < .01$, $\eta^2 = .19$. As seen in figure 10, the high drive load had significantly more speed errors than the low drive load condition. These results, along with patterns observed in gain and coherence, support that the manipulation of drive load was successful.

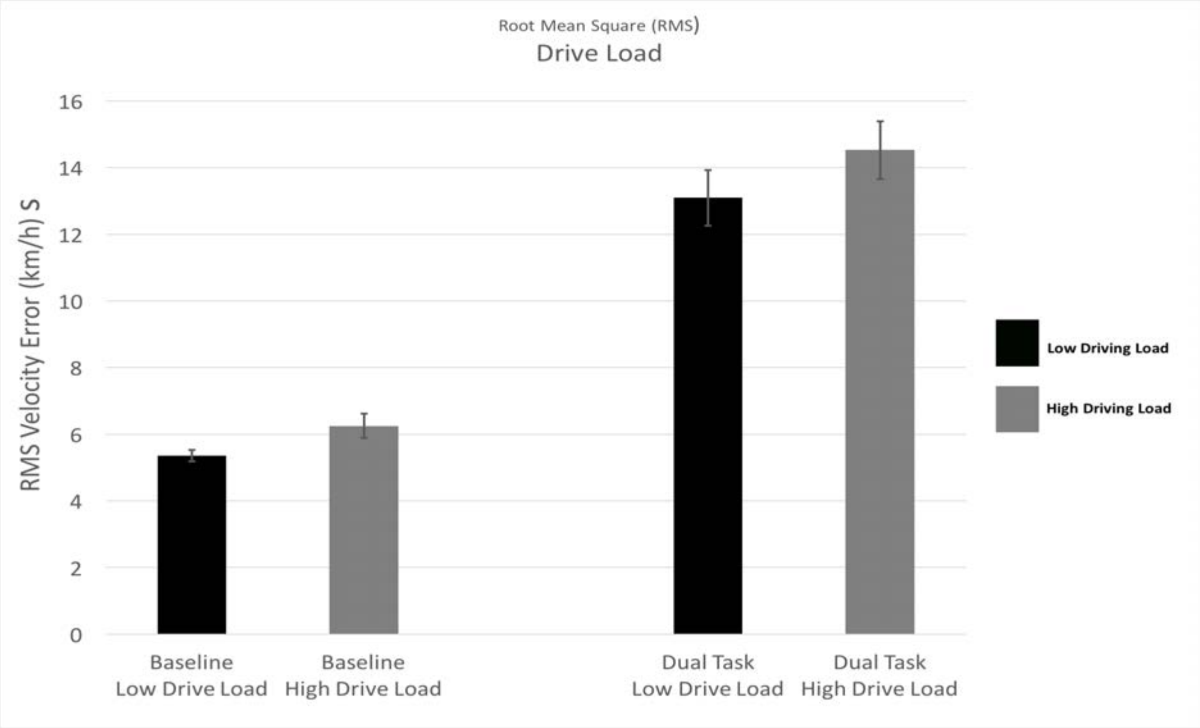


Figure 10. Depicts the root mean square for the main effect of drive load. The dual task bars represent conditions when participants were texting and driving. Contrariwise, the baseline bars represent performance for participants when they drove with no secondary task. The error bars depicted represent standard error.

Table 8. *ANOVA Source Table (RMS)*

Source	SS	df	MS	F	*p*	partial .η2
Device	42.77	1	42.77	0.98	.33	.03
Subjects Within Groups	1657.14	38	43.61			
Notification Type	5.56	2	2.78	0.28	.76	.01
Notification Type * Device	6.57	2	3.29	0.33	.72	.01
Notification Type x Subjects Within Groups	753.05	76	9.91			
Drive Load	123.37	1	123.37	9.14	<.01	.19
Drive Load * Device	9.55	1	9.55	0.71	.41	.02
Drive Load x Subjects Within Groups	512.86	38	13.50			
Notification Type * Drive Load	1.69	2	0.84	0.12	.89	.00
Notification Type * Drive Load * Device	4.26	2	2.13	0.30	.74	.01
Notification Type * Drive Load x Subjects Within Groups	542.84	76	7.14			
Total	3659.65	239				

4.1.4 Headway distance

The distance headway was defined as the average distance between the driver and the lead vehicle. Headway distance was calculated for each driver for each of the varying conditions of device type, drive load and notification type. A mixed-design ANOVA with device (phone versus watch) as a between-subjects factor and notification type (auditory versus tactile versus multimodal), and drive load (high versus low) as within-subjects factors. The results of the analysis can be seen in Table 9. Mauchly's test indicated that assumption of sphericity had been violated for the main effect of notification type. Therefore, the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity. As seen in table 9, no significant differences were found among the various comparisons.

Table 9. *ANOVA Source Table (Headway Distance)*

Source	SS	df	MS	F	*p*	partial .η2
Device	22.30	1	22.30	0.35	.56	.01
Subjects Within Groups	2472.85	39	63.41			
Notification Type (corrected with Greenhouse-Geisser)	120.25	1.537	78.23	3.25	.06	.08
Notification Type * Device	3.60	2	1.80	0.10	.91	.00
Notification Type x Subjects Within Groups	1442.01	78	18.49			
Greenhouse-Geisser	1442.01	59.945	24.06			
Drive Load	0.37	1	0.37	0.03	.87	.00
Drive Load * Device	0.16	1	0.16	0.01	.91	.00
Drive Load x Subjects Within Groups	512.52	39	13.14			
Notification Type * Drive Load	63.63	2	31.81	2.24	.11	.05
Notification Type * Drive Load * Device	18.18	2	9.09	0.64	.53	.02
Notification Type * Drive Load x Subjects Within Groups	1108.65	78	14.21			

4.2 Texting data

4.2.1 Time to engage

The average time to engage in the texting task was calculated for each driver for each of the varying conditions of device type, drive load and notification type. A mixed-design ANOVA with device (phone versus watch) as a between-subjects factor and notification type (auditory versus tactile versus multimodal), and drive load (high versus low) as within-subjects factors. The results of the analysis can be seen in Table 10. An interaction was observed between notification type and device, *F*(2,76) = 4.31 *p* <.05, η^2=.10. According to figure 11, the watch took longer to engage in the task than the phone. Additionally, for the watch, auditory seems to have taken much longer to begin the task than all other notifications types.

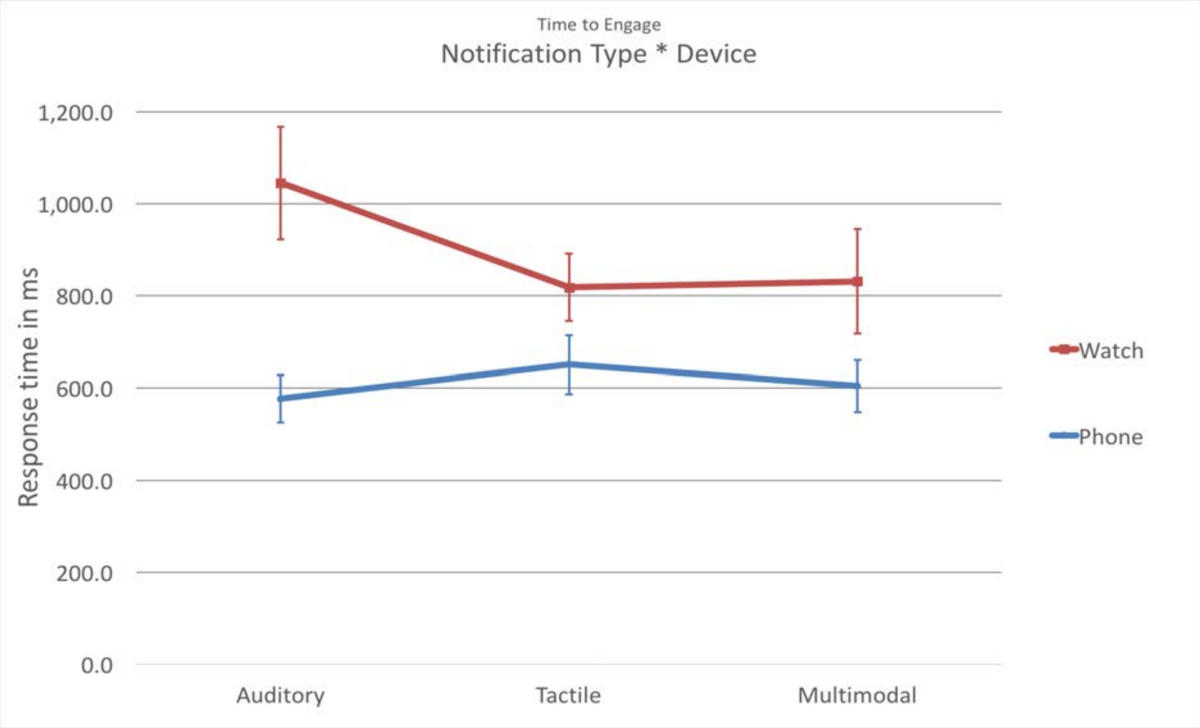


Figure 11. Depicts time to engage as a function of notification type and device. The error bars depicted represent standard error.

