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Hand-Held Texting is Less Distracting than Texting with the Phone in a Holder – Anyway, Don't Do It

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ABSTRACT

We studied the effects of texting while driving and the effects of mobile phone position (hand-held, holder) on drivers' lane-keeping performance, experienced workload, and in-car glance durations in a motion-platform driving simulator with 24 participants. Overall, we found the known negative effects of texting on lane-keeping performance, workload, and visual attention on road, suggesting that texting on the road in any manner is not risk-free. As a novel finding, we found that hand-held texting led to fewer lane-keeping errors and shorter total glance times off road compared to texting with the phone in a holder. We suggest the explanation is that the drivers had considerably more experience on texting hand-held than texting with the phone in a holder. In addition, the instability caused by the movements of the simulator was presumably easier to control while the phone was in hand compared to the holder. Surprisingly, there was a significant inverse correlation between the distance of the phone from the driving scene and total in-car glance duration as well as the number of in-car glances. The finding suggests that the participants made more inefficient but brief in-car glances towards the phone when the phone was closer to the driving scene than farther apart. The findings should be considered when planning legislation and designing novel in-car touch screen based interaction methods to replace interactions with mobile phones while driving.

Author Keywords

Text message, driver distraction, phone position, hand-held, holder, touch screen, distance, lane-keeping, workload, in-car glance durations

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H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces – Graphical user interfaces (GUI).

INTRODUCTION

Texting while driving has been found as one of the most risky secondary activities while driving in several studies (e.g., [1][2]). As a counter-measure, in several European countries, for instance, in Finland, drivers can get a fine for holding a mobile phone in their hand while driving. This means, for instance, that the driver can be fined if texting the phone in hand but not if the driver is texting while the phone is in a car phone holder (if the driving is interpreted otherwise as controlled). Unfortunately the legislative counter-measures seem to have a low impact on drivers' behaviours, as in Finland a recent poll by the Finnish Road Safety Council [8] indicated that over 30% of drivers text and over 50% read text messages while driving. According to the same poll, 45% of Finnish drivers do not use hands-free devices (e.g., holders or Bluetooth head-sets) during driving.

Current industrial efforts (e.g., MirrorLink: <http://www.mirrorlink.com/>) try to eliminate the use of mobile phones in the car by enabling similar interactions with dashboard-embedded touch screens and other controls. Physical dashboard controls, such as buttons on the steering wheel, as well as in-car voice control systems, are clearly more suitable for in-car use than the driver's touch screen smart phone, as these can decrease the visual demands of the secondary tasks [11]. However, it seems there are often implicit assumptions behind these efforts (as well as the regulations), suggesting that poking a touch screen fixed in the dashboard would be safer, for instance, for text entry than by a hand-held mobile phone while on the move.

We studied the rationale behind these regulative measures and implicit assumptions in a motion-platform driving simulator with 24 participants. There are several studies comparing hand-held and hands-free calls (e.g., [5]) but we are not aware of studies comparing the effects of hand-held texting and texting with the phone in a holder.

Based on earlier studies on the effects of texting on driving performance [1][2] we expected two main effects:

H1. Texting while driving leads to lower lane-keeping accuracy compared to baseline driving, and

H2. Texting while driving is experienced as significantly more demanding than baseline driving.

According to the theory of threaded cognition [14], significant practice on either of the tasks in a multi-tasking situation should lead to improved overall task performance. Here, we assumed the participants with experience on touch screen smart phones would have significantly more practice, and thus, much more well-rehearsed motor patterns for text entry with the phone in their hand than for text entry with the phone in a holder (outside the car). Thus, we predicted that:

H3. Texting the phone in hand leads to higher lane-keeping accuracy compared to texting with the phone in a holder,

H4. Texting the phone in hand is experienced as less demanding than texting with the phone in a holder, and

H5. Texting the phone in hand leads to decreased in-car glance durations compared to texting with the phone in a holder.

