The Design of a Study to Analyze the Influence of Texting while Driving

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ABSTRACT
We examine the influence of texting while driving to determine if there are driving impairments. Three participants took part in a pilot study in which they drove as normal for a few minutes and drove while texting for the same amount of time. The results indicate that texting leads to a reduction in speed and impaired participants ability to maintain a safe lane position while driving.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.
General terms: Human Factors
Keywords: Texting, Mobility, Mobile devices

INTRODUCTION
On September 12th, 2008 there was a collision between two trains in Los Angeles, CA. A later investigation showed that the engineer in charge had sent a text message 22 seconds prior to running a red light and hitting an oncoming train [1]. Moreover, a recent study highlights that texting while driving has greater accident risks than drinking alcohol at the legal limit or when under influence of cannabis [27]. In this work, we aim to determine the influence of texting with and without haptic feedback on navigation ability and the effect of motion on texting performance. The mobility conditions include standing, walking and driving. This work is in succession of previous work done on texting performance under different conditions [9 -13]. In light of the recent accident, it is important to determine the influence of texting on mobility performance to reduce accidents and in the long-term save lives. It is also pertinent to investigate the user interface used for texting in order to determine where improvements need to be made and which improvements would produce the desired effect of less distraction while performing an activity concurrently with texting on a mobile phone.

In this work, we design a study to investigate the impact of text entry using physical and virtual Mini-QWERTY keyboards on cell phones. We hypothesize that there will be different levels of performance on the different key-boards in conducting tasks with a reduced texting performance while driving and walking in comparison to standing.

RELATED WORK
There has been little previous research directly on the influence of tactile feedback on mini-QWERTY keyboard text input performance on mobile devices. Brewster et al. [3] investigated the benefit of adding vibro-tactile feedback for touch-screen keyboards on PDAs where a stylus was used to press the keys. Results showed significant improvements in text input performance in terms of text input speed, accuracy and error corrections when tactile feedback was added. In another laboratory study, Hoggan et al. [17] compared user performance on cell phones with finger-based text entry featuring physical and touch-screen mini-QWERTY keyboards. Again, tactile feedback had a significant positive effect on the usability of the cell phone and significantly diminished the overall subjective workload.

Also, limited studies have investigated the interaction with mobile devices while in motion. Vadas et al.[33] showed that walking compared to sitting negatively affected the text input and navigation performance and increased the overall workload when reading text on a visual display. In a similar study, Mizobuchi et al. [25] examined the relationship between walking and text input performance using a PDA and stylus. Their results showed a decrease in text input performance as users walked and text entry difficulty increased, but found no interaction effect between motion and button size. Also, Brewster et al.[3] found that participants enhanced their text input performance on a PDA with stylus equipped with an artificial tactile feedback while in transit on the subway, but input performance was not significantly different. However, they found a significant reduction in perceived workload. In the same natural, dynamic mobile setting, participants’ text entry performance was significantly better on a mobile device with a physical, button keyboard interface versus a finger-based text input touch-screen keyboard. Again, subjective performance levels were significantly higher on a keyboard with tactile feedback [17].

Thus far only few have examined the effect of driving on text input performance. In contrast, most of the research has focused on the impact of mobile phone calls on driving impairment. Only a recent study conducted by Reed &
Robbins [27] addresses the effects text messaging on driving behavior. Participants had to text on cell phones with standard keypads. Both quantitative and subjective driving performance measurements were taken when texting whilst driving on motorways using a high fidelity car simulator. Both measurements show the detrimental effects of texting while driving in terms of variability in lane position, average speed, reaction time and distance kept to a lead vehicle. In addition, writing text created a significant greater impairment than reading text messages. Also, completion time was significantly longer in the experimental condition than for the baseline measure. Interestingly, driving impairment caused by texting was significantly greater for female than male participants. These findings suggest that texting while driving increase the likelihood of car accidents dramatically. However, most of the reported evidence of driving impairment comes from people using a mobile device to phone call under simulated conditions [1, 24, 30], only a limited number of experimental studies report evidence of impairment collected in naturalistic environments [4, 7, 26]. Reed et al. [28] and Santos et al. [29] compared driving impairment between simulated versus naturalistic environments, and found that naturalistic settings have higher external validity and reliability. Interestingly, little research has looked explicitly to the effect of texting while driving in naturalistic settings [19]. Their results showed detrimental effects of texting on safety critical driving measures, perhaps most concerning is the fact that people spent up to 400 percent more time with their eyes off the road than they did when not texting.

