The Impact of Distraction on Driving Behaviour of Car Drivers in Urban Traffic. Results of a Simulator-Based Study.

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Abstract: Aim of this study was to evaluate the effect of different sources of distraction on driving behaviour. Six experimental conditions were included in three simulator tracks: (1) reading and writing texts, (2) talking on the phone (hand-held and hands-free), (3) eating and drinking. In total, 63 participants completed three experimental and one control track in the StiSim3 driving simulator. Simulator driving and self-reported data were gathered from all subjects, eye-tracking data for a part of the sample. Results, obtained by applying (generalized) mixed linear models, indicate that, compared with the other distraction sources, reading and writing of texts had most detrimental effects on the simulated driving (i.e. lower mean driving speed, increased reaction time and standard deviation of lateral position). The eye-tracking results are in line with this finding: percentage of gaze at relevant screen areas for text reading and writing was lower compared to control condition. Interactions were found with age and particularly gender, suggesting that females, and to some extent middle-aged drivers compared to young drivers, are more likely to engage in self-regulating activities than males when distracted. Finally, perceived effects of the different distraction sources were largely in line with actual driving performance.

1. Introduction

1.1 Background

Distraction in road traffic is a familiar and yet increasing area of concern for road safety. On an international level, it is estimated that distraction plays a role in 5% to 25% of all traffic accidents [1, 2]. In Austria, distraction together with inattention is the main cause in one third of all injury related traffic accidents [3]. The three distracting activities that take up most of the driving time are talking to passengers (15.3%), followed by eating and drinking (3.2%) and use of mobile devices (1.3%) [4]. A previous analysis of distracting effects of mobile phones showed that, although talking on the phone seems to have no effect on crash risk, visual-manual phone tasks, such as dialling or texting messages, significantly increase crash and near-crash risk. Furthermore, distracted drivers look away from the road for a long time and therefore distance. The average duration drivers have their eyes off the road is 23.3 seconds while texting messages, 7.8 seconds while dialling and between 0.5 and 2.5 seconds when starting a hands-free call [5].

Based on an extensive phone survey [6], it was found that the most common distractors in Austrian traffic are conversations with passengers (95% at least occasionally), followed by daydreaming respectively to be lost in thoughts (87%) and drinking (57%). Thirty-nine percent eat while driving at least occasionally. About one third of the responding car drivers call someone at least occasionally. Of these phone calls, 18.5% are made without a hands-free equipment. About half of the car drivers answer phone calls during driving at least occasionally, 32.6% of them do so hand-held. A further risk is reading and writing text messages. Forty percent state that they check for incoming messages, text actively or read text messages – 5% even "often". An extrapolation of answers from a previous survey, which focussed on phone use while driving, showed that about 73 million of text messages are sent from Austrian cars every year. Assuming that drivers do not look at the street for five seconds per text message, on an average speed of 50 km/h, Austrian cars would cover a distance of 128 times around the equator (5.1 million of kilometres) every year while driving blind.

A KFV-expert panel assessed the extent to which the attention required for participating in traffic is hindered by visual, auditory, motoric and/or cognitive demands while performing common side activities while driving. Phoning, texting (reading and writing) and eating/drinking were ranked as top three.

1.2 Research Questions

The aim of the current study was to evaluate the effect of these top three distracting activities on driving behaviour of experienced Austrian drivers, within a repeated measures design. The research questions were the following:

1. What is the impact of reading and writing text messages, hand-held and hands-free phoning, eating and drinking on five key aspects of driving behaviour and safety measures (speed, standard deviation of lateral position, detection and reaction time to sudden critical events, crashes)?

2. Which differences can be observed in gaze behaviour between different driving conditions (no distraction and six distracting activities)?

Although this is a well-researched topic, the aim is to add to the exiting literature by also including interactions with age and gender as well as subjective data.

This study is an extended replication of a Belgian study on the effects of texting on driving [7].

2. Methodology

2.1. Participants

The sample consisted of 63 participants, equally distributed over four groups by age category (20-34 and 35-49 years) and gender. Participation was voluntary. Inclusion criteria were: min. 5,000 km car driving in the last 12 months and experience with Samsung Galaxy smartphone. Participants were asked to bring their smartphone, earplugs (if available) and glasses. They were compensated with 50 EUR.

2.2 Materials

2.2.1 BRSI driving simulator StiSim3: The simulator consists of a fixed-base set-up including a car seat, steering wheel, pedals and an automatic gearshift for this study (see Figure 1). The driving scene is visualized up to a visual field of 120° using three LCD television screens. The simulation is displayed as a driver’s view from the inside of the car and allows a view of the surroundings through the front and side windows as it would be in a real car. The surrounding environment is displayed on three simulated mirrors on the screens. Dashboard information is displayed on the middle screen.

