Comparing the Effects of Integrated and Nomadic Navigation Systems on Distraction and Driving Performance

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ABSTRACT

This study aimed to analyse the hypothesized differences in driving performance between smartphone-based and car-integrated navigation systems, specifically investigating whether smartphone-based systems result in worse performance. Previous work in this field includes simulation-based and naturalistic studies aimed at discerning relations between driving performance indicators and car information systems, or more specifically their interface design and input modalities. The study was conducted in two phases: a requirements elicitation phase, including a survey and an expert interview, followed by testing in a naturalistic qualitative set-up. The study did not prove that driving performance with smartphone-based systems is lower compared to car-integrated systems. On the contrary, car-integrated navigation users reported significantly more often cases of unhelpful information and degraded decision making. Visual distraction is identified as the most important indicator regarding safety of navigation systems. Other typical distractions and driving performance measures relevant to navigation systems are unhelpful information, communication errors, conflicts with systems in the surrounding context, speed control and decision making. Streaming-based navigation systems were analysed as third type of navigation system. The study concludes by formulating hypotheses concerning differences between the three navigation system types and offers suggestions for future work, including broadening the research approach, further developing theory around this topic and deductive testing.

Repository: https://github.com/lrjohnst/master-thesis-is.

Keywords: Navigation Systems, Driving Performance, User Interface Design

1 INTRODUCTION

Recent years, progress of technology has brought smartphones and other highly versatile devices to the dashboards of cars. These devices can be helpful, such as voice assistants and navigation systems. Applications also have practical uses not related to driving, like messaging, calling, podcasting, checking the weather, or making reservations. Additionally, certain applications have purely the function of entertainment. These developments have had an impact on the way people drive and subsequently the safety of driving and traffic as a whole. Being distracted by for instance the car radio, intense emotions, or using a smartphone decreases the focus toward the rest of traffic, and also increases the probability of disrupting traffic or causing an accident. A large scale naturalistic study in the USA by Dingus et al [1] in 2019 reports a 3.5 odds ratio of getting into a car crash while using a cell phone, over a baseline of driving without distractions. Most countries installed a ban on non-handsfree telephone use while driving. Given almost 160-thousand violations of this ban in the Netherlands in 2021 [2], it can be established that many drivers have a tendency to get distracted by their phones while driving.

On the other hand, traffic today without information distribution is nearly unthinkable. There are various data the driver needs, delivered by assistance and control systems. As an example, Intelligent Speed Assistant (ISA) systems are able to either provide haptic or auditory feedback to the driver when the maximum speed is exceeded, or automatically limit the speed of the vehicle. ISA and other assistance systems have the potential of improving traffic safety [3]. There are also data that the driver does not primarily need, but is nevertheless provisioned with cars, such as entertainment and communication. Car infotainment systems divided by Kandemir et al into nomadic (external, such as smart phones) and integrated devices [4] consist of a broad range of applications like messaging, radio and navigation. These systems by themselves change rapidly, adding to the variety, versatility and complexity of tasks related to these systems. Also the interactions themselves have changed. Notably, many existing or new functions of car infotainment systems are controlled by touch screen, where before this has been done by knobs and buttons.

One issue that drivers encounter is the potential for an excess of information provided while driving that is not relevant or necessary for the task at hand. Studies have shown that drivers can become overwhelmed when presented with too much information, leading to increased stress, cognitive load, and ultimately reduced safety [5][6]. Navigation systems can have a positive effect on traffic safety as they prevent unnecessary searching and detours, but under the condition that the destination is entered into the system before starting to drive [7]. While navigation can be a necessary and useful tool to assist drivers in reaching their destination, the selection, presentation and timing of this information can be critical to avoid information overload and distraction. Therefore, finding the right balance between providing necessary information and avoiding unnecessary distractions is crucial for ensuring safe and efficient driving.

This study hypothesizes that the use of smartphones for navigation introduces numerous distractions, such as pop-ups and notifications, and these systems are not specifically designed with traffic safety in mind, posing greater danger to drivers compared to navigation systems that are integrated into the car. In this study, the impact of using an integrated navigation system on road safety was investigated in comparison to using a smartphone for navigation while driving. This study aims to provide empirical grounding for future designs of car navigation systems and related regulations, ultimately to improve traffic safety. Altogether this study provides an answer to the following main research question (RQ): *What are the differences in driving performance between car-integrated and smartphone based navigation systems?* The main RQ is answered by answering the sub questions below:

1. What are the specific distractions introduced by smartphone navigation systems that impact driving performance?
2. What are the specific indicators of driving performance that are relevant to the use of navigation systems?
3. How can these indicators be ranked in terms of their importance for evaluating the safety impacts of smartphone versus integrated car navigation systems?
4. Is there a statistically significant difference in specific driving performance indicators between drivers using smartphone navigation systems versus those using integrated navigation systems?
5. How do smartphone navigation systems and integrated car navigation systems differ in terms of their impact on driving performance indicators?
6. How can the results of this study be used to inform the design of smartphone based car navigation systems and regulations around their use to improve road safety?

In the second section of this document (related work) the results of a literature review are written. The third section contains an overall overview of the methodology. Sections four, five and six each describe the purpose, design, setup, methodology and findings to one of three data collection phases: survey (section 4), interview (section 5) and field observation (section 6). The seventh section provides perspective to the findings of the study and addresses points of validity and reliability. Conclusions are drawn from the study and suggestions are mentioned for future work in section eight. The document furthermore contains a list of references (section 9) and a set of appendices. Other supporting documents are available via the GitHub repository mentioned in the abstract.

2 RELATED WORK

This section aims to provide background about navigation systems (paragraphs below) and an overview of previous studies on navigation-assisted driving and its impact on road safety, including the types of distractions and interface design, as well as the indicators of road safety used in previous studies.

Car Navigation Systems (CNS) for consumers have been around since Mazda introduced them in 1990, at the time as a system integrated with the car [8]. Since, the market has additionally seen dedicated navigation devices (like a Garmin [9] or TomTom [10] device), smartphone navigation apps (like Google Maps [11]), and more recently, the linking of smartphone navigation apps to the car IVIS (hereafter 'streaming'). At least iOS (Apple CarPlay [12]) and Android (Android Auto [13]) currently support streaming. Streaming navigation can be considered a hybrid between nomadic navigation and navigation via the car integrated IVIS. It has the advantage of staying up to date automatically, contrary to other dedicated navigation devices or integrated IVIS navigation applications, which must be updated manually. Given that not everyone updates their navigation system [8], and assuming that an updated navigation system improves the user experience and potentially even safety, streaming navigation potentially has an advantage. Furthermore, in literature review, improvement of car safety has been identified as key driver to the field of car user interface design, which as a field does seem to have academic maturity [14].

2.1 Similar work

Grahn and Kujala conducted a study in 2020 that aimed to compare the degree of visual distraction caused by smartphone-based applications to that caused by a specialized application for cars (Carrio). The study involved two different experiments (n=97) conducted in a driving simulator. Visual distraction was measured in terms of distance driven with occluded vision (occlusion distance). According to their findings, the specialized application caused less visual distraction due to its specialized user interface design, the division of tasks into subtasks, and, to a lesser extent, the size of the screen. The same study found that task structure, specifically how tasks are divided into subtasks, is important. People tend to switch tasks at subtask boundaries, such as between words, and this has implications for reducing distraction in car information systems [15].

In an analysis of distraction by car infotainment systems, a team from University of Utah tested differences in cognitive load between various functions and interface components for car infotainment systems (IVIS). In this naturalistic study (n=120), distraction was measured using the ISO standardized Detection Response Task (DRT) measure, and by a set of subjective measures, gained by a questionnaire after each driving session. The research found significant differences between various applications (like navigation, entertainment, messaging or dialling) and various components of user interfaces with respect to driving performance [16].

2.2 Types of distractions

Navigation systems introduce various distraction types, classifiable as cognitive, visual, manual, and auditory [17][14], which can impact driving performance and road safety.

Numerous of the reviewed articles focus on visual distraction, which tends to be measured in terms of duration or frequency of glancing, or similarly fixation count or duration. It is also a core concept in the US National Highway Traffic Safety Administration 2013 driver distraction guidelines for in-vehicle electronic devices [18] which as reported by Kujala and Salvucci suggests three main guidelines to minimize: "(1) individual glance duration, (2) mean glance duration, (3) total glance time" [19, p.66]. Additionally, it should be noted that the same study notes that glancing and visual distraction are not necessarily equivalent.

While cognitive distraction by itself is difficult to measure, the adverse effect it has on driving performance has been observed in lab studies [20]. A benchmark of four measures of driver workload by McDonnell et al. observed Task Interaction Time to be most sensitive to work load differences between 40 tested cars, followed by DRT Miss Rate, NASA-TLX and DRT Reaction Time. Furthermore: the latter two measures were found to require a sample size larger than the sample size in their study (n=173) to have sufficient power [20].