Little available research proved the negative interaction effects of mobility on text input performance on both physical and touch-screen keyboards. However, better understanding in a wider mobile context is necessary to consolidate the interaction effect of on-the-go text input in conditions that control for the variability inherent in traffic scenarios.

INITIAL STUDY DESIGN

According to Clawson [8], who proposed the initial design of the study, participants will type for 5 twenty-minute session in the mobility conditions on both RIM BlackBerry 8320 and Apple iPhone. After 100 minutes of typing, the participants will switch to a second mobility condition and type for 100 minutes in this condition. Upon completion of the second condition, the participant will switch to the third and final mobility condition¹.

Besides measuring and providing direct feedback about users’ texting performance (speed and accuracy), several motion measures are obtained. However, since earlier described research confirms that mobility affects text entry performance and consequently impairs driving performance [25, 33], we explored methods aimed to quantify driving impairment. Obtaining measures for driving impairment increases reliability and contributes external validity to our work, which would enable us to draw valid conclusions. This study will quantify the effects of texting while driving by investigating driving performance. We will also measure the impact of driving on texting performance to determine the effect that these activities have on each other.

INITIAL PROCEDURE

During the first driving session, each participant will be asked to drive around the track for 5 minutes to familiarize themselves with driving the Porsche Cayenne. The participant will then be asked to type entries on the mobile device on which they have gained proficiency using from the previous standing and walking studies. Prior to the start of the text entry, a message containing the time on the mobile device will be sent via Bluetooth or cable to the laptop recording the Canbus data. This procedure is necessary for later synchronization of the data from the mobile device to the Canbus measurements.

While driving around the track for 20 minutes, each participant will be sent some lines of text obtained from the MacKenzie and Soukoreff Phrase Set [22] to type into the mobile device. Measurements including typing speed, words per minute (wpm) and other texting measures will be computed and saved on the device for later retrieval.

1 Last, at the end of the fifth driving session participants run a baseline measure wherein they are single tasked with the problem of how texting causes driving impairment we particularly focused on how to obtain and visualize the most valid representation of participants’ normal driving behavior. The NASA-TLX, a subjective workload assessment tool, will be administered to participants after the complete the first session and the last session of every condition, i.e. standing, walking and driving. This task is used to record their subjective workload while texting and driving [3, 17].

PILOT STUDY

After we conducted a literature study we examined the study design on the effects of texting while driving [1]. Our findings motivated us to further explore and implement different vehicle measures as complementary to the measures already taken on the mobile device. Interested in the problem of how texting causes driving impairment we particularly focused on how to obtain and visualize the most reliable measures. Besides this we aimed to find issues regarding safety, drivers’ in-car behavior and the usefulness of the existing track. Before the start of the pilot study we did several runs to determine maximum speed and braking distance. Moreover, to ensure safety an engine overkill switch and an additional pair of braking pedals were installed. The emergency switch is controlled remotely while the braking pedals can only be controlled from the passenger seat.

¹ For more details about the study design, we refer to the proposal from Clawson, 2008 [8].
PILOT STUDY DESIGN
To explore what kind of measures would be the most beneficial three pilot studies were conducted. In every condition the role of participants was taken by the researchers themselves while another researcher was sitting in the passenger seat from which he could control the computer system. Since the existing literature on driving impairment has shown that it almost unfeasible to assess driving impairment only by one single measure, we aimed to incorporate a variety of measures in our pilot study so that we can decide later what combination of measures give us the best results [8], [6].

