

Comparing the Effects of Integrated and Nomadic Navigation Systems on Road Traffic Safety

A Naturalistic Experiment

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ABSTRACT

To write.

1 INTRODUCTION

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

In a sense, the car has become an information unit. Traffic today without information distribution is nearly unthinkable. There are various data the driver needs, delivered by assistance and control systems. There are also data that the driver does not primarily need, but is nevertheless provisioned such as entertainment and communication. Car infotainment systems divided by Kandemir et al into Nomadic (external, such as smart phones) and integrated devices [3] consist a broad range of applications like messaging, radio and navigation. Modern cars contain a larger variety of infotainment systems. These systems by themselves change rapidly, for example further integration of smartphones with native car infotainment systems, 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 may have been done by knobs and buttons.

One issue that drivers encounter is the potential for an excess of information provided during certain stages of driving that may not be 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 [4][5]. Navigation systems may have a positive effect on traffic safety as it prevents unnecessary searching and detours, but under condition that destination is entered into the system before starting to drive [6]. 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. The results of this study provide empirical

grounding for future designs of car navigation systems and related regulations, ultimately to improve traffic safety. The following questions are formulated to which the answers provide these insights.

1. What are the specific distractions introduced by smartphone navigation systems that impact road safety?
2. What are the specific indicators of road safety 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 nomadic (smartphone) versus integrated car navigation systems?
4. Is there a statistically significant difference in specific road safety indicators between drivers using smartphone navigation systems versus those using integrated navigation systems?
5. How do nomadic (smartphone) navigation systems and integrated car navigation systems differ in terms of their impact on road safety indicators?
6. How can the results of this study be used to inform the design of future car navigation systems and regulations around their use to improve road safety?

Altogether this research will provide an answer to the following main research question: What is the impact of smartphone navigation systems versus integrated car navigation systems on road safety, specifically in terms of the distractions they introduce, relevant indicators of road safety, differences in impact on road safety indicators, and implications for the design of future car navigation systems and regulations around their use?

2 RELATED WORK

This section aims to provide 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.

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 [1]. 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 [1].

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) [2]. 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 dialing) and various components of user interfaces with respect to driving performance. Simulation studies such as Grahn and Kujala [1] or Jun Ma [3] are the most frequently used methodology in similar studies, followed by naturalistic studies as the second most common approach [4].

2.1 Types of distractions

Use of navigation systems may introduce various types of distractions, classifiable as cognitive, visual, manual, and auditory [3][5], 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. Visual distraction seems to be highly represented in previous studies into distracted driving. It is also a core concept in the US National Highway Traffic Safety Administration 2013 driver distraction guidelines for in-vehicle electronic devices [6] 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 [7]. 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 [8]. 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 [8].

While voice control allows the driver to keep the eyes on the road, a tradeoff 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 [3]. Mitigating high cognitive load by full text visual feedback in turn causes high visual load and time pressure, which in turn may be mitigated by visual feedback in the form of keywords and icons [5].

2.2 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 [4]. These IVIS-related tasks mentioned in this study can be considered unhelpful distractions, together with adjusting the radio, entertainment systems, dealing with irrelevant (navigation) data, and specifically to nomadic systems: popups and notifications by for instance social media or disruptions and interruptions of the navigation application.

User interface design for cars has been mentioned as ‘a community’ [5], pointing at the fact that it has a certain maturity as a field of study. This literature review has observed improvement of car safety to be a key driver of this field. Car navigation systems for consumers have been around since Mazda introduced them in 1990, at the time as a system integrated with the car [9]. Since, the market has additionally seen dedicated navigation devices (like a Garmin or TomTom device), smartphone navigation apps (like Google Maps), and more recently, the linking of smartphone navigation apps to the car IVIS, for instance by cable or Bluetooth. At least iOS (Apple CarPlay) and Android (Android Auto) currently support such features. The latter mentioned feature may be considered a sort of 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 [9], and given that an updated navigation

system improves the user experience and potentially even safety, the mentioned hybrid system potentially has an advantage.