While voice control allows the driver to keep the eyes on the road, a trade-off is that voice control tends to cause higher cognitive load compared to manual interaction (excluding touch screen). Steering wheel button control in combination with voice control have been found a beneficial combination for the more basic tasks [17]. Mitigating high cognitive load by full text visual feedback in turn causes high visual load and time pressure, which in turn might be mitigated by visual feedback in the form of keywords and icons [14].

2.3 Relation between interface design and driving performance

Comprehensive literature review by Oviedo-Trespalacios, et al resulted in an extensive list of secondary in-vehicle tasks such as conversing, reaching, answering calls, dialling, browsing, reading, texting and typing [21]. Additional IVIS-related non-essential tasks not explicitly mentioned by Oviedo-Trespalacios, et al, are adjusting the radio, dealing with irrelevant (navigation) data, and specific to nomadic systems: social media and messaging popups, or disruptions and interruptions of the navigation application.

Interaction modalities: Haptic feedback can help alleviate visual distraction and allow the driver to focus on the road [22]. Audio feedback, such as a "read aloud" feature, can also be helpful, although it is possibly not as effective in some situations and can still cause cognitive distraction [15]. Different input modalities for certain tasks, or different mixes of modalities are likely to have an effect on cognitive, visual or manual distraction. A 2022 study by Jun Ma et al suggests a well-designed touch screen can be more suitable for complex secondary tasks, compared to knobs and buttons, despite the fact that knobs and buttons are by themselves more simple to operate [17].

Multiple studies have identified navigation destination entry as highly demanding [22][23], and in at least two instances it was identified by direct experiment as the most demanding secondary task [16][17] among other common tasks such as text messaging, dialling and radio volume adjustment.

2.4 Driving performance indicators

Besides in-vehicle tasks, Oviedo-Trespalacios created an inventory of "Human Machine Systems" (HMS) performance metrics: "headway, lateral position (lane position), speed, crashes, and workload" [21, p.366]. In the current study, these metrics are considered synonymous to driving performance indicators.

Analysis reveals that the design of the IVIS interface affects driving speed. Engaging in activities such as conversing, dialling, or texting while driving leads to a decrease in driving speed and an increase in headways [21]. This is a well-known effect and named by Young and Regan as "compensatory or adaptive behaviour" [23, p.381]. Lane position has been found to be impacted by visual and manual load. Also voice control that generates cognitive load has been found to affect departures from the lane centre (more so than on speed control). Still voice control seems to distract less than operating a touch screen. [17].

Furthermore, it has been shown that voice control with full text visualization leads to higher headway variability, attributed to higher total glance durations [3].

The positive association between secondary tasks while driving and decreased driving performance seems to be moderated by environmental factors that impact the complexity of driving tasks [24]. Also minding the interdependencies of distraction variables, Kandemir, et al. propose the existence of “toxic task combinations” [25, p.28] in which tasks, while not overly burdensome on their own, may surpass a threshold when performed in conjunction with more complex tasks, such as dialling while simultaneously braking at a red light [25]. In a similar sense, Oviedo-Trespalacios have approached what they called “Mobile Phone Distracted Driving” [26, p.360] as a human-machine system. They have focused their observations not just on distractions by tasks, but also by conflicts that occur between combinations of tasks [26].

2.5 Methodology and Wiener Fahrprobe (WFP)

The qualitative methodology to measure driving performance used in the current study commonly called “Wiener Fahrprobe” is traced back to and attributed to “Behavior in Traffic Conflict Situations” by Ralf Risser in 1985 [27]. This methodology reflects the influence and origins of cognitive psychology. Risser’s study classified drivers by how frequent and for which reasons they would be involved in traffic conflicts, like near-collisions. To this end, the study observed behavioural measures such as speed adaptation and headway distance (distance between driver’s own car and the first car in front). Data was collected by a psychologist beforehand (psychological exploration) and by two observers during a series of driving sessions on a predefined track in Vienna.

Simulation studies such as Grahn and Kujala [15] or Jun Ma [17] are the most frequently used methodology in similar studies, followed by naturalistic studies as the second most common approach [21].

3 OVERVIEW OF METHODOLOGY

The data collection and analysis consists of two main phases, first a requirements elicitation phase in which findings are formulated about relations between distraction while driving and navigation systems. The requirements elicitation phase consisted of a survey (section 4) and an expert interview (section 5). In this phase, specific indicators of driving performance as well as common distractions relevant to the use of navigation systems are identified and statistically analysed (variables in table 1 serve as reference), as well as variables or contextual factors that might influence the relation between distractions and driving performance. Secondly, these findings are tested by applying the Wiener Fahrprobe method in a naturalistic, qualitative design.

F	Full sample including S, I and Z, dedicated and other
S	Sample of smartphone navigation app users
I	Sample of integrated CNS users
Z	Sample of streamed navigation from smartphone to board computer
f	Frequency
w(f)	Weighted frequency; f(Z) being the weighting factor
α	Significance level, set at 0.05 for all tests

Table 1: Variable names used throughout this document.

4 SURVEY

This section provides an overview of the survey goal, design, sampling approach, analysis methods and its findings.

4.1 Goal of the survey

A survey was conducted with the purpose of attaining first hand data about navigation assisted driving behaviour. This data would then be analysed to be able to describe the way people use navigation systems, how they might potentially get distracted by them, what the role of the navigation interface would be, and how potential distractions might affect driving performance.

4.2 Survey design

The survey was conducted online, was anticipated to take 10 to 15 minutes to complete and no incentive was offered to the anonymous participants. The participants answered questions concerning: (1) their use or of navigation systems while driving (e.g. how, what for, preferences, frequency), (2) in which ways they found they were distracted by their navigation systems, (3) how have they found those distractions to impact their driving performance, (4) how distractions are linked to their navigation system’s user interface. The resulting raw qualitative data was designed to be the main source of indicators such as events, distractors and their perceived effects on driving performance. A data dictionary containing the survey questions, their associated data types, and a concise reference string for each question is available in Dutch (original) or translated to English [1]. The data dictionary provides an overview of the survey questions and their respective variables.

At first, questions are asked to characterize the participant, for instance by frequency of car use or type of navigation system used. An introductory question was asked to get the participant to think about the topic. The participant was then asked to name up to five distractions specifically related to their most used navigation system. This open elicitation was followed by a five-point Likert-scale question asking the participants to rate in how far they felt they a defined distraction (based on distractions learnt from literature) occurred. The next two questions were similarly first an open question to name five negative effects of navigation-related distraction, followed by a Likert-scale mentioning common scenarios from the literature. The intention with these four questions was to look for potential relations between navigation related distraction, and driving behaviour. The same structure (an open question and then a Likert-scale question was then applied to gather data about perceived “bad instructions, and “interruptions”. The survey concluded with two open questions about (1) what the participant would like to see changed with regard to the interface of their navigation system, and (2) what the participant would like to further mention.

4.3 Sampling

The larger proportion of participants to the survey were recruited from the network of the researcher and a smaller proportion by distribution of flyers at fuelling stations in and around Utrecht, Netherlands. A total 80 of people participated, 13 of whom were disqualified due to not owning a driver’s license, not using any navigation system or incomplete answers. The first survey response was on April 29 and the last response was on June 8, with a mean completion time per participant of 1086 seconds.

4.4 Survey set-up

The survey was built, visually designed and published by use of an online tool named SurveyLegend (surveylegend.com) [28]. Filling in of the survey by participants and exporting the data took place on SurveyLegend. Participants were referred to the survey by either a shared URL, or by QR-code. Participants were explicitly told the survey results were anonymous. The survey was accessible between 29th April until 8th June (see also appendix 1). The final result set was then downloaded as CSV-file, to be edited and

[1] https://github.com/lrjohnst/master-thesis-is/blob/main/[G] Final Thesis/Appendix JP - Survey Data Dictionary

analysed using Excel and custom PHP and Python scripts written by the author.

4.5 Analysis methods

For the four open questions (1) “Name five distractions while driving related to your navigation system” (nav_distraction), (2) “Name five negative effects on your driving performance resulting from navigation system related distractions” (nav_behavior), (3) “Name a few examples of unhelpful information or instructions by your navigation system” (bad_instructions), and (4) “Name a few examples of interruptions of your navigation system while you are trying to use it” (interruptions), participants had five optional text fields to fill in. Open coding was performed on the answers (examples: appendix 2). While coding the researcher performed the translation from mostly Dutch responses to English codes. Specifically for ‘nav_distraction’ a second coding session was done to refine insights after the first coding session. Only the results of the second coding session were used in further analysis. For ‘nav_behavior’, 53% of responses were codable to terms of driving behaviour, but 47% were not and were discarded.

Following the coding, absolute frequencies of each response code were determined per group S, I and Z (variable names defined in table 1). To allow meaningful comparison of code frequencies per group despite varying sample sizes, weighted frequencies were used instead of absolute frequencies. For that reason, weighted frequencies were then calculated by dividing the absolute frequency by the number of participants in each group and then multiplying this value by the number of participants in the smallest group: f(Z)=15. This conservative approach employed the smallest group as the weighting factor with the purpose of avoiding extrapolation and its concurrent risk of inflated statistics based on a smaller sample, ultimately to enhance scientific rigour.

