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Do in-car devices affect experienced users' driving performance?

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ABSTRACT

Distracted driving is considered to be an important factor in road safety. To investigate how experienced user's driving behaviour is affected by in-vehicle technology, a fixed-base driving simulator was used. 20 participants drove twice in a rich simulated traffic environment while performing secondary, i.e. mobile phone and navigation system tasks. The results show that mean speed was lower in all experimental conditions, compared to baseline driving, while subjective effort increased. Lateral performance deteriorated only during visual–manual tasks, i.e. texting and destination entry, in which the participants glanced off the forward road for a substantial amount of time. Being experienced in manipulating in-car devices does not solve the problem of dual tasking when the primary task is a complex task like driving a moving vehicle. The results and discussion may shed some light on the current debate regarding phone use hazards.

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1. Introduction

The driving task is complex; next to managing the vehicle to stay on the road properly, the driver has to deal with thoughts, speed limits, flies, children, and other drivers who are doing similar things at the same time. Recent years have provided us with vast technological developments like smart phones and navigation systems, adding ease to life in general, but largely increasing the potential for the driver to engage in other, distracting, tasks while driving.

Distraction from driving has many faces, but basically consists of visual, manual, cognitive and auditory distraction [1]. Distractions may often combine these four modes (e.g., dialling the radio likely involves visual, auditory and manual resources). Definitions of distraction may be summarized as *diversion of attention away from driving, to a competing task* (see [2,3]).

In the 100-car naturalistic driving study, 100 instrumented cars were driven for a year or more, during which 69 crashes and 761 near-crashes occurred. Analyses showed that 80% of the drivers were inattentive to the road ahead at the moment just before a crash, while 65% of the drivers were inattentive before a near-crash [4]. Both crashes and near crashes were highly associated with cell phone and PDA (Personal Digital Assistant) use. Since the 100-car study large numbers of (smart) phones and also navigation systems have been sold, so the problem has likely aggravated. The current study therefore specifically focuses on the effects of a (contemporary) navigation system as well as drivers using their own mobile (smart) phones on driving performance.

The tasks associated with navigation systems and smart phones are, however, substantially different; phones may be used for having conversations, which is a cognitive, auditory task, as well as for operating tasks such as texting, e-mailing or 'facebooking'/'twittering', which is visual–manual with cognitive components. Navigation systems may provide route guidance instructions (auditory and visual), but at least the destination needs to be programmed, which may be done while driving (visual–manual task). Where phone conversations while driving have been investigated in an abundance of studies, texting and, in particular navigation systems related tasks were relatively scarcely the topic of investigation.

1.1. Mobile (smart) phones

Phone use while driving has been present and investigated for more than two decades (see [5]). Effects of phone conversations while driving have been assessed using driving simulators, instrumented vehicles on normal roads and on test tracks (a recent review of the literature can be found in [6]). Nevertheless, effects on driving performance, or more specifically on crash risk, are still under substantial debate [7,8]. Many

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countries have only forbidden handheld phone conversations [9], in spite of the fact that hands free conversations may cause equivalent effects on driving performance [10,11]. Potential effects of phone conversations while driving include a reduction in visual scanning for other traffic [12], which leads to a 'gaze' [13] to the centre of the road ahead. This effect may lead to reduced detection of peripheral events, for instance, traffic signs [14], whereas lane keeping performance seems to be hardly influenced [15]. Handheld conversations while driving lead to lower speed [15,16], whereas hands free driving may even increase speed compared to baseline driving [16]. Furthermore, having a phone conversation has been shown to increase workload anyway [17].

Operating a phone while driving has only become increasingly popular in the last decade, but few studies have assessed operating a phone compared to conversations per se. Still, it has been recognized as a hazard; while being involved in a phone conversation predominantly leads to cognitive distraction, reading and operating will additionally lead not only to visual distraction [18,19], but may also have a physical effect. This may lead to a substantial increase in reaction time [20], as well as deteriorated lateral control [18,21,22] and reduced speed [15,20]. Furthermore, drivers report higher mental workload while texting [18].

1.2. Navigation systems

Navigation systems have been available for drivers in private cars for about 15 years, and in recent years have become increasingly affordable for the mass market. Portable specific navigation devices are the topic in this study, specifically nomadic devices that are brought into the car by the driver, although navigation software has become available on smartphones as well [23]. Effects on driving performance have not received much attention in the literature.