Interaction modalities: Haptic feedback can help alleviate visual distraction and allow the driver to focus on the road [10]. Audio feedback, such as a “read aloud” feature, can also be helpful, although it may not be as effective in some situations and can still cause cognitive distraction [1]. 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 may be more suitable for certain complex secondary tasks, compared to knobs and buttons, despite the fact that knobs and buttons are by themselves more simple to operate [3].

Multiple studies have identified navigation destination entry as highly demanding [10][11], and in at least two instances it was even identified by direct experiment as the most demanding secondary task [2][3] among other common tasks such as text messaging, dialing and radio volume adjustment.

2.3 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 [4]. The mentioned metrics may be considered synonymous, or closely related to driver performance indicators.

Analysis reveals that the design of the IVIS interface affects driving speed. Engaging in activities such as conversing, dialing, or texting while driving leads to a decrease in driving speed and an increase in headways [4]. This is a well-known effect and named by Young and Regan as “compensatory or adaptive behavior” [11]. 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 center (more so than on speed control). Still voice control seems to distract less than operating a touch screen. [3]. Furthermore, it has been shown that voice control with full text visualization leads to higher headway variability, attributed to higher total glance durations [5].

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 [12]. Also minding the interdependencies of distraction variables, Kandemir, et al. propose the existence of “toxic” task combinations in which certain tasks, while not overly burdensome on their own, may surpass a certain threshold when performed in conjunction with more complex tasks, such as dialing while simultaneously braking at a red light [13]. In a similar sense, Oviedo-Trespalacios have approached what they called “Mobile Phone Distracted Driving” as a human-machine system. They have focused their observations not just on distractions by certain tasks, but also by conflicts that occur between combinations of tasks [14].

3 METHODOLOGY

The data collection and analysis consisted two main phases, first a requirements elicitation and the second an experiment. As an especially important ethical consideration to this study to minimize risks to the participants, researcher and other traffic, the researcher has explicitly requested compliance with traffic laws at all times during driving sessions, and to always put safety first when making decisions while driving.

3.1 Requirements elicitation

Specific indicators of driving performance as well as common distractions relevant to the use of navigation systems were identified through a comprehensive requirements elicitation

process involving a survey, an expert interview, and field observations. By a triangulated approach data was collected about behavior while navigation assisted driving, as well as variables or contextual factors that may influence the relation between distractions and driving performance.

Survey: An online survey was held among a total of 80 participants, 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. The mean frequency of weekly car use among qualified participants was 4.18 days. Tables 1 and 2 describe the reported used navigation systems among participants. The survey aimed to observe the behavior around navigation assisted driving by collecting a sample of car drivers in the Netherlands. Respondents were partly recruited by distribution of flyers via fueling stations across the country, but mostly by recruitment from within the network of the researcher. The respondents provided basic demographic data, and answered questions concerning: (1) their use or of navigation systems while driving (e.g. how, what for, preferences, frequency), (2) how they may or may not have found they were distracted by navigation systems, (3) how have they found those distractions to impact their driving performance, (4) how distractions may be linked to navigation user interface. The resulting raw qualitative data was the main source of indicators such as events, distractors and their perceived effects on safety.

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

Table 3: Frequencies 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 4: Frequencies navigation apps used

Expert interview: To the survey results were added the insights of a traffic safety researcher to provide context to the survey results to add to, weigh and rank indicators identified from the survey results. The interviewee is a scientist linked to the Institute for Road Safety Research (SWOV), experienced in analyzing naturalistic driving data, more specifically with regards to distraction in traffic.

The interview was conducted using a semi-structured format with a pre-determined list of topics to guide the discussion. The interview topics concern: (A) what the expert observes in driving behavior and traffic incidents that is linked to information system use while driving, (B) what differences the expert may or may not observe between use of integrated and nomadic information systems regarding driving behavior and incidents, (C) what the experts say should be done in terms of information system design or regulation to improve traffic safety, with regard to navigation systems. The interview was initially recorded by audio file and before analysis transcribed using ChatGPT whisper API. The transcription was then manually relistened, double checked, edited and coded manually by the researcher.

The data collected from the survey and expert interview, were analyzed to identify potential indicators of road traffic safety and navigation-assisted driving behavior. After each data collection step, qualitative results were edited and then coded, processed into a code book and content analysis took place. After finishing the three data collection steps, a combined content analysis took place and a narrative form analysis was written. Furthermore, based on a process of exclusion and ranking, the most important road safety indicators were selected for further experimental study.