To find any significant differences in the reported codes, a series of one-way chi-square tests was conducted on w(f) for each code, for each combination of variables S, I, and Z. In cases where the resulting p-value turned out higher than the predetermined significance level (α=0.05) or the expected frequency turned out smaller than 5, the corresponding result was disregarded. The tests aimed to assess whether the distribution of codes varied significantly across the different groups.

For each of the 15 individual Likert-scale questions, the results were coded into numbers starting from 1 (never applies), up to 5 (always applies) and descriptive statistics were compiled. The 15 result sets were tested for equalness of variance by F-test, normalcy by Shapiro-Wilk test and means across all permutations of the 15 variables were compared by Mann-Whitney test. Additionally, the rank biserial correlation was obtained from the larger of the two U-values resulting from the Mann-Whitney tests which provides a view on effect sizes between means comparisons by the equation: $r = 1 - 2U_{max}/n_1 n_2$ [29][30]. Conforming to guidelines described by Cohen, effect sizes between than 0.3 and 0.5 were considered moderate and were highlighted as findings to this study [31].

Furthermore, Pearson’s correlation coefficients (r-values) were calculated for all combinations of the 15 Likert-scales, within groups F, S, I and Z (appendix 3). For each resulting r-value, a confidence interval (CI) on 95% confidence level was calculated using the Fisher transformation method [32]. Each variable pair that corresponded to a CI lower bound value equal to or greater than 0.3 was analysed further by drawing correlation diagrams for each group F, S, I and Z (appendix 4). Finally, to address the RQs, relations between distractions, and driving performance indicators were highlighted as findings to the study.

4.6 Findings

Firstly, basic properties of the sample are analysed. Tables 2 and 3 describe the reported used navigation systems among participants. The overall mean frequency of weekly car use is displayed in table 4. A Mann-Whitney test suggests there is a significant difference between the means of groups *S* and *I* (p=0.0327), possibly increasing a confounding effect of variables.

Navigation system type (n=67)	*f*	*f/n*
Smartphone navigation (S)	33	0.49
Car-integrated (I)	16	0.24
Stream from smartphone to board computer (Z)	15	0.22
A dedication navigation device	2	0.03
Another navigation system	1	0.01

Table 2: Frequencies of navigation system type used.

Navigation app used (n=33)	*f*	*f/n*
Google Maps	25	0.76
Apple Maps	5	0.15
Waze	2	0.06
Flitsmeister	1	0.03

Table 3: Frequencies of navigation apps used.

	F	*S*	*I*	*Z*
Mean	4.2	3.8	5.1	4.3
St. Dev.	1.9	2.0	1.8	1.6

Table 4: Descriptive statistics reported weekly frequency of car use.

Examining figure 1 about the responses to the open question ‘nav_distractions’, notable differences in weighted frequency can be observed. Most notably it is observed that compared to groups Z and S, more group I participants report distractions related to "Bad instructions or difficulty interpreting”. This observation is supported by chi-square tests: p(S,I)=0.0234 and p(I,Z)=0.0056. This indicates that users of car-integrated navigation systems likely more often report cases such as “wrong route suggestions”, “system outdated”, or “instructions do not take into account maintenance or traffic”. Secondly, distractions related to code "Conflict between other system and navigation" appear to be reported less for group I compared to the other groups. This suggests that users of streaming or smartphone based navigation systems more often reported conflicts such as: “calling interferes with navigation”, “using other apps while navigating”, or “other

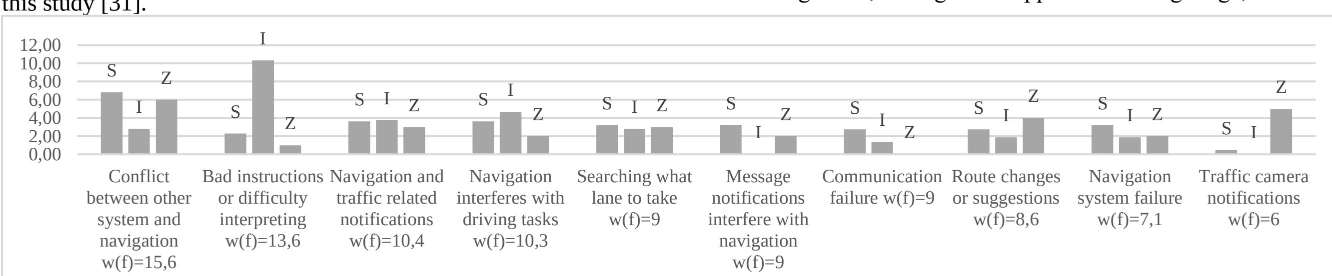

Figure 1: For each code: w(f) on y-axis, per group (S, I and Z) for reported navigation-related distractions (nav_distractions), sorted descending left to right by w(f).

apps overlay my navigation system", the latter indicating instances where another app takes precedence while driving and using navigation.

For the open question 'nav_behavior', the weighted frequencies of codes are represented in figure 2. Most notably it is observed that participants in group I report more negative effects related to "Decision making", compared to groups S and Z, which is supported by results of chi-square tests: p(S,I)=0.0239 and p(I,Z)=0.0288. Therefore it seems likely that users of car-integrated navigation systems more often report cases like "Becoming insecure / desoriented", "Missing an exit", or "Making illegal or dangerous move". Secondly, there seems to be a higher frequency for group I, compared to groups S and Z regarding reports of negative effects related to "Speed control". This suggests that car-integrated navigation system users would more frequently report cases such as "driving too fast or too slow".

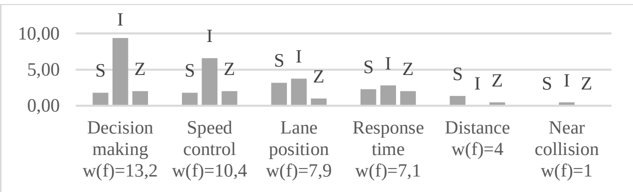

Figure 2: For each code: w(f) on y-axis, per group (S, I and Z) for reported nav. distraction-related behaviour (nav_behavior), sorted descending from left to right by w(f).

For the open question 'bad_instructions', weighted code frequencies are displayed in figure 3. Most notably, unhelpful information or instructions related to 'bad timing or bad data' appear to be reported more often within group I, compared to S or Z, only one of them statistically significant and with expected(f) above 5: p(I,S)=0.0387. This finding suggests that group I participants more often report cases such as "instructions not sufficiently ahead of time", or "outdated speed/road/traffic information". Secondly, not significant, but notably it seems that compared to groups I and Z, group S participants complain less about cases relating to "Confusing or conflicting" instructions, such as "suggests illegal/impossible move", "instructions conflict with road signs", "unclear which sorting lane to take".

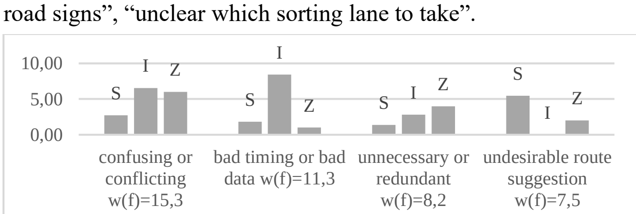

Figure 3: For each code: w(f) on y-axis, per group (S, I and Z) for reported unhelpful information/instructions (bad_instructions), sorted descending from left to right by w(f).

No significant differences were found when comparing the means of the Likert-scale questions (appendix 5) among the groups (S to I, I to Z, and Z to S) using Mann-Whitney tests (appendix 6). Examining effect sizes, seven comparisons were found to have a moderate effect, displayed in table 5. Despite the fact that none of the comparisons turned out statistically significant, they remained of interest as they served as preliminary conclusions to be tested during subsequent field observation sessions.

Relations between distractions and driving performance that stand out from Correlation Coefficients across all Likert-scale questions are: (1) Both 'difficulty shifting focus' (r=0.54) and 'situational awareness' (r=0.57) seem to be related to 'decreased reaction time'. (2) Occurrences of 'bad instructions' seems to be related to both 'more speed' (r=0.74), and 'speed control' (r=0.83) within group I. (3) Both 'glance duration' (r=0.86) and 'glance frequency' (r=0.77) seem to be related to 'less stable lane position' within group Z. (4) Both 'difficulty shifting focus' (r=0.8) and 'situational awareness' (r=0.85) seem to be related to 'reaction time' within group Z. (5) Within group S, no relations between distractions and driving performance were detected.

test	*n1*	*n2*	*diff*	*Umax*	*r*	*p*
z_behavior_wrong_turns vs. s_behavior_wrong_turns*	11	26	0,81	89	0,38	0,0667
s_distraction_awareness* vs. i_distraction_awareness	28	16	0,54	299	0,33	0,0504
i_behavior_more_speed* vs. z_behavior_more_speed	14	11	0,55	102	0,32	0,1542
i_behavior_speed_control* vs. z_behavior_speed_control	14	11	0,50	102	0,32	0,1679
s_behavior_speed_control vs. i_behavior_speed_control*	26	14	0,46	125	0,32	0,0897
z_behavior_lane_position vs. s_behavior_lane_position*	11	26	0,49	99	0,31	0,1195
z_behavior_reaction_time vs. s_behavior_reaction_time*	11	26	0,51	101	0,30	0,1402

Table 5: Effect sizes (r) for means comparisons Likert-scale questions. Variables marked with asterisk (*) have the higher mean.

