

Signal Sound Positioning Alters Driving Performance

André Lundkvist, Arne Nykänen, and Roger Johnsson
Luleå University of Technology

ABSTRACT

Many of the information systems in cars require visual attention, and a way to reduce both visual and cognitive workload could be to use sound. An experiment was designed in order to determine how driving and secondary task performance is affected by the use of information sound signals and their spatial positions. The experiment was performed in a driving simulator utilizing Lane Change Task as a driving scenario in combination with the Surrogate Reference Task as a secondary task. Two different signal sounds with different spatial positions informed the driver when a lane change should be made and when a new secondary task was presented. Driving performance was significantly improved when both signal sounds were presented in front of the driver. No significant effects on secondary task performance were found. It is recommended that signal sounds are placed in front of the driver, when possible, if the goal is to draw attention forward.

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INTRODUCTION

The number of systems in cars that need the driver's attention increases from year to year. These can include entertainment, communication or systems designed to help the driver, such as navigation or advanced driver assistance. All of these rely on information and interaction with the driver, which could in turn increase driver workload. Previous research has shown that cognitive processing of a secondary task has a negative impact on driving performance [1, 2, 3, 4, 5, 6, 7, 8]. Hence there is a risk that the driver does not have full attention on the road and can thereby miss vital elements in the surroundings. Klauer et al. [1] found from an analysis of driving data collected in traffic that drivers engaging in complex tasks can triple the crash risk as compared to an attentive driver. They also found that visual inattention was the main factor behind 78 % of the crashes that occurred in the study. Blanco et al. [2] discovered from three on-road studies that in-vehicle navigation systems which present multiple options of possible routes had a negative effect on driving performance compared to systems only presenting one route. The conclusion was that multiple options increase the required cognitive processing from the driver and that it negatively affects driving performance by reducing the situational awareness. The effect was found both when presenting information visually and audibly.

Shams and Kim [9] stated that the visual modality generally dominates for spatial tasks, for instance localization and object recognition, while the auditory modality dominates for temporal tasks such as timing between two events. However, it has been shown that auditory events help in locating spatial objects [10]. Shams and Kim [9] found that attention in one modality spreads to other modalities, and auditory events could therefore increase visual attention even when the sound had no direct meaning for the visual task. It has been

shown in other studies that auditory cues are effective for reducing reaction times in simulated driving environments [3, 4, 7, 8]. Ho and Spence [3] examined this by comparing spatial and non-spatial signal sounds and how it could direct the drivers' visual attention for situations when a car was rapidly approaching in front of the subject's vehicle (or behind, which could be seen through the rear view mirror). They concluded that "spatially predictive semantically meaningful auditory warning signals may provide a particularly effective means of capturing attention".

Most of the after-market navigation systems available today emit sounds from the position where the device is installed, which could be in conflict with the message's semantics. Lee [5] performed a study on the effect of congruency between sound source location and the message's semantics for in-vehicle navigation systems. The recall accuracy of navigation information was increased, and response time decreased, when the sound source location was congruent with the spatial information presented by sound, for instance when a verbal message for a left turn was played at the left ear of the driver.

Previous research gives good reasons to believe that driving performance and driver attention may be affected by sound and its location. It seems promising that using sound might reduce the workload and allow the driver to focus more on the road. Using spatially placed sounds for the tasks might also help in drawing attention to where it is needed using the attention capture capabilities of sound. The response time needed to interpret the signals might also be reduced, and could thus help the driver to operate the vehicle more safely. This study intends to evaluate the effects that the spatial positioning of sound signals has on driving and secondary task

performance for simulated driving using Lane Change Task (LCT) [11, 12] and Surrogate Reference Task (SuRT) [12, 13] as a secondary task.

Objective: How are 1) driving performance (measured using LCT) and 2) secondary task performance (measured using SuRT) affected by spatial placement of two sound signals; a sound informing that a lane change shall be made and a sound informing that a new secondary task shall be solved.

