# Simple In-Car Route Guidance Information from Another Perspective: Modality versus Coding*

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Abstract

A previous field study concerning electronic navigation aids showed an advantage of auditory presentation of route guidance instructions as compared to visual instructions in terms of navigational errors [1]. In the present paper an experiment is reported that tries to approach the issue of optimal route instructions in a more controlled environment. Under conditions of severe perceptual-motor load subjects were to interpret route instructions with slides depicting real world junctions. The results showed an advantage for verbal over spatial information. No significant effect of presentation modality was found. Implications for presentation of route guidance instructions are given.

## 1 Introduction

It is generally agreed upon that drivers who are severely mentally loaded have a higher risk on accidents (e.g. [2]). Therefore, mental overload should be precluded. One way to do this is by aiding the driver in the navigation task. However in that case care should be taken to prevent unnecessary mental workload by improper presentation of route information. Hence, the present paper addresses the issue how route guidance instructions should be presented in order to minimize driver workload.

The experiment that will be described here was conducted as the logical successor of an earlier navigation study carried out at the TNO Institute for Perception [1]. In that study subjects had to drive three specific routes in a medium sized Dutch city (Amersfoort) in which they were aided by either simple auditory or visual route guidance instructions. The study showed a significant advantage of auditory route guidance versus visual route guidance with respect to navigation errors. Because information modality (auditory versus visual) and code (verbal versus spatial) were confounded this advantage may have been caused by either one.

A few theoretical mechanisms can be found that make opposing predictions concerning optimal in-car route instructions. *Multiple resource theory* [3, 4] states that two concurrent tasks will only lead to interference if they tap the same resources whereas utilizing different resources will lead to minimal interference. Assuming that driving consists mainly of a control task with emphasis on visual/spatial resources the theory predicts that route instructions can be presented best auditorily and verbally instead of visually or spatially in order to minimize task interference. On the other hand, *stimulus-response compatibility* [5] states that information should be consistent with human expectations. Regarding route guidance instructions it predicts that spatial information should be employed in case it has the same form as the real-world junction (i.e. compatible navigation information). When spatial information is incompatible (e.g. 90° arrow and 135° turning) verbal information is preferred since spatial information is then assumed to induce inappropriate expectations. Finally, the recoding mechanism [6] assumes that humans tend to translate pictorial information into a verbal memory code. Should such verbal recoding take place with route instructions, as well, then the issue of spatial compatibility is of no significance and verbal information would be favorable since translation is superfluous.

One of the subjects' tasks in the present experiment was to perform a tracking task in a laboratory environment which enabled full control over task demands. A concurrent task involved interpretation of real-world scenes utilizing simple route instructions. Route instructions were presented in one of the following modes: auditory/verbal, visual/verbal, or visual/spatial. In order to keep information content equal among conditions only arrows with angles of either 0° or 90° were applied in the visual/spatial condition. Response times to the scenes served as prime indicator for optimal route instruction modality and format.

## 2 Method

### 2.1 Tasks

Subjects were confronted with a dual task situation in a laboratory environment. The *primary task* was a compensatory tracking task that simulated lane keeping. In this task, which was performed in the mock-up of the Institute's driving simulator, subjects had to countersteer the random movements of a slide projection in front of the mock-up. When crossing a specific limit on the left and right of the projection screen, a loud and aversive beep was produced until the projected slide was within limits again. This task demanded continuous attention and was chosen because it causes significant perceptual-motor load and has characteristics similar to lane keeping. The tracking task was explicitly labelled the primary task to the subjects and immediate feedback emphasized this.