5 EXPERT INTERVIEW

The second part of the requirements elicitation involved conducting and analysing the results of an expert interview, described below.

5.1 Goal of expert interview

To provide an expert's point of view and context to the data attained during the survey and literature review, but also to add new information, an interview was organised. One specific goal was to use the data from the interview to improve the accuracy of the theoretical model formulated during the requirements elicitation phase, for instance by enabling more accurate prioritization of driving performance indicators.

5.2 Interview design

The interview was conducted using a semi-structured format, guided by a list of topics shared with the interviewee two weeks prior. The following topic list was used: (1) distraction by navigation systems, (2) relations between navigation systems (specifically: interface and its surrounding context) and distraction, (3) effects on driving performance, (4) indicators of driving performance, (5) measuring driving performance, (6) how policy could be helpful. The topic list was designed to effectively dictate which topics would be discussed, but at the same time provide room for free interpretation by the participant, not to introduce unnecessary limits to the answers.

5.3 Participant profile

The participant is a scientist linked to the Institute for Road Safety Research (SWOV), experienced in analysing naturalistic driving data, more specifically with regards to distraction in traffic. The participant mentioned an example where they were involved in a large scale European study that had 120 cars fitted with cameras and sensors allowing them to collect approximately 100.000 hours' worth of driving data. Here, the participant focused on mobile phone use, while his colleague focused on navigation system use. The participant mentioned research that they would be starting, into Intelligent Speed Assistance (ISA), which is a part of many navigation systems. The hypothesis, as the participant described it would be that drivers drive faster on average with ISA, as they now have better overview on the current speed limit and are more confident getting closer to this limit.

5.4 Interview set-up

The idea to interview a participant from SWOV came up while reviewing work that it published [7]. A request for contact and for the interview was made by email which eventually resulted in an appointment. The interview took place at the SWOV office in The Hague and lasted approximately 75 minutes. The interview was recorded by use of the author's smartphone, which was tested for this purpose, prior. The author started at the first item in the topic list and asked in-depth questions. Divergence of topic was allowed, but eventually the author steered the discussion back to the topic list until all topics on the list were discussed. Halfway during the interview, a few print-outs of preliminary data from the survey were discussed, which was unplanned, but deemed valuable as it would help guide the conversation.

5.5 Analysis methods

Before analysis, the interview audio recording was transcribed using ChatGPT whisper API [33], with help of the OpenAI package for Python v0.27.0 [34]. The transcription was then relistened, double checked, edited and coded manually by the researcher. The coding method used in the study involved a systematic process of analysing the transcript to identify and categorize relevant facts and statements related to specific topics. The author initially read the interview to gain a general understanding of the content. Then, during a subsequent reading, facts and statements pertinent to the topics of driving distraction, driving performance, policy or other related areas of interest were extracted. The extracted information was organized in a table, where each entry was annotated with the corresponding topic category. This coding process allowed for the identification and categorization of key information within the interview data, enabling the researcher to focus on specific themes or topics of importance for further analysis. The researcher utilized the coded data as a foundation to construct the summary (section 5.6), which aimed to provide a concise overview of the key findings and insights from the interview. This systematic approach ensured that the summary was grounded in the data and aligned with the specific themes of interest.

5.6 Findings

Visual distraction was identified as the most dangerous form of distraction while driving. The interviewee mentioned that the probability of a car accident increases substantially after just two seconds of visual inattention. To measure and analyse these distractions and their effects, the Wiener Fahrprobe was proposed as a suitable method. Despite its reliance on subjective experiences, this approach offers the advantage of flexibility in capturing and describing unforeseen situations, and less resource intensive for a small scale naturalistic driving study.

Several key measures have been identified for evaluating driving performance, including Standard Deviation from Lane Position (SDLP), steer jerk, breaking delay, abrupt breaking, time to collision, time headway, post encroachment time, and speed control. The participant noted that to get reliable data on these measures, large quantities of data are required, although slightly less so on SDLP. The participant notes that people are generally adept at safely allocating attention while driving, as demonstrated by their ability to perform numerous tasks in the car with a relatively low number of accidents compared to the multitude of activities undertaken. Appropriate task breakdown in driving assistant applications tend to help drivers more safely allocate their attention compared to tasks that impose a time constraint. Attention and cognitive workload are important considerations in driving, and the concept of the "bathtub curve" has been introduced to illustrate the relationship between workload and attention. It emphasizes the need to maintain an optimal level of task difficulty and task load to ensure the driver can direct sufficient attention towards the road.

Navigation systems are helpful to driving performance by alleviating search behaviour and allowing drivers to focus more on driving tasks as opposed to navigating. The participant stated there is likely not a strong relation between navigation and the workload being too high or too low. As driving assistance systems assume increasingly prominent roles, their impact on driver attention becomes a subject of investigation. This investigation includes understanding the "bathtub curve" and its implications for workload and attention. Future developments may involve navigation systems guiding drivers' roles on specific sections of the road, when driving assistants are switched on or off.

6 FIELD OBSERVATIONS

The goal, design, sampling, set-up, analysis and findings to a series of field observations are described in this section.

6.1 Goal of field observations

To provide both empirical backing and falsification to the analyses resulting from the requirements elicitation phase, field observations were organised. Through these observations, actual behaviour and distractions of navigation assisted drivers, and events related to the navigation system itself were recorded. Furthermore, by directly observing participants' real-time behaviours and responses, nuances and details were captured that might have been missed in self-reported data, desk research and interviews.

6.2 Field observations design

A design in line with the Wiener Fahrprobe (WFP) method was chosen for the field observations. This method is recognized for its ability to collect qualitative data in a naturalistic setting, which was fitting to the present study as this approach is able to provide context to observations. A purely quantitative approach was avoided as it was deemed unrealistic to attain a large enough sample size to meaningfully perform statistical analysis. A coding system was employed for the field observations. The code list (refer appendix 7) contained driving performance indicators and common distractions derived from literature review, survey responses and the interview. The observer was granted liberty to register observations not directly related to any of the codes, thereby fulfilling both functions of the Wiener Fahrprobe: the coding and the free observer [27]. Observations were annotated with GPS coordinates, timestamp and current speed, which were recorded on a one-second interval using the Android app 'GPS Logger' [35]. For each session, additionally the navigation system type (S, I or Z) was recorded, and whether the participant used audio instructions.

6.3 Sampling

The sampling method to the field observation was similar to the method used in the survey (convenience sample, section 4.3). The one difference being that for the observation sessions, all of the participants came from the researcher’s network. In order to gather enough data in the groups S, I and Z, the researcher approached different contacts as needed. Less participants for group S were recruited than originally planned. Twelve individuals participated over a period of three weeks, of which one corresponding dataset was discarded due to a deviating route. Three group S participants (two Schiphol route, one Ede route) used the smartphone attached to the ventilation grille on the right side of the driver. Four group I participants (one Schiphol route, three Ede route) used integrated systems with car build years between 2012 and 2021. Four group Z participants (three Schiphol route, one Ede route) used Android Auto to stream Google Maps navigation to the board computer. For their efforts, the participants were offered an optional coffee and cake at the navigation destination.

6.4 Observation set-up

For convenience of the participants, two separate routes were defined, both approximately 40 minutes, and both taking place mostly on provincial roads. To increase the likelihood that the participant had to depend on his or her navigation system, in particular highways were avoided and for both routes the final approximately 5 minutes take place inside a town or city centre. The routes were chosen such that the participant's navigation system would reliably suggest the desired route when the destination was entered. Details of the routes are added to appendix 8. The participant was given the choice to start at either Ede, or Schiphol airport, but were not made aware of the destination. Driving sessions were planned such to avoid busy traffic or extreme weather. Upon starting the driving sessions the participant was given the destination address and instructed to use the navigation system to arrive. As an especially important ethical consideration to this study to minimize risks to the participants, researcher and other traffic, the researcher at this point explicitly requested compliance with traffic laws at all times during driving sessions, and to always put safety first when making decisions while driving. While driving, the observer used two android phones (one main, one backup) to record the session using GPS Logger [35]. The observer did not assist the participant while navigating. Furthermore, informal conversation carried on during the session.