METHOD

This experiment used Lane Change Task (LCT) [11, 12] which is a simple driving scenario and a secondary task based on the Surrogate Reference Task (SuRT) [12, 13]. A simple driving simulator was used for the driving scenario, consisting of LCT, a projector, a steering wheel and a secondary task screen (see Figure 1). The experiment was carried out in a sound recording studio at Luleå University of Technology. LCT and SuRT are laboratory tasks used to provide the subjects with a task similar to driving combined with a task similar to typical secondary tasks in a car, both allowing easy and controlled measurement of the subject's performance. The simplified setting limits the generalizability of the conclusions to be drawn, but as the objective of this study was to investigate how sound can be used to direct attention while driving the setup was considered suitable. Effects from changing positions of signal sounds were expected to be fairly small, and therefore an experimental setup giving sensitive and controlled measures was required. Even though this experiment does not prove that measureable effects will be reached under real driving conditions, it is likely that if positive effects can be shown using this laboratory setup there will also be positive effects of proper signal sound positioning for real car driving.



Figure 1. Driving simulator in a sound recording studio with the projected driving scenario (4 m in front of the subject), secondary task (1 m, approximately 45° to the right of the subject) and loudspeaker setup.

Lane Change Task (LCT)

LCT has been successfully used for repeatable and accurate retrieval of driving performance measures during simulated driving [12, 13, 14, 15], and is ISO standardized [11]. LCT consists of a straight road with 3 lanes. The task in LCT is to change lane when information is displayed on signs by the side of the road (see Figure 2). A total of 18

lane changes occur on every track, consisting of 6 different lane change types (driving in the left lane; change one or two lanes to the right, driving in the right lane; change one or two lanes to the left, driving in the middle lane; change one lane to the left or to the right) that are repeated 3 times each. The order of the signs is randomized between tracks to avoid learning effects. The distances between signs varies between 140-188 m (mean distance 150 m), and the length of a track is approximately 3000 m [12].

The lane change information is displayed 40 m before passing the sign, and the subject should start the lane change immediately when the information has been recognized. Before the information becomes visible, the signs are by default blank. Since LCT is quite easy in its default state, the difficulty of the driving scenario was increased by removing the blank signs completely, so that the information popped up when the car was 40 m in front of the sign's hidden location. This makes it more difficult to predict when a lane change should be performed. The change of settings has been suggested to make LCT more realistic with regard to safety critical events [16]. Furthermore, it gives a better measure of driver reaction time than the standardised measure. The standardised driving speed of 60 km/h was used in this study. Higher speeds would increase the driver workload and lower speeds decrease it. However, in pre-tests 60 km/h was shown to give a suitable workload. Choosing a suitable speed was found to be crucial for being able to measure effects from the positioning of the signal sounds on the tasks. When the workload was too low, the task was too simple and no effects were seen. When the workload was too high, the task was too difficult and the subjects were not able to manage it.



Figure 2. Screenshot from LCT. In this example, the subject should change to the left lane, as indicated by the arrow on the signs.

Measuring Driving Performance

The driving performance was measured by comparing the subject's location on the road with a reference driving path (see Figure 3). The reference path was linear, with all lane changes starting 40 m before the sign. The length of each linear lane change was 45 m or 60 m when crossing one lane or two lanes, respectively. The standard deviation from the reference path is used as a measure of driving performance (see Figure 3) and is defined by Equation 1 and 2:

$$d_s = \frac{1}{L_s} \sum_{y \in Y} \sqrt{(x_y - r_y)^2}$$


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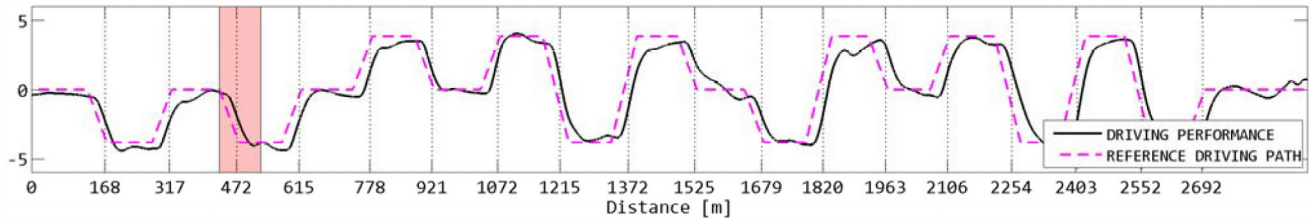


