

# Effects of manually entering navigator destinations while driving in a simulator

P.M. Valero Mora M.L. Ballestar Tarín A. Tontsch I. Pareja Montoro M. Sánchez García

INTRAS. Universitat de València, Valencia

E-mail: valerop@uv.es

**Abstract:** Distraction is regarded as one of the most important sources for traffic accidents, being a contributing factor in about 10–12% of accidents according to traditional crash studies. The use of electronic devices inside the car is a source of driver distraction that has generated a big concern in recent times. One major negative consequence of the in-vehicle use of these devices is a decrease of attention to stimuli in traffic. In order to study the consequences on driving performance, 43 subjects drove the driving simulator SIMUVEG while introducing directions in a navigator. Drivers' capability of keeping longitudinal and lateral control of the vehicle as well as awareness of the road scene was evaluated in this sample of drivers. Analysis of the measures revealed significant reduction of lateral and longitudinal control and of awareness of the visual environment, providing evidence of the negative consequences of interacting with electronic devices while driving.

## 1 Introduction

Driver distraction is a main causal factor in road accidents [1–4]. There is sufficient evidence to state that driver distraction and inattention are the main causes of traffic accidents and incidents and it is likely that the problem is increasing because of the incorporation of new technologies in the vehicle [5]. US accident data suggest that driver distraction and inattention are present in 25 to 50% of accidents [6], although in recent years, studies suggest that this proportion could be even higher [7]. In Spain, according to official data [8], distraction is present in 38% of traffic accidents. Distraction occurs when an event induces an attention shift from the main task, in this case from driving [2]. It can be visual (e.g. reading a map), auditory (e.g. listening to a conversation), biomechanical (e.g. tuning the radio) or cognitive (e.g. 'being lost in thought') [9].

There is a considerable amount of evidence that in-vehicle technology systems can be a source of distraction and consequently a cause of crashes [10–12]. Some of the technology-based distracters that people bring into their car are the so-called 'nomadic devices' like mobile phones, entertainment devices or portable navigation systems (PNDs) [12]. Many studies have focused on these individual sources of distraction for the driver, particularly mobile phones, navigation systems and other vehicle technologies [13–15]. These systems induce the driver to perform secondary tasks simultaneously with driving. In this sense, there is growing concern about possible negative effects, particularly those related to excessive workload and distraction [16]. The National Highway Traffic Safety Administration [6] has presented successive reports on the security implications of using mobile phones and navigation systems while driving [16, 17].

Most of these studies have been conducted in controlled environments in laboratories, on test tracks or in driving simulators. The results provide strong evidence that phones and other technologies in vehicles may adversely affect some aspects of driving. Experimental studies conducted in driving simulators or in specially equipped vehicles have shown that wireless phone use while driving adversely affects driver performance, including longitudinal (speed) control [18, 19] and lateral control [16, 20–24], less situation awareness [25] and increased reaction time [26, 27]. All these effects translate into an increased risk of involvement in accidents. Thus, the use of mobile phones while driving is associated with a fourfold risk of accidents during the brief period of a call [13]. In fact, some authors [7] estimated that these tasks may contribute up to 23% of accidents.

Among the technology-based distraction sources, navigation systems have experienced a very important popularisation in the last few years. From the point of view of safety, these devices have two main operations: destination entry and following of instructions. These two operations may have a 'visual, biomechanical and partly auditory' distracting effect on the driver [28]. Furthermore, there can be a cognitive distracting effect when attention is focused on the aforementioned operations [10].

Destination entry in navigation systems is the operation that has generated more concern related to safety [10] as it is a time-consuming activity and drivers often miss to programme their route before starting the trip [10, 28]. Studies of Srinivasan [29] and Lee and Cheng [30] also showed that driving performance was better when participants used a navigation device than when reading a map while driving, although Dingus *et al.* [31] did not find any difference between these two conditions. However, the

degree to which a driver is distracted by the device may depend strongly on his experience with the device, the usability but also his driving experience.

