Vibro-Tactile Information Presentation in Automobiles

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Abstract

This paper describes the potential of using vibro-tactile displays for automobile drivers. Technological developments in the field of driver support systems and tactile displays, combined with the ever increasing need to enlarge the capacity of the driver's information channel, form the reason to review the possibilities of in-car tactile displays and to identify some promising applications. In the second part of the paper, we describe a feasibility study in which we tested an in-car tactile display in a driving simulator. The results show that the tactile navigation display resulted in better performance compared to a visual display, and that it reduces the driver's workload. This study gives a first indication that employing the tactile modality may be a major step to accomplish safety improvements.

1. Motivation

In-car systems can have a negative effect on safety when they enlarge the workload or distract the driver [1]. The interaction of the driver with the in-car system may result in an overload situation in which the driver no longer processes all the information relevant for the driving task, which may result in errors and late detection of other road users [2]. Based on the assumptions of the multiple resource model [3] which predicts no performance degradation when independent resources are used, and the fact that most information in driving is visual, safety may be improved by presenting information via audition and touch instead of vision.

1.1. Vibro-tactile perception and displays

Vibro-tactile displays in general consist of arrays of vibrating elements coupled to the skin. Appropriate stimulation of specific receptors in the skin by means of applying localised vibration typically leads to a 'tickling' sensation at that specific location. Human vibro-tactile perception is sensitive to location, duration, frequency, amplitude and several other (derived) aspects of vibro-tactile stimulation. Obviously, the Braille reading skills of visually impaired people have proven our general ability to process complex spatio-temporal patterns presented to our skin.

1.2. The tactile modality in man-machine-interfaces

State of the art man-machine-interfaces (MMIs) almost routinely use the visual and auditive channel only. Using the haptic and tactile channel in MMIs is rather uncommon, despite good reasons to do so. Advantages of the tactile channel are, amongst others, that it is always ready to receive information, that it draws attention, that it is private, and that it can be used in a natural and intuitive way. The latter is of course dependent on the kind of information that is presented. Examples include displaying object properties such as roughness [4], and variants of a 'tap-on-the-shoulder' to present navigation information. Another good reason to incorporate the vibro-tactile channel in MMIs is that adding the tactile modality may enlarge the total effective information processing capacity of the user. It may thus free the overloaded auditory and /or visual modalities.

Recent developments resulted in small, cheap, robust, and readily available tactile display elements (e.g., those used in mobile phones and pagers). These simple elements can be combined into sophisticated displays. This will eventually result in the introduction of relative simple tactile displays which have a much larger information transfer capacity than the 1-bit 'your phone is ringing' message. Recent applications of these vibro-tactile displays hint at more intuitive ways of using the skin as an information channel [5]. For instance, it has been shown [6] that stimulating a single point on the torso immediately leads to a perception of external direction. Such an intuitive perception of external direction can be very useful in applications requiring a sense of spatial awareness, such as when navigating a car through an environment, operating in space [7] or when flying super-agile aircraft [8, 9].

1.3. Classes of information in car driving

After recognising the potential of applying tactile interfaces in an automobile, dimensions that need to be studied are the types of information and the coding possibilities that are suitable. We discern the following classes of information:

a) Spatial information. Spatial information may be one of the most promising areas of applying tactile displays [9]. First of all, the visual system is restricted in field-of-view. This means that it normally extracts spatial information from the 180° forward view only. Not perceiving relevant objects in space (e.g., cars in dead angles, crossing pedestrians) is a major cause of accidents. Secondly, presenting 3D information on a 2D visual display may result in errors and a high visual workload. Presenting such information to the skin is likely to reduce those problems.

b) warning signals. Since the tactile channel is always ready to receive information and has the characteristic of drawing the observer's attention, it is well suited for warnings. Furthermore, a visual warning on the dashboard may be on for a long time before the driver actually notices it, and auditive warning signals can be lost in tyre, radio, or conversation noise.

c) communication. Tactile displays allow silent and private communication. This is relevant since almost all of the communication of the car is meant for the driver only. Why bother the passengers with this information, especially when they are working or communicating with others?

d) coded information. This category encompasses all types of (abstractly) coded information available to the driver (e.g., speed, engine rpm, and fuel supply). Optimal ways of coding must be determined for each parameter. Information of this type could be presented when the driver asks for it, or when specific conditions or limits are reached.

e) general. Tactile / haptic information can also be used to guide the driver to different locations on the dashboard or the middle console, can give information on the settings of switches and buttons, can indicate preference points, etc., without the need of the visual modality.