6.5 Analysis methods

Firstly the raw data from the two Android phones were downloaded and archived. All observer notes were coded by either associating them with an existing code from the predefined list (appendix 7) or assigning a new code. In accordance with the Wiener Fahrprobe method [27], the initial 10 minutes of each driving session were not considered in the analysis. This strategy mitigated the impact of the observer's presence on the participant's behaviour. To further visualise and explore the data, all individual trips were plotted using Google Maps through the Google Maps API (specifically Roads API and JavaScript API) [36]. A custom PHP script automatically generated 12 sets of source code to plot the respective path on an interactive map, annotated with the corresponding observer notes. These 12 sets were then aggregated to compose four separate maps, one for each group: S, I, Z, and F.

6.6 Findings [2]

A direct link was observed between manual operation of navigation systems and lane position deviations across all groups. Distractions resulting from conversation with the observer led to missed or incorrect turns in three drives, irrespective of the group. Talking combined with navigating might be classified as "toxic task combinations", in terms of Kandemir et al [25, p.28]. Smoothest driving sessions with fewest distractions were noted with smartphone navigation (group S). While for groups Z and I there were message notifications coming up in the screen, there were none for group I. Furthermore, a larger variety of interactions with the navigation system was observed within group S, including operating the music player and the anecdote of 'facetiming while driving'. However, no relation was observed between such interactions and potential distraction or degraded driving performance. Two instances evidenced older or non-updated integrated systems (group I) causing extra search behaviour or wrong turns, notably on the Ede-Nunspeet route. These systems from group I generally appeared to be the most distracting.

7 DISCUSSION

The findings of this study show relationships between distraction and performance while driving and different types of navigation systems. This section provides context to the findings by discussing their underlying paradigms, limitations and implications.

7.1 Conceptual framework

During requirements elicitation, it was found streaming navigation systems were more prominent than anticipated. Consequently a third group (Z) was introduced. During analysis of the survey results, it was discovered that streaming navigation showed traits more similar to smartphone-based navigation rather than car-integrated systems. The similarity between groups S and Z becomes evident in the results of code-frequency comparisons (figures 1, 2, 3), including each of their corresponding significant findings. On the other hand, a lead to study potential differences between groups S and Z can be found in the moderate effect sizes observed in the differences of means between responses to Likert-scale questions (table 5 and appendix 5).

During the study, literature review and the expert's insights contributed to a clearer definition of the (cause-effect) relations between interface design, distraction, driving performance and road safety. The latter two were found to be overemphasized in the starting phase of this study. As the study progressed, the focus shifted more towards understanding distraction and driving performance, with somewhat less emphasis on interface design and road safety. This conceptualisation is displayed in figure 4.

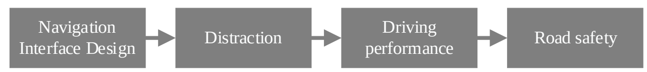

Figure 4: Conceptualisation of core concepts during this study.

7.2 Limitations

Reflecting on the conclusions drawn from this study, it is important to bear in mind several limitations associated with the study's methodological approach, sampling methods and analysis methods.

The survey and field observations employed a small convenience-based sample, predominantly sourced from the researcher's personal network. Consequently, a high degree of sampling error should be taken into account while interpreting this study's findings. Firstly, the current study's sample likely cannot represent the diversity found in a broader population, therefore any findings cannot be assumed to be generalisable to such a larger context. Secondly, the sampling method potentially compromises the reliability of the study, as similar research conducted with larger and more randomized samples might yield different outcomes.

This study presents means comparisons between Likert-scale questions with an effect size > 0.3 as findings. While the chosen rank biserial correlation provides "a degree of departure from the null hypothesis" [31, p10], it is a function of absolute differences, rather than variance, making it sensitive to the fact that the Likert-scale cannot be treated as continuous, negatively impacting robustness of the analysis. Furthermore, as none of these presented effects were found to be statistically significant, it is uncertain whether the measured effects were due to coincidence, which poses a challenge to the validity of the observations.

Inconsistent analysis results were found in the fact that the largest effect size was found between means of 'behaviour wrong turns' for group S and Z (table 5), but at the same time, the code 'Decision making' which includes cases of wrong turns was found to be similar between the same two groups (figure 2). In this light, the detected effect size should be assumed to be coincidental and not used in further analysis.

A few important features of the Wiener Fahrprobe method were not applied during the study. Firstly, missing the second, free observer might have prevented registration of unexpected distractions or driving performance aspects of the navigation assisted drives, as the free observer should be less biased by a coding schema. Furthermore, two different routes were used, which introduces a risk of confounding of variables. This risk is magnified by the fact that the samples were small and groups are unevenly distributed across the routes. While the findings of the

[2] The observations to the field work were plotted on an interactive map using Google Maps [36] and published online. The maps can be viewed via: https://master-thesis-is.lucasjohnston.nl.

observation sessions provide support to earlier observations, these findings by themselves should be interpreted with caution.

Reliance on a single expert interview creates a limitation to the perspective offered in this study, given that this approach precludes possibility for result saturation. This limitation is partially mitigated through the study's triangulation approach.

7.3 Relations to the research questions

This subsection aims to provide an interpretation of the findings in relation to the RQs. Not all questions can be answered with the findings in this study and a few questions are answered partly.

No compelling evidence was found to support the hypothesis that smartphone-based navigation systems degrade driving performance more, or worse compared to integrated or streaming-based navigation systems. Future work might consider indirect indications that were found. Firstly, situational awareness seems to be more problematic for group S (table 5), which in overall terms is related to reaction time (appendices figure 1). Secondly, cases of "conflicts between other systems and navigation" are reported more often for groups S and Z, which is understandable given that the smartphone offers more applications and does not have the navigation function as the central design theme. Thirdly, field observations showed a slightly larger range of non-driving related features that are used by group S and Z participants.

Between the expert interview and literature review, congruency was observed in the identification of the following driving performance indicators: lane position, (time to) collision, headway and speed control. Open answers to 'nav_behavior' were codable to "decision making", "lane position", "speed control", "response time", "distance", and "near collision", indicating a specific relevance for these indicators to navigation systems. The code 'decision making' (examples: appendix 2) cannot be linked directly to a driving performance measure found so far in literature, or mentioned by the expert. It includes errors in operating the car, or navigation errors. Furthermore, relations could be established between various navigation-related distractions and the measures 'reaction time', 'speed control' and 'lane position'.

The interview participant emphasized the importance of dividing tasks into subtask and further noted that limiting the time given to drivers to respond to an input request from the system is unhelpful to their ability to make decisions about attention allocation. This insight provides a navigation specific interpretation to similar observations by Grahn & Kujala [15].

Visual distraction emerges as highest ranking indicator in terms of evaluating safety impact of navigation systems, because of the interview participant's statement about the danger of prolonged glance durations, and the considerable attention previous studies have spent on this type of distraction. The emphasis on lane position is further supported by the current study's finding for group Z that lane position is related to glance duration (r=0.86), mirroring a connection observed in previous work, although in the latter case it was attributed to the broader concept of visual distraction [17]. Lane position has also been shown to be influenced by manual distraction in both the current study's field observations and previous research [17].

In terms of statistically significant differences in specific driving performance indicators between groups S and I, only the previously mentioned indicator 'decision making' was found to match this criterion. Field observations appear to support this finding, as evidenced by cases involving 'wrong turns', 'confusion', 'searching', and 'bad instructions'. Additionally, when focusing on distraction rather than driving performance, more statistically significant differences emerged which negatively distinguish car-integrated systems from other systems. Unhelpful distractions codable to "Bad instructions or difficulty interpreting" or "Bad timing or bad data" were found to differ in group I compared to other groups, with statistical significance, except for the latter code between I and Z. Not statistically significant, but notable in this respect is the difference of driving performance measure 'speed control', as shown in both the open question code frequencies (figure 2), and its related closed (Likert) question (effect size > 0.3). This observation might be characterized as "compensatory or adaptive behaviour" [23, p.381], where drivers decrease speed in an attempt to safely divide attention while dealing with a higher cognitive or visual load related to the navigation system. Correlation analysis within group I (appendices figure 3) provides further support, showing a relation between 'bad instructions' and 'speed control' (r=0.83). This shows, within the mentioned limitations of the methodological approach, that smartphone-based and car-integrated systems are not the same in terms of their impact on driving performance.

8 CONCLUSION AND FUTURE WORK

The study aimed to examine the distinctions between smartphone-based and car-integrated navigation systems concerning their potential impact on driving performance, with a particular focus on the mediating role of distraction. The initial hypothesis could not be proven. Smartphone based navigation systems are not evidently worse in terms of impact on driving performance, compared to car-integrated systems. Evidence to the contrary was found in the significant differences concerning reported and observed unhelpful information and degraded decision making with car-integrated systems.

Before focussing on the relations between navigation systems and driving performance, this study found that first a focus must be laid on distractions as a mediating variable between the user interface and driving performance. In the same sense, the relation of interface design, distraction, driving performance, ultimately to road safety must be further defined before attention should be directed on designing interfaces in such a way that they optimise driving performance.