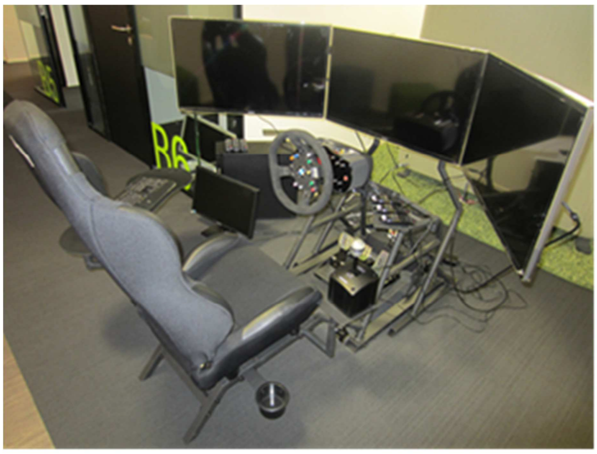


Fig. 1. *StiSim3 driving simulator*

2.2.2 Simulated test tracks and secondary tasks:

Four test tracks with a length of 5 km (8-10 minutes) with similar traffic characteristics were developed: two-lane-urban road, 50km/h speed limit (road signs), no red lights, moderate traffic, non-intrusive other road users, light curves left and right, daylight and fair weather (see Figure 2).

Fig. 2. *Snapshot of the driver's view on the track*

There were three (experimental) tracks involving secondary tasks and one control track in which no additional task was required. Every track consisted of four relevant sections. In total, each participant thus drove through 16 sections: 12 involving a secondary task and four control sections. The three experimental tracks included the following sections:

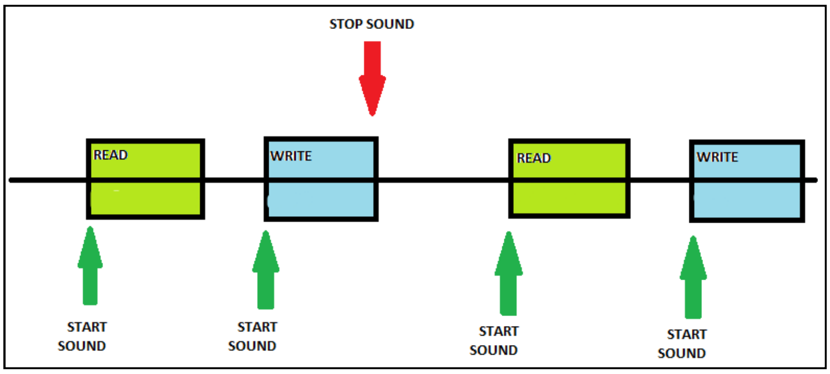
(1) Texting: two text reading and two text writing sections. In the reading tasks, participants were asked to read a real-time standard message (128 characters) ending with a request to send a message back; the texting tasks were to answer to the received message (five examples of vacation destinations respectively types of vegetables/fruits).

(2) Phoning: two hand-held phoning and two hands-free phoning sections, with naturalistic conversations with standard questions in a fixed order (“Name five examples of e.g. car brands, zoo animals)

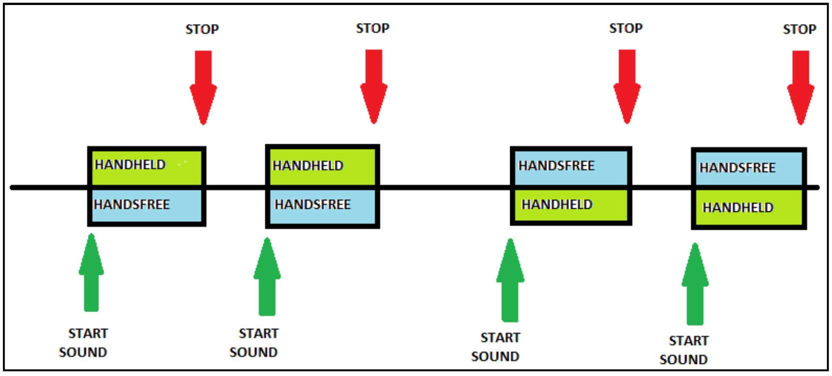
(3) Eating/drinking: one continuous eating task, respectively drinking task, running over two sections (including opening/unpacking)

The order of the sections was fixed in the texting scenario and counterbalanced between participants in the phoning and eating/drinking tracks. See Figure 3 for an overview of the experimental set-up.