2. Integrating tactile displays in the driver's workplace

For optimal safety, the workplace allows the driver to have both eyes on the road, both hands on the steering wheel, and both feet on or near the pedals. This safety strategy goes beyond keeping the driver's attention focussed on the road. A consequence is the increasing use of controls on the steering wheel, for example to control the radio, phone, or climate control system. However, using these controls as display is largely unexplored. Besides the primary and secondary controls, tactile displays can be incorporated in, for example, the pedals, the seat and the safetybelt.

2.1. Integrating tactile information with (existing) haptic information

Not all information in driving is visual. For example, forces in the steering wheel provide the driver with indispensable information on vehicle behaviour, road conditions, etc. Therefore, although presenting additional haptic information in controls may be an attractive option to present information [10], the interference with naturally available haptic information is a potential disadvantage. For example, presenting additional forces on the steering wheel to display course deviations sensed by a heading control system might interfere with the natural information. Using the tactile modality - such as a small vibration presented to the hands holding the steering wheel (not on the steering wheel itself) - may not have these consequences.

2.2. Joystick control: completely integrating haptic and tactile information

The introduction on a large scale of joystick control in automobiles may not be far away. Nowadays, joystick control is already applied in vehicles for the handicapped driver. The major advantage of the use of a joystick instead of a steering wheel is that the latter is a major source of injuries in case of accidents. Apart from the design issue of providing the correct force feedback information in joystick control, it also opens opportunities to integrate haptic and tactile information. Since the driver has his or her hands at a fixed position on the joystick (irrespective of the manoeuvre) the fingers and palm are interesting locations to present tactile information. An accompanying advantage is that the fingers are not only suited as display, but can also act. This opens up the possibility to design a fast, intuitive stimulus-response system.

3. Examples of applications: SAFE: Safety, Assistance, Fun, and Efficiency

Below, we will give some examples of tactile display applications in the car. We divide the applications in four categories - safety, assistance, fun, and efficiency - and provide some examples of each category.

Safety. Tactile information can help to make driving safer by enabling the 'hands on controls' strategy, by releasing the visual workload, and by presenting information in a natural and intuitive way. An example of the latter is displaying cars from behind, cyclist in the dead angles of mirrors, and crossing pedestrians in the periphery. The feasibility study described in Section 4 provides a first proof-of-concept of an in-car tactile navigation display, consisting of actuators in the seat.

Assistance. A simple and straightforward form of assistance is applying a tactile signal on the appropriate control. For example, a small tactile vibration on the handbrake-release-button can indicate the moment that there is enough torque on the wheels to pull up a slope. This probably allows even the most inexperienced driver to pull up smoothly. Van Winsum [11] used a tactile stimulus on the accelerator pedal to indicate when a speed limit was exceeded, and compared this way of displaying with an auditive message. The tactile display resulted in a decreased workload and faster responses.

Fun. The fun of tactile information probably lies in the fact that it enables silent and private communication with the machine, which is to a large extent just between the driver and the machine and of no concern to other passengers. An example is a tactile signal on the door handle when the lights are left on. The latter is much more fun than an annoying auditive signal that everybody in the parking lot can hear.

Efficiency. Optimising fuel consumption is an important issue in the automobile industry. Tactile displays can support a more efficient gearshift regime by the direct coupling of display and actuator. Indicating the moment to shift gears can be realised by a signal on the appropriate hand (e.g., via the steering wheel). The optimum will be the situation in which the fingers are already on the gearshift controls as in joystick control or when the gearshift controls are integrated in the steering wheel.

4. Feasibility study: in-car navigation displays

Research has shown that badly designed in-car displays can negatively effect safety. For example, a safety evaluation [12] of in-car displays that provide real time traffic information showed a 50% increase of the number of critical traffic situations (as judged by a driving instructor) of two badly designed interfaces as compared to two well designed interfaces. Earlier work at TNO Human Factors has shown that a tactile display that presents driving behaviour feedback results in a lower workload than an auditive display [11], and that tactile displays can be used effectively for presenting spatial information, such as the direction of waypoints [6]. The present study aims to investigate the feasibility of an in-car tactile navigation display. Special emphasis will be on workload. The hypothesis is that presenting information to the tactile sense will decrease the visual burden of car driving.

4.1. Design of the visual and tactile navigation symbols: the icons and vibrocons

In-car navigation displays present relatively simple visual symbols. Information is usually only presented when a course change is required: no message means go straight on. The information consists of two parts. The first part is the direction of the oncoming (course) change (e.g., left, right) and the second is the remaining distance to this change. The latter may be dependent on the road category or driving speed. We adopted this simple symbology in the present experiment.