From the current study, the hypothesis emerges that typical distractions for navigation systems relate to unhelpful information or instructions, such as outdated data, or otherwise communication errors between the system and the user (more so for car-integrated systems), and conflicts between other systems and the navigation system, such as message popups, or other applications interrupting the navigation (more so for smartphone and streaming based systems). Smartphone based systems are theoretically more problematic in terms of situational awareness, based on survey and interview results. Situational awareness, along with difficulty in shifting focus in turn are related to longer reaction time. In terms of driving performance, decision making in car operation and navigation, as well as speed control (the latter two more so for car-integrated systems) and lane position are typical driving performance indicators that can be related to navigation systems in general. In design of user interfaces, glance duration and frequency should be treated as crucial behavioural measures to optimize safety. Specifically a relation between visual distraction and lane position are implied by correlation analysis, as well as previous work [17]. The focus on glance behaviour should be approached in synchrony with decisions around input modalities, task interaction time and the surrounding context of the system, such as the hardware, position, and other applications. Smartphone and streaming based systems have similarities in terms of related distractions, decision making and speed control, but differences in terms of lane position, and reaction time. Furthermore, streaming based systems are hypothesised to differ from car-integrated systems in terms of speed control. Streaming based systems should therefore not be assumed to be of the same category as car-integrated, or smartphone based systems.

Future work is suggested to test and further develop the theoretical framework and hypotheses developed during the current study. A broader approach within the same framework could be to study relationships between user interface, distraction and driving performance for other applications used in the car, either or not essential to driving or navigating. Suggestions to methodological approaches are to further relate this study's findings to previous work, to repeat the survey in a similar fashion, but with a larger, more randomized sample, and finally to perform deductive studies using a simulator-based, or naturalistic set-up to provide empirical verification of findings within this domain. Future work would have the purpose of finding how exactly car information systems ultimately relate to traffic safety, so that these systems can be optimised accordingly.

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APPENDIX 1: SURVEY CHANGE LOG

A change log was kept to log any changes made to the survey, displayed in table A1.

Time	*Submits*	*Event or change*
29/04 22:00	0	Finalized the survey.
30/04 11:00	4	Corrections spelling errors.
30/04 15:00	7	Added extra question at the end: 'would you like to participate in a follow up study? Leave your email address'.
01/05 12:45	18	Simplified phrasing of questions 8, 9 and 10 (includes the two matrix questions), after feedback that the questions are complicated.
08/06 15:55	80	The survey was made unavailable for more responses.

Appendices table 1: Changes to the survey are displayed together with time of the change and number of submits at the time of the change.

APPENDIX 2: SURVEY CODE EXAMPLES

In the list below, for each open question (nav_distractions, nav_behavior, nav_bad_instructions, nav_interruptions) three response examples are shown for each code.

nav_distractions

- Bad instructions or difficulty interpreting
    1. Wrong route indication
    2. System not up to date
    3. Unclear instructions for lane position
- Conflict between other system and navigation
    1. Opening my WhatsApp message
    2. Google Maps minimized while using music player
    3. Other apps take precedence over navigation
- Navigation interferes with driving tasks
    1. Configuring the navigation
    2. App requests input
    3. Trying to arrive faster than ETA shown
- Message notifications interfere with navigation
    1. WhatsApp messages
    2. Messages popping up over my navigation screen
    3. Receiving messages despite having phone in do-not-disturb mode
- Communication failure
    1. Navigation not centred properly
    2. Voice too soft
    3. Not being able to see the screen well
- Traffic camera notifications
    1. Camera notification
    2. Repeating of camera notification (500m/200m/now etc)
    3. Traffic light camera notification
- Route changes or suggestions
    1. Alternative routes
    2. Shortest/fastest route options popping up
    3. Sudden reroutes and I cannot click them
- Navigation and traffic related notifications
    1. Slow traffic notification
    2. Notifications on screen such as time to take a break
    3. Notifications of cars standing still
- Navigation system failure
    1. Loses connection with app
    2. Freezes
    3. Shuts down
- Searching what lane to take
    1. Unclear which exit to take
    2. Looking which street to drive into
    3. Unclear which lane to use in multilane roads

nav_behavior

- Decision making
    1. Unclear instructions can lead to dangerous last minute manoeuvres
    2. Missing the turn in a village
    3. Current traffic situation different from navigation system – information not current and as a result desoriented
- Speed control
    1. Driving more often to the speed limit
    2. Speeding
    3. Driving too slow
- Lane position
    1. Swerving
    2. Using the other half of the road
    3. Steering wheel goes to the left because I'm looking at the screen
- Response time
    1. Breaking too late
    2. Longer response time
    3. Realising later that I need to break

nav_bad_instructions

- bad timing or bad data
    1. Vocally notifying late that I need to take the turn
    2. Instructions too late
    3. Incorrect slow traffic information
- confusing or conflicting
    1. Changes in the route because of new roads that are not known yet to the navigation system
    2. Legal U-turn and in fact not possible
    3. Unclear instructions (navigating)
- undesirable route suggestion
    1. Exit in Italy to impassable roads
    2. Alternative route that is longer
    3. Notifying there is a better route and I have to respond quickly by touching the screen
- unnecessary or redundant
    1. On the highway on the right-side information is shown about restaurants, fuelling stations, etc
    2. Road construction
    3. Repeat of traffic camera notification

nav_interruptions

- Conflict between other system and navigation

    1. While operating the radio, navigation screen is barely visible, but navigation instructions are still shown on the heads up display
    2. Music player
    3. When I get a call, navigation shuts down
- Connection issue
    1. When my phone is not connected properly
    2. GPS failure
    3. Connection to Android car shuts down
- Call or message
    1. Calling
    2. Some times when I get a call
    3. When I get a call, I get a smaller view of the navigation app right bottom
- Sudden failure
    1. Not booting
    2. Empty battery
    3. Phone falls from holder

APPENDIX 3: LIKERT SCALE QUESTION CORRELATION MATRICES

	distraction_manual	distraction_awareness	distraction_shift_focus	distraction_mental_load	distraction_glance_frequency	distraction_glance_duration	behavior_more_speed	behavior_less_speed	behavior_speed_control	behavior_lane_position	behavior_reaction_time	behavior_wrong_turns	behavior_operating_errors	bad_instructions	interruptions
distraction_manual	X	0,48	0,62	0,25	0,54	0,45	0,24	0,43	0,19	0,34	0,50	0,30	0,36	0,14	0,10
distraction_awareness	X	X	0,50	0,52	0,47	0,33	0,42	0,29	0,27	0,39	0,57	0,31	0,25	0,13	0,22
distraction_shift_focus	X	X	X	0,48	0,54	0,56	0,31	0,30	0,17	0,35	0,54	0,42	0,28	0,21	0,15
distraction_mental_load	X	X	X	X	0,27	0,40	0,31	0,17	0,27	0,28	0,40	0,25	0,44	0,28	0,35
distraction_glance_frequency	X	X	X	X	X	0,54	0,12	0,33	0,12	0,39	0,42	0,34	0,34	0,10	0,10
distraction_glance_duration	X	X	X	X	X	X	0,23	0,35	0,12	0,43	0,33	0,31	0,43	0,19	-0,02
behavior_more_speed	X	X	X	X	X	X	X	0,31	0,57	0,46	0,19	0,23	0,35	0,22	0,09
behavior_less_speed	X	X	X	X	X	X	X	X	0,45	0,42	0,47	0,27	0,32	0,32	0,01
behavior_speed_control	X	X	X	X	X	X	X	X	X	0,60	0,19	0,34	0,22	0,42	0,01
behavior_lane_position	X	X	X	X	X	X	X	X	X	X	0,40	0,33	0,27	0,18	0,28
behavior_reaction_time	X	X	X	X	X	X	X	X	X	X	X	0,37	0,21	0,25	0,18
behavior_wrong_turns	X	X	X	X	X	X	X	X	X	X	X	X	0,32	0,29	0,23
behavior_operating_errors	X	X	X	X	X	X	X	X	X	X	X	X	X	0,31	0,17
bad_instructions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0,14
interruptions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Appendices table 2: Correlation matrix Likert-scale questions Full set (F).