A post hoc Tukey HSD test was performed to compare all linear combinations of device by notification type for time to engage. The results of the Tukey HSD can be seen in Table 11. Of the fifteen comparisons, eleven were significant. When comparing the phone to the watch, each notification setting was significantly different to all others. For example, auditory settings for the phone were significantly different (*p* <.01) between the auditory, tactile and multimodal settings for the watch. The same is true when comparing tactile and multimodal settings for the phone to the watch, suggesting the time to engage was longer for the watch than the phone. This conflicts with the previous investigations of the smartwatch and smartphone (Giang et al., 2014; Giang et al., 2015).

Another interesting observation is when comparing notification types within each device. The watch had significant differences (*p* <.01) when comparing auditory notifications (M= 1045.20, SD= 121.95) to both tactile (M= 818.29, SD= 73.20) and multimodal (M= 831.51, SD= 113.25), but not tactile (M= 818.29, SD= 73.20) to multimodal (M= 831.51, SD= 113.25). The phone did not yield any significant differences between the various notification types, suggesting that notification types influence time to engage for the watch but not the phone.

Table 10. *ANOVA Source Table (Time to Engage)*

Source	SS	df	MS	F	*p*	partial .η2
Device	4882724.68	1	4882724.68	21.30	.001	.36
Subjects Within Groups	21.21	38	0.56			
Notification Type	367073.67	2	183536.83	1.64	.201	.04
Notification Type * Device	964991.59	2	482495.79	4.31	.017	.10
Notification Type x Subjects Within Groups	8512583.00	76	112007.67			
Drive Load	765.92	1	765.92	0.01	.909	.00
Drive Load * Device	8001.11	1	8001.11	0.14	.711	.00
Drive Load x Subjects Within Groups	2176187.74	38	57268.10			
Notification Type * Drive Load	47072.31	2	23536.15	0.23	.798	.01
Notification Type * Drive Load * Device	229623.87	2	114811.93	1.11	.336	.03
NotificationType * Drive Load x Subjects Within Groups	7894532.02	76	103875.42			
Total	25083577.09	239				

Table 11. *Tukey HSD comparison of time to engage for the interaction between device and notification type*

A	B	Mean Diff	Cohen's *d*
Phone with Auditory	Phone with Tactile	73.40	--
	Phone with Multimodal	27.21	--
	Watch with Auditory	467.86**	1.15
	Watch with Tactile	240.94**	0.88
	Watch with Multimodal	254.16**	0.66
Phone with Tactile	Watch with Auditory	394.46**	0.93
	Watch with Tactile	167.54**	0.56
	Watch with Multimodal	180.76**	0.45
Phone with Multimodal	Phone with Tactile	46.18	--
	Watch with Auditory	440.64**	1.06
	Watch with Tactile	213.73**	0.75
	Watch with Multimodal	226.95**	0.58
Watch with Tactile	Watch with Auditory	226.91**	0.52
	Watch with Multimodal	13.22	--
Watch with Multimodal	Watch with Auditory	213.69**	0.42

* p <.05   ** p <.01

4.2.2 Time to complete

The average time to complete the texting task was calculated for each driver for each of the varying conditions of device type, drive load and notification type. A mixed-design ANOVA with device (phone versus watch) as a between-subjects factor and notification type (auditory versus tactile versus multimodal), and drive load (high versus low) as within-subjects factors. The result of the analysis can be seen in Table 12. Significant differences were observed for the main effect of drive load ($F(1,38) = 5.87$ $p < .05$, $\eta^2 = .13$) and device, $F(1,38) = 4.29$ $p < .05$, $\eta^2 = .10$. Figure 12 depicts the main effect of driving workload, which shows that drivers took longer to complete the task when the drive load was low versus high. This indicates a strategy was employed to assist with the higher drive load. Participants would expedite the secondary texting task in order to shift attention back to the difficult driving scene. Figure 13 displays the time to complete for each device. Specifically, the watch took longer to complete the task compared to the phone, indicating the watch was harder to use while driving compared to the phone.

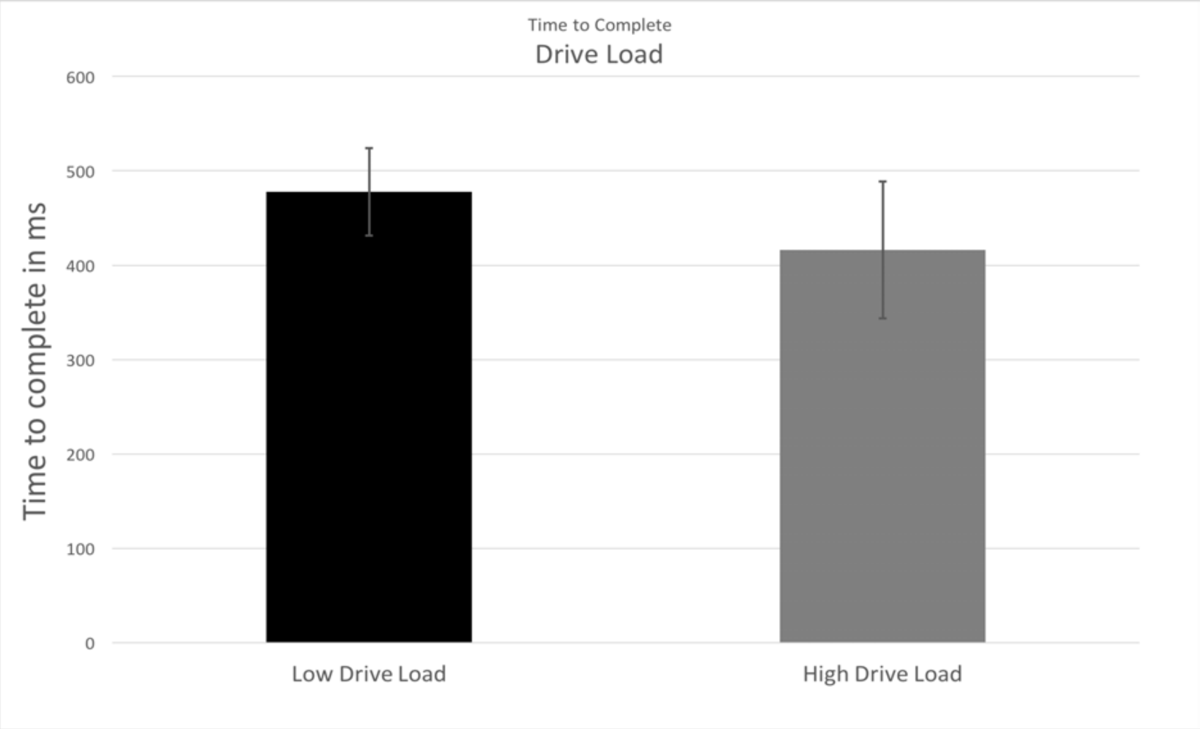


Figure 12. Depicts the time to complete for high and low driving workload. The error bars depicted represent standard error.

