USER ACCEPTANCE AND EFFECTIVENESS OF WARNING AND MOTOR PRIMING ASSISTANCE DEVICES IN CAR DRIVING

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ABSTRACT: This paper deals with driving assistances that intervene when a lane departure is imminent. Previous work [1] showed that motor priming devices (devices prompting the driver to take action by means of an asymmetric steering wheel vibration) were the most effective warning systems. The present experiment tries to qualify the different lane departure warning systems not only in terms of effectiveness but also in terms of acceptability. For this, both objective and subjective data were collected. Firstly, the study shows that acceptability and effectiveness are not necessarily correlated, and can even be contradictory. From an ergonomics point of view, we claim that a compromise should be reached between those criteria. Secondly, we show that a combined mode (sound and motor priming) could be a solution to find such a compromise. Finally, a perspective for further research is to better combine the modalities, through improved synchronization of the driver sensations.

1 INTRODUCTION

In order to contribute to the ergonomic design of safety devices for critical situations in cars, a research project on Human-Machine cooperation (Predit-Prevensor) deals with lateral control situations where additional devices are assumed to enhance safety. For Hoc and Blosseville (2003), safety devices in car driving can be classified into four levels of Human-Machine cooperation [2]: (1) perceptive mode, (2) mutual control mode, (3) function delegation mode and (4) fully automatic mode. In the particular case of lateral control, some proposed safety devices belong to *mutual control mode*. This means that drivers have full control of their vehicles, but their driving behavior can be criticized (*warning mode devices*). Moreover, safety devices can lead drivers to correct their trajectory (*motor priming)* by inducing asymmetric vibrations in the steering wheel for example.

Previous studies on safety devices applied to lateral control show ambivalent results. The effect of motor priming in steering wheel was found to depend on inter-individual variations ([3]; [4]), and in some cases, driver response went opposite to the suggested action [3]. However, [1] demonstrated by a comparative evaluation technique that, among five driving assistance devices, all belonging to mutual control mode, motor priming was found to be superior in terms of effectiveness. Indeed, the asymmetric vibrations on the steering wheel seem to guide the driver to take the correct action. Nevertheless, acceptability of such vibrations was not discussed.

In accordance with this finding, the present study aims at checking advantages of the *mutual control mode* for lane departure prevention, and particularly the superiority of motor priming when induced through the steering wheel. Beyond effectiveness measures and theoretical utility [5], the users point of view regarding similar driving assistances is assessed. Investigating drivers' *subjective* side is particularly justified by the fact that Human-Machine cooperation is considered as a management of interferences between different agents [6]. Actually, the study of the representations of the system, the attitudes and the motivations are crucial to understand how and why the human feels either comfortable or reluctant to cooperate with the machine, in order to control the dynamic driving situation. In other words, what the users think and expect from the device, as well as how they perceive it, needs to be evidenced. More generally, comfort or discomfort, pleasure or displeasure, satisfaction or dissatisfaction ([7]; [8]) constitutes the heart of this framework.

In this paper, motor priming through the steering wheel is presumed to be more effective than a warning, because the direct intervention on the action level should improve corrective maneuvers and situation diagnosis. However, for the same reasons, drivers could reject this assistance. Besides, a study on social acceptability of driving assistance devices showed that users' judgments are unfavorable when the assistance takes more or less control of the driving situation [9].

Following this idea, a mode that combines motor priming and auditory warning is proposed. In this case, it is assumed that a sound reminding driving on rumble strips is potentially acceptable. Furthermore, [10] showed that when preexisting or direct association between the sound and the event is strong, this pairing tends to be learned and retained more readily. This may induce that auditory warning implying strong or direct association with the event should be more understandable and thus acceptable. The aim of this paper is therefore to check whether combining motor priming with auditory warning improves driver acceptability along with keeping device effectiveness.

2 METHOD

2.1 Participants

Twenty participants (16 men and 4 women) ranging from 23 to 52 years old (mean = 34) took part in this study. Sixty percent of them cumulated more than 10-years driving experience. Participants were volunteers from Renault workers and none of them was involved in the design process of driving assistances.

2.2 Material

2.2.1 Simulation

Experimentations took place on a dynamic driving simulator (Cards2, developed by the Technical Centre of Simulation of Renault). The platform consists of a driver's cabin (on top of an hexapod) with a manual gearbox and a 150° vision of the driving scene. The cockpit was specifically equipped with the following devices: (1) haptic seat, (2) haptic steering wheel (vibration or asymmetric oscillations) and (3) 3D sound. Simulated driving scene was a country road, where "legal" speed limitations were fixed at 80km/h on straight lines and 70km/h in curves.