The main function of a navigation system is to provide route guidance to a driver, turn by turn, visually and/or auditory. The driver does not need any paper map, notes with instructions, or pre-trip search and learning by heart. Compared to driving with a paper map, route guidance has been found to decrease mental workload, increase speed and improve drivers' lateral performance [24]. Though leading to a somewhat increased speed, route guidance decreases drivers' exposure to traffic due to the shortened routes, which might be safer [25,26].

At the start of the ride, the navigation system must be programmed in order to provide the proper route guidance. Besides destination entry, drivers may operate the device for several other reasons such as adjusting the volume or the screen or check for current traffic jams on the route. Most often, this is done using a touch screen, although other options such as voice control and remote controls are available as well.

Compared to voice control, destination entry through a touch screen keyboard requires much more time to complete, and renders a higher standard deviation of lateral position (SDLP) [27]. It has also been reported that drivers tend to drive with reduced speed while operating a navigation system [27,28] and that they look less towards the road ahead [28,29].

1.3. Approach

The current study investigates several types of distraction to the same experienced users in the same environment. The distractions come from two types of modern, extended devices that have improved considerably over the years, as may have drivers' strategies of using them. Experienced users have learned to some extent to use the devices which could lead both to lower task demands (as the secondary task may be easier) and a higher capability of dual tasking (Task Capability Interface model, [30]). Thus, they may be expected to show fewer negative (learning) effects while participating in the study (cf [31]).

The main research question is: to what extent is driving, in a driving simulator, affected by two current sources of distraction, i.e. navigation system and mobile phone use. Specifically, driving performance is investigated while following route guidance and performing destination entry, while having mobile phone conversations and texting, as compared to driving without secondary task.

2. Method

2.1. Participants

In total 21 paid volunteers participated in the experiment; one suffered from simulator sickness and was removed from the study, i.e. 20 persons remained. They were recruited via posters and newsletters at Delft University of Technology (DUT). All participants reported to be frequent users (at least once a week) of both navigation systems and mobile phones, and indicated to drive at least 10,000 km per year (M = 23,638, SD = 6893). The research sample consisted of 6 females and 14 males aged 27–59 (M = 37.65; SD = 9.75) and had their drivers' licence for 2 to 39 years (M = 15.55, SD = 9.32). By definition of Rothengatter et al. [32], the sample does not include any novice drivers, and most (13 of 20) participants should be classified as very experienced drivers.

2.2. Apparatus & driving environment

The fixed base driving simulator (see Fig. 1) consisted of a mock up car with real car seat and controls, and three screens. Its software was developed by StSoftware© [33]. The system allowed for recording several variables, derived from lateral and longitudinal position in the virtual world such as speed and position on the road, at 10 Hz. Two webcams were used to record the drivers' face and the central screen. The simulator was set up in an air conditioned room that allowed for a constant 20° Celsius, in order to minimize simulator sickness [34].

Two simulated tracks were implemented that resembled different parts of a 'real' route that was driven in the framework of the EU INTERACTION project in the Delft–Leidschendam area. The first track consisted of about 10 km urban area (50 km/h speed limit) and 9 km of motorway (100 km/h limit), while the second track resembled a 10 km interurban road consisting of several speed zones (50, 70, 80, 100 km/h). Road signs, layout and size were simulated as accurately as possible, whereas other surroundings (buildings, trees, etc.) were mimicked more loosely. Other traffic was programmed to drive interactively, resembling off-peak real life traffic density. The first two kilometres of both tracks were used for familiarising participants with driving in the simulator.

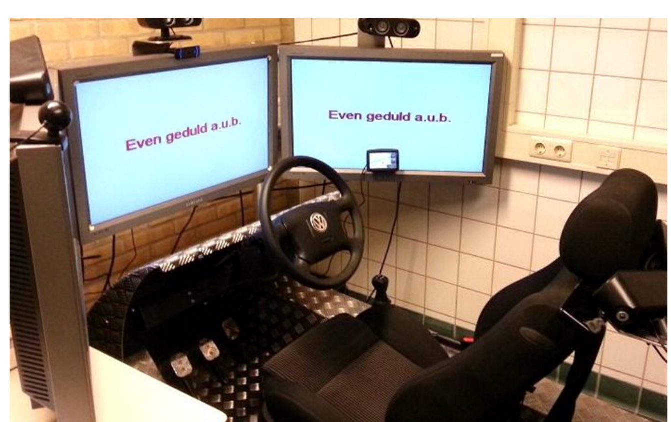

Fig. 1. The driving simulator, with the touch screen navigation system attached to the right hand screen.

