Driving with navigational instructions: Investigating user behaviour and performance

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Abstract

This paper reports the results of an inter-disciplinary study investigating user preferences and performance in relation to spoken in-car route guidance. In-car navigation systems are becoming increasingly popular. However, despite large amounts of research assessing the presentation of spatial information, and the usability and interaction issues surrounding the interfaces, there has been much less investigation of the impacts of auditory presentation of route information. We addressed this issue using a multi-disciplinary approach to collect both qualitative and quantitative data through questionnaires and user experiments. Our research identified a user preference for auditory presentation of route information, as well as a memory advantage for auditory over visual presentation. We also found that simple auditory route instructions could be followed without significant interference to a simulated driving task, whereas more complex auditory instructions did cause interference. Taken together, this research highlights the importance of the design of spoken route guidance instructions in minimising the cognitive demands that they impose.

Keywords

In-car navigation; route guidance; spoken instructions; auditory instructions; cognitive demands; driving simulator

1 Overview

Over the last decade, researchers have become increasingly interested in the levels of driver distraction caused by a range of in-car devices (see Young & Regan, 2007, for a review). Much of this research has focused on the effects of in-car mobile phone use. However, a recent rise in the popularity of in-car navigation systems has also sparked research into the distraction that these devices might cause. Whereas many studies have compared different visual presentations of route information, substantially less research has examined the presentation of auditory navigation instructions. More specifically, although a number of studies have investigated the optimal timing for presentation of auditory route information (e.g. Green & George, 1995; Ross, Vaughan & Nicolle, 1997; Wu, Huang & Wu, 2009) as well as the most effective types of informational content for these instructions (e.g. Burnett, 2000), there is much less research on the cognitive demands imposed by the act of processing auditory instructions of any kind, and on the impact that these cognitive demands might have on the task of driving.

Here, we present a multi-disciplinary study examining people's preference and performance during the use of auditory route information while driving new and unfamiliar routes. We address this issue using several different research methods (including questionnaires, a laboratory study of abstract memory and a simulator experiment) with the aim of providing a wider perspective on the question than is possible using a single research method alone. Our preliminary questionnaire investigates people's reported use of the auditory instructions available from their in-car navigation devices. Experiment 1 then asks whether spoken route information is remembered more effectively than the same information presented in other forms. Finally, in Experiment 2 we examine whether increasing the levels of complexity in the spoken instructions can lead to reductions in performance in a simulated driving task. Our study is novel in bringing together these relatively disparate approaches to address a single research question, so each of the approaches that we use draws on a different background literature. For this reason, we describe the research background separately for each section of the study, before integrating the findings in the final conclusion section.

2 Questionnaire

We began our research with a preliminary questionnaire designed to extract information about people's everyday use of in-car navigation systems and their preferences. Navigation systems are designed to be flexible, such that users can engage with them in different ways, according to their own preferences (e.g. Svahn, 2004). It is, therefore, important to undertake an initial assessment to establish whether users have specific preferences in terms of how the route information is presented. We investigated this issue using a questionnaire consisting of nine items in total. Here, we focus on the two items that related most closely to the use of auditory instructions. Sixteen participants (nine male, aged 18-50, all regular users of in-car navigation devices by self-report) gave free-form responses which we then categorised and coded.

> *Item 1: Do you ever turn off the spoken directions on your in-car navigation device? If so, why?*

In response to this item, only 25% of participants reported ever using the visual display for full navigation, in the absence of auditory instructions. This number corresponds closely with a recent online survey on a much larger scale, which found that only 21% of respondents reported using either the only visual display or mainly the visual display, with the remaining participants making substantial use of the auditory instructions (Forbes, 2006). The correspondence between the results of the two studies is striking, given that participants in our questionnaire gave detailed free-form written responses whereas the online survey required check-box responses from a restricted set of options. Together, these converging findings indicate that the vast majority of users of in-car navigation devices choose to receive auditory instructions from their devices while driving.