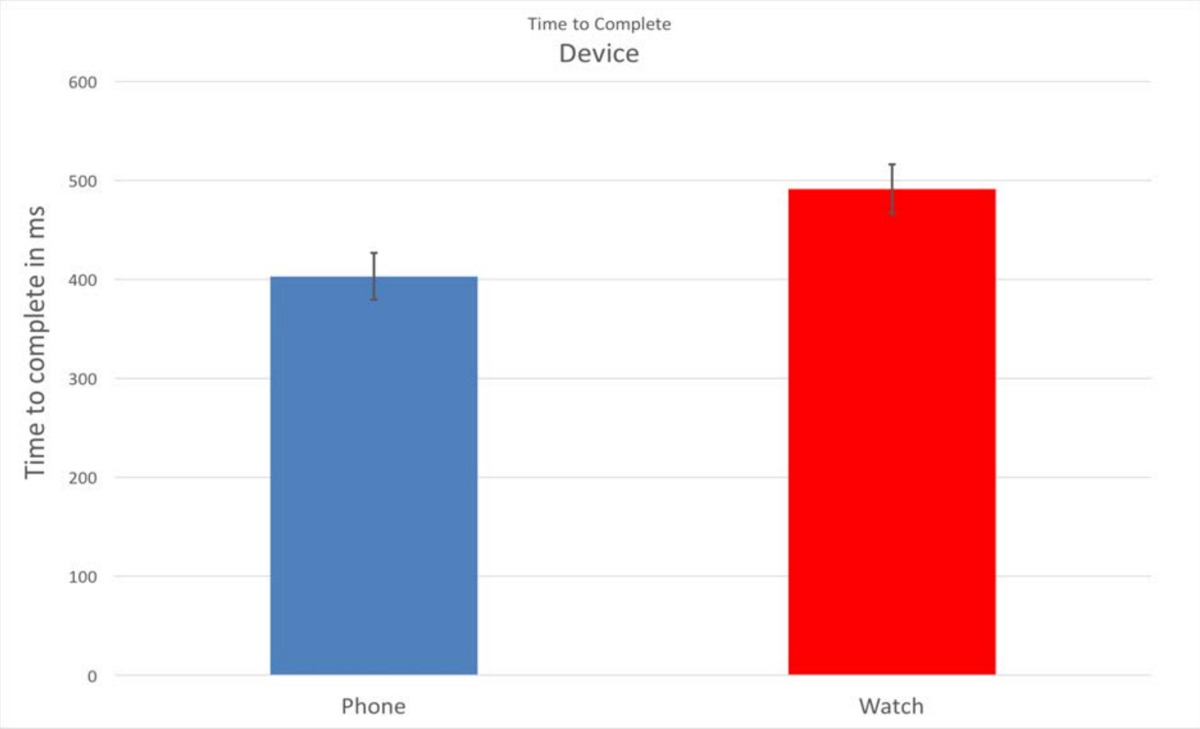


Figure 13. Depicts the time to complete for each device. The error bars depicted represent standard error.

Table 12. *ANOVA Source Table (Time to Complete)*

Source	SS	df	MS	F	*p*	partial .η2
Device	618503.59	1	618503.59	4.29	.04	.10
Subjects Within Groups	5478506.69	38	144171.23			
Notification Type	130677.81	2	65338.91	1.20	.31	.03
Notification Type * Device	44937.92	2	22468.96	0.41	.66	.01
Notification Type x Subjects Within Groups	4124504.12	76	54269.79			
Drive Load	217972.98	1	217972.98	5.87	.02	.13
Drive Load * Device	10410.05	1	10410.05	0.28	.60	.01
Drive Load x Subjects Within Groups	1411272.60	38	37138.75			
Notification Type * Drive Load	132138.50	2	66069.25	1.42	.25	.04
Notification Type * Drive Load * Device	199104.01	2	99552.01	2.14	.12	.05
NotificationType * Drive Load x Subjects Within Groups	3534338.73	76	46504.46			
Total	15902367.00	239				

4.3 Glances

The number of Glances were manually counted using the video footage of participant which was filmed from a camera attached to the steering column. After the participant received the notification from the mobile device the count began and concluded when they hit the tap to send button (see Figure 1). The average glances were calculated for each driver for each of the varying conditions of device type, drive load and notification type. A mixed-design ANOVA with device (phone versus watch) as a between-subjects factor and notification type (auditory versus tactile versus multimodal), and drive load (high versus low) as within-subjects factors. The results of the analysis can be seen in Table 13. A significant interaction between device and notification type was observed, *F*(2,76) = 3.36 *p* <.05, η^2=.08. Figure 14 depicts the interaction between device and notification type. While the result shows that more glances to the watch were made compared to the phone, the difference in glances were only a fraction of a glance apart.

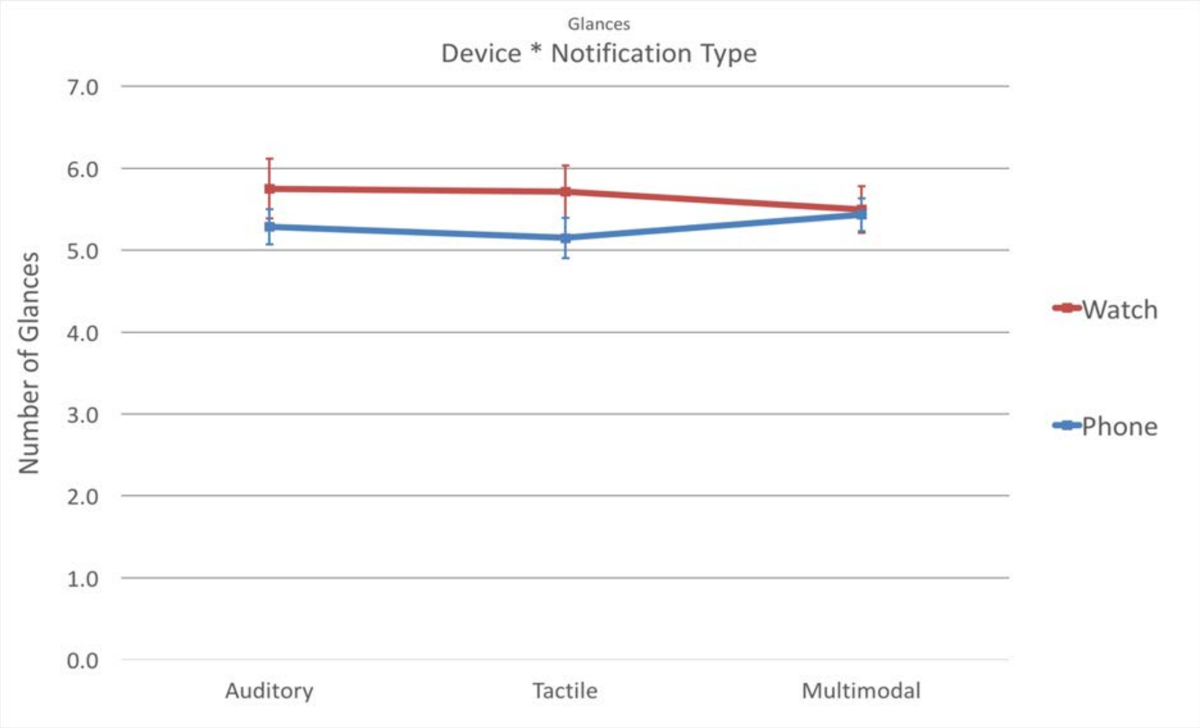


Figure 14. Depicts the number of glances as a function of device and notification type. The error bars depicted represent standard error.

A post hoc Tukey HSD test was performed to compare all linear combinations of device by notification type for the number of glances. The results of the Tukey HSD can be seen in Table 13. Of the fifteen comparisons, nine were significant. However, the effect sizes in the table show that there was very little effect.