In addition, we wanted to see if the two texting tasks would pass the verification criteria for in-car tasks by NHTSA [10]:

1. Individual off-road glance durations: *“For at least 21 of the 24 test participants, no more than 15 percent (rounded up) of the total number of eye glances away from the forward road scene have duration of greater than 2.0 seconds while performing the testable task one time.”*
2. Mean off-road glance duration: *“For at least 21 of the 24 test participants, the mean duration of all eye glances away from the forward road scene is less than or equal to 2.0 seconds while performing the testable task one time.”*
3. Total off-road glance duration: *“For at least 21 of the 24 test participants, the sum of the durations of each individual participant’s eye glances away from the forward road scene is less or equal to 12.0 seconds while performing the testable task one time.”*

We weren’t able to make quantitative hypotheses of the effect sizes because we did not find well-validated computational cognitive models or tools such as Distract-R [12], for modelling touch screen text entry interactions on a smart phone by a driver.

METHOD

We studied the effects of texting while driving and the effects of the mobile phone position (hand-held, holder) on participants’ lane-keeping performance, experienced workload, and in-car glance durations.

Design

The experimental design followed a within-subjects 3 x 1 design for the analyses of texting on lane-keeping performance and experienced workload over three trials (baseline, hand-held, holder):

1. Baseline drive (without texting)
2. Driving and texting when the mobile phone was hand-held in a driver-preferred (constant) position, and
3. Driving and texting when the mobile phone was in a mobile phone holder.

For the comparative analyses of phone position on lane-keeping performance and in-car glance durations, a within-subjects 2 x 1 design (hand-held, holder) was used. The distance from the phone to the road’s vanishing point was used, where needed, in the glance analyses for controlling the effects of the gaze movement distance on the in-car glance durations.

Participants

A total of 24 participants took part to the study. Half of the participants were female (12) and half male (12). The participants’ age range was between 19 to 45 years ($M=27.3$). In order to avoid the known novice driver effects on visual sampling performance [19], all the participants had at least 10 000 kilometres (10 to 550 tkm, $M=134$ tkm) or two years (2 to 27, $M=9.8$) of driving experience, and had experience on touch screen smart phones. Ten participants informed that they had experience of driving and texting at the same time, and 14 participants informed that they do not text while driving. Further, all the participants had normal or corrected vision and they were right-handed fluent Finnish speakers. The participants were recruited by sending an invitation through public university e-mail lists and via social media. Each participant was rewarded with a car charger and a car holder for a mobile phone for taking part in the study.

Apparatus

The experiment was conducted at the Driving Simulator Laboratory of the Department of Computer Science and Information Systems in the University of Jyväskylä, Finland. The driving simulator consists of CKAS T2S 2-DOF motion platform, longitudinally adjustable seat, force-feedback steering wheel and pedals, as well as three 40” screens with a total resolution of 4320 x 900 pixels (3 x 1440 x 900, see Figure 1). The screens are installed on the platform eccentrically in order to provide a feeling of sitting on the driver’s seat in a passenger car with left-hand side steering. The distance between the front screen from the participants’ eyes varied between 100 and 119 cm depending on the position of the driver’s seat. Correspondingly, the left screen was roughly 90 to 106 cm whereas the right side screen was roughly 112 to 127 cm away from the participant’s eyes. The driving environment comprised of an empty straight highway with three lanes slightly curving to both left and right.



Figure 1: The driving simulator on a 2-DOF motion platform and the driving environment.

Automatic transmission was used and the driving scene included a Head-Up Display (HUD) with a speedometer and a rpm meter.

All the participants used a Samsung Galaxy S3 GT-I9305 Android (4.4.4) smart phone with a touch screen and a qwerty-keyboard to perform the tasks. In the holder trial, the distance of the participant's eyes to the phone in the holder varied between 52 and 74 cm depending on the position of the seat. The holder was a Capdase HR00-CV01 air vent car holder installed securely on a rack on the right side of the steering wheel. A video camera was used to record participants' face and eye movements with the frame rate of 25 fps.

Procedure

Before the experiment each participant was asked to read and sign an informed consent form. The participants were also asked to tell their personal information: age, gender, driving experience in years, estimated life-time driving kilometres, and the usage of mobile phone while driving (yes/no). All the participants were introduced to the mobile phone used in the experiment and shown how to find

special marks such as an exclamation mark from the keyboard. After that, participants were taken to the driving simulator and the seat of the simulator was adjusted for the participant. First the participants practiced driving in the simulator in a city scenario. After the city scenario the participants practised also the actual highway driving scenario for the trials. Once they reported to feel comfortable with driving, the experiment started.