2.2.2 Interview

An open interview inspired by explicitation interview techniques ([11]; [12]) was performed. These techniques aim to explore implicit, pre-thought-out aspects of a physical or mental action. The objective of the interview was to collect the description of the action (effectively) realized by the driver. Interviewer has to guide drivers to operate a thinking-out of their experience and to put it into words. Techniques of explicitation allow « to help the user to describe his activity such as it took place in this situation, such as what he did, perceived, thought and felt during that specific situation» ([7]; [8]). Although we did not perform a real explicitation interview as defined by Vermersch, we were strongly inspired by those techniques by using non-inductive questioning. The aim was to collect verbal reports on feelings, senses, internal states, thoughts that were lived by the driver with a driving assistance device.

2.3 Driving assistances

Five driving assistance devices were assessed in this study. All these devices were activated in case of imminent lane departure (with axial line or bank line).

- The *auditory warning* mode consisted of a lateral 3D sound coming from the side where lane departure occurred. The emitted sound was similar to a rumble strip noise.
- The *wheel vibratory warning* mode was produced by a lateral haptic vibration from the side where lane departure occurred.
- The *motor priming* mode was generated by an asymmetric haptic stimulation on the steering wheel. In other words, jolts on the steering wheel indicated the direction of the trajectory to adopt. The stimulation was not sufficient in itself to correct the trajectory.
- The seat *vibratory warning* was produced by a lateral haptic stimulation from the side where lane departure occurred.
- The *combined mode* consisted of a combination between the *auditory warning* mode and the *motor priming* mode.

2.4 Procedure

After a familiarization phase with the driving simulator, participants performed ten laps, of five minutes each. Runs were alternated between lap, with and without assistance. After assisted laps, the experimenter interrogated briefly the driver about what he or she had *just experienced*. To control any order effect, presentation of various assistances was counterbalanced among the participants.

Driving scenarios were defined to control lanes departures. Every assisted ride consisted of four critical events, two before the curves' entry and two on straights lines. The non-assisted ride also consisted of two to four critical events. For each critical event, a slight gusts of wind occurred (drivers were unaware of this occurrence) in parallel with a distraction task to provoke lane departures. This relatively “ecological” secondary task was supported by a screen placed in the driver's cockpit at the usual place of the radio and was set up in order to distract the driver by means of a “*reading task”* (scrolling of a list of three words per second).

Drivers had been instructed to adopt a "laid-back" driving attitude and to keep both hands on the steering wheel in “10:10” or “9:15” time position. They were informed that the beginning of the reading task would be randomly indicated by a beep sound for several times. The importance to maintain attention on reading while maintaining steering wheel angle was strongly emphasized until the end of secondary task (which was synchronized with the assistance onset if present). At last, drivers were invited to maintain speed driving as far as possible with speed limit standard and to respect those standards. Experimenter reassured participants that these experimental conditions were made to provoke lanes departures.

After each lap, participants were asked to describe their own personal experiences when lane departures occurred: what happened for them? What were their feelings or thoughts? At the end of the experiment these short descriptions were re-examined with the subject in a way to avoid inductive questioning. These post interviews took place in the simulator’s cockpit to facilitate drivers’ remembrance of the assisted driving. Afterwards, subjects were invited to classify the assessed modalities in order of preference (without ex-aequo).

2.5 Data analysis

Three types of data were analyzed: performance measures (lane departure durations), rankings and verbalizations. Only rankings and verbalizations are detailed in this paper for eighteen participants out of the twenty original because of a destroyed tape. Further details about performance values can be found in Navarro et al [13].

2.5.1 Ranking

Assistance devices were statistically analyzed in terms of order of preferences. Ranking results were used to find which modality was the favorite and which one was unfavorable. In addition, *Friedman* non-parametric test was used to highlight, if applicable, significant differences between modalities.

2.5.2 Analysis of contents

The detailed analysis of verbalizations underlined four discursive categories: a) Sensory sensation (pleasantness, inconvenience, unpleasantness, etc.); b) Interpretation of the type of alert (lane departure), of its location (side departure), and the corrective action required (towards the lane centre); c) Perceived utility; d) Attitudes (satisfaction, dissatisfaction, etc.). Those categories were evidenced thanks to content analysis methods. First, we categorized participants’ speech in positive and negative dimensions; then we extracted and classified spontaneous verbal reports able to describe drivers’ acceptability. In addition, the previously mentioned emergent categories are close to some well-known acceptability criteria in Human-Machine Interaction field ([5]; [14] for instance). Through this analysis we wanted to identify in details, from actual experiences of the subject, the inherent reasons for approving or rejecting such or such modality.

2.5.3 Driving performances

The variable retained was the *lane departure durations*. Values were interpreted in terms of effect of the assistance device on lateral departure. In other words, we were interested in the time saved thanks to the assistance device.

3 RESULTS

3.1 Rankings

The rankings (fig.1) show a first approach of the compared levels of systems acceptability.