However, many respondents report making use of both the auditory and the visual information simultaneously. For example, 71% of respondents to the online survey mentioned above indicated that they preferred to receive route guidance information in both spoken and visual forms (Forbes, 2006). It is, therefore, also important to investigate the relative priority that users assign to the different presentation modalities and this was the aim of the next item.

> *Item 2: Under what circumstances do you look at the visual display of your in-car navigation device? What information do you typically seek from the visual display?*

In response to this item, 75% of participants reported that they only used the visual display for clarification, elaboration or reminders of the auditory instructions. This finding confirms the central importance of the auditory instructions to the majority of users.

Overall, our preliminary questionnaire investigation indicates that the majority of users of in-car navigation devices elect to receive ongoing spoken route guidance information and that they give this information a relatively high priority. This reinforces the importance of research into the ways in which auditory instructions might be processed and the demands that such processing might impose. In line with this aim, our first experiment examined the possibility that auditory route guidance information might be remembered more effectively than information presented through other modalities.

3 Experiment 1: Route memory

A range of laboratory studies have demonstrated an advantage for spoken rather than written presentation, in tasks of short term-memory (e.g. see Penney, 1975 for a review), long-term memory (e.g. Carroll & Korukina, 1999; Conway & Gathercole, 1987) and comprehension and reasoning (e.g. Jakimik & Glenberg, 1990; Markman, Taylor & Gentner, 2007). These results have often been interpreted as indicating that auditory presentation might afford better representations of the temporal order of information (e.g. Glenberg & Swanson, 1986), and might also encourage a greater focus on relational information (e.g. Markman et al., 2007). Given that the successful use of navigational instructions requires both memory for temporal order and some degree of relational processing, these studies might suggest that auditory presentation would be better than written presentation for delivery of navigational instructions.

However, the fact that driving involves continual visual demands in itself suggests that written presentation might present more problems than auditory presentation, regardless of the direction of any memory advantages. Instead, when navigational information must be presented visually, it is more conventional to use map-based, rather than written, presentation. However, none of these earlier studies considered navigational information per se and this research has therefore not typically investigated memory performance for directions presented in the form of a map. Here we compare memory for navigational information presented in map, written and spoken formats, with the aim of identifying which presentational format leads to the best memory performance.

3.1 Methods

3.1.1 Participants

20 participants aged between 18 and 34 (mean age 23.0) gave informed consent before taking part in the experiment. All were regular users of in-car navigation devices by self-report. Participants were paid a single fee for participating in this and another, unrelated experiment. To avoid introducing any systematic bias, the order in which they took part in the two experiments was alternated so for half the participants this was the first experiment, while for the others it was the second.

3.1.2 Stimuli and apparatus

The experiment ran on a laptop PC and was programmed using PST's E-Prime 2.0. Stimuli consisted of 10 test routes and two example routes. Each route consisted of six steps: two left turns, two right turns, and two straights. The routes were generated by randomising the order of these six steps, though the same 12 routes were then used with all participants. We used routes involving six steps because this constituted enough information to present a reasonably challenging memory task while not exceeding the amount of information that can typically be stored in working memory.

Each route was presented once in each of three forms: Map, Spoken, and Written. Figure 1 illustrates an example of a map stimulus. The spoken routes used three recordings of a woman's voice saying "left", "right", and "straight", stored as three separate audio files, each exactly 1s in length, which were played in sequence and repeated as necessary for each route. Written instructions were also generated by E-Prime, and presented in two rows of three words in order to avoid simple shape or contour of the written text being available as a cue. The written instructions were presented in the centre of the screen, in 18 point Courier New font. Photos of crossroads (all of which depicted three roads visibly leading left, right, and straight ahead) provided visual feedback following responses. The pictures were selected at random (with the constraint that no picture could repeat within a trial) from a bank of 14 possible pictures.