	distraction_manual	distraction_awareness	distraction_shift_focus	distraction_mental_load	distraction_glance_frequency	distraction_glance_duration	behavior_more_speed	behavior_less_speed	behavior_speed_control	behavior_lane_position	behavior_reaction_time	behavior_wrong_turns	behavior_operating_errors	bad_instructions	interruptions
distraction_manual	X	0,45	0,56	0,18	0,52	0,39	0,32	0,28	0,16	0,29	0,49	0,37	0,25	-0,11	0,10
distraction_awareness	X	X	0,44	0,52	0,38	0,15	0,59	0,08	0,45	0,43	0,40	0,39	0,24	-0,03	0,23
distraction_shift_focus	X	X	X	0,41	0,50	0,56	0,44	0,19	0,24	0,45	0,41	0,46	0,21	-0,01	0,14
distraction_mental_load	X	X	X	X	0,13	0,16	0,42	0,25	0,35	0,34	0,44	0,03	0,39	0,29	0,43
distraction_glance_frequency	X	X	X	X	X	0,38	0,06	0,06	-0,14	0,21	0,37	0,31	0,30	-0,07	0,14
distraction_glance_duration	X	X	X	X	X	X	0,24	0,16	-0,19	0,24	0,14	0,26	0,39	-0,07	-0,26
behavior_more_speed	X	X	X	X	X	X	X	0,32	0,58	0,68	0,35	0,20	0,36	-0,10	0,08
behavior_less_speed	X	X	X	X	X	X	X	X	0,47	0,35	0,53	0,41	0,51	0,37	0,07
behavior_speed_control	X	X	X	X	X	X	X	X	X	0,66	0,37	0,35	0,16	0,31	0,04
behavior_lane_position	X	X	X	X	X	X	X	X	X	X	0,31	0,32	0,11	0,09	0,28
behavior_reaction_time	X	X	X	X	X	X	X	X	X	X	X	0,52	0,24	0,28	0,10
behavior_wrong_turns	X	X	X	X	X	X	X	X	X	X	X	X	0,16	0,13	-0,07
behavior_operating_errors	X	X	X	X	X	X	X	X	X	X	X	X	X	0,28	0,01
bad_instructions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-0,06
interruptions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Appendices table 3: Correlation matrix Likert-scale questions Smartphone (S).

	distraction_manual	distraction_awareness	distraction_shift_focus	distraction_mental_load	distraction_glance_frequency	distraction_glance_duration	behavior_more_speed	behavior_less_speed	behavior_speed_control	behavior_lane_position	behavior_reaction_time	behavior_wrong_turns	behavior_operating_errors	bad_instructions	interruptions
distraction_manual	X	0,04	0,40	0,04	0,31	0,14	0,34	0,46	0,45	0,31	0,36	-0,06	0,48	0,31	-0,28
distraction_awareness	X	X	0,21	0,54	0,31	0,25	0,36	0,33	0,27	0,20	0,42	0,00	0,09	-0,04	-0,03
distraction_shift_focus	X	X	X	0,52	0,58	0,67	0,34	0,64	0,47	0,51	0,60	0,28	0,16	0,21	-0,14
distraction_mental_load	X	X	X	X	0,50	0,74	0,00	0,16	0,07	0,13	0,53	0,50	0,26	-0,18	0,20
distraction_glance_frequency	X	X	X	X	X	0,77	0,24	0,70	0,40	0,30	0,54	0,40	0,00	0,13	0,00
distraction_glance_duration	X	X	X	X	X	X	0,22	0,44	0,37	0,22	0,60	0,50	0,17	0,18	0,15
behavior_more_speed	X	X	X	X	X	X	X	0,50	0,75	0,21	0,00	0,19	0,22	0,74	0,00
behavior_less_speed	X	X	X	X	X	X	X	X	0,70	0,34	0,40	0,28	0,05	0,39	-0,36
behavior_speed_control	X	X	X	X	X	X	X	X	X	0,42	0,21	0,47	0,12	0,83	0,18
behavior_lane_position	X	X	X	X	X	X	X	X	X	X	0,69	0,18	0,06	0,03	0,03
behavior_reaction_time	X	X	X	X	X	X	X	X	X	X	X	0,07	0,24	-0,24	-0,20
behavior_wrong_turns	X	X	X	X	X	X	X	X	X	X	X	X	0,12	0,42	0,53
behavior_operating_errors	X	X	X	X	X	X	X	X	X	X	X	X	X	0,19	0,06
bad_instructions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0,32
interruptions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

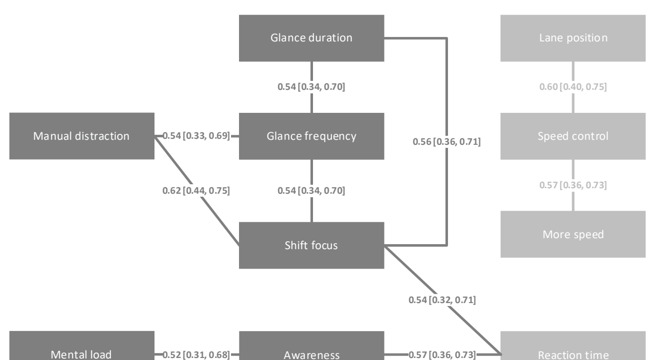
Appendices table 4: Correlation matrix Likert-scale questions Integrated (I).

	distraction_manual	distraction_awareness	distraction_shift_focus	distraction_mental_load	distraction_glance_frequency	distraction_glance_duration	behavior_more_speed	behavior_less_speed	behavior_speed_control	behavior_lane_position	behavior_reaction_time	behavior_wrong_turns	behavior_operating_errors	bad_instructions	interruptions
distraction_manual	X	0,67	0,84	0,43	0,65	0,69	-0,02	0,69	0,19	0,51	0,58	0,34	0,46	0,51	0,18
distraction_awareness	X	X	0,76	0,58	0,62	0,57	0,28	0,55	0,09	0,36	0,81	0,33	0,37	0,55	0,15
distraction_shift_focus	X	X	X	0,50	0,66	0,62	0,10	0,60	0,00	0,40	0,80	0,44	0,40	0,70	0,34
distraction_mental_load	X	X	X	X	0,37	0,64	0,71	0,12	0,33	0,50	0,34	0,61	0,76	0,73	0,64
distraction_glance_frequency	X	X	X	X	X	0,67	0,17	0,59	0,55	0,77	0,39	0,33	0,67	0,39	-0,14
distraction_glance_duration	X	X	X	X	X	X	0,24	0,57	0,49	0,86	0,41	0,30	0,74	0,60	0,29
behavior_more_speed	X	X	X	X	X	X	X	0,29	0,38	0,31	0,01	0,17	0,53	0,31	0,23
behavior_less_speed	X	X	X	X	X	X	X	X	0,36	0,52	0,41	-0,07	0,34	0,29	-0,13
behavior_speed_control	X	X	X	X	X	X	X	X	X	0,85	-0,09	0,37	0,73	0,32	0,15
behavior_lane_position	X	X	X	X	X	X	X	X	X	X	0,26	0,39	0,83	0,55	0,21
behavior_reaction_time	X	X	X	X	X	X	X	X	X	X	X	0,16	0,09	0,62	0,35
behavior_wrong_turns	X	X	X	X	X	X	X	X	X	X	X	X	0,67	0,68	0,68
behavior_operating_errors	X	X	X	X	X	X	X	X	X	X	X	X	X	0,58	0,39
bad_instructions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0,69
interruptions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

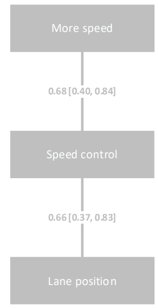
Appendices table 5: Correlation matrix Likert-scale questions Streaming (Z).

APPENDIX 4: LIKERT SCALE QUESTION CORRELATION DIAGRAMS

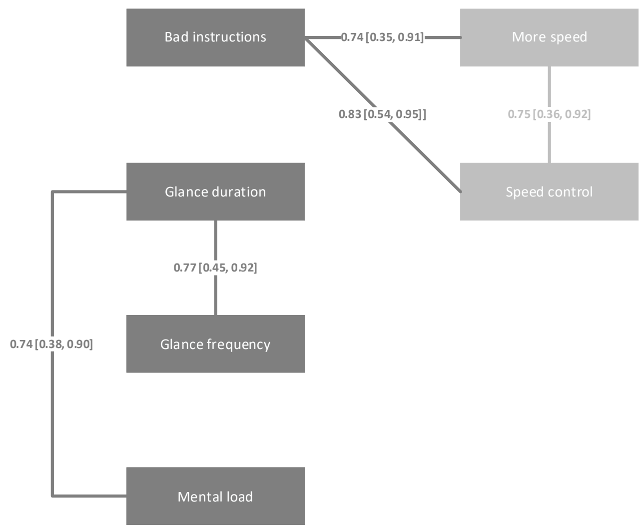
Correlation diagrams for each group (S, I, Z, F), for all correlations where lower bound of the confidence interval is at least 0.3. The lighter grey column on the right indicates measures of driving performance. Darker grey columns on the left indicate distractions.



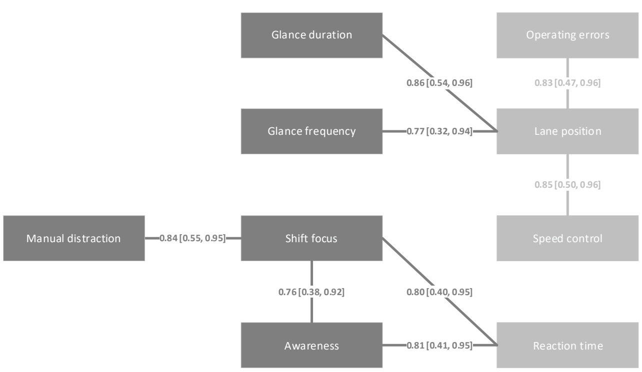
Appendices figure 1: Cross-variable correlation coefficients and 95% level confidence intervals for Full set (F).