The participants were instructed to prioritize the driving task and they were also told that there was no hurry to complete the writing tasks. However, the text message should be written correctly. In every driving task the participants were asked to keep the middle lane. However, the definition of a lane excursion (in detail) was not instructed for them in order to avoid unnatural visual behaviours focusing merely on the lane markings and the corners of the speedometer. They were instructed to try to keep the driving speed at 80 kilometres per hour and to obey traffic rules. In the hand-held trials, the participants were asked to hold the mobile phone in a way that felt natural to them. They were also told to hold the mobile phone in the same self-selected position during the whole driving task. The mobile phone holder was on the right side of the steering wheel and the position was the same for everybody. The holder position as well as the most popular hand-held phone positions are illustrated in Figure 2.

Each participant completed three trials: baseline drive (for two minutes), driving and texting when the mobile phone was hand-held, and driving and texting when the mobile phone was in the mobile phone holder. The orders of the trials were counter-balanced across the sample in order to avoid unwanted learning effects. For the texting trials, after accelerating the first time to 80 kilometres per hour, the participants were instructed that they can start writing the text message.

Both messages were 69 characters long and in Finnish. The messages were: *"Moi! Olen tulossa kotiin. Osta kaupasta maitoa ja laita sauna päälle."* and *"Hei! Olen tulossa kotiin. Osta maitoa kaupasta ja laita sauna päälle."* (In English: *"Hi! I am coming home. Please buy milk from the*



Figure 2: Texting the phone on the holder versus the most popular hand-held texting styles. From left: phone on the holder, phone on the lap, phone in between the participant and the steering wheel, and phone close to the steering wheel.

store and put the sauna on.”). Because of possible undesired learning effects the two slightly different messages were used in the two texting trials. The text to be written was constantly visible above the keyboard and the text entry field on the screen. Participants were able to see the text message during the tasks so the recalling would not distract them.

After each task, the participants filled in a NASA-TLX questionnaire [4] to enable evaluations of the level of experienced workload. Two different experimenters conducted the experiments but they followed the exactly same procedure.

Analysis

The dependent variables measured lane-keeping performance, experienced task workload, and in-car glance durations. The percentage of the total duration spent out of the own lane of the total trial duration was measured in order to evaluate lane-keeping performance. Reduced NASA-TLX (no weighting) was used for measuring experienced task workload. The in-car glance duration metrics were based on the NHTSA’s [10] driver distraction guidelines for in-vehicle electronic devices: mean duration of in-car glances, total in-car glance duration, and the percentage of over-2-second in-car glances. The visual demands of the driving scenario were at a similar or even at a higher level than the demands of the NHTSA recommended scenario (see [6]).

In the hand-held texting trial, the participants were told to hold the phone in their hand in a manner that felt natural for them. Various styles were used and the distance of the phone to the driving scene varied accordingly (see Figure 2). The distance from the centre of the phone to the road’s vanishing point was measured for each participant, as this point was taken as the main target for focal visual information while driving on an empty road after [13]. In order to control the effects of the varying distance in this trial, we normalized those in-car glance duration metrics that correlated with the distance by dividing the measured values by the distance for the both texting trials.

Two data reducers coded independently the lane excursions and the in-car glance durations from the video material frame by frame (25 fps) using Noldus Observer XT software (version 12). A lane excursion was defined to start when the right or left lower corner of the HUD meters exceeded a white lane marking on the road. A ruler was used to determine the location for road points where the lane marking was cut off (see Figure 1). It should be noted that because this definition was not explicitly instructed for the participants, the absolute percentages of lane excursions are artifacts of our particular driving simulation and scenario (as with any simulator), and should not be taken as predictive values for lane excursions on real roads. However, we consider the relative differences between the trials reliable. The in-car glance durations were coded following the SAE-J2396 standard [15].

Inter-rater reliability was analyzed with Observer XT by the percentage of agreement for the combined agreement on data of six independently coded trials by the two data reducers for the individual lane excursion durations (in total 715 s) and for the individual in-car glance durations (in total 681 s). Observer XT calculates the percentage of agreement as $\text{agreements} / (\text{agreements} + \text{disagreements}) * 100\%$. The inter-rater reliability for the lane excursion durations was 96.7%, and 96.2% for the in-car glance durations.