Visual and tactile symbols were made for three distances: 250, 150, and 50 m. Distance was indicated alphanumerically for the icon, and by timing for the vibrocon. The icons (arrow plus distance) were presented on a separate LCD display left of the steering wheel with a resolution of 64 by 64 pix. In an analogue way, we developed the tactile coding principles. Based on a pilot study, the following were the most appropriate ways to code the direction and distance, respectively:

Direction of the course change:

- location: a tap on the left or right side of the body,
- motion: simulate motion to the left or right by activating several actuators in a specific spatio-temporal pattern.

Distance to the next waypoint:

- rhythm: by presenting the course change patterns at closer intervals, a smaller distance to the waypoint is indicated,
- intensity: a higher intensity of the course change pattern indicates a smaller distance.

In the present experiment, we used rhythm to code distance. The timing parameters of the vibrocons are depicted in Table 1. Direction was coded as follows: a left turn was indicated by activating four tactors under the left leg (vibrocon left), turn right by four tactors under the right leg (vibrocon right), and go straight by the consecutive activation of the tactors from back to front under both legs with a burst duration of 60 ms and an inter stimulus interval of 0 ms (vibrocon straight). Table 1 reads as follows: the vibrocon ’left at 50 m’ consists of activating the tactors under the left leg five times for 60 ms with inter stimulus intervals of 52, 40, 32, and 20 ms.

Table 1. Timing parameters of the vibrocons.

distance	burst duration	inter stimulus interval	number of bursts
250 m	60 ms	264, 264 ms	3
150 m	60 ms	264, 212, 160, 108, 52 ms	6
50 m	60 ms	52, 40, 32, 20 ms	5

4.2. Method

4.2.1. Subjects, task, instruction, and performance measures. Six male and two female drivers participated. Their age was between 23 and 51 years. All were experienced drivers, had normal vision, and had experience with driving simulators. They drove 12 experimental routes in a driving simulator, preceded by a familiarisation run. During this run, the drivers could get used to the simulator, the driving environment, the icons and vibrocons, and the instructions. The instructions were: a) to employ a normal driving style, including the priority rules and speed limits applicable, b) to follow the messages of the navigation system, c) to use the direction sign on the steering wheel (i.e., left / right) directly after receiving the navigation message, and d) to react directly on the stimuli of the Peripheral Detection Task (PDT, see below) by pressing a finger switch.

During the complete route, a PDT was presented. The PDT is based on the narrowing of the visual view as function of workload [13, 14, 15]. The PDT is able to measure the workload during driving and to measure workload peaks of short duration. [11]. The PDT presented red squares in the left periphery of the visual field (between 11-23°, 2-4° above the horizon) for 1s. The stimuli were presented with a random interval between 3-5 s. The participant's task was to react as fast as possible to the stimulus by pressing a finger switch, attached to the index finger of the right hand.

The 12 runs were divided over three conditions based on the modality in which the navigation information was presented: visual only, tactile only, and visual plus tactile. The runs were blocked accordingly. After each block, the participant filled in the BSMI, a standardised subjective mental effort rating [16]. The BSMI has an interval scale. Three other perfomance measures were calculated for each route: the mean reaction time to the PDT, percentage detected PDT stimuli, and the reaction to the navigation information, expressed in the remaining distance to the next waypoint at the moment of indicating direction. The order of the conditions was balanced over the subjects, the different routes were balanced over the conditions.

4.2.2. Apparatus. The experiment was run in the TNO LoCo simulator. This driving simulator has a 180 × 30° field of view, rear-view mirrors, haptic feedback in the controls, automatic gear change, and interactive traffic. The database chosen for the present experiment was an urbanised area, measuring 3 × 3 km. Included were town roads, traffic signs, interactive traffic lights, interactive traffic, intersections with different priority situations, and roundabouts. Primary data (including position, heading, steering wheel angle, etc.) were stored with 60 Hz sampling frequency. The tactile actuators were Special Instrument MiniVib 4 vibrators. These are small boxes (18 × 22 mm) and present a 250 Hz vibration. The vibrators were mounted in the seat (four for each thigh, in a straight line from rear to front) with a centre-to-centre distance of 4 cm). Based on the distance to the next waypoint (250, 150, 50 m), the navigation symbol (icon, vibrocon, or both) was presented. Each icon was presented till the next icon appeared or the wapoint was reached.

4.3. Results and discussion

The results of each performance measure were analysed by a within subjects analyses of variance with modality (3) as independent variable. Significant effects ($p < .05$) were present for the BSMI (mental effort) rating, and the distance to the waypoint at which the subject reacted to the navigation message. The means are presented in Figure 1 and 2, respectively.