2.3. Experimental design

The repeated measures research design consisted of four experimental conditions: phone conversation, texting, driving with route guidance and entering a destination, each with a baseline condition. The comparative condition for driving with route guidance consisted of way finding using a paper map, while the baseline for all experimental conditions involved driving the same route without a device.

Each participant participated in all (eight) conditions. Carryover and learning effects were controlled for by partial and reverse counterbalancing. The partial counterbalancing was performed for track 1 (see Table 1), on which the driving with route guidance, texting and destination entering were performed. The destination entry section was followed by the texting section, and difficult to perform. Therefore it was decided never to combine them in one drive. Furthermore, for convenience reasons it was decided that phoning and texting could always take place in a single session, so the participants only needed to bring their personal (smart) phone to one session (see paragraph 2.5.1).

Next, the two tracks (see Table 1) were reverse counterbalanced over the two meetings, so the drivers could meet four distinct track orders (i.e., first drive track order 1 → 2, second drive 2 → 1, or vice versa). In total, this led to eight distinct potential orders, and the participants were assigned such that at least two met each of the eight orders.

2.4. Procedure & materials

The participants were asked to drive in the simulator twice, with at least seven days between appointments. Five participants were driving the simulator prior to participating in other parts of the INTERACTION project on a comparable route. They provided their informed consent during the first visit, while the others had already consented to participate in the full study. Each visit to the simulator, the participants were told they would have two drives, with a short break in between during which a few questionnaires would have to be completed.

The questionnaires contained the Rating Scale Mental Effort, RSME [35,36] in order to get an indication of how much effort the drivers reported to put into each task. Next, during the first drive, another questionnaire, developed in the INTERACTION project, was filled in, and in the second meeting break the Driver Behaviour Questionnaire, DBQ (as used in [37,38]) was completed.

Before the start, the participants were provided with information about the test drive, dependent on the specific experimental condition they were in. They were always instructed to drive as they normally would. Bugs in the software could occasionally cause objects to behave unnaturally (i.e., indicating the wrong way, not giving priority), due to the complex environment, thus instructed, this was ignored by the participants. The participants were informed that cameras would be recording them. After they had adjusted their seat and felt comfortable, the test drive was started. The fact that each drive included over two kilometres of getting used to driving the simulator was not told to the participants in order to avoid any intentional changes in behaviour.

After finishing the two drives, the participant filled in RSME's for the remaining conditions, and signed a receipt for receiving a gift voucher.

2.5. In-vehicle tasks

2.5.1. Phone conversations

The participants were requested to use their own (smart) phone for texting and having a conversation.

For the handheld phone conversation, the participant was called by an experimenter, from a remote location. The experimenter held a conversation based on a questionnaire that was devised for the INTERACTION project, which consisted of (translated) questions from the Rosenbaum Verbal Cognitive Test Battery (as used in [39]; see [40]), and of questions used by [41]. It consisted of four blocks with five types of questions: True or false questions (e.g., France is a bigger country than Luxembourg), listing questions (i.e. towns beginning with an A), describing questions (i.e., describe a relative), repeating a sentence and answering a question (e.g., which girl is taller if Jane is shorter than Kim?). Each conversation took about seven minutes.

2.5.2. Texting

Texting was performed on a nine kilometre motorway track (speed limit 100 km/h). When the participant reached a certain point, the experimenter asked whether he or she was ready to send a few text messages, allowing the participant to reach for the phone. Then the experimenter asked the participant to text the first sentence from Dutch children's songs (four different texts of 50–63 characters). As soon as the participant had finished texting, the experimenter asked to type in the next text, going on to a maximum of four texts, depending on the participant's texting speed.

2.5.3. Route guidance versus paper map

Driving with route guidance was implemented using the driving simulator's built-in device resembling a simple navigation device mounted on the dashboard providing auditory and visual (arrows) cues 200 and 50 m before the turn. In the 'no guidance' condition, the participants received a paper map of the driving environment (see Fig. 2). The participants were informed that all intersecting streets and side-streets present were also drawn, the tunnels/overpasses (grey) and roundabouts were shown on the map, and the first two were shown in the simulator to give the participant a feeling of the map's scale. In case the participant was about to take a wrong turn, the experimenter interfered, redirected and registered the error.