PILOT STUDY PROCEDURE
During the pilot study participants had to go through a session of three conditions in subsequent order. First, to become comfortable with driving around the closed track and to the highly instrumented Porsche Cayenne participants were instructed and asked to drive for a period of approximately 5 minutes. After a short break - and with the understanding that they had become acquainted to the situation - they now were assumed to be ready to accomplish the baseline condition. Therefore they were instructed to drive around in a pace they felt comfortable with so that the collected data represented their normal driving behavior best. After 20 minutes of driving they were giving a short break followed by the experimental condition that again took 20 minutes, however this time texting on the RIM Blackberry 8320. While driving around the track each participant had to re-type sentences obtained from the MacKenzie and Soukoreff Phrase Set [22]. All the sentences were selected to be short enough to fit on one single line so that they could be read easily and without scrolling. Their texting performance was echoed back by information about their accuracy (percentage) and typing speed (wpm), all data is saved to the blackberry and available for later retrieval.

DRIVING TRACK
To assess the ability of our participants to input text while driving and to obtain measures about their driving impairment, we chose to let them drive on a closed track located near the Georgia Tech campus. The driving track is shown in Appendix B and is approx. 130m by 90m. Participants are required to drive around the outer edges of the track; that is they are not supposed to drive down the parts of the track that are marked with an "x" (Appendix 1). They were told that they could speed up or slow down freely as long as they tried to do their best to continue texting and driving. Moreover, the researcher sitting next to them was instructed not to interrupt the participant but instead observe their behavior and to report afterwards. Interestingly, it was assumed that participants would mostly do the texting with both hands; however the high number of curves forced them to put more effort in controlling the car. In accordance with the existing literature we decided to redesign the track for the remaining pilot studies and to make it less curvy, this is also a requirement when steering wheel reversals are obtained as a measure for driving impairment [16], [23]. Moreover, redesigning the track increases safety in general since two telephone poles were fairly close located on a curvy part of the existing track (Appendix B, track 1). We used cones to mark the new lanes of the track and tried to optimize the length of the straight lanes as much as possible. (Appendix B, track 2).

VEHICLE MEASUREMENTS
A 2006 Porsche Cayenne shown in Appendix A, which was used in the DARPA Urban Challenge [14] was the selected vehicle for use in our study because the vehicle was already equipped with adequate sensors. The sensors available in the car include GPS and IMU unit, Vision, Radar and Laser sensors, vehicle control sensors including gear selection, steering, and acceleration or braking. The vehicle control sensors are linked to a CANbus (Controller Area Network) from which measures of interest can be extracted. The vehicle is also equipped with amber safety strobe and emergency stop pushbuttons for safety reasons. More detailed explanations of the sensors can be found in the technical paper [15].

For the purpose of our study, we extract the driving measures that are deemed acceptable for measuring driving impairment. Brookhuis et al [6] define driving impairment based on measures such as speed variability, swerving, braking and lateral deviation. By extracting these measures from the data we are able to make stronger claims about the effects of texting on driving performance.

ANALYSIS OF DATA
Driving speed is a critical measure for determining driver impairment. We obtain the driving speed and time using information from the CANbus data. For each experiment, the participant was asked to drive at a comfortable speed within the driving range. We then compute the average speed and deviations from the average. For each of the conditions driving and driving & texting, we compare the average speed and deviations to determine if there are significant changes in speed. We use a t-test to determine to assess the statistical difference between the means of both conditions. Based on past studies [6] steering wheel reversals are considered to be very informative. According to [21, 23], steering reversal rates can be used to measure steering performance and task difficulty. We compute the zero crossings, which is the number of times the steering wheel crosses the zero angle position. We also compute the steering reversals as the number of times the steering wheel movement is reversed.

Braking frequency is used to determine how often a participant brakes in each of the conditions; driving and driving & texting. We assume that there will be significant differences in the number of times of braking for each condition.

Positional GPS data is recorded at a frequency of 2hz from the Cayenne as it is driven around the track. By ana-
lyzing the position of the car over time, we calculate the instantaneous lateral deviation of the car. The participant is asked to drive for some duration without any unusual distractions in order to establish a baseline expectation of where the car should be at any given point in time. To define the baseline, we choose a lap at random from the collection of control laps. For each data point defining that lap, find the nearest point on each other lap. The average of these points represents the expected position at that given time. After the experimental data has been collected, we define the absolute deviation of a data point to be the distance to the nearest point on the baseline. Statistical data is then generated from this data.