Some countries have enacted bans for PND entry while driving, for example, France and UK, see [32]. In Spain, a recent legislative action punishes drivers operating a navigator while the vehicle is moving with three points in the penalty point system and a fine of 200€ [8]. Also, some devices lock the input option in certain safety critical situations and others allow destination entry exclusively when the car is stationary [10].

There is evidence that manual entry in electronic devices while driving is associated with deterioration in lateral position and lane keeping [33, 34], slower mean speeds [34], more frequent glances at the device and greater periods of driving with eyes off the road [33]. Deterioration of lateral position is related with poorer control of the vehicle and slower mean speed is considered a result of compensating for the perceived loss of control caused by the non-driving-related task [35]. Increase of the time spent keeping the eyes on the device against on the road is another important indicator for the detrimental aspects of PND manipulation. However, it could be argued that, for driving, it is not necessary to keep your eyes constantly on the road but successive glances on and off road might be sufficient for detecting the relevant information. Results of Rassl [36] suggest that, in case of distraction, drivers make more but shorter glances to the road. However, it is unclear whether drivers are still able to detect and process the relevant information outside the car while performing these short glances. When perceptual task demand increases, the processing capacity for the periphery decreases [37]. In consequence it is plausible that drivers might not be able to appropriately detect relevant information while working on the PND device.

In summary, as direction entry in a navigator is a task that can be interrupted at any moment, it can be argued that detection of external objects may still be performed at a reasonable level while operating the navigator. This argument is probably assumed by many drivers who enter destinations in the navigator routinely when the car is moving in order to justify their behaviour. The aim of this paper is not only to assess the effect that manual destination entry has on driving performance but also whether the visual detection and effective processing of external elements relevant for driving is also affected

## 2 Purpose of the study

The purpose of this study is the evaluation of the negative consequences of manipulating a navigator on driving performance. Three aspects will be considered: speed and lateral control of the car and road scene awareness.

It is expected that vehicle control will be impaired while entering destinations in the navigation device. Vehicle control is subdivided into lateral control and longitudinal control. Decrease of lateral control is expected to be the dominant impairment. Lateral control is measured by means of the time remaining until the car crosses lane boundaries [Time to line crossing (TLC), see 0]. Longitudinal control, measured through speed, is expected to decrease as well as result in trying to compensate for the reduction in lateral control. It is considered that this compensatory behaviour will be unsuccessful if the workload associated with operating the navigator is high, and consequently the speed reduction is not sufficient for maintaining safe levels of lateral control.

Regarding road scene awareness, its assessment involves evaluating whether the drivers look to external stimuli but also if they correctly process these stimuli. Previous research has shown that distracting tasks inside the vehicle will affect the visual behaviour of the drivers by taking their eyes off the road for certain periods of time [36]. However, it could be argued that the drivers may still process most of the external stimuli using short glances oriented off the car. As operating a navigator is a task that can be interrupted at any time, the drivers might still be able to draw most of the important external information by interrupting data entry intermittently and scanning the environment searching for relevant information. Nevertheless, as this process is surely less efficient than the scanning carried out without manipulating the navigator, it is hypothesised that the drivers' ability to detect and correctly process external stimuli will be reduced when manipulating the navigator.

In order to investigate the effects that destination entry while driving has on driving performance and road scene awareness, a driving simulation study was conducted collecting data of vehicle dynamics and the drivers' perception of external stimuli.

## 3 Method

### 3.1 Participants

Forty-three subjects (23 male, 20 female) with a valid driving licence participated in the experiment. The participants were mainly contacted at the university among students and the administrative staff. Their ages ranged between 22 and 70 years. Fig. 1 shows the distribution of ages which corresponds with the age pyramid of Spanish car drivers. All participants have normal or corrected-to-normal visual acuity. A fixed amount of €30 was paid to the subjects for their participation.