(a) Texting track



(b) Phoning track



(c) Eating/drinking track

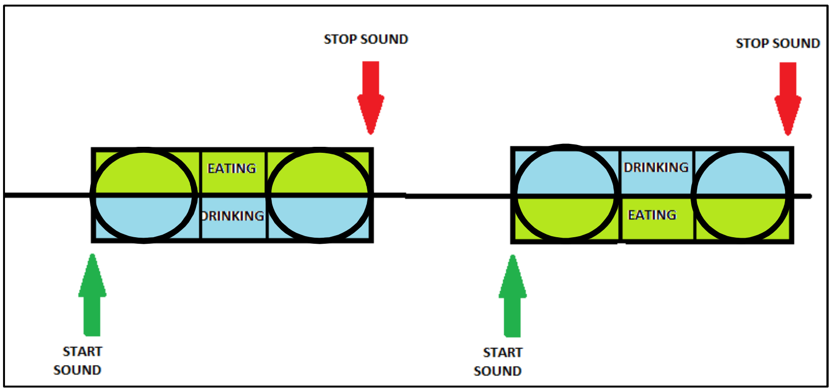


Fig.3. *Schematic outline of the four task sections in the experimental tracks, which were used for final analysis: in subfigures a) and b) the blocks and in c) the circles in the blocks. The blocks refer to the time windows of each experimental task, with start and stop sounds for initiating and ending (if not finished before) the task. The different tasks above and under the centre line in b) and c) refer to the counterbalanced order between participants.*

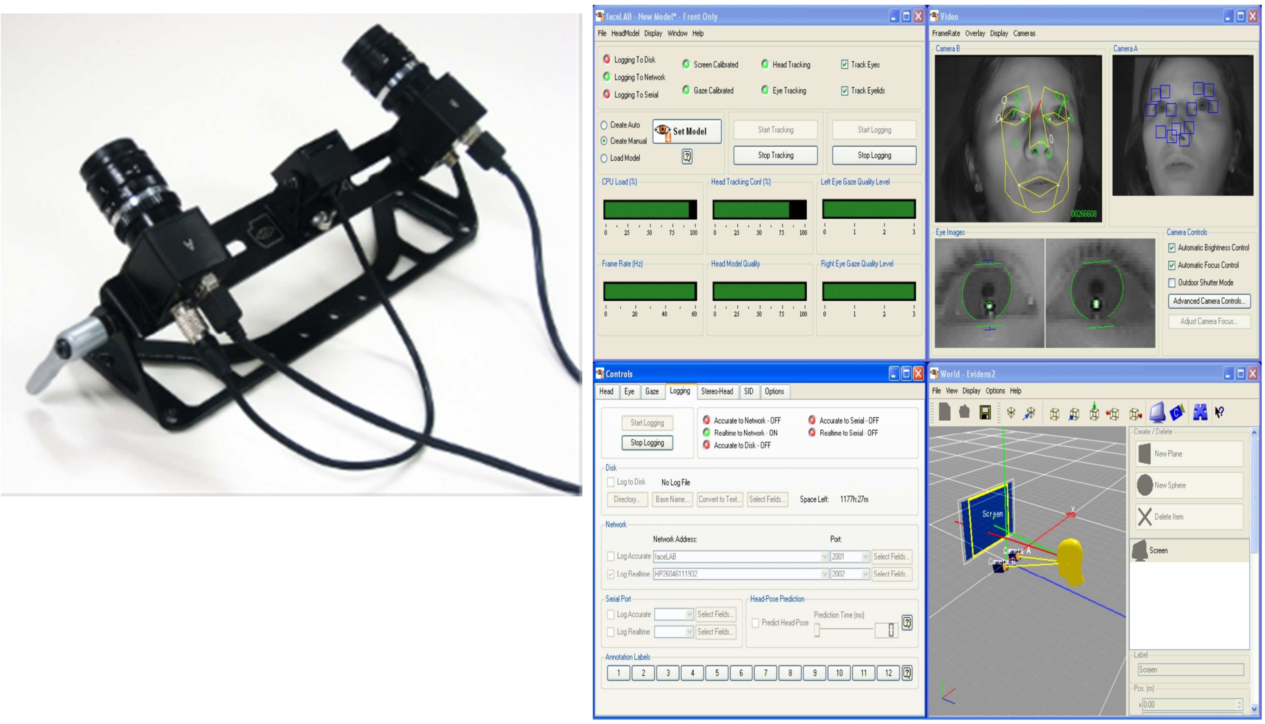
Start and end point of each section was identical in the four scenarios. In order to reduce order effects some environmental characteristics within each section differed. In the tracks with secondary tasks the onset and stop of the tasks was announced by a start and stop sound programmed in the scenario.