Table 13. *ANOVA Source Table (Glances)*

Source	SS	df	MS	F	*p*	partial .η2
Device	8.69	1	8.69	1.10	.30	.03
Subjects Within Groups	300.93	38	7.92			
Notification Type	0.24	2	0.12	0.26	.77	.01
Notification Type * Device	3.11	2	1.55	3.36	.04	.08
Notification Type x Subjects Within Groups	35.17	76	0.46			
Drive Load	0.68	1	0.68	1.82	.19	.05
Drive Load * Device	0.85	1	0.85	2.27	.14	.06
Drive Load x Subjects Within Groups	14.25	38	0.38			
Notification Type * Drive Load	0.92	2	0.46	1.59	.21	.04
Notification Type * Drive Load * Device	0.35	2	0.18	0.61	.55	.02
Notification Type * Drive Load x Subjects Within Groups	22.07	76	0.29			
Total	387.25	239				

Table 14. *Tukey HSD comparison of glances for the interaction between device and notification type*

A	B	Mean Diff	Cohen's *d*
Phone With Auditory	Phone With Multimodal	0.17	--
	Phone With Auditory	0.12	--
	Watch With Auditory	0.49**	0.37
	Watch With Tactile	0.46**	0.38
	Watch With Multimodal	0.24	--
Phone With Tactile	Phone With Multimodal	0.29*	0.28
	Watch With Auditory	0.61**	0.44
	Watch With Tactile	0.58**	0.46
	Watch With Multimodal	0.36**	0.3
Phone With Multimodal	Watch With Auditory	0.31**	0.24
	Watch With Tactile	0.28*	0.24
	Watch With Multimodal	0.06	--
Watch With Tactile	Watch With Auditory	0.03	--
Watch With Multimodal	Watch With Auditory	0.25*	0.18
	Watch With Tactile	0.21	--

* *p* <.05 ** *p* <.01

4.4 Post questionnaire

The scores for each question on the post questionnaire (see Appendix D) were averaged for each question and each device and compared using a between-subjects ANOVA. Averages and standard deviations for each question can be reviewed in Table 15. The analysis revealed that participants did not rate either device significantly more distracting than the other, *F*(1,38) = 0.16 *p*= .69. Nor was the rating of difficulty significantly different between the two devices, *F*(1,38) = 1.15 *p*= .29. None of the notification types, auditory (*F*(1,38) = 0.36 *p*= .55), tactile (*F*(1,38) = 0.67 *p*= .42) or multimodal (*F*(1,38) = 0.62 *p*= .44) were viewed as more distracting between the two devices either. Participants did not report that auditory (*F*(1,38) = 1.06 *p*= 32) or multimodal (*F*(1,38) = 1.21 *p*= .28) notifications caused them to access each device sooner.

However, participants felt that tactile notifications on the watch (M= 5.85, SD= 1.18) caused them to access the device faster than those that experienced the same notification on the phone (M= 5.06, SD= 1.11), *F*(1,38) = 1.21 $p < .05$ $\eta^2 = .28$. Thus, it would appear participants are consciously unaware of the difference in texting (i.e. time to engage and time to complete) and driving performance (i.e. gain and coherence) between the watch and phone at the various notification type settings.

Table 15. *Summary of averages and standard deviations of rating for each device for each question on the post survey*

	Phone		Watch	
Question	Average	STD	Average	STD
1. How distracting was the device?	5.22	1.17	5.40	1.53
2. Rate difficulty of reading from device while driving.	3.94	1.30	4.40	1.31
3. How distracting was audible notifications?	3.78	2.02	3.40	1.85
4. How quickly did you access the device with auditory notifications?	5.22	1.06	5.60	1.23
5. How distracting was tactile notifications?	2.78	1.56	3.25	1.94
6. How quickly did you access the device with tactile notifications?	5.06	1.11	5.85	1.18
7. How distracting was multimodal notifications?	4.61	2.17	4.05	2.21
8. How quickly did you access the device with multimodal notifications?	5.39	1.09	5.80	1.20

CHAPTER 5

DISCUSSION

The purpose of this dissertation was to quantify the level of driving distraction mobile devices create at each method of notification delivery at varying drive loads. This should determine whether or not previous contrasts between the watch and phone were fair comparisons (Giang et al., 2014; Giang et al., 2015). More importantly, the impact of notification delivery on driving distraction were first studied in this dissertation.

5.1 Summary of results

5.1.1 Glances

Measures outside of driving performance included glances, time to engage and time to complete. Although an interaction between notification type and device for glances was observed, there was not much of an effect. As seen in Figure 14, each device and notification type was only a fraction of a glance apart. In addition, the post hoc analysis revealed each significant comparison had a small effect size (see Table 14). Given that glances were mostly unaffected by notification type and drive load, hypothesis 4 which indicated driving and texting performance would be worse for smartwatch conditions compared to smartphone conditions, was not supported.

5.1.2 Time to engage

The time to engage was considered the time between when the notification was first received and when the participant initiated the texting task by pressing the tap to reply button (see figure 1). Time to engage is of particular interest to this dissertation because it gives an indication of how well each notification type and device are able to obtain the attention of a driver. There was a significant interaction observed between notification type and device (see Figure 11). Thus, the latter part of the second hypothesis stating drive load and notification types would affect texting performance was supported. Two interesting observations from the interaction can be observed in Figure 11. First, a difference in time to engage were found between the two devices. In addition, the time to engage of each notification type within each device appears very different.

It is particularly interesting that the watch had a longer time to engage than the phone. This was inconsistent with the previous literature findings (Giang et al., 2014; Giang et al., 2015) and counterintuitive, given the accessibility the watch provides. One explanation would be that drivers are strategizing. Before the experiment, participants were instructed to text when it is safe to do so (see Appendix C). If they needed to, participants could delay the time to engage to maintain driving safety. Literature has shown that, when driving and dual tasking, drivers employ compensatory strategies in an attempt to maintain safety. For example, drivers may slow down or select situations of low complexity for secondary task execution (Cooper, Vladisavljevic, Medeiros-Ward, Martin, & Strayer, 2009; Fitch & Hanowski, 2011). Thus, drivers might have delayed using the watch because it was more difficult to use than the phone. Consistent with the previous literature, they waited 25% longer to complete (Cooper et al., 2009; Fitch & Hanowski, 2011) compared to the phone, as shown in Figure 13. Thus, understanding that the watch required more time, drivers delayed the start of the task until they knew they had time to accommodate the task. The ability to allow participants to strategize has set this dissertation apart from the previous literatures (Giang et al., 2014; Giang et al., 2015). Thus it could explain the difference in result from Giang et al. (2014) and Giang et al. (2015), in which participants were instructed to engage in the texting task as quickly as possible.

It is interesting that although participants rated the watch slightly harder to use than the phone, the difference was not significant (see Table 3). Therefore, even though it took participants longer to use the watch and accordingly they had to strategize when dual tasking with it, they did not consciously acknowledge it. The lack of awareness actually increases the likelihood of drivers to use it while driving (Hallett, Lambert, & Regan, 2011).

Another interesting observation for the time to engage was that notification types for the phone were not significantly different between each other, although for the watch the opposite was true. Significant differences with relatively high effect sizes were found between auditory (M= 1045.20, SD= 121.95) and tactile (M= 818.29, SD= 73.20, and between auditory and multimodal (M= 831.51, SD= 113.25) (see Table 11). Perhaps tactile and multimodal notifications on the watch were better able to obtain the attention of the driver. If these notifications are able to grab the attention of a driver, these settings could perhaps be dangerous. As previously discussed, when engaging in dual tasking while driving, literature suggests drivers use compensatory strategies to maintain driving safety (Cooper et al., 2009; Fitch & Hanowski, 2011). If a particular device with a particular notification signal interrupt these strategies, driving safety could be further compromised. Additional investigations should seek to understand if notifications settings, particularly tactile and multimodal, delivered from the watch divert attention resulting in bypassing compensatory strategies.