The *secondary task* consisted of a choice reaction task and was the task of main interest in the present experiment. While tracking, subjects

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were confronted with route guidance information. After disappearance of the information, the neutral slide in front of the mock-up was replaced by a slide depicting a three or four way intersection. Then subjects were to respond on a seven button pad about the direction of the road on the slide as indicated by the route instruction. Route instructions were presented in auditory/verbal, visual/verbal or visual/spatial format. Auditory/verbal and visual/verbal instructions consisted of the Dutch equivalents of TURN LEFT, GO STRAIGHT ON, and TURN RIGHT and were either spoken aloud or printed on an in-car screen. Visual/spatial instructions consisted of perpendicular or straight arrows on the same screen. These arrows were incompatible when the slide depicted a turning of about 45° (between straight on and perpendicular) or 135° and compatible when the turning angle was 0° or 90°. These three conditions were varied between subjects. All instructions were accompanied by a brief buzz, in the auditory/verbal condition shortly before the auditory message and in the visual conditions immediately after the message or graph had been drawn on the screen.

## 2.2 Stimuli and Responses

Real world slides were utilized as stimuli. The slides were divided into two sets, i.e. familiar and unfamiliar. The familiar set contained 7 slides which were repeatedly presented during training and the experiment. Familiar slides were used to evaluate effects of familiarity and to prevent statistical noise in the reaction time data due to unfamiliarity. Each individual slide of this set was presented 30 times while training and 16 times in the experiment. The unfamiliar set contained 56 slides of which each was shown only once. All slides in both sets depicted three or four-way intersections and were taken from the central front position of a van windshield.

In Table 1 all nine combinations of route instructions and responses are shown. The third row of the table shows the position of the seven push buttons on the button pad relative to a central touch sensor. Each button had to be pushed eight times yielding a total of 56 responses per experimental block. Response order was completely randomized over blocks and subjects. Two particular groups of eight responses were randomly divided for each experimental block into a group of four responses that was accompanied by the guidance instruction GO STRAIGHT ON (response 4 and 6 - Table 1) and a group of four that was accompanied by the instruction TURN LEFT (response 3) resp. TURN RIGHT (response 7). Doing this yielded 9 stimulus response possibilities.

## 2.3 Apparatus

The experiment was carried out in the car mock-up at the TNO Institute for Perception. The mock-up is an instrumented fixed base car cab. In front of the mock-up slides were projected via a mirror which rotated horizontally according to a random track but was also under control of the subjects through the wheel. Generation of the random mirror movements and incorporation of subject steering activities were under control of an IBM-AT3 with external stimulus-response interface. The slide movements were based on the second order integral of a white noise signal (sometimes referred to as red noise). This caused the amount of higher frequencies in the slide movements to be limited. The steering sensitivity was 8.4 cm slide shift per degree steering movement. The slide beep limits were 64 cm to the left and right of the central position of the slide projection which equals two times 7.6° visual angle from the position where the subject was seated. It took the wheel 15° to rotate for moving the slide projection between the two beep limits. The top-top values of the noise signal equalled steer rotation of 150°. As measures for tracking precision were chosen Root-Mean-Square (RMS) error relative to the central slide position and the percentage of total time that subjects were off-track.

Slides were projected by two Kodak slide projectors one containing a neutral slide and one containing the stimulus slides. Slide projections of both projectors overlapped completely. The projector with the stimulus slides was under full control of a second IBM-AT3 which selected the slides to be presented and controlled shutters in front of each projector. Thus, while closing the shutter in front of one projector the other was opened. This resulted in very quick slide transitions. One projector was placed on top of the other and both projected through the shutters onto the same rotating mirror.

The IBM-AT3, that controlled the projector and the shutters, also controlled the presentation of navigation instructions and measured and stored response times. Visual route instructions were presented on an electro-luminance screen mounted high on the dashboard (see Fig. 1). Auditory information consisted of a digitally pre-recorded male voice and was clearly audible. The screen, its position on the dashboard, and the auditory/verbal and visual/spatial instructions were similar to those used in the former field study [1].