Lateral deviation is defined as the distance from the automobile's current position to its expected position (expressed as the center of the track or a baseline constructed from control laps). By measuring this deviation, we compute how far off course the driver is at any point in time. Relative deviation is defined as the distance of a point from a linear best-fit line through neighboring data points. Unfortunately, we were not able to extract any meaning from its results. Additional work on this measure is required before it should be used.

RESULTS
After the first pilot study we came to the conclusion that participants mostly drove with one hand and used the other one for the texting, we decided to redesign the track after the first run (Appendix B, track 2). This means that we are required to run a separate analysis on the data. The length of run for all four participants differed, however, we assumed that driving impairment was similar regardless of the driving time on the track. Thus, someone driving really bad for the first 10 minutes is assumed to drive as bad in the following 10 minutes for each condition. Further, due to an unknown cause the CANBUS data (not GPS data) from a participant 2 was lost during the first pilot study. Therefore, for the first CANBUS analysis we only used the data from participant 1 while for the second analysis we combine the results from participant 3 and 4.

EXPERIMENT 1
For the analysis of CANBUS data a T-test was carried to compare the means of speed and steering wheel activity. A significant effect between the baseline condition (M = 14.4413, SD = 2.158) and experimental condition (M = 11.751, SD = 1.6289) was found for speed (T (175798) = 296.332, p < .001)) but neither for steering wheel activity (T (250880) = 0.89, p = .3735) nor for the number of steering zero crossings (T (744) = .0469, p = .9626). A Chi-square statistics was used to analyze the number of steering reversals but again a non significant results was found (X^2 (2) = 2.804459, p = .246048). The number of braking was not of interest for this run because the participant only used the brake once in both conditions.

Also, for the analysis of GPS data a paired T-test was used to compare the average of absolute deviation and relative deviation both in meters. No significant effects between the control condition and experimental condition were found for neither absolute deviation (M = -.20, SD = .31, t = -.88, p = .54) nor for relative deviation (M = -.00, SD = .03, t = -.14, p = .91). See Appendix D, figure 17 for an overview of GPS data. For participant 1 the maximum absolute deviation was 0.60 for the baseline condition and 3.51 for the experimental condition. For participant 2 the maximum absolute deviation was 0.82 for the baseline condition and 0.62 for the experimental condition.

EXPERIMENT 2
Since participant 3 and 4 both took part in the study after the track was redesigned, a paired T-test was carried out to compare the means of the speed and steering wheel activity. We did not find a significant result for speed (T (2) = 1.0718, p = .239, one-tailed). In addition, we found a non significant result for steering wheel activity (T (1) = -.9151, p = .2641, one-tailed) and the number of zero crossings (T (1) = 1.0225, p = .4141) A Chi-square statistics was used to analyze the number of braking events but no significant effect was found (X^2 (1) = 2.2541891, p = .11). Furthermore the number of steering wheel reversals were analyzed for each person separately with a Chi-square analysis, for participant 2 a no significant result found (X^2 (2) = 3.35067, p = .187245) where four participant 3 there was (X^2 (2) = 11.12769, p = .003).

Again, for the analysis of GPS data a paired T-test was used to compare the average of absolute deviation and relative deviation. This time we found a significant effect for average absolute deviation between conditions (M = -.14, SD = .01, t = -.54.69, p = .01). In contrast, for average relative deviation no effects were found (M = .08, t = .00, p = .99). For participant 3 the maximum absolute deviation was 0.58 for the baseline condition and 0.75 for the experimental condition. For participant 4 the maximum absolute deviation was 0.38 for the baseline condition and 0.82 for the experimental condition.