### 3.2 Experimental design

A repeated measures design was used in our experiment. Every individual went through the two conditions of driving and operating the navigator (WITH) and driving and not operating the navigator (WITHOUT). The two conditions were counterbalanced, so half of the individuals did the WITH condition first, and the other half did the WITHOUT condition first. Subjects were randomly

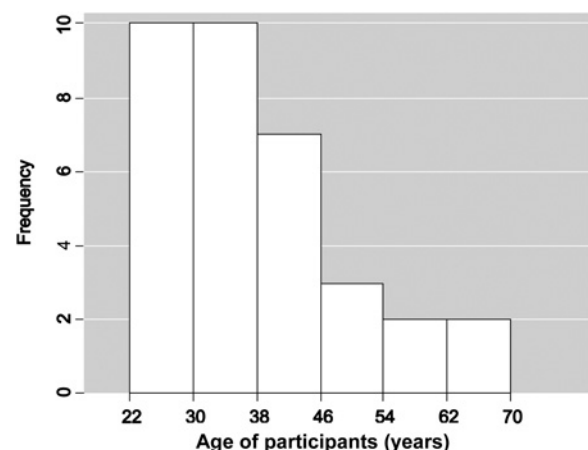


Fig. 1 Age distribution of participants

assigned to the groups. Every subject drove for a training period before the actual experiment started. Data from the training part were removed and not used for analysis.

### 3.3 Test materials and equipment

The high-fidelity driving simulator SIMUVEG (see Fig. 2) was used for this experiment. This is a fixed platform simulator with three screens of a size  $6 \times 1, 5$  m, which guarantees that participants have their field of view completely covered under normal conditions. Three XGA projectors with 2000 lumens display 3D images in real time created using in-house developed software [38] running in a standard computer that is connected to a sensorised car – a Renault Twingo with sensors in the steering wheel, brake, throttle and so forth. The car features manual transmission, a rear view mirror and two side view mirrors. Finally, the audio system of the driving simulator reproduces 3D audio and Doppler effects.

Subjects drove through a scenario with two different parts, namely, a low traffic highway part designed to acquaint the drivers with the basics of driving in the simulator, and a two-way rural road part with several traffic conflicts such as a truck stopped on the verge of the lane, a tailing car, curves and so on. The first part (4.5 km of 18 km) was regarded as training and was not analysed. The training track takes place on the same rural road as the experimental track and, by driving through it, drivers get used to the operations of the car such as steering, braking, speeding and so forth.

A commercial navigator (TomTom Go 710) was used in the experiment. Participants were instructed in its usage before they sat in the car and typed in addresses in order to get used to the device. A list of addresses to be introduced in the navigator was prepared beforehand. Once the experiment was running and the participants were driving, each address was read aloud to the subjects so they had to enter it afterwards. Once they had succeeded in entering one address, a new one was provided to them. However, note that the participants were not hurried up, so their task allowed choosing the most appropriate moments for introducing the addresses and also for interrupting and resuming the task. Actually, it is assumed that, although destination entry was not performed continuously by the participants because of the conditions of the traffic the whole task of evaluating the traffic to find a proper gap for entering addresses, whereas evaluating whether interrupting

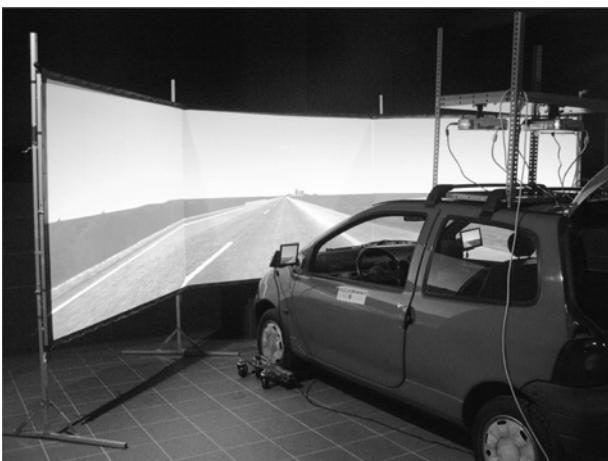


Fig. 2 Driving simulator SIMUVEG

the introduction because of traffic conditions, and resuming afterwards was running all the time during the condition of using the navigator. Hence, even though it could be claimed that only specific aspects of the task are responsible for the distraction, for example, entering the addresses or identifying the proper gaps in traffic, this paper will not make such a distinction.