Table 1 Combining three navigation instructions and seven responses yielding nine S-R combinations.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| AV/VV | turn left | turn left | turn left | go straight on | go straight on | go straight on | turn right | turn right | turn right |
| VS | ↰ | ↰ | ↰ | ↑ | ↑ | ↑ | ↱ | ↱ | ↱ |
| response | ○ ○ ○<br>○ ○ ○<br>● ○ | ○ ○ ○<br>● ○ ○<br>○ ○ | ● ○ ○<br>○ ○ ○<br>○ ○ | ● ○ ○<br>○ ○ ○<br>○ ○ | ○ ● ○<br>○ ○ ○<br>○ ○ | ○ ○ ●<br>○ ○ ○<br>○ ○ | ○ ○ ●<br>○ ○ ○<br>○ ○ | ○ ○ ○<br>○ ○ ●<br>○ ○ | ○ ○ ○<br>○ ○ ○<br>○ ● |
| response number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

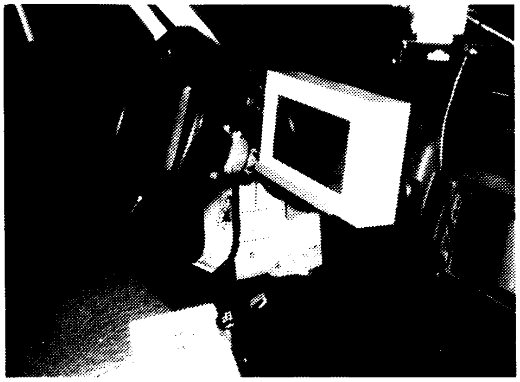

Fig. 1 Interior of the mock-up showing the position of the button pad, its lay-out, the screen for presentation of visual information and part of the infrared observation camera.

### 2.4 Subjects

In total, twenty-six males served as subject, including two who were replaced due to motion sickness. All were between 20 and 40 years of age, had normal vision, used no spectacles, and were right-handed.

### 2.5 Procedure

The experiment consisted of two stages, a practice stage and an experimental stage. The *practice stage* had three goals. First, to familiarize subjects with the tracking task, second to familiarize them with the set of slides used (i.e. the familiar set) and, third, to learn to push the appropriate buttons without looking. The practice stage began with a short general briefing about the experiment and its objectives. Subjects were instructed to always use their left hand for controlling the wheel and their right index finger for responding to the route guidance information and slides by pushing the appropriate buttons. After each response they had to return their right index finger to the rest position (i.e. the touch button) in the centre of the button pad. Next a specific instruction was given that pertained to the tasks in the practice stage. In it subjects were instructed to carry out the tracking task and concurrently respond on the button pad with the buttons under the appropriate angles to all turning points that were available on each projected stimulus slide. For instance, a slide containing a turning point to the left under 45° and one to the right under 135° required the third and seventh button to be pushed (counting clockwise, see Table 1).

In the *experimental stage* subject carried out two or three blocks of 56 responses. All subjects performed two blocks involving concurrent tracking and responding, i.e. one with familiar slides and the other with unfamiliar slides. The order of these two blocks was counterbalanced over subjects. In addition, half of the subjects in each condition performed the choice reaction task without concurrent tracking in a third block. This was done in order to assess costs of performing the two tasks at the same time. Each block was introduced by a written instruction. A particular slide required one response only. Errors were indicated by a short, high pitched tone but the slide always disappeared immediately after a response so corrections were not possible. Each block began and ended with a two minute tracking-only period in order to obtain the individual single-task tracking performance level. The tracking-only period at the beginning of a block was started by the experimenter only after the subject had lined up the vehicle corresponding to the movement of the slide.

In both visual conditions subjects had the opportunity to scan the in-car screen with the guidance instruction for two seconds. In the auditory condition the instruction was presented during this period. After this the instruction screen was erased and the neutral slide in front of the car was replaced by the stimulus slide. The reaction time counter was started at the moment the stimulus slide was displayed. Subjects then had to respond on the button pad according to the route instruction and the slide. Two tenths of a second after responding (or after four seconds without responding) the stimulus slide was replaced again by the neutral slide. Discounting the reaction time, each of these stimulus-response cycles took 8.7 sec.