3.1.3 Design and procedure

The experiment consisted of a total of 30 trials, consisting of each of the 10 routes presented in each of the three modalities (Map/Spoken/Written), in a random order without repetition. For each trial, participants were first presented with a route, after which they were required to repeat the six steps of the route using the computer's arrow keys (LEFT, RIGHT, and UP for straight ahead). In all cases the presentation of the route lasted 6s: this duration was set by the Spoken condition, which consisted of 6 audio recordings, each lasting 1s; the Written and Map versions of the routes were therefore displayed for the same period. Participants were given visual feedback in the form of photos of road scenes, which changed with each key press, in order to make it clear that the key press had been registered. Participants were informed beforehand that the photos contained no task-relevant information and were for feedback purposes only. Prior to the 30 experimental trials, participants were given 6 practice trials to make sure they understood the task. The practice trials consisted of two test routes in each of the three conditions, in a randomised order. The routes used in the practice trials were not re-used in the experimental trials.

3.2 Results

Accuracy on each trial was assessed in terms of the number of correct steps recalled before the first error. Perfect performance would thus result in a score of 6, and, for example, a mistake in recalling the fourth item would result in a score of 3. Responses made after an error were discounted in this way, because the task required serial recall, so a mistake early on in the sequence would be likely to affect all subsequent responses. Participants' mean accuracy scores were calculated separately for each condition. A one-way repeated-measures ANOVA using the factor of instruction modality (Map/Spoken/Written) was carried out on the accuracy scores. This revealed a significant main effect of modality, $F(1.37, 25.6) = 14.25$, $MSE = 9.71$, $p < .001$, $\eta^2 = 0.17$; note that Greenhouse-Geisser corrections were carried out on the degrees of freedom for this comparison, as Mauchly's test indicated that the sphericity assumption had been violated. Throughout this paper, similar corrections are made for all comparisons where the sphericity assumption is violated. Paired two-tailed t-tests revealed no significant difference in recall between the Spoken condition (mean score = 5.02) and the Written condition (mean score = 5.04, $t(19) < 1$, $d = .04$). However, recall in the Map condition (mean score = 4.04) was significantly worse than in both the Spoken condition ($t(19) = 4.07$, $p = .001$, $d = .88$) and the Written condition ($t(19) = 3.91$, $p = .001$, $d = .91$).

3.3 Discussion

Memory for a short route made up of six simple directions was significantly worse when presented in map format than when presented as a spoken or written list. Thus sequences of navigational information that are short enough to be held in working memory (as are the directions typically presented by in-car navigation devices) are likely to be remembered better when they are presented in spoken form than when they are presented in map form.

With this set-up, we did not replicate the auditory advantage over written presentation that had been seen in previous research. This is likely to relate to the many differences between our experimental design and those of previous studies. However, given the impracticality of presenting lists of written instructions to a person while they are driving, this result is not of central interest to our research question. Instead, the important finding relates to the memory advantage of auditory presentation over map-based presentation.

The stimuli used in the current experiment were deliberately kept simple and abstract in order to allow us to match the task demands as closely as possible between the different presentation methods tested. For this reason our stimuli differ somewhat from the types of information typically presented by in-car navigation devices. This issue is addressed in Experiment 2, in which we used a driving simulator to investigate the impact of auditory navigation instructions in a much more lifelike scenario. Nevertheless, although in-car navigation devices often present reminders of directions at a very short lead time, they also typically present more detailed information significantly in advance, in order to allow appropriate preparatory actions to be taken (e.g. lane changes, indication measures etc.). Effective use of the devices therefore requires the retention of reasonably complex sequences of information (e.g. “at the end of the road turn right, then go right at the roundabout, third exit”). The overall finding from Experiment 1 – that auditory presentation may deliver a memory advantage over map-based presentation – therefore highlights an important potential advantage of the in-car presentation of auditory route information (in addition to the most obvious advantage that auditory presentation does not impose visual demands which might interfere with the visual requirements of the driving task). Coupled with our questionnaire findings suggesting a user preference for the auditory presentation mode, these results reinforce the importance of the auditory instructions in delivering safe and effective in-car route guidance. However, it is important to acknowledge that the task of processing and responding to navigation instructions in any sensory modality will involve some level of cognitive demand. The focus of our final experiment was therefore to investigate the potential impacts of the auditory instructions on driving performance.