5.1.3 Time to complete

Another facet of the texting performance that was quantified was time to complete. Time to complete was the time from when they initiated the texting task by hitting tap to read until they finished reading the displayed passage and hit tap to send (see Figure 1). As discussed above, the main effect of device was significant (see Figure 13). Specifically, the texting task took longer to complete on the watch than the phone. Given that both time to engage and time to complete were longer on the watch, it would appear that the watch was harder to use while driving. Thus, the latter part of the first hypothesis stating that texting performance would be worse on the watch is supported. There are a few reasons why the watch may have been harder to use. First, it could be argued that the watch is a novel device that they may not have known how to use. However, this might not be the case since the software created for both devices was identical and extremely simplistic. Users did not need to understand how to operate the watch to use the customized texting software. As seen in Figure 1, all controls were on screen and in identical locations. A second possible explanation could be that because the watch is fixed to the wrist, users had to use both hands to operate the watch compared to the phone thus making it harder to text and drive. In other studies this would be an issue but not in the present study as drivers did not operate the steering wheel and were free to use both hands. Another explanation could be the difference in screen size. The phone screen is almost 3 times larger than the watch screen. Thus, for the watch everything on the screen must be smaller including font and the buttons. This would be a plausible explanation for the data considering that smaller font takes longer to read. For example, Beymer, Russell, and Orton (2008) found that smaller font requires longer fixations that results in slower reading. In addition, consider that reading can be more problematic with the vibrations of a moving vehicle (Holden et al., 2009). Future research should confirm if font size on the watch has caused the longer time to complete.

The main effect of drive load for time to complete was also significant. According to Figure 12 the higher drive load had a faster time to complete compared to the low drive load conditions. This result is very interesting because intuitively it would seem drivers handling a more challenging driving environment might take longer to complete the secondary texting task. One possible explanation could be that drivers tried to complete the text message quickly so that they could get back to the challenging driving environment. In each driving session, participants had at least 25 to 30 seconds to follow the lead vehicle before the text message would occur. In that time, drivers could assess the driving style of the lead vehicle. Based on the inherent risk of collision, drivers can adapt how they handle the secondary texting task. More investigations are needed to confirm this assertion

5.1.4 Local driving measures

Among the three local driving measures only gain and coherence yielded results of any significance. As previously discussed, no significant differences were observed among measures of phase (see Table 5). Therefore, the focus will remain on gain and coherence. Interestingly, both gain and coherence had an interaction between notification type and drive load. This supports the first portion of hypothesis one. Overall, two interesting observations appear in these results. First, post hoc comparisons show that tactile notifications have significantly different levels of gain from auditory and multimodal within each drive load setting. Specifically, when the drive load is low, tactile has more gain than both auditory and multimodal notifications. Inversely, when the drive load is high, tactile has significantly less gain than the other two. Another interesting observation was that high drive load had more gain and coherence than low drive load conditions. In other words, driving performance was better for the high drive load conditions compared to the lower drive load conditions. Observing better driving performance when conditions are more challenging is surprising and counterintuitive.

As previously discussed, gain is considered as the amplitude of response relative to the input value. In this case the input would be the lead car's speed changes, and the response amplitude derives from the driver's changes in speed from the accelerator and brake. As gain decreases below one, it is an indication of the degree of driver distraction (Andersen & Sauer, 2007; Brackstone & McDonald, 2007; Brookhuis et al., 1994; Kang et al., 2008). Thus, the lower the number the greater the implied distraction. When reviewing Figure 2, we see similar quantities of gain for auditory and multimodal conditions for both high and low drive load conditions. Specifically, less gain for low drive load conditions compared to high drive load conditions for both notification types. In fact, gain is identical between them for low drive load conditions, and only slightly different in high drive load conditions. Thus, the second hypothesis specifying that multimodal notifications would have the strongest affect on driving performance was not supported. Multimodal enhancement should have made its signal more salient among the other two notification types especially in high drive load conditions (Ho et al., 2007; Lewis et al., 2013a; Murata et al., 2013; Politis et al., 2014; Santangelo et al., 2007; Santangelo & Spence, 2007a). As the hypothesis specifies, multimodal enhancement should divert attention when multitasking causing compromised performance for the primary task as seen in laboratory studies (Santangelo et al., 2007; Santangelo & Spence, 2007a). There are a couple different reasons why this did not occur.

First, multimodal enhancement may not have occurred because the drive load was not challenging enough. According to load theory, when a primary task requires all attentional capacity, distractions are less likely to gain attention because there is no capacity remaining for them (Lavie, 1995, 2005; Lavie et al., 2004; Lavie & Tsal, 1994; Lewis et al., 2013a). This was observed in Santangelo et al. (2007) and Santangelo and Spence (2007a) laboratory experiments in which perceptual load was increased and unimodal sensory blindness occurred. In these circumstances, multimodal enhancement can occur because it is unaffected by the workload (Santangelo, Ho, et al., 2008; Santangelo & Spence, 2007b). Thus, if the high drive load condition did not utilize all attentional capacity, multimodal enhancement would not occur. Therefore, future research should focus on additional levels of drive load to investigate whether multimodal enhancement is possible in this context.

The second reason why multimodal enhancement was not observed derives from this particular sample's experience sending text messages while driving. Personal experience with texting and driving was captured on the screening questionnaire (see Appendix A and question 6). It was revealed that 78% of participants reported that they engage in texting while driving. It is well known that as activities are practiced together, tasks become automatic, which frees up attentional capacity. For example, Spelke, Hirst, and Neisser (1976) had their participants perform two tasks: read a text silently for comprehension while simultaneously copying words dictated by the experimenter. Obviously, this is a very challenging task that requires immense attentional capacity. At first, participants read much more slowly than normal. However, after only 6 weeks of practice, they were reading at normal speed. Because participants had become so skilled, the dictation task became automatic which freed up attentional capacity to perform the copying task. Thus, reading while copying had become no more difficult than walking while carrying on a conversation. Therefore, if 78% of our participants have already practiced texting while driving, it could become an automatic, or at least partially automatic, process for them, which consequently minimizes the utilization of attentional capacity to perform these tasks.

Recall that if the drive load does not utilize all attentional capacity, multimodal enhancement would not occur. Therefore, future research could focus on capturing a sample with limited experience texting while driving.

Another particularly interesting observation was the different levels of gain for tactile notifications compared to the other notification types. According to Figure 2, auditory and multimodal notification types have lower levels of gain in low drive load conditions and higher levels of gain in high drive load conditions. Contrariwise, tactile had a consistent amount of gain for both drive load conditions. One might wonder how device type interacts with drive load and notification type. Figures 4 and 5 depict the various levels of gain for each device as a function of notification type and drive load. When comparing these two figures, it would appear that the watch has more variability for ringtones than the phone. Specifically, tactile notifications for the watch appear to have the opposite pattern from all other notification types. The straight line representing tactile in Figure 2 was derived from averaging scores between the watch and phone. The opposite levels of gain for the watch suggest that tactile notifications are not as distracting with low drive load conditions but more distracting during high drive load conditions. This might be due to a lack of experiencing notifications from the watch. Consider that 90% of the sample did not own a smartwatch. Perhaps the difference in experiencing sensations on the wrist rather than the lap (where the smartphone resided) caused the difference in gain. In other words, auditory notifications could have been quickly identified as a text messaging alerts given prior experience with auditory alerts from their smartphones. However, tactile notifications presented by themselves to the wrist could appear novel to participants. More investigations are required to completely understand why tactile notification settings for the watch appears to have an opposite function (drive load by notification type) from all others.

Finally, the pattern observed in the driving data, specifically better performance (i.e. gain and coherence) in high drive load conditions versus low drive load conditions was particularly interesting. For example, when reviewing the interaction between notification type and drive load (see Figure 2) there was more gain in high drive load conditions than low drive load conditions. This was also observed within the same interaction that occurred for coherence (see Figure 8). Once again it is observed within the interaction for gain between frequency and drive load. Figure 7 shows the exact same function for high, medium and low frequencies but a shift upwards from low drive load to high drive load. There are two possible explanations for better performance in high drive load versus low drive load.