## 3 Results

Fig. 2 depicts the off-track percentage as a function of presentation mode and experimental period. An 8 x 2 x 3 (subject x slide familiarity x presentation mode) analysis of variance (ANOVA) on RMS and off-track measures only showed a significant effect of subjects when tracking in the dual-task (experimental) condition was evaluated. Incorporating the 2 minutes pre- and post-single tracking-period as separate factor (three levels) revealed a main effect of period (RMS data, $F(2,42)=9.49$, $p<0.001$; ratio data, $F(2,42)=13.3$, $p=0.000$) which indicated that tracking was poorer during the dual-task condition with all navigation aids. The interaction between presentation mode and experimental period was not significant ($F<1$). Newman-Keuls tests showed that the percentages of time being off-track in pre- and post-experimental single tracking did not differ, whereas pre-experimental/experimental, and experimental/post-experimental performance differed significantly ($p<0.01$). Newman-Keuls tests on RMS data indicated all periods to be different, pre-experimental/experimental ($p<0.01$), experimental/post-experimental, and pre-experimental/post-experimental (both $p<0.05$).

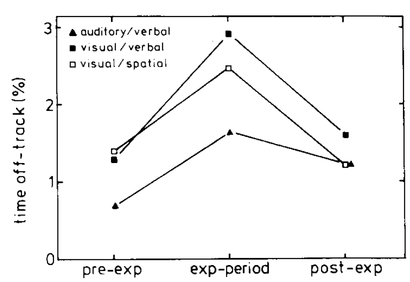


Fig. 2 Off-track percentage as a function of single (pre-exp and post-exp) versus dual task (exp-period).

Fig. 3 shows mean *reaction times* (RT) as a function of response number (tracking only, n=24). These data do not include RTs to incorrect responses and responses to slides with high error rates (see below). The most prominent feature of the figure is that auditory/verbal presentation yielded fastest responses and visual/spatial slowest. Visual/verbal response speed was intermediate. This was consistent over all response numbers with the exception of response 7. The figure also shows clearly that in all presentation conditions, responses to the instruction to go straight on were fastest (response 5 - see Table 1) followed by responses to perpendicular turnings (2 and 8). In contrast, responses to turn left or right under 45° (and to a lesser degree under 135°) were especially slow.

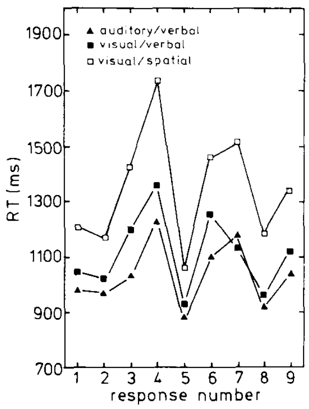


Fig. 3 Reaction times as a function of response number. Collapsed over familiar and unfamiliar slides in the tracking conditions.

Finally, familiar slides led to faster responding (about 90 ms) than unfamiliar slides (Fig. 4). These effects were confirmed by an 8 x 2 x 3 x 9 (subject x slide familiarity x presentation mode x response number) ANOVA on RT which yielded significant main effects for slide familiarity ($F(1,21)=18.2$, $p<0.001$), presentation mode ($F(2,21)=4.51$, $p<0.03$), and response number ($F(8,168)=26.8$, $p=0.000$). Newman-Keuls tests on presentation mode showed auditory/verbal and visual/spatial, and visual/verbal and visual/spatial to be different (resp. $p<0.01$ and $p<0.05$) whereas auditory/verbal and visual/verbal were not significantly different.

A 4 x 2 x 3 x 9 (subject x tracking/no tracking x presentation mode x response number) ANOVA on response times was carried out in order to evaluate effects of concurrent tracking. Main effects of presentation mode ($F(2,9)=4.78$, $p<0.04$) and response number ($F(8,72)=14.5$, $p=0.000$) were found again. Newman-Keuls tests showed, once more, differences between auditory/verbal and visual/spatial, and between visual/verbal and visual/spatial to be significant ($p<0.05$). The difference between auditory/verbal and visual/verbal was not significant. In addition a main effect of tracking ($F(1,9)=4.43$, $p<0.07$) was found which indicated that responses in the no-tracking condition were about 80 ms faster as compared to the dual task condition. Yet, no significant interactions with absence or presence of concurrent tracking were found.