4 Experiment 2: Simulator study

It has been proposed that each sensory modality has its own pool of dedicated processing resources (e.g. Wickens, 1980, 2002). According to this view, because driving imposes demands that are primarily visual and manual, it might seem plausible to assume that additional auditory information can be processed to some extent without significant cost. In line with this idea, spoken navigation instructions have been shown to be easier to process and respond to than visual instructions or a combination of spoken and visual instructions (Labiale, 1990; Moldenhauer and McCrickard, 2003). Spoken navigation instructions have also been shown in real driving conditions to produce better driving performance than visual instructions or a combination of spoken and visual instructions (Jensen, Skov & Thiruravichandran, 2010). Thus, overall, the research seems to agree that spoken instructions are one of the safest ways to present navigational information while driving.

However, despite the relative safety of the spoken instructions, it is important to acknowledge that the task of processing and responding to ongoing information in any modality exerts cognitive demands. In line with this view, there is evidence to suggest that even auditorily-presented information can interfere with the task of driving. For example, research now broadly agrees that use of a mobile phone interferes with driving performance (e.g. Horrey and Wickens, 2006; Strayer and Johnston, 2001) despite the fact that the information is delivered auditorily under these circumstances. One might argue that the level of cognitive demand imposed by a phone conversation is greater than that imposed by the use of navigation information, but this of course depends on the exact level of complexity of the auditory navigation instructions produced by the system in question.

There is one study that systematically manipulated the complexity of the auditory instructions presented, finding some limited evidence that driving performance drops as auditory complexity increases (Liu, 2001). However, this study involved a system for delivering many different types of driving-related information, including messages about vehicle state and road conditions, as well as navigation information. The information system in question was, therefore, far more complicated than any of the in-car navigation devices we are aware of. In addition, participants were required to make highly complicated responses (e.g. button presses in response to engine warnings) which were substantially more complex than those required for the real-world task of driving a car in response to navigational information. Thus, it is difficult to draw conclusions from this study in relation to the current research question, because it focused on a very different type of information delivery system, with much higher levels of complexity than a standard in-car navigation device.

Nevertheless, the issue of the level of complexity of auditory instruction that can be tolerated alongside the driving task would seem to be crucial for the effective design of in-car navigation systems. For example, studies investigating the optimal timing for presentation of auditory route information typically suggest that two instructions should be presented together (or “stacked”) if they would otherwise arise too close together in time to allow for optimal timing of presentation. This approach clearly prioritises the time of presentation over the complexity of the information presented, but there is little research at the moment to justify such an approach.

4.1 Methods

4.1.1 Participants

Twenty-six undergraduate participants (aged 19-21) gave informed consent before taking part in the study. One person withdrew due to motion sickness, leaving 25 participants in total, 7 of whom were male.

4.1.2 Stimuli and apparatus

Figure 2 illustrates the simulator set-up, which consisted of an adjustable seat located 170-190cm from a 145 x 196 cm projection screen, along with a Logitech force-feedback steering wheel mounted on a fixed frame and foot pedals 26 cm from the edge of the seat. An XGA image with a wide field of view (approximately 90^{o} x 45^{o}) was projected by a wall-mounted Hitachi XGA ED-X3280 Multimedia Mobile LCD Projector 280 cm from the screen. The eye-height for the observer was set at 1.55m with an eye to screen distance of 1.5m. A Dell Dimensions XPS computer, running Microsoft XP, with an Intel Pentium 4 CPU 3.46 GHz processor, and an nVidia GeForce 6800 GTO graphics card, generated and presented the stimuli and recorded the responses. The computer-generated stimuli were scripted using Python and Vizard (Development Edition; WorldViz, Santa Barbara, CA).

The projection depicted a basic road circuit, consisting of tall buildings either side of a stretch of road with either two or three lanes (see Figure 3 for an example road scene). All sections of the circuit were straight roads with right angled corners. Pedestrians appeared at random times during the driving task, 50m ahead of the current position and either walking transverse across the road (hazardous) or along the pavement (non-hazardous). Button-press responses to pedestrians were collected through buttons located directly under the participant's thumbs on the steering wheel. If the participant failed to respond to a hazardous pedestrian, the image was removed to prevent collision when the driver reached a distance of 10m away. At a driving speed of ~40mph that meant that the driver had ~2.25s to respond before the image was removed and the event was labelled as a "miss".