Appendices figure 2: Cross-variable correlation coefficients and 95% level confidence intervals for group Smartphone (S).



Appendices figure 3: Cross-variable correlation coefficients and 95% level confidence intervals for group Integrated (I).



Appendices figure 4: Cross-variable correlation coefficients and 95% level confidence intervals for group Streaming (Z).

APPENDIX 5: MEANS LIKERT-SCALE SURVEY QUESTIONS

	$\bar{x}(S)$	$\bar{x}(I)$	$\bar{x}(Z)$
distraction_manual	2,04	1,75	2,00
distraction_awareness	2,61	2,06	2,46
distraction_shift_focus	2,11	1,81	2,23
distraction_mental_load	1,79	1,56	1,85
distraction_glance_frequency	2,21	2,00	2,15
distraction_glance_duration	2,29	2,25	2,23
behavior_more_speed	1,81	2,00	1,45
behavior_less_speed	2,69	2,57	2,18
behavior_speed_control	2,04	2,50	2,00
behavior_lane_position	2,58	2,36	2,09
behavior_reaction_time	2,69	2,36	2,18
behavior_wrong_turns	2,81	2,50	2,00
behavior_operating_errors	1,88	1,71	1,55
bad_instructions	2,04	2,14	2,09
interruptions	2,08	1,57	1,64

Appendices table 6: Means of answers to Likert-scale questions. Cells marked grey indicate mean comparisons with effect size > 0.3.

APPENDIX 6: LIKERT SCALE QUESTIONS MEAN COMPARISONS

Rank Biserial Correlation Coefficients (r) based on Mann-Whitney U statistic for all means comparisons across groups S (Smartphone), I (Integrated) and Z (Streaming). The Likert-scale questions are divided into two groups: (1) distraction (appendices table 7), and (2) behaviour (appendices table 8).

test	*n1*	*n2*	*diff*	U_{max}	*r*	*p*
s_distraction_awareness vs. i_distraction_awareness	28	16	0,54	299	0,33	0,05
i_distraction_shift_focus vs. z_distraction_shift_focus	16	13	0,42	82	0,21	0,29
s_distraction_manual vs. i_distraction_manual	28	16	0,29	263	0,17	0,32
s_distraction_shift_focus vs. i_distraction_shift_focus	28	16	0,29	263	0,17	0,31
i_distraction_mental_load vs. z_distraction_mental_load	16	13	0,28	88	0,16	0,44
s_distraction_mental_load vs. i_distraction_mental_load	28	16	0,22	260	0,16	0,35
i_distraction_awareness vs. z_distraction_awareness	16	13	0,40	90	0,13	0,53
s_distraction_glance_frequency vs. i_distraction_glance_frequency	28	16	0,21	253	0,13	0,44
z_distraction_awareness vs. s_distraction_awareness	13	28	0,15	159	0,13	0,51
i_distraction_manual vs. z_distraction_manual	16	13	0,25	94	0,10	0,66
z_distraction_glance_duration vs. s_distraction_glance_duration	13	28	0,05	168	0,08	0,69
i_distraction_glance_frequency vs. z_distraction_glance_frequency	16	13	0,15	96	0,08	0,73
i_distraction_glance_duration vs. z_distraction_glance_duration	16	13	0,02	111	0,07	0,77
z_distraction_shift_focus vs. s_distraction_shift_focus	13	28	0,12	192	0,05	0,79
z_distraction_manual vs. s_distraction_manual	13	28	0,04	175	0,04	0,84
z_distraction_glance_frequency vs. s_distraction_glance_frequency	13	28	0,06	176	0,03	0,87
z_distraction_mental_load vs. s_distraction_mental_load	13	28	0,06	183	0,01	0,99
s_distraction_glance_duration vs. i_distraction_glance_duration	28	16	0,04	224	0,00	1,00

Appendices table 7: Table sizes (r) for means comparisons of distractions across groups S, I and Z.

test	n1	n2	diff	Umax	r	p
z_behavior_wrong_turns vs. s_behavior_wrong_turns	11	26	0,81	89	0,38	0,07
i_behavior_more_speed vs. z_behavior_more_speed	14	11	0,55	102	0,32	0,15
i_behavior_speed_control vs. z_behavior_speed_control	14	11	0,50	102	0,32	0,17
s_behavior_speed_control vs. i_behavior_speed_control	26	14	0,46	125	0,32	0,09
z_behavior_lane_position vs. s_behavior_lane_position	11	26	0,49	99	0,31	0,12
z_behavior_reaction_time vs. s_behavior_reaction_time	11	26	0,51	101	0,30	0,14
i_behavior_less_speed vs. z_behavior_less_speed	14	11	0,39	100	0,29	0,21
i_behavior_wrong_turns vs. z_behavior_wrong_turns	14	11	0,50	99	0,29	0,22
z_behavior_operating_errors vs. s_behavior_operating_errors	11	26	0,34	104	0,27	0,17
z_behavior_less_speed vs. s_behavior_less_speed	11	26	0,51	105	0,27	0,20
s_behavior_reaction_time vs. i_behavior_reaction_time	26	14	0,34	226	0,24	0,18
i_behavior_lane_position vs. z_behavior_lane_position	14	11	0,27	94	0,21	0,35
z_behavior_more_speed vs. s_behavior_more_speed	11	26	0,35	113	0,21	0,28
s_behavior_wrong_turns vs. i_behavior_wrong_turns	26	14	0,31	214	0,17	0,36
i_behavior_operating_errors vs. z_behavior_operating_errors	14	11	0,17	89	0,16	0,49
i_behavior_reaction_time vs. z_behavior_reaction_time	14	11	0,18	89	0,15	0,52
s_behavior_operating_errors vs. i_behavior_operating_errors	26	14	0,17	206	0,13	0,47
s_behavior_more_speed vs. i_behavior_more_speed	26	14	0,19	162	0,11	0,56
s_behavior_less_speed vs. i_behavior_less_speed	26	14	0,12	202	0,11	0,56
s_behavior_lane_position vs. i_behavior_lane_position	26	14	0,22	200	0,10	0,60
z_behavior_speed_control vs. s_behavior_speed_control	11	26	0,04	144	0,00	1,00

Appendices table 8: Figure 1: Effect sizes (r) for means comparisons of behaviour across groups S, I and Z.

APPENDIX 7: CODING SCHEMA

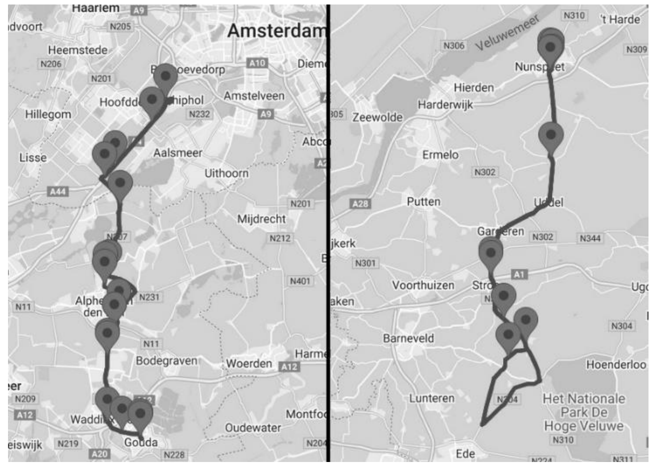
The coding list that was used as (optional) annotations during driving sessions is displayed in table appendices table 9.

1	SDLP
2	Steering jerk
3	Abrupt breaking
4	Time headway
5	Speed control
6	Difficulty decision making
7	Response time
8	Near collision
9	Navigation interferes with driving task
10	Navigation and traffic related notifications
11	Bad instructions or difficulty interpreting
12	Route changes or suggestions
13	Conflict between other system and navigation
14	Navigation system failure
15	Traffic camera notifications
16	Searching what lane to take
17	Communication failure
18	Message notifications interfere with navigation
19	Manual distraction
20	Awareness
21	Shifting focus
22	Mental load
23	Glance frequency
24	Glance duration
25	More speed
26	Less speed
27	Speed control
28	Lane position
29	Reaction time
30	Wrong turns
31	Operating errors
32	Bad instructions
33	Interruptions

Appendices table 9: Observation session coding list.

APPENDIX 8: FIELD OBSERVATION ROUTESR

Route one lead from Wekeromseweg 1, 6718SC, Ede to Dominee Martiniuslaan 6, 8071GW, Nunspeet. Route two lead from Schiphol Boulevard 800, 1118BN Schiphol to Lem Dulstraat 3, 2801EN Gouda. Routes depicted in appendices figure 5.



Appendices figure 5: Route from Schiphol to Gouda (left); Route from Ede to Nunspeet (right). This image contains outtakes from Google Maps [36] and GeoBasis-DE/BKG ©2009.