DISCUSSION
Although the observations during our pilot study clearly showed the effects of the experimental condition on driving performance, we did not succeed in coming up with statistical significant results for most of the measures we took. Perhaps the most obvious explanation for not finding a significant difference between the two conditions is the number of participants that took part in our pilot study. Moreover, since we haven’t analyzed the texting data it might be that participants used a different strategy. By this we mean that participants 1 and 3 may have focused more on text input and less on driving, while person 4 might used the opposite strategy. Nevertheless, Appendix D, figures 2, 3 and 4 shows that maximum speed and average speed decreases dramatically in the experimental condition. The overall speed analysis in Appendix D figure 1 shows a reduction in average speed in texting versus non-texting in both experiments 1 and 2 while experiment 3 seems to have about the same average speed for
both conditions. Likewise, the plots of speed over time in Appendix D, figures 2, 3 and 4 indicate lower speeds while texting for participants 1 and 3. It is also apparent that participant 4 drove at generally faster speeds than the other two participants. In addition, Appendix D, figures 5, 6 and 7 show comparisons of the average speed, standard deviation and the maximum speed for the three experiments. Overall, in all 3 experiments we observed that drivers tended to reduce speed in the texting condition. This means that while a participant is texting there is not as less variability in speed as the participant maintains a steadier speed. Interestingly, a possible explanation for this phenomenon is proposed by Reeds and Robbins [27] as they argue that people are aware of the risk induced by texting while driving and that they deliberately chose to reduce speed in order to increase safety. Besides speed measure we also used steering wheel activity as an indicator of driving performance. Steering wheel reversals is proposed as an adequate measure of driving task demand [21]. However, we did not find a significant result and since we only had 3 participants the results are tentative. Steering wheel reversal as the number of zero crossings Appendix D, figure 15 have varying results for each condition in all experiments, it is suggested that these measures depend too heavily on the number of curves and that they only should be taken on straight lanes [16, 23]. Given that we are planning to use the track in future studies as well it is worthwhile considering other measures. Perhaps the standard deviation of steering wheel activity might be a more reliable indicator since driving on a closed track allows it to compare between conditions. Appendix D, Figures 9, 10 and 11 show the average steering activity with error bars for the three experiments. Appendix D, Figure 8 gives an overall comparison of the average steering wheel position. It should be noted that in experiment 1 and 2 there is no difference between the steering averages when comparing texting versus non-texting while experiment 3 shows a difference. Appendix D, Figures 12, 13 and 14 show the number of times the steering wheel movement is reversed between angles 0.5 to 2.5 degrees, 2.5 – 4.5 degrees and 4.5-6.5 degrees. Most of the steering wheel movements occurred within 0.5 to 2.5 degrees, that is only mostly small corrections in wheel movement was made. The braking counts from the three experiments indicate how often the participant used the brakes. From Appendix D, figure 16, there were varying results based on all three experiments. Participant 1 only braked once in both conditions which was at the end of the 20minute study interval. Participant 3 however, braked less while texting and participant 4 braked the same amount of times for both conditions. These results suggest that overall braking information may not necessarily provide substantial information to draw solid conclusions on, although it can be used as a complementary measure of driving impairment. Another interesting issue we came across was that while texting participants tended to rely on the researcher sitting in the passenger seat. Although the researcher was instructed not to interrupt the participant or go give any warnings signals in case the car deviates to far from the track, participants perceived to have more trust during the texting condition. We argue that this example shows how cognition can become distributed over a person’s social environment in order to keep better focus on the tasks at hand [20]. Since the engine can be controlled using the overkill switch remotely, it is better for the researcher to sit in the back sit of the vehicle. Moreover, because participants are expected to be typing experts by the start of the full study we assumed that they prefer to control the steering wheel with both hands and input text with both hands as well. However, during the pilot study we observed that participants frequently use one hand to control the steering wheel and the other hand for texting. Although the participants in this study were not experts typists, these two observations brought up the idea of doing an in car behavior study in which are able to measure the amount of time someone is paying attention to the device and if they actual do make use of both hands for text entry. Hoskin et al. [19] found that spend even up to 400 percent more time with their eyes off the road when texting, than when not texting.

SAFETY ISSUES

The pilot study with the three experiments was very informative and led to constructive adjustments. From experiment 1, it was discovered that the track had too many curves and several telephone poles close to the track which were a safety concern. To avoid the telephone poles, the driving track was redesigned for experiments 2 and 3. In the future the driving track will need to be redesigned to have more straight driving sections as most related work calculates measures while driving on a straight path. In addition, the stopping distance of the vehicle after applying the emergency stop button and the brakes were measured as safety features. The results indicate a stopping distance while driving at a speed of 20mph for three different stopping conditions. The first condition involves the driver braking suddenly, the second condition involves the researcher braking with the hand brake and the third condition involves the researcher braking with the hand brake and using the emergency stop button to kill the engine while the driver presses the gas pedal. The stopping distance was computed to determine how far the vehicle would move after each condition. For condition 1 the stopping distance was 24.9 feet, condition 2 had a stopping distance of 25.6 feet while condition 3 had a distance of 33 feet.