First, consider how the drive load conditions were defined. The driving task requires participants to follow a lead vehicle with a variable speed profile. It is the lead vehicle's speed profile that defines high and low drive load. Specifically, the lead vehicle maintains the same average speed but in high drive load conditions it has greater speed variance (by twice the amount) compared to low drive load conditions. Therefore, the speed changes in the low drive load conditions could have been so small that they did not necessitate actions by the driver. For example, if the lead car briefly decreases its speed by 4 mph, the person following may not react with the brake, but simply allow the speed change to be absorbed by the following distance. The gain for this transaction would appear to be insufficient because of the failure of response by the driver. Coherence, which is the correlation of the participant's speed profile to the lead vehicle, would also be compromised. Inversely if the lead vehicle decreases its speed by 8 mph, a reaction would be required by the participant to avoid a possible collision. Thus, the gain and coherence for this situation would appear sufficient because of the required response by the driver. If this explanation were true than we would see a similar slope in the baseline conditions for both gain and coherence. However, when reviewing Figures 3 and 8, the baseline scores did not slope but were a straight line. Therefore, another explanation must be considered.

Compensatory strategies could be a second explanation for the difference in gain and coherence between drive load conditions. Specifically, drivers strategized during high driving workload conditions, thus applying more effort to the driving environment resulting in higher gain and coherence. Inversely, in the low drive load conditions, they underestimate the driving environment, applying more effort to the texting task resulting in lower gain and coherence. Consider that during every driving session participants had 25 to 30 seconds of driving to evaluate the environment before the texting notification was received. Based on their evaluation they then decide how much time can be applied to the text messaging task. Figure 12 reveals that strategies regarding the amount of time spent on the text message (i.e. time to complete) were employed. Even though participants were encouraged to delay engagement in the secondary texting task (i.e. time to engage), there is no significant findings that show any delay with regards to drive load. Nor was there any evidence that glances were different among the two driving conditions. Regardless, it would seem that shortening the time spent on the texting task helped both gain and coherence scores for high drive load conditions.

5.1.5 Global driving measures

Global measures such as headway distance and RMS speed error are traditional measures researchers have used in the past to gauge driving distraction (Greenberg et al., 2003; Kang et al., 2008; Roskam et al., 2002). A particularly interesting observation was the difference between the global and local measures. For example, an interaction between notification type and drive load was observed for both coherence and gain. Specifically, a consistent pattern of better performance for both coherence and gain for high drive load versus low drive load was detected. In addition, tactile was distinguished among other notifications as having different levels of gain as a function of drive load. These interactions were not significant in the global measures, suggesting global measures in this case were not as sensitive as local measures for spotting driving distraction. Essentially headway distance did not yield any significant results, while RMS velocity error only detected differences between drive load conditions. In this experiment, local measures were more informative than global measures.

RMS velocity error did provide this study with confirmation that the high drive load manipulation was significantly more challenging than the low drive load condition. As seen in Figure 10, there were significantly more speed errors for the high drive load condition compared to the low drive load condition. These differences occurred when participants were texting and driving (dual task) as well as when they drove with no secondary task (baseline). In addition, about twice the amount of speed errors occurred when they were texting and driving compared to when they were just driving. No significant results were derived from headway distance, and RMS merely confirmed the manipulation. Taken together, local measures were more informative than global measures in this experiment.

5.2 Applications

These results can be directly applied to promote driving safety in two ways, from the design standpoint as well as to educate drivers. First, as new models of smartwatches and smartphones are designed, driving safety should certainly be considered. Within the context of this study, if particular signals are better at obtaining attention of the driver, then those signals should be disabled during driving. However, it appears that the results of this study are not as straight forward. Driving performance varied depending on the drive load, device and notification type. The results of this study indicate that the watch seems to be more challenging to use behind the wheel. In addition, tactile notifications from the watch produce less gain in more dangerous situations. Overall, both the watch and phone had the worst driving performance in low drive load conditions. Drivers seem to underestimate the environment which leads to more mistakes. Given these results, designers would need to make a system that understands the drive load on the driver to adapt the correct notification signal that provides the least distraction. This of course would be challenging, and as a result drivers should consider disabling notifications all together when operating a vehicle.

Previous literature has observed a correlation between the perceived risk of cell phone use while driving and actual usage (Hallett et al., 2011). As previously discussed, driving performance was worse when drivers seemed to underestimate the environment. This study could improve driving safety by notifying drivers of these potential dangers. If drivers understand the risks of underestimating the roadway hazards, drivers would be less likely to engage in the behavior (Hallett et al., 2011). Additionally, drivers were not consciously aware of how challenging the smartwatch was to use while driving. Participants' time to engage in texting was further delayed compared to smartphones, indicating they were more strategic when using them. The time to complete was also longer, indicating the texting task was more challenging on the watch compared to the phone. However, participants were not consciously aware of this, since they did not rate the watch significantly more difficult to use than the phone. This study could also educate participants of the difficulty of using a smartwatch while driving, and hopefully prevent its use.

5.3 Limitations

As previously discussed the measures of driving performance used in this dissertation to determine distraction were extremely robust. Specifically, the local measures (i.e. gain and coherence) were sensitive to detect smaller defects in driving that the traditional global measures could not detect. However, one particular limitation was not the measures themselves but the window of time for which the driving data was captured. Recall that a dual task window was created that represented the time in which participants were actively engaged in the texting task as they drove. It was constructed on the bases of two considerations: first the mobile texting software sent a text message around 25 to 30 seconds after the start of the driving session; second the longest time to engage and time to complete were used to create the end of the window. The dual task window was an assumption, and was the period of time all driving measures were derived. Obviously, participants could finish their text before or after the window of time expired. If participants finished reading the text message after the window, additional data was lost. Inversely, if participants quickly read the message before the end of the dual task window, then data was included during a time when the participant was actually not dual tasking. Essentially, the latter could dilute the observed affect the texting task creates within the driving performance measures. This could be why we did not observe strong affects in coherence and phase. An ideal situation would be to synchronize the driving simulator with the texting application. Each window of time can be then individualized for each driving session, rather than creating a generic dual task window within which the driving data was analyzed.

Another limitation is the two levels of drive load. Although RMS along with both gain and coherence confirmed the high drive load condition had significant shifts in performance, it would be interesting to observe more than two drive load levels. As previously discussed, multimodal enhancement was not observed. Perhaps it was because the high drive load condition in this dissertation was not challenging enough to acquire the total amount of attentional capacity of the participants. Having additional drive load conditions could expose when multimodal enhancement occurs.

An additional limitation was that steering control was not measured, since the current study did not involve use of the steering wheel. Previous literature has successfully detected an increase in lane deviation when texting from a mobile phone while driving (Brace, Young, & Regan, 2007; Caird, Johnston, Willness, Asbridge, & Steel, 2014). Given smartwatches involve the use of two hands, it should be more challenging to text from the watch. Future research should measure lane deviation for each mobile device at the various ringtone settings.

We also did not track the ownership of smartwatches. One could argue that as individuals become more familiar with smartwatches they may before better with them. However, in Giang et al. (2015) newest article they compared smartwatch owners to non-owners and did not find a difference.

Although we were able to screened participants for visual acuity we did not have a way to acquire tactile and auditory sensitivity. Although no sensitivity issues were reported, it should be noted that their auditory and tactile sensitivity could have played a role in their ability to perceive the signals from the watch and phone.

Finally, the sample that participated in the study is another limitation. Two specific characteristics of the sample could have possibly affected the outcome. First, the sample were highly experienced at texting and driving. For example, 78% of participants reported that they engage in texting while driving. In addition, part of the criteria for participation was to have at least two years owning and operating a car and smartphone. They also reported sending an average of 30 text messages per day. This implies the sample may have had plenty of practice texting while driving. Consider that Spelke et al. (1976) saw dramatic improvements in dual task performance from their participants after only 6 weeks of practice. A diverse sample of those that do not text and drive could help to provide a broader picture of driving impairment as a result of drive load, notification type and mobile device.

The second characteristic of the sample was their age, specifically they were very young (M= 21.7 years old, SD= 4.5 years). Perhaps with age, texting and driving could become more challenging. Laurienti, Burdette, Maldjian, and Wallace (2006), observed multimodal enhancement occurred more so with their older sample compared to their younger sample. Perhaps as we age, multimodal notification types become more distracting.