One of the experimental tasks involved in recognising traffic signs presented to the drivers on the simulator screen. These signs showed up for 5 s on the right side of the screen in 12 pre-specified moments of the simulation along the circuit and were clearly visible. The objective of this task was to measure two aspects of road scene awareness: ‘detecting roadside objects’ [39] and carrying out cognitive processing about their meaning. Thus, the participants’ task involved not only perceiving the stimulus but indicating whether what was shown were ‘true’ traffic signs or ‘false’ traffic signs. ‘True’ traffic signs were taken from Spanish traffic regulations and ‘false’ traffic signs were created by manipulating these traffic signs and making them ‘pseudosigns’, that is, signs similar to the actual signs but which do not really exist. Some examples of pseudosigns are: the original sign is rotated (Fig. 3), a non-realistic speed limit is set (200 km/h), or a sign is not logically possible in the place where it is set (stop sign without intersection).

### 3.4 Experimental task

The subjects drove the experimental scenario while performing the following experimental tasks. No specific goals were set and only a general recommendation of doing as best as possible was expressed to the drivers.

- Introducing addresses in the navigator as they were read aloud by the experimenter. The subjects had to find the address in the navigator that the experimenter indicated to them. The subjects could work at their own pace for doing this task. Once they had finished, a new address was read to them.
- Determining if the signs presented to them were true signs or pseudosigns and telling so to the experimenter. This task involved periodically scanning the side of the screen to check for a traffic sign popping up and then processing it to decide whether the sign was true or false (and saying it aloud).

All drivers behaved as expected, introducing addresses at their own pace and at the same time trying to identify the signs appearing on the screen. It could have happened that some drivers gave up entering addresses and focused only on the sign recognition aspect of the task; however, no evidence of this behaviour was identified in any of the drivers.

### 3.5 Measures

Driving simulators offer a number of measures potentially useful for evaluating performance. A classification of these



Fig. 3 Example of sign and pseudosign used in the experiment

measures [39] distinguishes three main categories, namely, measures of longitudinal control, measures of lateral control and awareness of the environment. Longitudinal control can be measured in different ways. One way is using the time to collision (TTC) with a car in the front. This measure has a high validity as low values of TTC indicate critical incidents, but it requires a guidance vehicle in the front of the car so it may make the driver feel too constrained in its driving. Another way of evaluating longitudinal control is by measuring the speed, which was the method chosen in our case.

Lateral control admits to be evaluated also using different measures. Hence, the standard deviation of the lateral position gives information about the variability of the position of the vehicle within the lane. However, this measure is affected spuriously by factors related with the vehicle and the road, such as lane width, curvature and speed of the vehicle (ISO, 2003). In turn, TLC is less affected by factors like the ones mentioned before, and also can be measured with accuracy in driving simulators [40]. As an illustration, Fig. 4 shows two scenarios for computing TLC. The left side of Fig. 4 shows a trajectory that does not follow a straight path that consequently causes several moments where TLC reaches values close to zero, meaning that the car is very close to go off road. On the right side of Fig. 4 the car has a straight trajectory with TLC values close to infinite as the car is not in danger of reaching lane boundaries.

Finally, awareness of the environment was measured with the task of guessing whether traffic signs were true or false described above.