4.1.3 Design and procedure

Participants were briefed on how to use the driving simulator and asked to drive normally and keep to the left hand side of the road, following navigation instructions where necessary. They were asked to press either one of the buttons on the steering wheel whenever they saw a pedestrian walking into the road. Pressing the button removed the pedestrian and registered that a hazard had been detected. They were also instructed to ignore pedestrians walking on the pavement who did not present as a hazard.

The complexity of the navigation instructions was systematically varied for each participant. In the first 'control' condition, participants drove without any directions from the experimenter. Next came the 'simple' condition, in which participants were given simple verbal directions by the experimenter such as 'turn left at the end of the road'. Finally, participants completed the 'complex' condition, in which they were given compound directions such as 'take the next right turning, then take a left turning after that.' The experimenter verified online that directions were correctly followed, and the next instruction was only given once the previous direction had been completed. Each condition lasted approximately eight minutes, giving a total run-time for the experiment of around thirty minutes.

Various aspects of driving performance were measured: reaction time (RT) to hazardous pedestrians (msec), percentage of hazardous pedestrians missed, steering waiver (deg/s) and average speed (mph).

4.2 Results

Table 1 shows the driving performance measures as a function of auditory instruction condition. A one-way repeated measures ANOVA using this factor (control vs. simple vs. complex) was run on each of the four performance measures.

	Control condition	Simple condition	Complex condition
RT to hazardous pedestrians (msec)	691	674	692
Hazardous pedestrians missed (%)	1.5	3.2	5.5
Speed (mph)	38.44	38.68	41.25
Steering waiver (deg/s)	0.40	0.43	0.62

Table 1: Averages of participants mean reaction times, percentage of target pedestrians missed, speed and steering waiver in Experiment 2, as a function of auditory instruction condition (control vs. simple vs. complex).

No main effect of auditory instruction condition was found in the RT data ($F < 1$, $\eta^2 = 0.008$). Thus, the varying demands of the auditory navigation instructions had no significant impact on the speed with which participants responded to hazardous pedestrians.

By contrast, there was a significant main effect of auditory instruction condition in the percentage of missed hazardous pedestrians ($F(2,48) = 5.84$, $MSE = .002$, $p =.005$, $\eta^2 = 0.15$). Paired two-tailed t-tests revealed no significant difference between the control and simple condition ($t(24) = 1.55$, $p = .13$, $d = 0.31$). However, a significant difference was found between the complex condition and the control condition ($t(24) = 3.14$, $p = .004$, $d = 0.63$) and a marginally significant difference was present between the complex condition and the simple condition ($t(24) = 2.02$, $p = .055$, $d = 0.40$).

A significant main effect of auditory instruction condition was also found in the average speed data ($F(1.45,34.83) = 5.31$, $MSE = 15.83$, $p =.017$, $\eta^2 = 0.07$). As was the case for the missed pedestrian analyses, paired two-tailed t-tests revealed no significant difference between the control and simple conditions ($t < 1$, $d = .05$). However, significant differences were found between the complex condition and the control condition ($t(24) = 2.36$, $p = .027$, $d = 0.47$) and the complex condition and the simple condition ($t(24) = 3.85$, $p < .001$, $d = 0.77$).

The analysis of average steering waiver also revealed a significant main effect of auditory instruction condition ($F(1.56,37.40) = 12.90$, $MSE = .037$, $p < .001$, $\eta^2 = 0.20$). Just as in the missed pedestrian and average speed analyses, there was no difference between the control and simple conditions ($t < 1$, $d = .17$), however significant differences were identified between the complex condition and the control condition ($t(24) = 3.85$, $p < .001$, $d = 0.77$) and the complex condition and the simple condition ($t(24) = 5.02$, $p < .001$, $d = 1.00$).