In each section one critical event (CE) was programmed (16 in total) which required braking and/or a full stop depending on the driver's speed. The critical event was always a pedestrian suddenly crossing the road from behind parked cars on the right side (see Figure 4).

Fig. 4. *Critical event*

2.2.3 Questionnaires: a pre- and a post-questionnaire had to be completed before and after the experiment as well as a post-ride questionnaire after each experimental track to assess how the drive and tasks were experienced. In the current paper, only the subjective post-ride data will be discussed, including items like perceived required effort, self-evaluation of driving performance and perceived effects of the distraction tasks.

2.2.4 Eye-tracking: The FaceLab automotive desktop system was used for gaze-tracking in a nonintrusive way. This device allows tracking of eye-movements up to 90° horizontally (i.e. central simulator screen) and head movements up to 180°. FaceLab (see Figure 5) uses a set of cameras as a passive measuring device. These cameras were placed on a platform just behind the steering wheel, without hindering the participants’ view on the central screen. Using the EyeWorks Premier Analysis Software real-time data integration with the StiSim simulator could be applied. With EyeWorks, each driven test track was captured on video including a visual overlay of the gaze-tracking on the track scene of the simulator’s central screen.



(a) Hardware

(b) Software

Fig. 5. *FaceLab technology*

2.3 Procedure

After arrival, the participant filled in the pre-questionnaire. Then the different experimental devices were checked (phone/earplugs). Phone settings were: removed shell case, sound off, display unlocked. Automatic word filling was not changed from the original setting. A trial of texting took place as well as of phone answering with and without earplugs. Finally, something to eat and to drink was chosen. The simulator part started with the configuration and calibration of the eye-tracker. Only if calibration resulted in a mean angular error below 2° without central deviations, eye-tracking was included. First two familiarisation rides (10 minutes) took place, including another trial of phoning with earplugs. Then all devices were placed on a chair on the right side of the driver and standard start-up instructions were given. Participants were asked to drive as they normally would under similar circumstances. Then the three experimental and control tracks were driven according to the prefixed counterbalanced order. After each drive, a post-ride questionnaire was administered, and at the end of the entire experiment another post-questionnaire. The entire procedure lasted approximately 75 minutes.

2.4 Study design and analysis

This study was a laboratory experimental repeated measures (within-subjects) design with one control and six experimental conditions. The order of the conditions was counterbalanced between the participants to reduce fatigue or learning effects. Besides within-subject comparisons of experimental and control conditions, the recruited sample also allowed between-group comparisons based on two age categories (20-34 and 35-49 years) and gender. For all participants driving and self-reported data were gathered, as well as eye-tracking data for a part of the sample.

The effects of different types of distractors were evaluated on five key driving parameters. The definitions of these dependent variables were derived from previous research investigating effects of distraction on driving [e.g. 8, 9, 10]. Matlab © (Release 2015a, Mathworks) was used to extract the five dependent variables:

- **Mean speed**: Mean of the driver speed within each relevant section (m/s)
- **SDLP**: Standard deviation of the lateral lane position of the driver vehicle, referenced in relation to the centre of the vehicle with respect to the roadway centre dividing line, within each section (m).

The relevant sections begin at the start sound (task onset) and continue until just before the onset of the critical event (see Figure 6). Free segments without traffic lights, road hazards or other events are required as these influence the speed and SDLP. In case of a crash before the CE, the speed value was invalid.

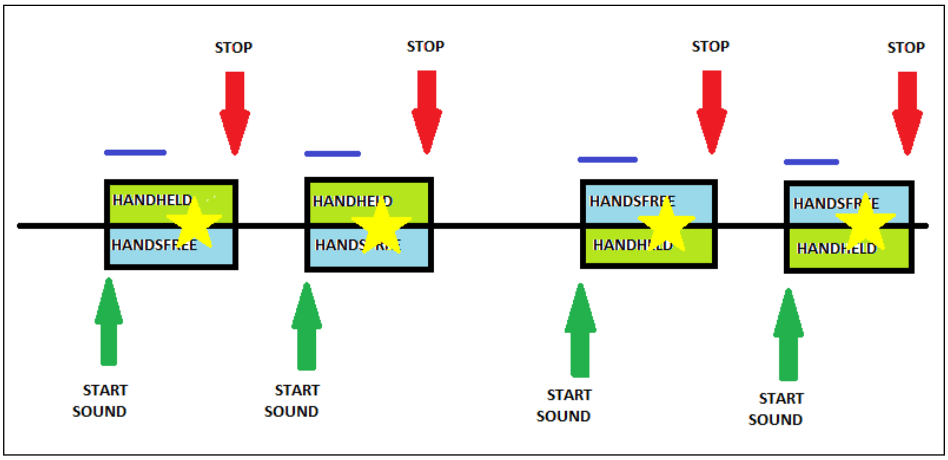


Fig. 6. *Relevant sections for mean speed and SDLP in the texting track*
Defined section for measuring mean speed and SDLP: ▬ *(line above boxes)*
Star = critical event

- **Detection time and reaction time to critical events:** Time difference between the onset of the CE (t0 = when speed CE > 0 m/s = pedestrian starts to cross) and a 10% throttle or gas pedal release (for DT) and a 10% brake pedal press (for RT) relative to the CE onset (t0) (s). This 10% criterion was used to avoid accidental releases/presses.