5.4 Future research

Future research should concentrate more on the affect of notification types on driving performance. Specifically, the variability of gain for the notification types on the watch compared to the notifications on the phone. Given 90% of this sample did not own a smartwatch, their experience with smartwatches is most likely limited. Perhaps the difference in experiencing tactile sensations on the wrist rather than the lap (where the smartphone resided) caused the difference in gain.

Future research should also concentrate on additional drive load levels. Unlike previous literature, we did not observe multimodal enhancement (Ho et al., 2007; Lewis et al., 2013a; Murata et al., 2013; Politis et al., 2014). According to load theory, the driving environment must be challenging enough to require higher levels of attentional capacity (Lavie, 1995, 2005; Lavie et al., 2004; Lavie & Tsal, 1994; Lewis et al., 2013a). Perhaps the high drive load condition was not challenging enough for drivers. Having additional drive load conditions could expose when multimodal enhancement occurs.

Future research could also seek a more diverse sample. The sample in this experiment was comprised of younger individuals of which 78% reported they text while driving. Their experience in practicing texting while driving could have minimized the affect it had on our driving measures (Spelke et al., 1976). In addition, older individuals could have been more affected by the notification types, considering they are more likely to experience multimodal enhancement (Laurienti et al., 2006).

5.5 Conclusion

To date, few comparisons of driving distraction have been made between the smartwatch and smartphone. Those that have, have assigned different notification types to different devices (Giang et al., 2014; Giang et al., 2015). The results of this investigation indicate that future comparisons should take into consideration the assigned notification type to each device and drive load. Specifically, time to engage for the watch was influenced by the notification type. Notification type along with drive load also influenced gain and coherence levels. Specifically, it appears that the gain produced for tactile notifications on the watch at the two drive load settings contrasts all other notification types.

Another important observation was how compensatory strategies were utilized by participants. Given the chance, participants use compensatory strategies to maintain driving safety. For example, this experiment contrasted previous experiments for it's time to engage (Giang et al., 2014; Giang et al., 2015). Overall time to engage was longer for the watch compared to the phone despite its accessibility. These results conflicted with previous literature (Giang et al., 2014; Giang et al., 2015), but could be explained by this experiment allowing participants to strategize when they engaged in texting while driving. Previous literature has indicated when faced with a challenging secondary task, drivers will delay its execution until the environment is of lower complexity (Cooper et al., 2009; Fitch & Hanowski, 2011). It also appeared that compensatory strategies were used to assist with drive load. With a higher drive load, participants spent less time on the texting task to allow them to quickly switch their focus back to the challenging driving environment. Allowing these strategies into the laboratory helped this experiment to produce a result that more so reflects the real world.

The watch appeared to be harder to use while driving compared to the phone. As previously mentioned participants strategized by delaying the texting task more so than the phone. In addition, participants took 25% longer to complete the texting task on the watch compared to the phone. Regardless of how much harder the watch was to use, surprisingly neither device had significantly worse scores from one another within the various driving measures. In fact, drive load was one of the major contributors to driving performance. Counter to what one might predict, low drive load conditions had lower gain and coherence scores compared to high drive load conditions. It appeared that drivers may have underestimated the potential dangers of low drive load. Given they spent significantly more time attending to the texting task in the low drive load conditions compared to the high drive load conditions.

Lastly, local and global driving performance measures were both captured in this experiment. Global measures such as headway distance and RMS speed error are traditional measures researchers have used in the past to gauge driving distraction (Greenberg et al., 2003; Kang et al., 2008; Roskam et al., 2002). The results revealed that local measures such as gain, phase and coherence were more sensitive than global measures. For example, gain and coherence detected interactions between notification type and drive load, while both global measures did not. Local measures are able to detect even subtle defects in driving performance. Realistically, car crashes occur because of a multitude of factors (Dingus et al., 2016). Factors that could not be realistically replicated in the laboratory within a simulator. Thus, the sensitivity of the local measures assist in establishing contributing factors in the limited laboratory environment.

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APPENDIX

Appendix A. Screener Survey

Q1. What is your preferred email address?

____

Q2. Are you a native English speaker?
- ○ Yes, English is my first language.
- ○ No

Q3. Please indicate how long you have been driving a MOTOR VEHICLE....
- ○ LESS than 2 years driving experience.
- ○ MORE than 2 years driving experience.

Q4. Please indicate below how long have you been using a SMARTPHONE (in years).
- ○ LESS than 2 years using a smartphone
- ○ 2 years using a smartphone
- ○ 3 years using a smartphone
- ○ 4 years using a smartphone
- ○ 5 year using a smartphone
- ○ 6 years using a smartphone
- ○ 7 years or more using a smartphone

Q5. Do you text and drive in your everyday life?
- ○ Yes
- ○ No
- ○ I don’t care to answer

Appendix B. Consent Form

WICHITA STATE UNIVERSITY
FAIRMOUNT COLLEGE OF LIBERAL ARTS AND SCIENCES
Department of Psychology

Consent Form

Texting on a smartwatch versus a smartphone: A comparison of their effects on driving performance

Purpose: To understand the level of driving distraction that mobile devices produce when using them while driving.

Participant Selection: You were selected as a possible participant in this study because you fit the criteria of the population that are a native English speaker, aged 18 to 35 years, have a valid driver's license and have at least 2 years of experience driving and using a smart device. You will be one of 40 participants recruited from Wichita State University.

Explanation of Procedures: If you decide to participate, you will read aloud text messages from either a smartwatch or smartphone while you drive in a simulator. A post survey is administered at the end that inquiries about subjective perception of the level of difficulty, distraction and clarity of perceiving each device. The entire experiment should take approximately 1 ¾ hours.

Discomfort/Risks: There may be minimal discomfort or risks associated with participation in a study utilizing a driving simulator (e.g. fatigue, eye strain, dizziness, etc.). If you do experience such discomforts with this study, you may withdrawal at any time or not answer any questions on the post survey that make you feel uncomfortable. Additional help is also available at the Counseling and Testing Center. Please visit http://webs.wichita.edu/?u=COUTSTCTR1 on the web. The Counseling and Testing Center may also be reached by calling (316) 978-3440 or sending an e-mail to wanda.holt@wichita.edu. You will be given a 10-minute break at the mid-point of the study. However, you may also take a break at any time.

Benefits: Depending on the results it could raise public awareness to the potential dangers of engaging in text messaging while driving.

Confidentiality: Every effort will be made to keep your study-related information confidential. However, in order to make sure the study is done properly and safely there may be circumstances where this information must be released. By signing this form, you are giving the research team permission to share information about you with the following groups:

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- The Wichita State University Institutional Review Board

The researchers may publish the results of the study. If they do, they will only discuss group results. Your name will not be used in any publication or presentation about the study.

Please note the recording of your experimental session created today will be destroyed on January 1st 2018.

Payment to Subjects: You will receive 7 SONA points for your participation in the study. Should you need to withdraw you will still receive credit for the time you completed (1 credit for every 15 mins).

Refusal/Withdrawal: Participation in this study is entirely voluntary. Your decision whether or not to participate will not affect your future relations with Wichita State University. If you agree to participate in this study, you are free to withdraw from the study at any time without penalty.

Contact: If you have questions during the study, please ask the experimenters. If you have additional questions about this research you may contact Joel Persinger (joel.persinger@wichita.edu, 316 206-3774) or Dr. Rui Ni (Rui.Ni@Wichita.edu, 316-978-3886). If you have questions pertaining to your rights as a research subject, or about research-related injury, you can contact the Office of Research and Technology Transfer at Wichita State University, 1845 Fairmount Street, Wichita, KS 67260-0007, telephone (316) 978-3285.

You are under no obligation to participate in this study. Your signature below indicates that:

- You have read (or someone has read to you) the information provided above,
- You are aware that this is a research study,
- You have had the opportunity to ask questions and have had them answered to your satisfaction, and
- You have voluntarily decided to participate.

You are not giving up any legal rights by signing this form. You will be given a copy of this consent form to keep.