4.3 Discussion

With the exception of the reaction time data, the performance measures appear to agree very clearly on the effects of auditory navigation instructions on driving performance. Whereas the addition of simple auditory instructions did not impact significantly on any of the performance measures tested, the addition of more complex instructions significantly reduced driving performance, leading people to miss a larger proportion of hazardous pedestrians, and to drive faster, with more steering waiver.

It is possible that the finding of a speed increase in the complex condition (by comparison to the control and simple conditions) may reflect the fact that this condition was presented last in the experimental procedure, by which time participants would have been practised on the driving task, perhaps causing them to increase their driving speeds regardless of any effects of the auditory instructions. We note, however, that this account would predict a speed increase in the simple condition by comparison with the control condition, yet such an effect was not observed. In addition, this type of practice effect would have worked in the opposite direction for the remaining measures (reaction time to hazardous pedestrians, missed hazardous pedestrians and steering waiver), all of which would be expected to improve with increased task practice. Thus, the fact that people drove with more steering waiver and were more likely to miss hazardous pedestrians in the complex condition, despite the potential for additional practice in that condition, can only be said to strengthen these findings.

Overall, this experiment demonstrates that a single spoken instruction can be processed, recalled and followed without causing significant interference to driving performance (as measured in this set-up). However, a compound instruction, consisting of two sequential directions, can provide sufficient processing demand to cause significant performance decrements in a simulated driving task. These findings are in line with those of Liu (2001) who also demonstrated driving performance decrements associated with increases in the complexity of auditory information presented. However, whereas Liu’s set-up presented very complex information requiring a range of manual responses, our findings extend these observations to a task that more closely mimics the standard user experience of automated route guidance. The fact that a relatively small increase in information complexity (i.e. the presentation of two directions as compared with one) can lead to significant impairments in driving performance highlights the importance of careful management of the exact level of demand imposed by the spoken route guidance instructions.

5 Conclusions

This research demonstrates the central importance of spoken instructions in delivering safe and effective in-car navigation instructions. It also highlights the effectiveness of a mixed-method approach in addressing such issues. Through this inter-disciplinary approach, we found a user preference for auditory route information and a memory advantage for auditory (vs. map-based) presentation of sequences of simple directions. We also demonstrated that simple auditory route information could be processed and followed without obvious interference to a simulated driving task, supporting earlier work demonstrating a processing advantage for spoken over visual route guidance instructions (e.g. Jensen, Skov & Thiruravichandran, 2010; Labiale, 1990; Moldenhauer and McCrickard, 2003). However, when the auditory instructions were made more complex, this led to significant performance decrements, indicating that the exact level of demand imposed by the auditory presentation of route guidance information is critical in determining whether or not such information will interfere with the driving task. Future research could address this issue further, with the aim of balancing the need for detailed navigation information against the requirement to keep the processing demands low enough to prevent reductions in driving performance.

The current research focused on the navigation of new and unfamiliar routes because this is the task for which users most commonly employ route guidance systems (e.g. Svahn, 2004). However, interestingly, a significant proportion of users also report keeping their in-car navigation devices active when driving in familiar areas (for example, 35% of the respondents in Svahn's survey reported that they 'always' or 'often' left their system on in well-known environments). Although the cognitive demands involved in navigating a familiar route are likely to be much lower than those required for navigating an unfamiliar route, the presence of auditory instructions will impose significant processing demands even under familiar conditions (and without many of the workload reduction benefits present in unfamiliar situations). The impacts of this more passive usage of the spoken route guidance information could therefore form an interesting focus for future research.

As a final note, we acknowledge that the increased availability of effective in-car route guidance information is likely to have reduced the overall demands on drivers navigating new routes, particularly when compared with the use of maps (e.g. Burnett & Joyner, 1993; Regan, 2007). However, our research indicates that the widespread use of spoken navigation instructions is nevertheless likely to be imposing a significant demand on drivers and research aimed at minimising those demands is therefore likely to be of ongoing value.

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8 Figure captions

Figure 1: Example of map route used in Experiment 1

Figure 2: Illustration of simulator set-up in Experiment 2

Figure 3: Example of road scene used in Experiment 2