Repeated measures ANOVAs and paired samples two-tailed t-tests were used for testing the hypotheses on the glance metrics. For each ANOVA, assumptions of sphericity were confirmed. If the assumption of sphericity was violated, degrees of freedom were adjusted with the Greenhouse-Geisser correction. In addition, we analysed the correlations between the in-car glance metrics and the distance of the phone from the driving scene with Pearson’s r in order to validate for which metrics, if any, the effects of the distance should be controlled in the glance duration comparison between the texting trials. For the statistical analyses the alpha level was set to .05. For paired comparisons, we adjusted the alpha level with Bonferroni correction. Where applicable, partial eta-squared was used as a measure of effect size.

RESULTS

Lane-keeping performance

The lane excursion data indicates significant main effect of trial on the percentage of total trial time spent out of the lane, $F(2, 46) = 17.372, p < .001$, partial $\eta^2 = .430$ (see Figure 3). The percentage of time spent out of the lane was significantly lower for the baseline trial than for the hand-held trial (mean difference: 11.00 percentage points, $p < .001$) or for the holder trial (mean difference: 19.47 percentage points, $p < .001$). When the two texting trials are compared by subtracting the baseline percentage of each participant from the texting trial percentages, there is a significant difference between the texting trials indicating lower percentage for the hand-held trial, $t(23) = 2.305, p = .031$, mean difference 8.47 percentage points, 95% CI [.87, 16.08].

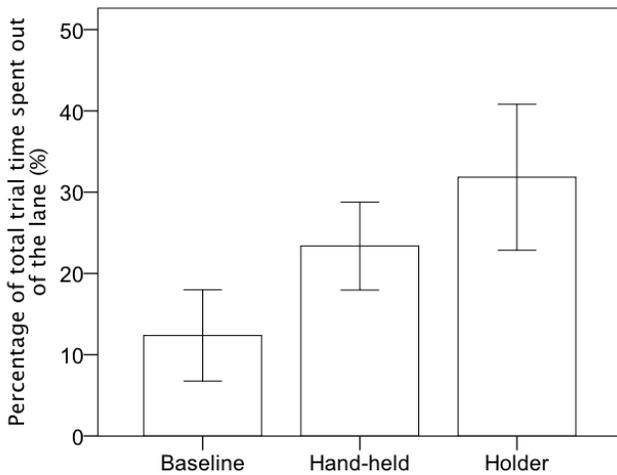


Figure 3: Percentage of total trial time spent out of the lane per trial. Error bars: 95% CI.

Experienced workload – NASA-TLX

The experienced level of task workload was evaluated with a reduced NASA-TLX questionnaire (no weighting). Significant main effect of trial was found, $F(2, 46) = 68.697$, $p < .001$, partial $\eta^2 = .749$ (see Figure 4). The baseline trial was rated considerably and significantly less demanding than the hand-held trial (mean difference: 31.29 units, $p < .001$) or the holder trial (mean difference: 33.72 units, $p < .001$). However, there were no significant differences between the texting trials in the experienced task workload (mean difference: 2.43 units, $p = .47$).

Distance of the phone from the road's vanishing point

In the holder trials, the distance of the phone from the road's vanishing point was always constant 58 cm and varied between 46.5 and 82.5 cm in the hand-held trials. Surprisingly, there was a significant *inverse* correlation between the distance and total in-car glance duration, $r(22) = -.302$, $p = .037$. There was also a significant inverse correlation between the distance and the number of in-car glances, $r(22) = -.289$, $p = .047$. In order to control the effect of the distance, we normalized the total in-car glance durations by dividing the individual values by the distance of the phone from the driving scene for the following analyses. For the mean in-car glance duration ($p = .784$) or the percentage of over-2-second in-car glances ($p = .485$) there were no significant correlations with the distance, and thus, these will be used directly as such in the following analyses on in-car glance durations.

In-car glance durations

Mean in-car glance durations per phone position are displayed in Figure 5. The mean durations stayed well below the 2.00 s verification threshold by NHTSA [10] in both trials, as can be predicted already by Wierwille's early visual sampling model [19]. The 85th percentiles for the mean in-car glance durations were 1.69 s for the hand-held and 1.77 s for the holder trial, indicating a clear pass on this verification criterion. There was no significant difference

between the trials on the mean in-car glance durations ($p = .146$).