Exclusion: Several factors restricted the feasibility of testing certain indicators, including availability of resources, ethical concerns related to unacceptable risks in road traffic, and personal aspects that are too subjective and difficult to quantify. Based on such factors, certain indicators were excluded from further experimental study.

Ranking: The importance of each indicator on road safety was assessed using a weighted scoring system that takes into account both the severity and prevalence of the safety risk. The survey data was the most important source for determining the prevalence of safety risks, while severity was mostly determined by the outcome from the expert interviews.

3.2 Experiment

To answer question number four as stated in the introduction, a naturalistic experiment was conducted. 40 participants were recruited by the same method as the previous survey, of which 20 commonly use smartphone navigation, and 20 commonly use integrated navigation. Each participant drove a predetermined route while following navigation instructions. Road safety indicators were measured through methods such as GPS logging. Ideally, to increase reliability of the results, multiple methods were used concurrently. It was hypothesized that the integrated navigation system group will show better road safety indicators compared to the smartphone navigation system group. If the results would confirm the hypothesis, it would provide grounds for future empirical study into how nomadic navigation systems may be improved. The collected data was analyzed using statistical techniques, including descriptive statistics, t-test, and regression analysis, to compare the road safety indicators between the two groups. The statistical significance level will be set at $p < 0.05$.

H0: There is no significant difference in road safety indicators between using a smartphone navigation system and an integrated navigation system in a car.

The independent variable in this study is whether participants use a smartphone navigation system (A) or an integrated navigation system (B). The dependent variable is a specific road safety indicator or set of indicators that were identified through the requirements elicitation process. It is important to note that while distraction is a possible mediating variable in the relationship between navigation system type and road safety, it is outside the scope of this study to measure distraction directly.

The lack of control over variables in this naturalistic study posed risks to both validity and reliability. These risks include bias through confounding variables and the presence of uncontrollable external factors.

4 RESULTS

The study aimed to examine the distinctions between smartphone-based car navigation systems and car-integrated navigation systems concerning their potential impact on driving performance, with a particular focus on the mediating role of distraction. Additionally, this research sought to analyze the implications of these differences for the design of car navigation systems and the formulation of

regulations pertaining to their future utilization. The study consisted three data collection phases: (1) Survey, (2) expert interview, and (3) controlled experiment. Throughout this results section the following variable names are used (table 5).

S	Sample of smartphone navigation app users
I	Sample of integrated car navigation system users
Z	Sample of streamed navigation from smartphone to board computer
Φ	Relative salience

Table 6: Variable names used throughout this section

4.1 Description of survey results

For the open questions “Name five distractions while driving related to your navigation system” and “Name five negative effects on your driving performance resulting from navigation system related distractions”, participants had five optional text fields to fill in. Open coding was performed on the answers, codes were counted and a relative salience was calculated by the formula for Φ below. To account for the fact that the participant has a certain response closer to top-of-mind, earlier fields are assigned higher weights. The assigned weights are: weight(field1)=5, weight(field2)=4, weight(field3)=3, weight(field4)=2, weight(field5)=1.

$$\Phi = \frac{(\text{weight} * \text{count})}{\sum_{i=1}^5 (\text{weight} * \text{count})}$$

After coding of answers to the open question “Name five distractions while driving related to your navigation system”, the codes were counted, grouped by variables S, I and Z. The relative salience was calculated. Two important outtakes of this analysis show a noticeable difference between group I on the one hand and groups S and Z on the other.

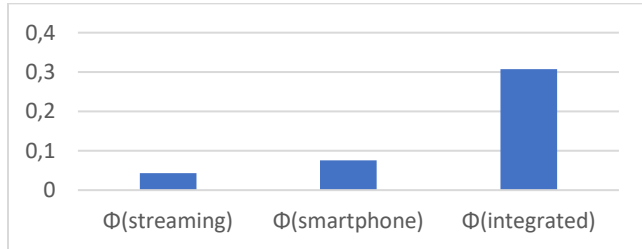


Figure 1: Comparison of relative salience for code “Bad instructions or difficulty interpreting”. Notice how Φ for group I stands out compared to S and Z.