2.5.4. Destination entry

A retail TomTom XL Live navigation system was used for destination entry. Before the drive, the participants were asked to demonstrate how they would enter a destination, to check whether they understood the device menu. When an example destination was entered successfully, the drive started. During the drive, the experimenter read six destinations that would take 14 to 17 button operations each. As soon as a destination entry was finished and the route had been selected, the experimenter would read the next, to keep the participant constantly busy entering destinations until reaching the end of the selected part of the route.

Table 1
Four tasks, each with baseline condition, and assignment to tracks.

	Track 1			Track 2
Layout	Urban	Urban	Motorway	Interurban
Speed limits (km/h)	50	50	100	50, 70, 80, 100
Phone tasks			Texting	Handheld conversation
Phone baseline			Normal driving	Normal driving
Navigation system task	Follow route guidance	Destination entry		
Navigation system baseline	Paper map way finding	Normal driving		

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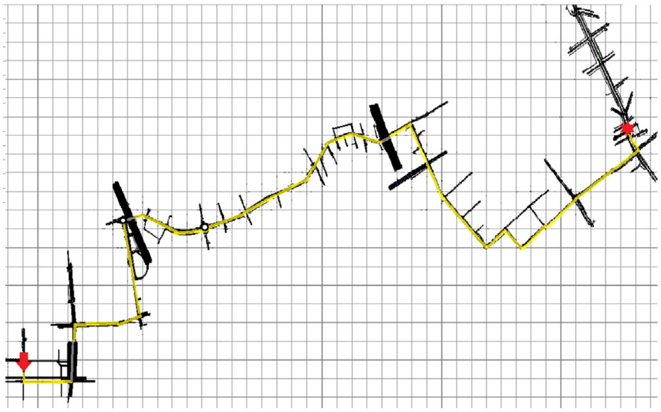

Fig. 2. The paper map. Participants were requested to use this map to drive from the starting point (red arrow) to the red asterisk.

2.6. Dependent variables

On the one hand, a driver may compensate for a secondary task, increasing demand, by decreasing speed. On the other hand speed and trajectory may not be compensated for due to too high task demands, leading to loss of control (cf., [30]). The measures of driving performance thus included speed, standard deviation of speed and standard deviation of lateral position (SDLP). In order to calculate the SDLP, lane changes were removed from the data, and SDLP was calculated for each driving lane. Furthermore, RSME scores were obtained, following Fuller's reasoning [30] that through 'stepping on the accelerator of mental (…) effort' (p. 464), the capability component of the TCI model may increase. Looking ahead is regarded a high priority task by [30], that may suffer from increasing task demands. Therefore glancing behaviour in terms of percentage of time eyes off the road (%TEOR) and number of glances off the road (#GEOR) were assessed. Glancing behaviour was scored manually, based on the webcam recordings, using six-second movies (14 frames per second) starting on fixed locations, and should therefore be considered a coarse measure. Concerning secondary task performance, the number of texts sent, destinations programmed, the number of questions answered during the phone conversations and the number of route errors were recorded. Only straight sections where drivers could select their driving speed freely were included in the analyses.

Pairs of variables with non-normally distributed difference scores (Kolmogorov–Smirnov test with Lillifors correction, $p < .05$) were analysed using the Wilcoxon signed-rank test, other variables that did meet the assumption of normally distributed data were analysed using the paired samples *t*-test.

The experimental conditions differed in, for instance, the specific speed limits present on the route, due to the fact that a real world route was replicated. For that reason analysing statistical differences between conditions was not regarded useful. Therefore, only baselines and experimental conditions for each variable on each task are compared.

3. Results

3.1. Phone conversation

Table 2 shows the results for the phoning task versus baseline driving. As this task was performed on a ring road with several different

Table 2
Means and standard deviations (in parentheses) for (handheld) phone conversations and their respective baseline (N = 20), and effect sizes for significant pairs.