Basic additional principles are that both are only determined within the “CE time window”, starting from CE onset until the CE was passed). Calculations are ignored in case of a crash with the CE and/or overtaking. In case the 10% criterion cannot be met at the CE onset, it was considered a missing value.

- **Crash with CE:** yes/no

The following subtasks were valid for analysis:

- Reading/writing texts: take phone, open text box, read/write, send back, lay back
- Hand-held/hands-free phoning: take phone, open call / pick up via earplugs or phone, listen/talk, lay back
- Eating/drinking: take food/bottle, open, eat/drink without long pauses, lay back

Mathematical models were developed for the five dependent driving variables using R software for statistical computing and graphics (R Core Team, 2015). The base models include age category (2), gender, number of kilometres driven in the last 12 months, a composite score of self-reported distraction behaviour while driving, and task order in the experiment (to capture biases from ordering) as fixed factors (independent variables) and subject as random factor. Linear Mixed Models (LMM) were made for continuous driving variables and Generalized Linear Mixed Models (GLMM) for crashes (binomial). The purpose of these models is to estimate the effects of the different independent variables on each dependent driving variable, while taking into account random effects (heterogeneity across individuals).

The self-report composite is a score of reported frequency of involvement in the six experimental distraction activities while driving in the past 12 months (pre-questionnaire).

The aim of the eye-tracking analysis was to determine visual distraction; thus, to find out how much time participants looked at (respectively aside) driving relevant areas during the secondary distraction tasks. Different measures are suggested in literature. Fixations, percent road centre, field relevant for driving and areas of interest have been used for analysing eye-tracking data [11]. In this study, gaze frequency and duration were analysed for different “driving relevant areas” which were created using the software EyeWorks Video Analysis: the road centre, the rear mirror, the speedometer and the tachometer.

IBM SPSS Statistics 22 was used for analysing the self-reported and eye-tracking data.

3. Results

3.1 Simulator driving variables

The participants’ performances on the five driving variables were compared for the different distracting tasks. The results of the continuous variables are presented in the boxplots (median, upper/lower quartile, minimum/maximum and outliers) in Figure 7.