Further studying a potential difference between reported “bad instructions or difficulty interpreting” by one-way chi-squared test resulted in a significant difference between groups I and Z ($p=0,0039$), which indicates that users of car-integrated navigation systems more often report cases such as “wrong route suggestions”, “system outdated”, or “instructions do not take into account maintenance or traffic”.

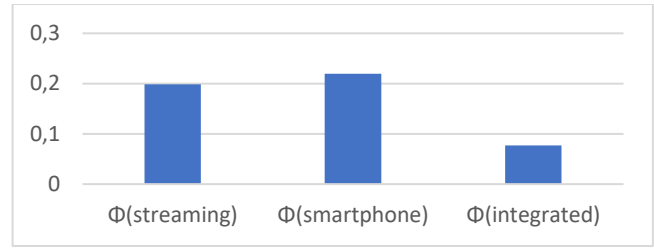


Figure 2: Comparisons of relative salience for code “Conflict between other system and navigation”. Notice how Φ for groups S and Z stands out compared to I.

Further studying a potential difference between reported “conflicts between other systems and navigation” by one-way chi-squared test resulted in significant differences between groups S and I ($p=0,0047$), and groups S and Z ($p=0,0495$), suggesting 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 apps overlay my navigation system”, indicating instances where another app takes precedence while driving and using navigation.

Code	p(S,I)	p(S,Z)	p(I,Z)
Conflict between other system and navigation	0,0047	0,0495	-
Bad instructions or difficulty interpreting	0,1336	-	0,0039
Navigation interferes with driving tasks	0,4054	0,0578	-
Searching what lane to take	0,2059	0,2059	-
Navigation and traffic related notifications	0,2482	0,1317	-
Route changes or suggestions	-	0,5271	-
Navigation system failure	-	-	-
Message notifications interfere with navigation	-	-	-
Communication failure	-	-	-
Traffic camera notifications	-	-	-

Table 4: p-values for one-sided chi-square tests for codes (rows) between groups S and I, S and Z and I and Z.

To the grouped 5-point Likert scale question “How often do the following distractions occur while using your navigation system?”, descriptive statistics are displayed in table 4.

Variables	p (T-test)	p (M-W)
distraction_manual	0,2702	0,3169
distraction_awareness	0,0379	0,0504
distraction_shift_focus	0,2309	0,3054
distraction_mental_load	0,3156	0,3506
distraction_glance_frequency	0,3778	0,4427
distraction_glance_duration	0,8826	1,0000

Table 1: Mean comparisons using T-test (second from right) and Mann-Whitney (right) tests between groups I and S for 6 Likert-scale questions related to “How often do the following distractions occur...”

For each of the previous 17 Likert-scale questions in the previous three tables, a t-test was conducted to compare the responses between groups S and I. Given the significance level of $\alpha=0.05$, significant differences between groups were found in

questions “question A” ($p=0.0153$) and question B ($p=0.0419$) / no significant differences were found.

The survey resultset by itself does not seem to support a hypothesis that there is a difference in driving performance between users of a car integrated navigation system and users of a smartphone based navigation system / suggests that (drivers in group I / group S) are more often distracted by their navigation system.

Encoding the open-ended questions seems to explain why the difference between the groups is <such/so>. While group I complains mostly about <code, code and code>, group S complains about <code, code, and code>, indicating that <distraction concept from literature> applies more to <group>.

- analyse the differences between the groups by coding from text as well as from t-tests and regression analyses.
- Besides differences, also highlight patterns.
- explain how these findings relate to the RQs.

4.2 Description of interview results

Visual distraction was identified as the most significant and 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 analyze these distractions and their effects, the Wiener Fahr Probe 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 SDLP (standard deviation from lane position), steering jerk, breaking delay, abrupt breaking, time to collision, time headway, post encroachment time, and speed control. Task breakdown in driving assistant applications are more effective in safely allocating drivers' 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 play a helpful role in driving performance by alleviating search behavior and allowing drivers to focus more on driving tasks as opposed to navigating. 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.

5 DISCUSSION

To write.

6 CONCLUSION

To write.

7 REFERENCES

To compile.