Speed limit (km/h) Length analysed (m)	50 150		70 200		80 1600		100 1200	
Condition	Phone	Baseline	Phone	Baseline	Phone	Baseline	Phone	Baseline
Mean speed (km/h)	55.70 (6.27)	54.72 (5.72)	77.27 (10.59)	85.11 (8.62)	69.89 (6.47)	74.37 (3.87)	80.69 (10.91)	96.47 (8.22)
Test statistic, p-value	$t = .54, p = .60$		$z = -3.50, p = .002^*$		$t = -3.26, p = .004^*$		$t = -5.44, p = .000^*$	
Effect size (r)	N.S.		r = −.63		r = .60		r = .78	
SD of speed (km/h)	3.14 (1.32)	2.29 (1.05)	6.50 (3.32)	10.10 (3.93)	3.72 (.94)	3.34 (.81)	2.59 (.82)	1.80 (0.57)
Test statistic, p-value	$t = 2.66, p = .016$		$t = -2.77, p = .012$		$z = -1.33, p = .200$		$t = 3.603, p = .002^*$	
Effect size (r)	r = .52		r = .54		N.S.		r = .64	
SD of lateral position (m)	.128 (.062)	.096 (.055)	.177 (.090)	.144 (.087)	.224 (.048)	.198 (.046)	.207 (.063)	.222 (.066)
Test statistic, p-value	$t = 1.91, p = .071$		$t = 1.08, p = .296$		$t = 1.78, p = .091$		$t = -.83, p = .416$	
Effect size (r)	N.S.		N.S.		N.S.		N.S.	
Percentage time eyes off forward road (%)							6.32 (8.11)	15.00 (10.77)
Test statistic, p-value							$t = -3.28\ p = .004^*$	
Effect size (r)							r = −.60	
Number of times eyes off forward road (#)							.55 (.61)	1.50 (1.10)
Test statistic, p-value							$z = -3.08, p = .002^*$	
Effect size (r)							r = −.69	
Average duration of glance off road (s)							.298 (.370)	.503 (.344)
Test statistic, p-value							$t = -1.91, p = .071$	
Effect size (r)							N.S.	
Max glance duration off road (s)							.635 (.371)	.614 (.329)
Test statistic, p-value							$t = .19, p = .901$	
Effect size (r)							N.S.	
Rating scale mental effort (mm)							73.00 (19.67)	37.55 (24.69)
Test statistic, p-value							$t = 5.26, p = .000^*$	
Effect size (r)							r = .77	

* Significant at $\alpha = .05$ (2-tailed), t refers to *t*-test, *z* refers to Wilcoxon signed-rank test for non-normal data.

Note: r is calculated using $r = \sqrt{\frac{t^2}{t^2+df}}$ for paired samples t-tests, and $r = \frac{Z}{\sqrt{N}}$ for Wilcoxon signed-rank tests. Results for eyes glancing were obtained only at a 100 km/h section, RSME scores regard the entire condition.

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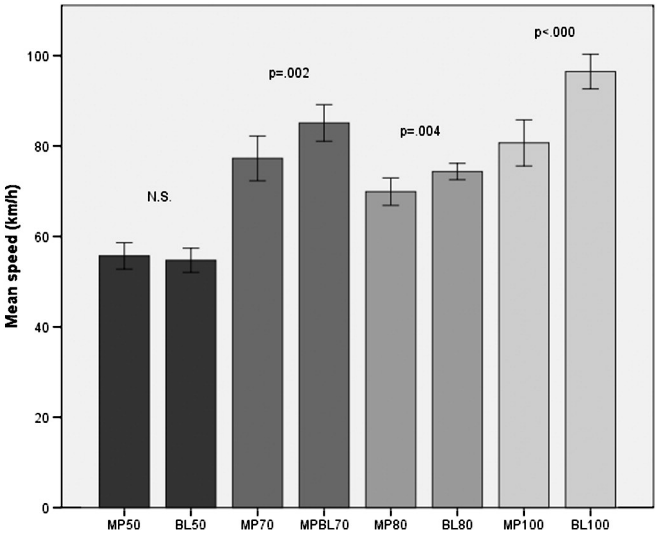

Fig. 3. Mean speed including 95% confidence intervals and p-values during a phone conversation (MP) and baseline (BL) driving for the four speed limits (i.e., 50, 70, 80, 100 km/h).

speed limits, the results are presented for all four different speed limits separately. We found no significant effects on SDLP, but the drivers did slow down significantly during the phone conversation compared to baseline. This was, however, not the case for the 50 km/h speed limit section (see Fig. 3). The phone conversation rendered higher scores for RSME, and the participants glanced off the forward road less often, and for a shorter period of time.