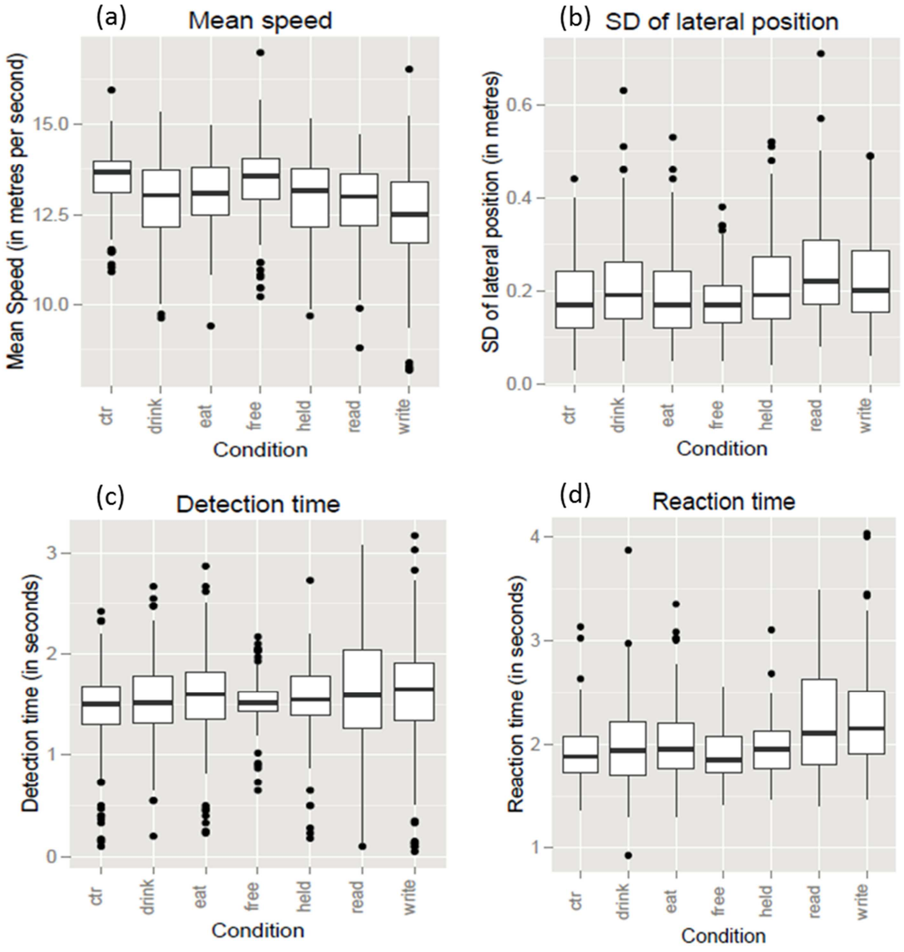


Fig. 7. *Boxplots for the continuous driving measures*
a Boxplot mean speed
b Boxplot standard deviation of lateral position
c Boxplot detection time to critical event
d Boxplot reaction time to critical event

Figure 7(a) shows that the mean speed was generally lower in all distraction tasks as compared to control, except for the hands-free phoning condition. Figure 7(b) shows that the measures of variability of the lane position were highest for text reading, and Figure 7(d) indicates that mainly reading and writing text messages slowed down reactions as compared to control.

To further investigate whether these differences are statistically significant, (generalized) linear mixed models were developed. Table 1 presents the parameter estimates (Est.) and standard errors (S.E.) for the different factors in the models for the five driving measures. Only the results for the significant interactions are presented in the table.

Table 1. *Parameter estimates and standard errors for the different factors in the (G)LMM models for the driving variables.*

Term	Mean speed		SD of lateral position[1]		Detection time		Reaction time		Crashes	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Intercept	13.16***	0.36	0.20***	0.02	1.43***	0.11	1.97***	0.10	-3.89**	1.19
Text reading	-0.82***	0.19	0.05**	0.02	0.24*	0.11	0.37***	0.08	3.34**	1.15
Text writing	-1.13***	0.19	0.02 ’	0.01	0.15	0.10	0.31***	0.07	1.75	1.29
Hand-held phoning	-0.68***	0.19	0.01	0.01	0.22*	0.10	0.03	0.07	1.89	1.24
Hands-free phoning	-0.30	0.19	-0.001	0.01	0.09	0.11	-0.02	0.08	2.32	1.21
Eating	-0.76***	0.19	-0.01	0.01	0.14	0.11	0.11	0.08	2.19	1.32
Drinking	-0.94***	0.19	0.02	0.01	0.12	0.10	0.11	0.07	2.19	1.30
Self-report composite	0.14	0.13			0.01	0.04	-0.01	0.04	0.16	0.21
Age category (ref: 20-34)	-0.17	0.22	0.02	0.02	0.05	0.08	0.08	0.07	1.89	1.09
Gender (ref: female)	-0.06	0.23	-0.03*	0.01	0.06	0.08	-0.03	0.07	-0.02	0.79
Km last 12months	0.08	0.10			-0.01	0.03	-0.02	0.03	-0.03	0.15
Task order (1 to 16 tasks)	0.01*	0.01			-0.01	0.00	-0.01**	0.00	-0.16***	0.03
Interactions										
read x gender	0.51*	0.21					-0.22*	0.09		
write x gender	0.63**	0.21					-0.14’	0.08		
held x gender	0.45*	0.21			-0.24*	0.12				
drink x gender	0.75***	0.21					-0.16’	0.08		
read x age catg.			0.05*	0.02						
write x age catg.	-0.49*	0.21					0.20*	0.08		
held x age catg.			0.05*	0.02						
eat x age catg.			0.04*	0.02						

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘’’ 0.1

[1] Due to much noise in the data, this model was simplified by removing the self-report composite, km driven last 12 months, task order and the interactions with gender. In the full model, there was only one significant interaction effect with gender.

3.1.1 Mean speed and standard deviation of lateral position: All distraction tasks led to a significant decrease of mean speed compared to control, except for hands-free phoning. Text writing displayed the biggest effect on the driver's speed. Gender also plays a major role for specific experimental conditions: women drove significantly slower during drinking, text writing, hand-held phoning and text reading. Middle-aged participants drove significantly slower than young ones during text writing. On SDLP, generally very small effects of the different experimental conditions were observed. However, there was one significant effect: while text reading the SDLP was significantly higher than in the control condition (a trend during text writing). Male participants in general showed better lane keeping than females. Furthermore, the older age group (35-49) had significantly more deviations from the central lane position as compared to the younger group (20-34) during text reading, hand-held phoning and eating.