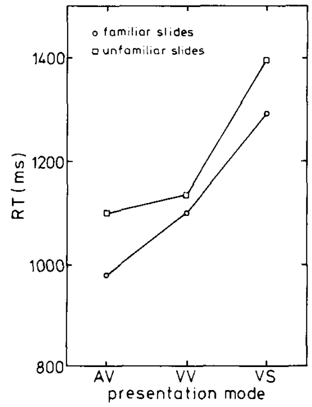


Fig. 4 Reaction times in the tracking conditions as a function of slide familiarity and presentation mode. AV stands for auditory/verbal, VV for visual/verbal, and VS for visual/spatial.

Initial evaluation of *error scores*, per slide in the unfamiliar set, showed five slides to have yielded more than 33 percent incorrect responses. All responses to these slides were discarded from further analyses. These slides belonged to response 1 (1), 5(1), 6(1), and 7(2 slides). Error analysis of the remaining responses utilizing a log-linear model showed main effects of familiarity ($\chi^2=5.61$, df=1, $p<0.02$) and response number ($\chi^2=28.51$, df=8, $p=0.000$) indicating that responses to familiar slides contained less errors than to unfamiliar slides (6.3 versus 7.5%) and response numbers 3, 4, and 7 showed peaks in error (errors for response 1 to 9 were resp. 5, 4, 10, 12, 4, 4, 12, 3, and 8%). Error evaluation of the responses that subjects gave in the tracking versus no-tracking analysis only showed a main effect of response number ($\chi^2=32.45$, df=8, $p=0.000$) and not of tracking.

## 4 Discussion

The major results of the experiment are: first, that auditory/verbal route guidance information led to fastest responses, visual/verbal to slower responding, and visual/spatial to the slowest responses. Yet, the difference between auditory/verbal and visual/verbal did not reach significance in contrast to the other pairwise comparisons. Second, single versus dual task analysis of the response task indicated that responses in dual-task conditions were significantly slower. However, this effect did not change when presentation code or modality were altered. Tracking performance was also significantly reduced by the presence of the concurrent response task. But no significant effect of presentation mode was found in tracking scores. Third, the results showed a main effect of slide familiarity on the reaction times in the response task over all conditions but no differential effects indicating that the pattern of results for familiar and unfamiliar slides was equal.

The counter-intuitive finding that presentation modality of the navigation instructions did not play a significant role in tracking performance is probably caused by the fact that very simple visual messages were presented which were clearly indicated by an auditory signal. Multiple resource theory [3, 4] predicts increased dual task interference with overlapping resources in the tracking and choice-reaction task. This has not been found, neither in the tracking data nor in the response data, excluding an explanation of the data in terms of dual task interference. The absence of presentation mode effects in the tracking data and in the error scores of the response task suggests that reduced performance under dual task conditions was more due to overlap of central or motor resources than to overlap of visual resources. Because of the same pattern of reaction times over responses in spatial and verbal conditions an explanation in terms of stimulus-response compatibility [5] can also be excluded. The finding that verbal coding (auditory/verbal and visual/verbal) yielded faster responses than spatial coding (visual/spatial) suggests that spatial information was translated into a verbal memory code [6]. The reason that responses, while utilizing the same memory code, were faster in the verbal conditions can be explained by the increased possibility to prepare ones responses, the significance of which has been shown before (e.g. [7]).

Regarding the issue of how to present route guidance information best, the present experiment suggests that modality is of minor importance as long as route guidance instructions are of a simple nature and visual information is accompanied by an auditory warning. The information code seems to be more important. There are at least two possible explanations of the data with different consequences for actual guidance information. If indeed, individuals translate spatial guidance information - even when always compatible - into a verbal code (e.g. because of improved retention) then guidance information should be presented verbally especially in cases it is presented long before a junction. If verbal recoding was only utilized in the present experiment because spatial information was usually not compatible then spatial information might have an advantage over verbal instructions in case of consistent compatibility. This would mean that spatial information is to be preferred in actual route guidance. Obviously, further research is required on this issue.

A final conclusion is that even with a verbal presentation format subjects tended to expect perpendicular or straight turnings. Whether spatial instructions are able to change such expectancies remains to be seen.

## 5 References


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