The total in-car glance durations per phone position are displayed in Figure 6. The difference between the trials approaches significance, $t(23) = 2.018$, $p = .055$, 95% CI [-.26, .21, 1.10]. When we normalize the total in-car glance durations by dividing the values by the distance of the phone from the driving scene, there is a significant difference between the trials in favor of the hand-held trial, $t(23) = 4.189$, $p < .001$, mean difference .31 normalized units, 95% CI [.16, .47]. However, it should be noted that both texting tasks were highly unacceptable when the mean values are compared to the NHTSA [10] verification criteria of 12 s. The 85th percentiles for the total in-car glance durations were as high as 92.84 s for the hand-held and 103.60 s for the holder trial, indicating a definite fail on this criterion for both in-car tasks. The comparison is, however, dependent on the arbitrary text length to be typed given for the participants. With, for instance, a 7-character response, the total in car glance durations would definitely be much shorter.

There was no significant difference between the trials on the percentage of over-2-second in-car glances ($p = .279$). The mean values for the both trials are close to the NHTSA [10] verification criteria of 15 percent (see Figure 7). The 85th percentiles were 28.2% for the hand-held and 30.5% for the holder trial, indicating a clear fail for both tasks on this criterion.

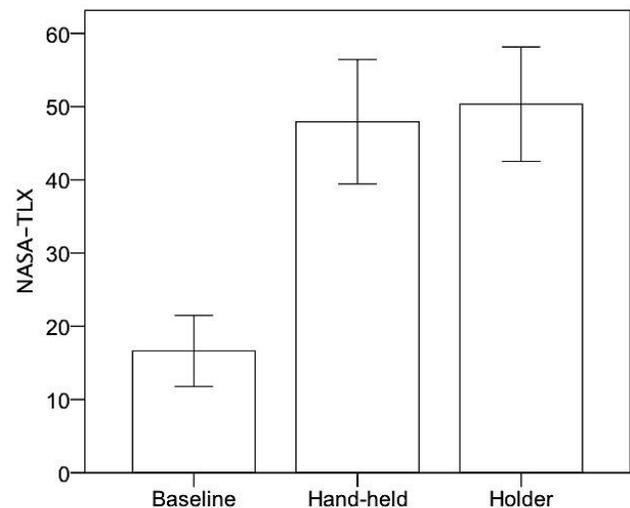


Figure 4: Total workload per trial (NASA-TLX, max 100). Error bars: 95% CI.

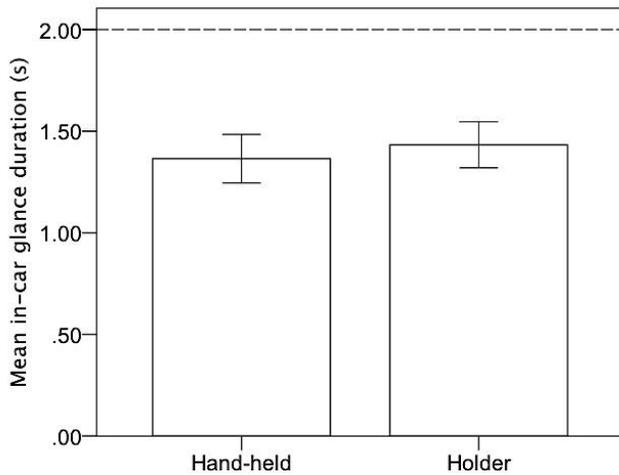


Figure 5: Mean in-car glance duration (s) per phone position. Error bars: 95% CI. NHTSA (2013) verification threshold at 2.00 s.

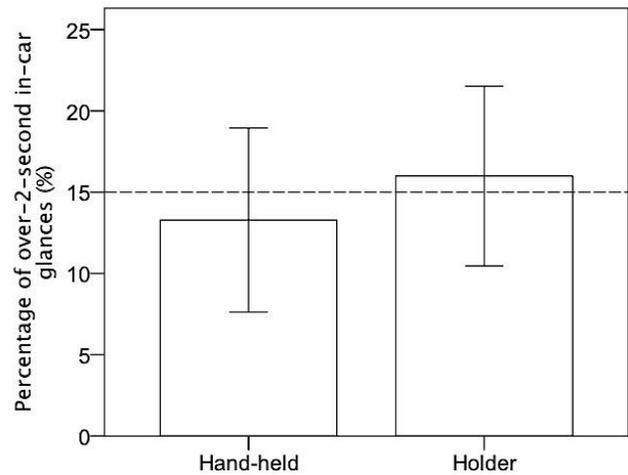


Figure 7: Percentage of over-2-second in-car glances per phone position. Error bars: 95% CI. NHTSA (2013) verification threshold at 15%.