3.1.2 Detection and reaction time: The LMM indicates that the time to detect critical events increased significantly during text reading and hand-held phoning. Furthermore, female participants detected the critical events significantly slower than the males during hand-held phoning. The LMM for reaction time indicates slower reactions to critical events while reading and writing text messages compared to control. There was also a significant task order effect suggesting a learning effect. By counterbalancing task order, this effect was controlled for. Furthermore, female participants reacted significantly slower during text reading and to a lesser extent also during text writing and drinking (trend). Middle-aged participants reacted significantly slower to critical events during text writing.

3.1.3 Crashes: In total, there were 83 crashes with critical events during experimental and control conditions. Most pedestrians were hit during text reading. The GLMM indicates that text reading led to a significantly higher probability of accidents. There was also a clear learning effect, related to the expectation of the critical events, leading to fewer accidents in following tasks. This was expected so task order was counterbalanced.

3.2 Post-ride questionnaires

The questions asked after each experimental test track focussed on the subjective evaluation of driving performance while performing the different distraction tasks. All questions were answered on a 7-point rating scale, with score seven indicating most (detrimental) effects. Task related differences were analysed with the Friedmann Chi-square test, p values are reported in the text below. The results show that participants perceived most negative effects on their driving during texting (reading and writing). More specifically, participants evaluated their general driving performance as significantly poorer during the texting tasks than during the phoning, eating and drinking tasks ($p \leq 0.01$). Also, the perceived needed effort differed significantly ($p \leq 0.01$), with text writing requiring most effort (mean score of 6.2 on 7) followed by text reading (5.5) and hand-held phoning (4.3). Self-evaluated driving performance (“How well do you think you drove during the task?”) also differed significantly ($p \leq 0.01$). The evaluation was worst during text writing (6.4), followed by text reading (5.9) and hand-held phoning (5.1). The different distraction tasks required significantly different levels of concentration ($p \leq 0.01$). Participants indicated that most concentration went to text writing, then text reading, followed by hands-free phoning. According to the participants, the distraction tasks also differed significantly in their effects on driving speed ($p \leq 0.01$). Text writing led to the biggest decrease of driving speed while for hands-free phoning the smallest decrease was perceived. Further, participants perceived significantly more difficulty to keep the central lane position during texting (writing and reading) as compared to the other distractions ($p \leq 0.01$). Finally, the different tasks had different effects on perceived awareness towards road hazards ($p \leq 0.01$). Participants felt less aware during texting as compared to the other distractions.

3.3 Eye-tracking

Gaze data were available for 37 participants (for other participants, calibration was not valid or they were excluded after data cleansing). Furthermore, sample size varies between conditions. The tasks “eating” and “drinking” were subdivided into “opening/unpacking” and “consuming”. Due to little data on “drinking in terms of consuming” (n=9) this condition was excluded from further analysis.

Figure 8 presents the average gaze on driving relevant areas during control and distraction tasks.

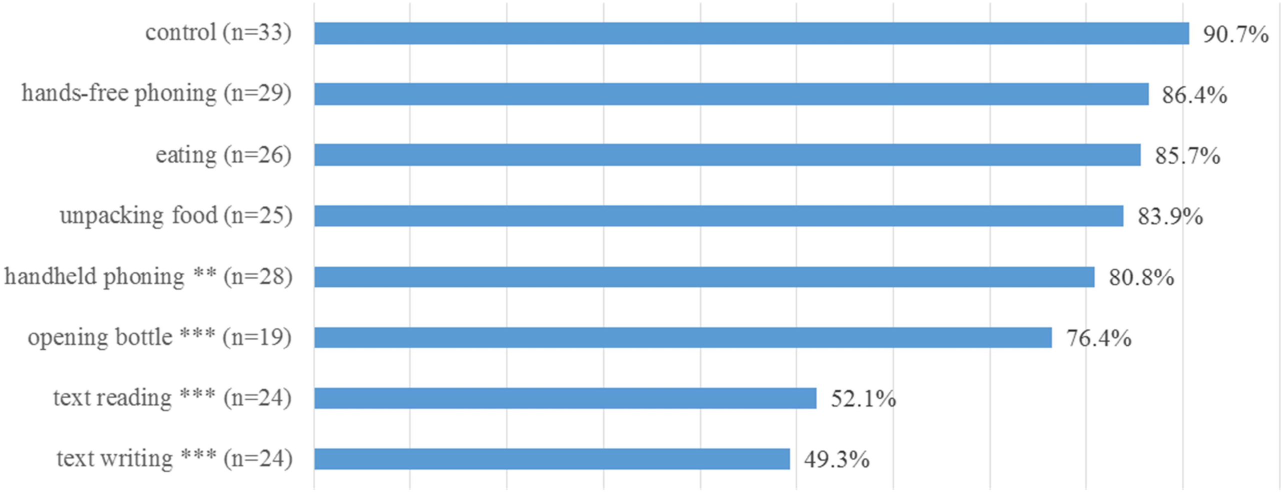


Fig. 8. *Average gaze on driving relevant areas during different conditions*
*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05*