3.2. Texting

The results for texting are shown in Table 3. Texting was performed on a 100 km/h motorway. The results show a substantial reduction in speed during texting, as well as a higher standard deviation of speed and a considerably increased SDLP. The participants glanced off the road ahead for a longer period of time, and also more often. Furthermore, the average and maximum glance duration was longer. Effort ratings were substantially higher for the texting condition than in the baseline condition. During texting, four crashes occurred that were most probably due to having the eyes off the road and swerving (the crashes were removed from the data).

3.3. Destination entry

The results for entering destinations versus baseline driving are shown in Table 4. Average speed was substantially lower while entering destinations, as compared to the baseline condition, and the participants had their eyes off the forward road scene for a considerably longer period of time, but the number of glances off the road ahead was not substantially different from baseline driving. However, the glances were significantly longer during entering destinations. SDLP was higher, indicating more swerving during operating the navigation system. Ratings for mental effort were substantially higher in the experimental condition.

3.4. Route guidance versus paper map

The results for both way finding conditions are presented in Table 5. The participants did not drive significantly faster during route guidance, while subjective efforts, indicated by the RSME scores, during driving

Table 4
Means and standard deviations (in parentheses) for entering destinations during driving and respective baseline (N = 20).

Speed limit (km/h)	50	
Approx. length analysed (m)	450	
Condition	Destination entry	Baseline
Mean speed (km/h)	41.86 (6.071)	51.85 (6.722)
Test statistic, p-value, effect size (r)	t = −5.46, p = .000*, r = .80	
Standard deviation of speed (km/h)	2.721 (.842)	2.781 (.805)
Test statistic, p-value, effect size (r)	z = −.236, p = 0816, N.S.	
Standard deviation of lateral position (m)	.259 (.089)	.144 (.048)
Test statistic, p-value, effect size (r)	t = 5.607, p = .000*, r = .79	
Percentage time eyes off forward road (%)	60.91 (20.01)	22.41 (17.61)
Test statistic, p-value, effect size (r)	t = 8.46, p = .000*, r = .89	
Number of times eyes off forward road (#)	2.85 (1.089)	2.35 (1.663)
Test statistic, p-value, effect size (r)	z = −1.54, p = .124, N.S.	
Average duration of glance off road (s)	1.337 (.598)	.470 (.306)
Test statistic, p-value, effect size (r)	t = 5.39, p = .000*, r = .78	
Max glance duration off road (s)	1.86 (.676)	.621 (.407)
Test statistic, p-value, effect size (r)	t = 6.48, p = .000*, r = .83	
Rating scale mental effort (mm)	78.30 (27.51)	41.30 (26.87)
Test statistic, p-value, effect size (r)	t = 5.51, p = 000*, r = .78	

* Significant at α = .05 (2-tailed), t refers to t-test, z refers to Wilcoxon signed-rank test for non-normal data.

Table 3
Means and standard deviations (in parentheses) for texting and their respective baseline (N = 20).

Speed limit (km/h)	100	
Approx. length analysed (m)	5100	
Condition	Texting	Baseline
Mean speed (km/h)	93.39 (11.70)	107.04 (12.05)
Test statistic, p-value, effect size (r)	t = −5.66, p = .000*, r = .79	
Standard deviation of speed (km/h)	1.60 (.60)	1.15 (.55)
Test statistic, p-value, effect size (r)	t = 2.67, p = .015*, r = .52	
Standard deviation of lateral position (m)	.318 (.084)	.185 (.044)
Test statistic, p-value, effect size (r)	t = 6.60, p = .000*, r = .83	
Percentage time eyes off forward road (%)	49.76 (17.12)	19.71 (15.31)
Test statistic, p-value, effect size (r)	t = 8.03, p = .000*, r = −.88	
Number of times eyes off forward road (#)	3.25 (1.12)	2.05 (1.61)
Test statistic, p-value, effect size (r)	t = 2.70, p = .014*, r = −.53	
Average duration of glance off road (s)	.962 (.335)	.576 (.360)
Test statistic, p-value, effect size (r)	t = 3.98, p = .001*, r = .67	
Max glance duration off road (s)	1.500 (.591)	.664 (.389)
Test statistic, p-value, effect size (r)	z = −3.81, p = .000*, r = .85	
Rating scale mental effort (mm)	86.00 (28.29)	31.85 (22.34)
Test statistic, p-value, effect size (r)	t = 6.86, p = .000*, r = −.84	

* Significant at α = .05 (2-tailed), t refers to t-test, z refers to Wilcoxon signed-rank test for non-normal data.