Figure 3. Example of a driving performance analysis. The linear dashed curve is the reference driving path, while the solid black curve is the driving path performed by the subject. The deviation between these curves is used for measuring the driving performance. In this analysis, only the deviation around each sign (40 m before to 55 m after the sign) was used to measure performance. An example of the area used in the analysis is marked with a shaded area (shown for one sign only).

$$D = \frac{1}{S} \sum_s d_s$$

2

where d_s is the subject deviation in a section, Y_s , around a sign, x_y is the subject lateral position at the longitudinal position y , r_y is the lateral position of the reference path at the longitudinal position y , and L_s is the length of the section. The total deviation is then given as the mean value of all sections, see Equation 2, where S is the total number of sections (number of lane changes). The analysis was only performed in proximity to the signs, starting 40 m before the sign until 55 m after the sign (example shown as a shaded area in Figure 3) which constitutes a section Y_s . All lane changes in the experiment were made within this range. By only doing the analysis around the signs, random variations in how the subjects positioned themselves within a lane were reduced. This way, the driving performance measure became more affected by reaction time than lane keeping performance.

Secondary Task

The secondary task software was based on the Surrogate Reference Task (SuRT) [12, 13]. The secondary task was to locate a circle with a slightly larger radius on a screen displaying a number of distractor circles. For the distribution of circles, the screen was sectioned into a matrix and 66 randomly selected sections out of 130 contained a circle. Each circle's position was randomized within a section. This distribution scheme was utilized to avoid drastic changes in difficulty level and uneven distributions. See Figure 4 for a screenshot of the secondary task. The subjects answered on which side of the centreline of the screen the larger circle was located by the use of 2 input buttons, positioned to the right of the steering wheel. The idle time between tasks was randomized between 2-5 seconds so that the appearance of a new task could not be predicted. A preliminary study was conducted to determine the time interval. It was subjectively determined over several trials that 2-5 seconds gave a good balance between driving and working on the secondary task. The various parameters for the secondary task can be found in Table 1. The secondary task performance was measured as response time from that a new task was displayed to user input. Error rate and number of answers were recorded.

Table 1. Parameters used for the secondary task.

Parameter	Value	
Number of Distractors	65	
Distractor Radius	14	px
Target Radius	20	px
Circles' Thickness	2	px
New Task Delay Time	2-5	s
Screen Resolution	1280 x 1024	px
Screen Size	19	in

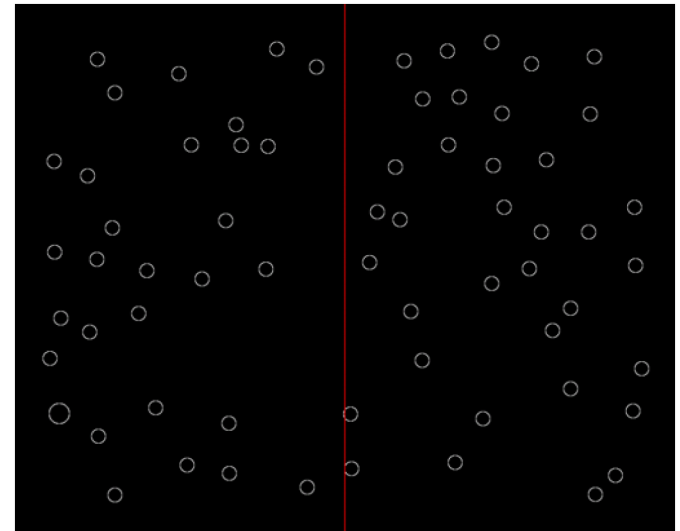


Figure 4. Secondary task example screen. The larger circle is located on the left side of the centerline.

Sound Signals

Custom software was written for real-time analysis of output data from LCT to allow sounds to be played simultaneously when new sign information was displayed. The LCT software remained unchanged; however the engine sound was removed during the experiment to avoid masking of the examined signal sounds. The driving task sound was a composition of 3 repetitions of a click sound to give the impression of a turn signal. The second click was pitch shifted down 200 Hz. The time signal can be seen in Figure 5. The secondary task sound was a Microsoft Windows XP sound (ding.wav), commonly used in Windows XP to indicate that there is information on the screen. The secondary task triggered the sound when a new task was presented, of which the time signal can be observed in Figure 6.