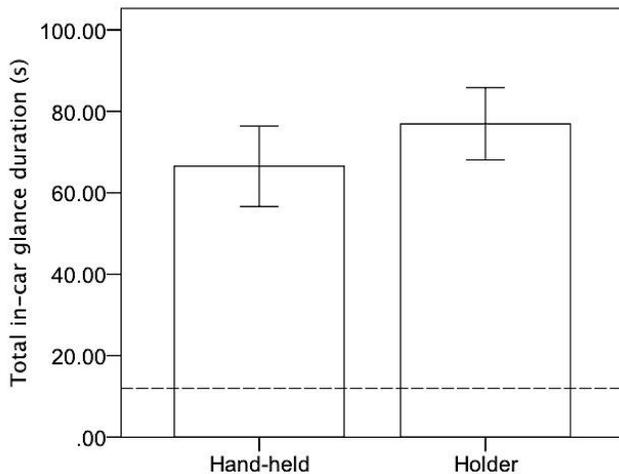


Figure 6: Total in-car glance duration (s) per phone position. Error bars: 95% CI. NHTSA (2013) verification threshold at 12.00 s.

DISCUSSION

The effects of texting while driving and the effects of the mobile phone position (hand-held, holder) on participants' lane-keeping performance, experienced workload, and in-car glance durations were studied in a motion-platform driving simulator study with 24 participants. We made five hypotheses:

- H1. Texting while driving leads to lower lane-keeping accuracy compared to baseline driving,
- H2. Texting while driving is experienced significantly more demanding than baseline driving,
- H3. Texting the phone in hand leads to higher lane-keeping accuracy compared to texting with the phone in a holder,

H4. Texting the phone in hand is experienced less demanding than texting with the phone in a holder, and

H5. Texting the phone in hand leads to decreased in-car glance durations compared to texting with the phone in a holder.

We found the known negative effects of texting on driving [1][2], in particular on lane-keeping performance (H1 supported) and experienced task workload (H2 supported). Obviously, texting led also to less visual attention on road in both texting trials compared to baseline driving, which can explain the decreased lane-keeping performance and why the participants felt the total workload increased almost threefold while texting compared to driving only.

Although texting in both phone positions was found to lead to negative consequences, H3 was also supported: the data indicates that hand-held texting led to higher lane-keeping accuracy than texting with the phone in a holder. The theory of threaded cognition [14] offers a plausible explanation for the effect. The theory suggests that practice on a task can significantly reduce interference effects on other simultaneous tasks. All the participants had a significant amount of experience on texting a touch screen smart phone on their hand (even if the majority were not texting at all while driving). The placement of the touch screen phone on a car holder forces the user to alter their well-rehearsed motor and visual task patterns, which can lead to a new situation (and a task) for the driver, and thus, to the observed effects on task performance.

In a similar fashion, the theory of threaded cognition [14] may explain the observed decrease in total glance times off road when texting hand-held compared to texting with the phone in a holder when the effects of the distance of the phone from the driving scene were controlled (H5 partly supported). Well-rehearsed tasks can be performed more efficiently with fewer resources (visual resources in this

case) than novel tasks. In addition, the instability caused by the movements of the simulator's motion platform was presumably easier to control while the phone was in hand compared to the holder. The instability may have increased the visual demands of texting when the phone was in the holder by increasing demand of pointing accuracy. Our driving simulator had only two degrees of freedom, and although it is capable of simulating some of the road surface roughness, the demand of pointing accuracy for buttons on fixed touch screen displays is probably even greater on real roads. However, there were no significant differences between the hand-held and holder trials with the other NHTSA [10]-based in-car glance metrics (mean in-car glance duration or percentage of over-2-second in-car glances). This suggests that the participants were equally inefficient in visual sampling towards the smart phone display even if the total visual load of the hand-held texting was lower compared to the holder texting.