There was no monitoring of the performance on destination entry as we did not consider it limited to only the observable part of introducing directions manually. We considered the secondary task as all the process of deciding whether the traffic conditions were acceptable for starting the introduction of directions and also for stopping the introduction, that is, it included non-observable parts. We had thought that secondary task performance deteriorated if a driver stopped introducing directions completely but this did not happen in any case. We believe that this setting resembles the natural situation where drivers manipulate the navigator while driving when they feel it will not interfere too much with driving.

### 3.5.1 Variables used in the study: The specific variables used in our study were:

- *Mean speed (MS)*: Low values in this measure are usually related to increased mental workload. Drivers often try to



**Fig. 4** Two trajectories of car with values of TLC close to zero (left) or infinite (right)

compensate increased workload by reducing speed (ISO, 2003).

- *Percentage of lateral control (PLC)*: TLC was used for measuring lateral control. Thus, it was computed whether there was any episode of  $TLC < 2$  s every ten metres and then the percentage of subsections with at least one episode of such type was calculated. The result is subtracted from 100. The final value is a figure between 0 and 100, where 0 means low and 100 high lateral control.

- *Percentage of correct identification of traffic signs (PTS)*: Number of signs identified divided by the total number of signs presented by 100.

## 4 Results

The results will first be presented with descriptive statistics for the dependent variables measured in this study, namely, MS, PLC and percentage of correct identification of traffic signs (PTS). Then, results for within-subject analysis of variance comparisons will be used to evaluate the impact of using the navigator while driving.

Table 1 shows the descriptive statistics for the three dependent variables. The results are split according to the two conditions of the study: manipulating a navigator while driving (WITH navigator) against non-manipulating the navigator while driving (WITHOUT navigator). This table allows drawing a first impression of the results obtained in the experiment. Hence, the MS of the drivers ranged between a minimum of 36.67 km/h (in the WITH condition) to a maximum of 102.35 km/h (in the WITHOUT condition) and the mean was 64.75 and 79.25 km/h, respectively.

PLC has a limit of 100 but it can be seen that any participant achieved this maximum, as the best result is 93.33%. Minimum values are about 51% in the condition WITHOUT and 26% in the condition WITH. Mean values are 60 and 76%, respectively.

Finally, although average values of PTS are 49 and 85% for the conditions WITH and WITHOUT, there were participants that were able to identify correctly all the signs and had 100% performance, whereas others scored 0%, so they did not recognise any or almost any of the signs.

As a preliminary analysis, we examined whether there are significant differences in performance between men and women and across age groups. In this sense, the effect of using the GPS while driving is similar in all groups. Young drivers (25 years) and adults (25–50 years) obtained similar results. Older drivers (aged 50 years or more) reduced their speed more and seemed to be more concerned with the control of the vehicle and the perception of signals, although no significant differences were found ( $p > 0.05$ ). Furthermore, no differences were observed between men and women. Slightly more women lost control of the vehicle but again no significant differences ( $p > 0.05$ ).

**Table 1** Descriptive statistics for the dependent variables in the study

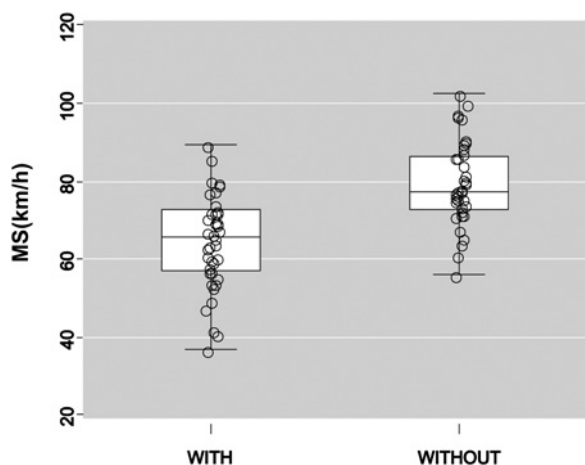
	Min	Max	Mean	St. Dev.	Asym.	Kurtosis
MS WITH, km/h	36.67	89.38	64.73	12.12	-0.25	-0.26
MS WITHOUT, km/h	56.28	102.35	79.25	10.42	0.37	-0.03
PLC WITH, %	26.85	93.33	60.51	16.13	0.17	-0.30
PLC WITHOUT, %	51.14	92.75	76.07	9.02	-0.89	0.89
PTS WITH, %	0.00	100.00	49.69	29.08	-0.10	-0.97
PTS WITHOUT, %	11.11	100.00	85.37	22.63	-1.52	1.68