Participants showed the longest average gaze on driving relevant areas during driving without any distracting activity (control). ANOVA post-hoc (Dunnett-T) test results comparing the different experimental tasks with the control condition indicate that during texting (both writing and reading), the average gaze on driving relevant areas decreased significantly to half of the time driven ($p < 0.001$). Furthermore, hand-held phoning ($p = 0.007$) and opening the drink bottle ($p < 0.001$) led to significantly fewer gaze on relevant areas. Regarding age, no significant differences were found. A significant gender-difference was found for text reading, with male participants more often averting their eyes from driving relevant areas (52.8%) than female participants (42.1%).

4. Summary and conclusions

The results of this study show that text reading had most significant effects on the driving behaviour. Participants drove slower, had worse central lane positioning, responded slower to critical events and had more accidents. During text writing, speed decreased even more, and participants responded significantly slower to critical events. In line with this, eye-tracking data revealed that gaze percentage to driving relevant areas decreased to 52.1% during text reading and even to 49.3% during text writing. This confirms the visual distraction caused by texting. These results are partly in line with Boets and colleagues [7], where also a significant effect on the speed during text reading and writing and a significant increase of detection and reaction time while text reading were observed. In the current study additional significant effects of text writing on reaction time and of text reading on accidents were found – which is generally more in line with other studies [e.g., 12, 13]. The effects of hands-free phoning were rather limited but this condition suffered from quite some invalid (missing) data due to earplug handling problems. On the other hand, the results show that hand-held phoning had endangering effects on driving. Of the six sources of distraction studied, eating and drinking had the least effects on simulated driving (decreased mean speed), although gaze results separately focussing on the act of opening a bottle indicated that this did have clear negative impact on the visual behaviour while driving.

Mean speed was generally affected by the distraction sources, suggesting a general compensatory mechanism to increase the margin for error when being distracted. In conclusion, these results indicate that the distracting tasks competing most with the different resources required for driving (i.e. texting involves visual, cognitive and manual resources), have the biggest impact on the task of safe driving. This is in line with other studies [e.g., 14, 15].

There was a rather good resemblance of the ranking of distraction sources based on “perceived effects” and “effects on driving performance”. Participants indicated that both texting tasks required most effort and had biggest effects on their driving, followed by hand-held phoning, while this was clearly perceived less for the other tasks. For texting this is in line with other research [e.g., 16]. Nevertheless, subjective, visual and drive data did not fully match: e.g. text writing was perceived as most detrimental, matching with the gaze data results, but text reading had most effects on the driving. Discrepancies in subjective and drive are also found in other studies [e.g. 17]. The subjectively worst rated distraction task did match with the biggest decrease of mean speed though (text writing), a compensation mechanism which might have lowered the occurrence of effects on other driving parameters.

There were some interesting interaction effects for age and gender, suggesting that specific distraction sources influenced the driving behaviour of female and middle-aged participants differently. Females showed more compensatory behaviour during texting, hand-held phoning and drinking. Middle-aged participants (35-49) especially had less good lane keeping ability during texting, hand-held phoning and eating, and they drove significantly slower during text writing. This result is partly in line with other studies indicating that older drivers decrease their speed more than young drivers, although detrimental effects of in-vehicle distractions also often seem to be quite stable over age and gender groups [e.g., 14, 18]. It should be noted that the interaction effects for texting could also be related to exposure differences: male and young participants reported significantly more to have texted while driving in the last year and middle-aged participants reported a much smaller number of received/sent text messages on an average day.

In conclusion, the results of this study add to the weight of scientific evidence that texting – compared with phoning, eating and drinking – has clear degrading effects on driving performance, leads to significantly more visual distraction and leads to an increased accident risk. Subjective data also rank texting as most demanding and most affecting the driving behaviour, but subjective, visual and drive data are not completely in line. The results furthermore suggest that there are some particular age and gender related effects of different distraction sources, but these can also be linked to different levels of exposure. A suggestion for further research are study designs allowing drivers to decide themselves how and when to perform distracting activities (strategic compensation). Considering the rapid technological evolutions of communication devices, a multitude of possible additional distraction activities affecting visual, manual and cognitive resources, can be expected in future. Combined efforts with regard to legislation, enforcement, blocking technologies, campaigns and education continue to be required.

5. References

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