Surprisingly, there was a significant inverse correlation between the distance of the phone from the driving scene and total in-car glance duration. We expected a positive correlation, as greater distance from the driving scene should mean greater gaze transition time between the device and the road. However, there was a significant inverse correlation also between the distance and the number of in-car glances, and no correlations between the distance and mean in-car glance duration or the percentage of over-2-second in-car glances. This means that the closer the phone was to the driving scene, the more glances were made towards the phone but that the individual glance durations stayed within similar range across the different positions. The finding suggests that the participants made more inefficient but brief in-car glances towards the phone when the phone was closer to the driving scene than farther apart. This could suggest the drivers divided visual attention between focal (the in-car task) and peripheral (lane-keeping) vision while the phone was close to the driving scene [16].

The participants did not report the hand-held trial less demanding than the holder trial (H4 rejected). This is an interesting discrepancy that should be further studied. It seems the participants experienced the same level of workload regardless of the phone position. It is possible that the (experienced) task workload and the task performance or (objective) demands are not necessarily in a linear relationship, as suggested by the multiple resources theory by Wickens [18]. The participants may have evaluated task demands also on other resources than on the visual resources only. However, NASA-TLX does not enable this level of analysis on the experienced demands on different information processing resources.

Together with visual distraction ("eyes off road") and cognitive distraction ("mind off road"), manual distraction is often listed as one of the basic forms of driver distraction. Manual distraction is defined as "any physical

manipulation that competes with activities necessary for safe driving" by [3] (p.62). Typically this refers to driver's other hand (or both hands) being off the steering wheel. One could argue that there is more potential for manual distraction when texting hand-held than when the phone is in a holder. However, the possible increase in manual demands while texting hand-held did not come visible in the lane-keeping performance. Actually our fairly experienced drivers seemed to drive more accurately while texting with only one hand continuously on the steering wheel (the hand-held trials) than with the possibility to place the both hands intermittently on the steering wheel (the holder trials). However, the situation could be different when driving a vehicle with manual transmission.

We let the participants adopt different styles for holding the phone in the hand-held trials (Figure 2). Some of them placed the phone close and above the steering wheel, possibly enabling the use of peripheral vision for lane-keeping [16] while texting. The holder can undermine drivers' ability to develop these kinds of beneficial multitasking strategies.

The findings should be considered when planning legislation and regulations on drivers' on-road behaviors. In the worst case scenario a fine for (well-rehearsed) hand-held texting could lead to a undesirable scenario, in which the driver is encouraged to text in a less efficient, less pleasant, and less safe way than what the driver has been used to. A better option than this would be a total ban for texting while driving, although polls such as [8] suggest that fines and regulations won't stop drivers from texting. More efficient counter-measures could be educational or technical, such as autonomous driving assistants or distraction warning systems. Novel in-car user interfaces for text entry is another significant avenue (e.g., [9]). Text entry via dashboard touch screens has been observed to be visually highly demanding, and thus, risky activity while driving (e.g., [7][17]). A good goal for user interface designers would be such novel in-car user interfaces for texting, which the drivers are able to use in a safe manner without much practice as efficiently and comfortably as when texting with their hand-held smart phones without the driving task simultaneously competing for the same information processing resources. It would be naïve to think that the current in-car dashboard embedded touch screen based interaction methods to replace interactions with smart phones while driving would be able to achieve this goal.

CONCLUSION

The effects of texting while driving and the effects of the mobile phone position (hand-held, holder) on participants' lane-keeping performance, experienced workload, and in-car glance durations were studied in a motion-platform driving simulator with 24 participants. The known negative effects of texting on lane-keeping performance, workload, and visual attention on road were found. The data also indicates a novel finding that hand-held texting led to

improved lane-keeping accuracy and decreased total glance times off road than texting with the phone in a holder. Suggested explanation is that the drivers were significantly more experienced in hand-held texting than texting with the phone in a holder, and thus, owned well-rehearsed motor patterns for the hand-held condition. Additionally the instability caused by the movements of the simulator was supposedly easier to control when the phone was hand-held compared to the holder. Surprisingly, there was a significant inverse correlation between the distance of the phone from the road and total in-car glance duration as well as the number of in-car glances. The finding suggests that the participants made more inefficient but brief in-car glances towards the phone when the phone was closer to the driving scene than farther apart. The findings should be considered when planning legislation and designing novel in-car touch screen based interaction methods to replace interactions with mobile phones while driving.

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