Table 5
Means and standard deviations (in parentheses) for following route guidance and respective driving with a paper map (N = 20).

Speed limit (km/h)	50	
Approx. length analysed (m)	680	
Way finding condition	Route guidance	Paper map
Mean speed (km/h)	48.71 (3.74)	47.71 (4.15)
Test statistic, p-value, effect size (r)	t = 1.207, p = .242, N.S.	
Standard deviation of speed (km/h)	3.048 (.937)	3.165 (0.816)
Effect size (r)	t = −.65, p = .522, N.S.	
Standard deviation of lateral position (m)	.176 (.027)	.181 (.035)
Test statistic, p-value, effect size (r)	t = −.684, p = .502, N.S.	
Percentage time eyes off forward road (%)	14.00 (12.20)	19.41 (15.21)
Test statistic, p-value, effect size (r)	t = 1.88, p = .075, N.S.	
Number of times eyes off forward road (#)	1.45 (1.191)	1.75 (1.164)
Test statistic, p-value, effect size (r)	z = −1.11, p = .268, N.S.	
Average duration of glance off road (s)	.468 (.422)	.594 (.440)
Test statistic, p-value, effect size (r)	t = 1.34, p = .196, N.S.	
Max glance duration off road (s)	.720 (.500)	.526 (.433)
Test statistic, p-value, effect size (r)	t = 1.78, p = .091, N.S.	
Rating scale mental effort (mm)	48.75 (31.33)	68.05 (21.97)
Test statistic, p-value, effect size (r)	t = −2.17, p = .043*, r = .45	

* Significant at α = .05 (2-tailed), t refers to t-test, z refers to Wilcoxon signed-rank test for non-normal data.

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with a map were substantially higher. Other differences between driving with route guidance and using a paper map were not significant.

4. Discussion

The main objective of this study was to investigate how experienced users of in-car devices performed the driving task in a simulator under various distracted and baseline conditions.

4.1. Limitations

Although a driving simulator provides excellent opportunities for investigating distractions that one would not dare to require from a driver in real traffic, the results should be approached with care. Firstly, the car does not move like a real car does, in braking, steering, accelerating. Even though the drivers had sufficient experience not to let the driving task as such be interfered by inexperience, the simulated driving task inarguably is somewhat different. Secondly, some participants reported some dizziness, or light nausea afterwards and other forms of light discomfort due to simulator driving, which may have had its influence on driving performance.

The route as simulated in this study was quite complex, which adds perhaps to realism, but makes it more difficult to program and perhaps to drive, as reflected in relatively high baseline mental effort scores of 32–50 (compared with for instance De Waard [42], who found real road effort scores of 15–30). Moreover, most participants had no experience with driving in a simulator, whereas people do learn to drive better through practicing [31]. Finally, in real life, drivers may be quite aware of the dangers of distracted driving and only seldom engage in doing so by carefully planning for less complex situations [6].

4.2. Handheld phone conversation

The participants rated the handheld conversation while driving to be demanding. They lowered their speed during the conversation, except for the 50 km/h speed limit sections. A closer look at these data revealed that the vast majority of the participants slowed down in the 70, 80 and 100 km/h sections, i.e., 18, 15 and 17 participants respectively (out of 20). For the 50 km/h section only seven participants slowed down. The two sections with a 50 km/h speed limit both followed immediately after an 80 km/h limit section, so supposedly during phoning the participants did not slow down (sufficiently) because they missed the 50 km/h sign. Alternatively, the participants experienced this as an unexpected disruption of the required speed and kept on driving at the same speed as they did on the previous section (cf. [43,44]). Consistently, the fact that on the 70 km/h limit sections the participants drove faster than on 80 km/h sections is most probably due to the 70 km/h sections following a 100 km/h limit section, whereas the 80 km/h sections were surrounded by two 50 km/h sections. Lane keeping did not seem to change over the two conditions, which may logically be connected to the fact that the participants less often and shorter glanced away from the forward road scene during phoning (cf. [13]).