Other issues to be considered for the design of a full blown study include the addition of cameras to the car infrastructure, this will enable the ability to monitor other details of driving while texting including how often one hand is used versus two hands while texting on the mobile phone, eye gaze/head tracking, that is how much time is spent attending to the device versus the amount of time spent attending to the driving task. It is also noteworthy to determine the effects of the re-
researcher being in the car while the study is ongoing. During experiment 1, the researcher provided verbal feedback to prevent the participant from hitting the telephone poles, therefore having the researcher in the car and expecting feedback in emergency situations would lead to the participant relying on the researcher for driving safety while paying more attention to the texting. It will be necessary to develop a method which does not involve the driver relying on the researchers’ cognition.

CONCLUSION
The combination of increased mental workload required to read the sentence on the display and to write a text message, the control impairment caused by the physical act of holding the phone and simultaneously the steering wheel and the continuous shifting of visual orientation between the phone display and the road ahead resulted in significantly impaired ability to maintain safe road position and constant speed.

FUTURE WORK
Both pilot studies exposed several inadequacies on the developmental part and initial design. Most important is to re-design the track, which included too many sharp curves and two dangerous objects. In addition, a traffic light used as distracter needs to be added to the experimental setup of the track. During sessions, the traffic light will switch a few times systematically from green to red; participants will be required to stop at a red light. This way we measure inattention-blindness in the dual-task condition wherein the disruptive effects of cell phones on driving are due in large part to the diversion of attention from driving and road signs to the texting [18, 32]. A reflecting light beam blocked by the passing Porsche Cayenne can trigger the traffic light a few decimeters before facing it. This data will later be correlated with the braking information to determine if the participant stopped. Further, the GPS receiver only outputs position and time information, however, to calculate swerving the heading of the car needs also to be generated by the receiver. In addition, the output frequency of the position message is currently 2Hz, however, to improve precision the frequency must be upgraded to 10Hz. Due to time pressure the total distance has yet to be computed by adding up the vector length of two consecutive positions. With additional time, improvements could be made to the GPS analysis application. Due to extremely limited development resources and limited utility of the program beyond this study, there exists only a most basic means of user interaction with the program. Providing a graphical interface would allow easier use of the application, as well as enabling us to visualize the data. In addition to being more intuitively useful to a human user, a graphical representation of the data may highlight certain inaccuracies or suggest improvements to the calculation process. Significant development resources were devoted to the creation of a relative deviation measure that ultimately was not ready for usage. With more time, the feature could be completed. Another concern is to correlate cell phone information with car data; both smart phones need to be synchronized with the data acquisition in the car to relate concurrent behavior. We figured out that Bluetooth is the best solution for timestamp transmission, but haven’t been able to implement this yet. This will be done in the final development stage of the RIM Blackberry. Moreover, the Apple iPhone is also still in its early development. As both devices are ready for deployment we can run a third pilot study on a re-designed track containing a traffic light with the Porsche Cayenne equipped to measure all envisioned driving impairment metrics. The next step is than to write a program that by means of sliding window approach measures the relational effect of texting on driving and vice versa. Furthermore, two matters we are currently considering are to add cameras and eye trackers to the car infrastructure to observe participants. The cameras can give us detailed information about how participants hold the cell phone and simultaneously the steering wheel, i.e. one-hand versus two-hand holding of device. Additionally, with eye tracking we can gauge the distribution of visual attention on the road ahead and on the cell phone display.

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REFERENCES


APPENDIX

APPENDIX A: THE PORSCHE CAYENNE

APPENDIX B: DRIVING TRACK
Track 1                                      Track 2

APPENDIX C: OVERVIEW MEASURES DRIVING IMPAIRMENT

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APPENDIX D: FIGURES

Speed Analysis

Overall Speed Analysis: Average Speed

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7
Steering Wheel Reversals

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15
Braking

GPS Data

Figure 16

Figure 17