#### 4.1 Mean speed

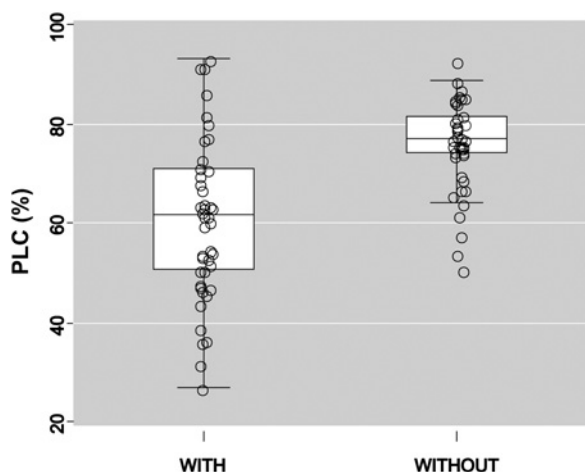
The MS of the driver is a measure related with the longitudinal control of the vehicle. Although the mean speed of a driver depends on his/her individual aptitude and attitude, the difference in speed between conditions can be interpreted as evidence of a reduction of the control of the vehicle. Indeed, in our experiment, manipulating the navigator reduced the mean speed of the drivers by about 15 km/h ( $t(42) = 9.758$ ;  $p < 0.0001$ ). Hence, although participants in the WITHOUT condition maintained an average speed of 79.25 km/h, in the WITH condition the average speed dropped to 64.73 km/h. Fig. 5 shows that there were no outliers in the data and that distributions in both conditions were symmetric and had similar spread.

#### 4.2 Lateral control

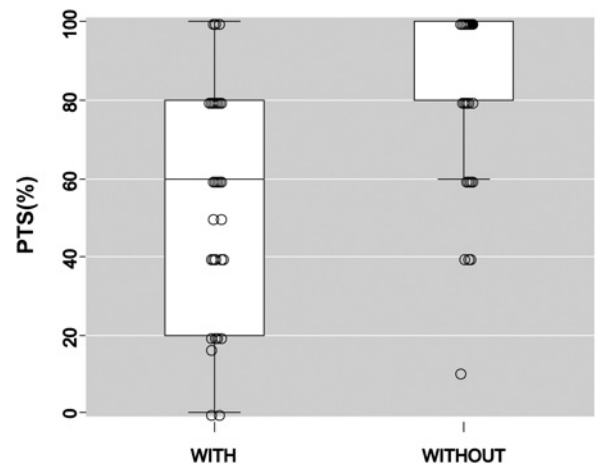
Manipulating the navigator while driving affected the participant's lateral control of the vehicle as drivers not using the navigator (WITHOUT) reached a score of 76 PLC in average whereas those using the navigator (WITH) obtained an average of 60 in PLC. This difference was significant  $t(42) = 6.67$ ,  $p < 0.001$ .



**Fig. 5** Mean speed for the conditions manipulating a navigator (WITH) and non-manipulating the navigator (WITHOUT)



**Fig. 6** Differences in PLC between drivers manipulating a navigator (WITH) and non-manipulating the navigator (WITHOUT)



**Fig. 7** Differences in PTS between drivers manipulating a navigator (WITH) and non-manipulating the navigator (WITHOUT)

Fig. 6 shows the boxplot comparing the lateral control in the two conditions. Note that using the navigator had the effect of reducing the average lateral control but also increasing the spread of the distribution of the scores.