These results contribute to the current debate on whether phone conversations really affect risk (cf. [7,45]). On the one hand, it could be argued that since neither lateral performance nor glance behaviour is affected (much), added to a (safe) slower driving, phoning while driving may not be that much more hazardous than normal driving. In addition, if drivers are aware of the risks, and self-regulate the timing of conversations to sensible moments, it seems reasonable to suggest that phone conversations may not be as risky as previously thought. On the other hand, however, some participants missed an important, i.e. speed sign, so it is important that drivers should be aware of the distracting nature of phone conversations, which seems more demanding than passenger conversations [46]. Moreover, emotional conversations may be less harmless than mundane talks ([47]; cf. [48]). Furthermore, answering and dialling still require a visual–manual act, hence increasing risk, even in case of hands free installation [49].

4.3. Texting

The participants reported texting during driving to demand most effort on average. One of the causes may be the fact that most participants had a touch screen smart phone, which is difficult to operate compared to button phones, due to limited feedback on finger position. Moreover, four participants indicated never to text while driving in normal conditions. It seems that especially SDLP suffered from distraction by texting, followed by mean speed. Furthermore, the participants had their eyes off the road for about 50% of the time, which is comparable to earlier research findings (e.g. [18]). Four drivers had a “crash” while texting instead of watching the road. Manually operating the phone, be it for a short time, apparently adds to the statement in the previous paragraph about the risks of distraction (see also [5]).

4.4. Destination entry

Destination entry results showed the same trend as texting, though the tasks may not be fully comparable here due to different speed limits and road design. This was expected due to the visual–manual nature of both tasks. The longer glances and the higher percentage eyes off road time as compared to texting may be the result of the fact that the navigation system was placed on the right hand screen (see Fig. 1), which implied that the participants needed to turn their head slightly away from the forward road. In addition, the urban area may have been more interesting than the more tranquil motorway environment. Both lower speed and degraded lane keeping follow the lines of earlier work [27].

4.5. Following route guidance

The route guidance versus paper map results revealed few significant differences. The participants did report higher mental effort scores for driving with the paper map; so following the route using the map apparently was not too easy, which confirms earlier findings [25]. Two participants recognized the route from driving it before (both lived in the area near the route) although it was not a habitual route, i.e. they would normally not drive this specific sequence of roads.

4.6. Synthesis

In summary, the participants, all experienced users of both mobile phone and navigation systems, generally drove significantly slower in all distracting conditions, and found that the secondary tasks required more effort, compared to baseline driving. Visual–manual tasks appeared to cause loss of control including deteriorated lane keeping performance, in line with Fullers TCI model [30]. Texting on a motorway in this study led to a 72% increase in SDLP, while destination entries on an urban road led to an 80% increase. Furthermore, the participants significantly reduced glancing to the forward road, both by number and duration of glances. Thus, through the comparison with texting, prohibiting destination entries while driving seems to make sense, in spite of arguments against this (e.g., [50]). Keeping an eye on the road seems helpful in keeping in control of the vehicle. In conclusion, being experienced in manipulating in-car devices does not solve the problematic effects of dual tasking when the primary task is a complex demanding task like driving a moving vehicle.

This finding may be due to two lines of reasoning. First, one might argue that drivers become habituated to the risks involved in potentially dangerous behaviour, so that they are no longer capable of assessing the real risks involved in their behaviour (cf [51]). This would lead to lower efforts compensating for increased risk, which in turn affects driving performance, according to the TCI model [49]. This would imply that

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education on risk and awareness of risk might help diminish the detrimental effect. On the other hand, it might be that drivers, even though they may be experienced in each of the two tasks, just may not be able to perform the two tasks concurrently. In that case, only a few supertaskers [52] would be capable by talent. Either way, most should be advised to just refrain from demanding secondary tasks while driving.

4.7. Conclusion

The results indicate that most secondary tasks lead to a decrease in driving speed, while visual–manual tasks additionally take drivers' eyes of the road, deteriorating lateral performance. Regarding the results of the mobile phone conversations per se, it seems reasonable to suggest that drivers, through careful planning, may well be able to compensate for the distracting effects of the conversation by slowing down. The fact that they are able to keep their eyes on the road may be indicative of this, though distraction from relevant signs is looming continually.

Additional research data are needed to identify to what extent the impacts hold for these tasks in real life driving.

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