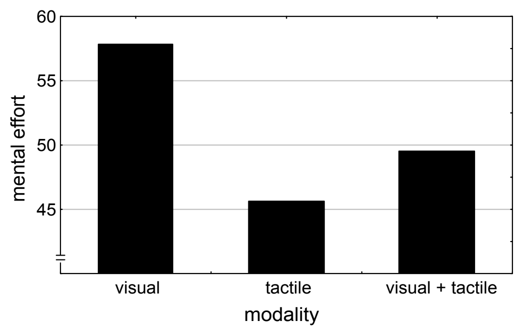

Figure 1. The effect of modality on the mental effort.

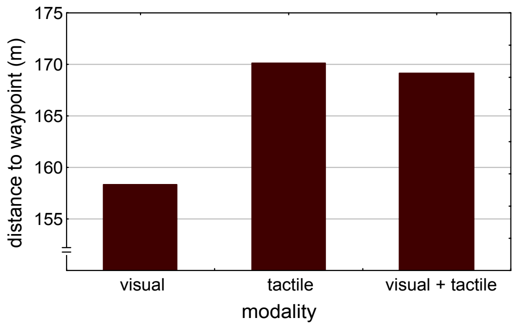

Figure 2. Effect of modality on the remaining distance to the oncomming waypoint when the driver reacts to the navigation message.

The analysis of the mental effort shows that the rating in the visual only condition is about 25% higher than in the tactile only condition. The rating in the visual + tactile condition is in between. The same order of conditions is also present on the remaining distance to the waypoint at which the driver reacts to the navigation message (here a higher score indicates better performance). The means indicate that drivers react faster to the tactile messages than to the visual messages, while the score for the tactile + visual condition is close to the tactile only score. Since the first navigation message is presented 250 m before the waypoint, it means that the mean distance to react to the message is 80 m in the tactile condition and 92 m in the visual condition, an increase of 15%.

Both effects show the superiority of the tactile modality over the visual modality for presenting navigation messages: Drivers react faster to the message, and with less mental effort. The fact that adding the visual modality to the tactile messages reduces performance may be due to the fact that some drivers check the tactile message by looking at the visual display, especially during the first runs with the tactile displays. Afterwards they stated that it takes some time to learn to 'trust' the unusual tactile messages. This extra check reduces performance and increases the mental effort.

The MANOVA on the performance in the PDT did not result in a highly significant of condition ($p < 0.10$). The means for the percentage detected stimuli and the reaction time are given in Figure 3. Both PDT measures showed better performance in the tactile-only condition.

The PDT data objectively confirm the result of the mental effort rating scale: the tactile navigation display results in a decreased workload as compared to a visual navigation display.

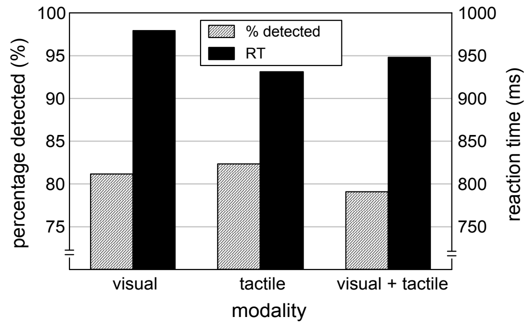

Figure 3. Effects of modality on the performance in the peripheral detection task.

4.3. Conclusions

The results of the feasibility study show the superiority of the tactile navigation display over the visual display in the current set-up: faster reaction, lower mental effort and lower workload. These are the first indications that using the tactile modality in automobiles may improve the quality and safety of the man-machine-interface. However, we recommend performing field experiments with an instrumented vehicle and expert opinions to measure the effects on vehicle control and traffic behaviour

. However, it may be expected that the results in real driving may be even more pronounced. There are several reasons for this. For example, in the present set-up, the PDT stimuli were presented on the same side (left) as the visual navigation messages. With the visual display located on the opposite side, effects of a narrowing field of view will be stronger for the visual-only condition. Another important aspect is that in the driving simulator the navigation display and the outer scene are presented at the same distance. On the road, the driver must adjust to the light levels and focal distance when switching between the navigation display and the outer scene. Furthermore, some of the participants indicated that it takes more (training) time for them to learn to 'trust' the tactile messages than one three-minute training run.

5. General Conclusions

Using vibro-tactile displays in cars appears to be a useful concept, as the list of potential applications and initial proof-of-concept study shows. Its major promise is to improve the safety, efficiency, and fun of car driving. The technological feasibility is certainly high; the required displays can be constructed from cheap and robust elements that are now on the market. Former research showed the superiority of a tactile display over an auditive display for warning the driver when exceeding a speed limit. The present experimental data show that a tactile navigation display results in faster reactions to the navigation messages and lower workload and mental effort than a visual display. Vibro-tactile displays seem to offer a valuable answer to the demand of the automotive industry to improve the man-machine interfaces in cars.

6. References

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