#### 4.3 Recognised signs

Use of the navigator while driving led to an average reduction of 35% of the percentage of signs correctly identified. Participants in the WITHOUT condition named on average 85% of the signs correctly, whereas those in the WITH condition named only about 50% correctly. The difference was significant  $t(42) = 6.9$ ,  $p < 0.001$ . Actually, 27 out of the 43 subjects managed to perform perfectly (PTS = 100%) in the WITHOUT condition whereas only three obtained the same result in the WITH condition (Fig. 7).

### 5 Discussion

The results of this paper provide evidence of the negative effects on three measures of driving performance of manipulating a navigator while driving. Two of these measures, PLC and MS, are related to two main aspects of vehicle control, namely, lateral control and longitudinal control. The other measure, PTS, reflects the capability of paying attention to external stimuli important for driving and can therefore be linked to awareness of the situation. The three measures were significantly impaired by the task of entering addresses while driving.

Indeed, the results found are not different from those obtained for using other devices in the car such as for example mobile phones [41]. This is so despite the dissimilarities between the task of entering addresses and that of having a conversation. Thus, while a phone conversation is a non-interruptible task that forces the driver to turn his/her attention partially away from the road, entering addresses in a navigator is a low priority, highly interruptible task that is consequently seen by many people as compatible with driving. Hence, some drivers may perceive navigator manipulation as non-risky because they are able to interrupt it whenever traffic conditions require it. This view, however, is not compatible with our results that indicate that the effects on driving performance are not absent and that, consequently, there is probably an increased crash risk.

Note, however, that this paper does not consider the different parts of the task of destination entry responsible for the distraction. Hence, although in this paper we deal with the task as a whole, it is possible that the detrimental effects observed could be pinpointed to specific parts of it. Thus, inputting addresses might be responsible for the main effects, whereas the periods where the distraction is basically cognitive – for example, choosing the right slot for starting the manipulation – might not be contributing to the effects observed. However, results of a similar experiment carried out in our laboratory about text messaging [42] show that the cognitive effort of deciding about the suitable moment for interrupting an entering task has distracting effects on its own. This result was obtained by comparing sections of the road with a similar degree of difficulty where the driver was just thinking about introducing information in a device but not actually doing it, with moments where the driver did not have to introduce any information at all. These results suggest that the different parts of the task of manipulating the navigator may have distinct contributions to the distraction that would be interesting to analyse separately.

The conclusions stated in the previous paragraphs require some caution. Firstly, all the usual limitations associated with being in an artificial situation as of a simulator against driving in real traffic apply here; in particular, in our experiment, participants seemed to prioritise the task of entering directions above the other tasks whereas in real life they may behave differently. However, note that they exhibited this behaviour without receiving explicit instructions for behaving in such a way so it is possible that drivers cannot avoid to be engaged with this type of task in spite of its low priority. Secondly, the task in our experiment was not realistic in that the participants had to enter a number of directions consecutively, whereas in practice drivers usually do not enter more than one direction per trip. Finally, in real life, the problem of keying a direction is sometimes even more extensive, as ensuring that the direction is valid or that it refers to the right place and handling with potential usability problems is often problematic and may require that the driver be engrossed in more complex interactions with the device than permitted in our experiment.

The results of this study confirm previous research about the influence of distraction on driver performance – for example [16, 18]. However, as mentioned, the study has limitations and opens the way for further research. For a better understanding of the influence of driver distraction in traffic accidents, it would be desirable to gain naturalistic driving data that observes drivers in their natural setting [43] and hence, portrays actual information about occurrence, course and consequences of navigator use. Also, the different components of the task of entering addresses in a navigator could be studied separately in order to understand their different contributions to the measures considered.

## 6 Acknowledgments

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