____
Printed Name of Subject

____ ____________________
Signature of Subject Date

____
Printed Name of Witness

____ ____________________
Witness Signature Date

Appendix C. Experimental instructions

Smartwatch Experiment Instruction

Thank you for participating in our experiment. This introduction explains your task in the experiment.

In this experiment, your primary task is to control the speed of your car while following a lead vehicle in a driving simulator. You must maintain a safe distance of about 2 seconds from the car in front of you. To do this you will operate the brake and gas petal. There will be no need to operate the steering wheel because the steering is automated. When the simulator begins, you will have about 5 seconds of automated driving to demonstrate the desired distance to maintain from the lead vehicle, a white sports utility wagon. After the 5 seconds has expired a tone will sound signifying that you now have control over your vehicle. From time to time the lead vehicle's speed will change, it could even apply it's brakes. The priority for you is to make sure you change the speed of your vehicle accordingly to maintain your safe distance.
Within certain parts of the experiment you will be asked to perform a secondary task, reading text messages from either a smartphone or smartwatch. Within these trials you will need to read aloud each text message shown on the mobile device while we record you. Typically, the mobile device will make a beep sound or emit a tactile vibration after an intermittent amount of time. When this occurs you will open the passage of text by hitting the "Tap to Read" button. Once the message is open you will read the passage aloud. When finished, you will hit the "Tap to Send" button. It is important not to forget to hit the "Tap to Send" button, because it helps us to record accurately when you finished reading the passage. Don't forget this is a secondary task! Just as in real life, when texting and driving, the priority is safe driving. Therefore, if you must delay this task to maintain safe driving, please do so.

Since we are investigating multitasking please reframe from any activity when we are recording data. These activities include answering personal texts, phone calls or socializing with our research assistant. If you carry on a conversation with our research assistant (the person administering the experiment), this will add an additional task for you while you are performing the experiment. Thus instead of just measuring your performance while texting (in singular) now we are measuring your ability to text while having a conversation. This will change our measurement, skew our data, and so we would have to exclude your data from the study.
Thank you for your cooperation and good luck!

Appendix D. Post Driving Survey for Smartphone

Post Driving Smartphone Survey

This section asks questions about your daily mobile usage and driving habits

Please read the text of each question carefully before answering.

1. **Please tell us the average amount of text messages you send per day.**
   Regardless of mobile device (tablet or mobile phone) what would be the average amount of text messages you send per day?

   ____

2. **Please tell us the average amount of miles you drive per day.**
   Think about your yearly average of miles you drive, how would that break down to miles per day?

   ____

This section asks questions about READING information from the smartphone

Please read the text of each question carefully before answering.

3. **How distracting do you think it was to use the PHONE to READ text while you drove?**
   Please tell us how distracting it was to read text from the smartwatch while you drive.

	1	2	3	4	5	6	7	
Not distracting	○	○	○	○	○	○	○	Very distracting

4. **Please rate the difficulty level of READING text on the PHONE while you drove.**
   Please tell us how easy it was to READ text using the smartphone while you drove.

	1	2	3	4	5	6	7	
Easy to read	○	○	○	○	○	○	○	Hard to read

This section asks questions about AUDIBLE alerts from the smartphone

Please read each question carefully before answering.

5. **How distracting was the AUDIBLE notifications to receive on the PHONE while you drove?**
   Please tell us how distracting it was to receive an audible notification on the phone while you drove.

   1 2 3 4 5 6 7

---

6. **How quickly you were able to access the device when receiving AUDIBLE notifications on the PHONE while you drove?**
   Please tell us how quickly you were able to begin reading the message after receiving an audible notification on the phone while you drove

	1	2	3	4	5	6	7	
Not very quick	○	○	○	○	○	○	○	Extremely quick

This section asks questions about TACTILE alerts from the smartphone

Please read each question carefully before answering.

7. **How distracting was the TACTILE notifications to receive on the PHONE while you drove?**
   Please tell us how distracting it was to receive an audible notification on the phone while you drove.

	1	2	3	4	5	6	7	
Not distracting	○	○	○	○	○	○	○	Very distracting

8. **How quickly you were able to access the device when receiving TACTILE notifications on the PHONE while you drove?**
   Please tell us how quickly you were able to begin reading the message after receiving an audible notification on the phone while you drove.

	1	2	3	4	5	6	7	
Not very quick	○	○	○	○	○	○	○	Extremely quick

This section asks questions about BOTH tactile & audible alerts from either the smartphone

Please read each question carefully before answering.

9. **How distracting was the BOTH tactile & audible notifications to receive on the PHONE while you drove?**
   Please tell us how distracting it was to receive an audible notification on the phone while you drove.

	1	2	3	4	5	6	7	
Not distracting	○	○	○	○	○	○	○	Very distracting

10. **How quickly you were able to access the device when receiving BOTH tactile & audible notifications on the PHONE while you drove?**
    Please tell us how quickly you were able to begin reading the message after receiving an audible notification on the phone while you drove.

	1	2	3	4	5	6	7	
Not very quick	○	○	○	○	○	○	○	Extremely quick

Appendix E. Post Driving Survey for Smartwatch

Post Driving Smartwatch Survey

This section asks questions about your daily mobile usage and driving habits

Please read the text of each question carefully before answering.

1. **Please tell us the average amount of text messages you send per day.**
   Regardless of mobile device (tablet or mobile phone) what would be the average amount of text messages you send per day?

   ____

2. **Please tell us the average amount of miles you drive per day.**
   Think about your yearly average of miles you drive, how would that break down to miles per day?

   ____

This section asks questions about READING information from the smartwatch

Please read the text of each question carefully before answering.

3. **How distracting do you think it was to use the WATCH to READ text while you drove?**
   Please tell us how distracting it was to read text from the smartwatch while you drive.

	1	2	3	4	5	6	7	
Not distracting	○	○	○	○	○	○	○	Very distracting

4. **Please rate the difficulty level of READING text on the WATCH while you drove.**
   Please tell us how easy it was to READ text using the Smartwatch while you drove.

	1	2	3	4	5	6	7	
Easy to read	○	○	○	○	○	○	○	Hard to read

This section asks questions about AUDIBLE alerts from the smartwatch

Please read each question carefully before answering.

5. **How distracting was the AUDIBLE notifications to receive on the WATCH while you drove?**
   Please tell us how distracting it was to receive an audible notification on the watch while you drove.

	1	2	3	4	5	6	7	

6. **How quickly you were able to access the device when receiving AUDIBLE notifications on the WATCH while you drove?**
   Please tell us how quickly you were able to begin reading the message after receiving an audible notification on the watch while you drove

	1	2	3	4	5	6	7	
Not very quick	○	○	○	○	○	○	○	Extremely quick

This section asks questions about TACTILE alerts from the smartwatch

Please read each question carefully before answering.

7. **How distracting was the TACTILE notifications to receive on the WATCH while you drove?**
   Please tell us how distracting it was to receive an audible notification on the watch while you drove.

	1	2	3	4	5	6	7	
Not distracting	○	○	○	○	○	○	○	Very distracting

8. **How quickly you were able to access the device when receiving TACTILE notifications on the WATCH while you drove?**
   Please tell us how quickly you were able to begin reading the message after receiving an audible notification on the watch while you drove.

	1	2	3	4	5	6	7	
Not very quick	○	○	○	○	○	○	○	Extremely quick

This section asks questions about BOTH tactile & audible alerts from either the smartwatch

Please read each question carefully before answering.

9. **How distracting was the BOTH tactile & audible notifications to receive on the WATCH while you drove?**

   Please tell us how distracting it was to receive an audible notification on the watch while you drove.

	1	2	3	4	5	6	7	
Not distracting	○	○	○	○	○	○	○	Very distracting

10. **How quickly you were able to access the device when receiving BOTH tactile & audible notifications on the WATCH while you drove?**

    Please tell us how quickly you were able to begin reading the message after receiving an audible notification on the watch while you drove.

	1	2	3	4	5	6	7	
Not very quick	○	○	○	○	○	○	○	Extremely quick