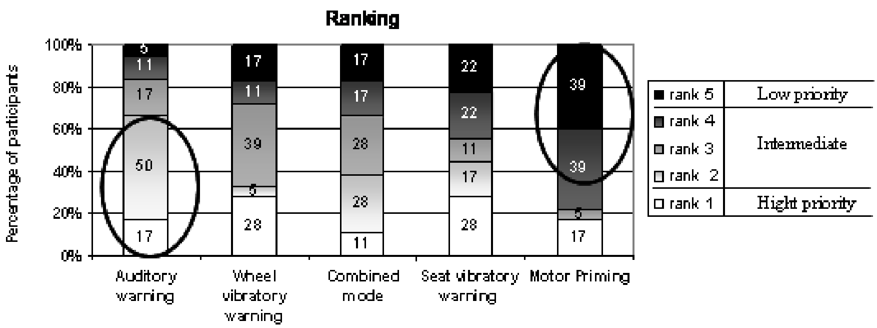

Fig.1. Proportion by rank of the relative classification in order of preference

Figure 1 illustrates participants' *relative preferences* for auditory warning. It appears mainly as a second choice (50% in rank 2). While sound is globally preferred, results regarding vibratory warnings (seat and steering wheel) are scattered. In addition, combined mode is rather scattered (39 % in rank 1 and 2 and 34 % in rank 4 and 5). Finally, motor priming device obtained the worst results, mainly classified between rank 4 and 5. *Friedman* test did not reveal significant global differences of driver's assessment of the modalities, probably due to the few number of participants. Moreover, figure 1 shows that differences between auditory warning and motor priming are sensible (tendency). Furthermore, verbal reports (§ 3.2) corroborate this idea.

3.2 Analysis of content

➢ Auditory warning appeared to be the least intrusive modality. Indeed, some positive comments underline the non-aggressive aspect of this modality: "this one is really soft"; "this one is probably the least violent"… Analogy of the simulated noise along with perceptible noise of real driving (rumble strips) enabled drivers to represent themselves as having a lane departure. Attitudes were rather favorable, but many drivers had some doubts about discriminating this sound in real vehicle's sound environment: "I thought there were a lot of signals in the vehicle, so how can I distinguish this one from another one"…

- Motor priming device was outlined as the most intrusive modality. Globally lateralization was generally not well perceived: "the jolts are not indicative, it's like a back and forth movement"... In addition, jolts in the steering wheel disturbed some drivers who confused it with their usual driving sensations on the steering wheel. This confusion could have caused troubles such as a feeling of trajectory lost of control for example: "I have the impression not to control the car"…

- Combined device presented different perceptive representations. Two perceptive profiles were evidenced: those who used both signals and those who used one of the most salient signals according to the individual's sensibility: "I had the feeling to react because of the sound and not because of the sensation detected by my hands" or "the sound, it is like I did not hear it because there is a lot of things". Additionally, risks of confusion inherent to stimulation in the steering wheel were evoked.

- Vibration warning on the steering wheel caused various representations. First, lateralization was not well perceived (felt on both hands) but some drivers reported that the signal allowed them to anticipate correction. Besides, many participants were confused and annoyed.

- Vibration warning on the seat revealed a scattering of preferences. Globally, lateralization was perceived without ambiguity but it was not systematically associated to lane departure side. Furthermore, the location of the vibrations can be annoying.

3.3 Acceptability vs. effectiveness

Auditory warning was generally preferred, without being ideal as reported by some drivers. In addition, drivers rejected motor priming device whereas opinions relative to combined device were scattered. Figure 2 shows driving effectiveness with respect to tested modalities.

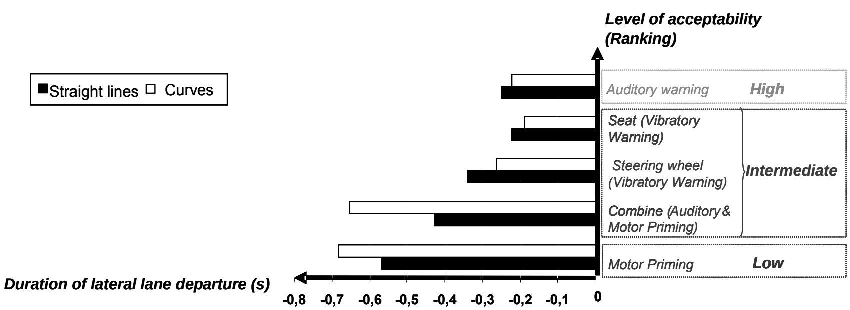

Fig.2. Effects of the auditory warning [high acceptability] and the motor priming [low acceptability] on lateral lane departure durations (normalized against control condition)

For further details regarding performance measurements, see Navarro et al [13].

Statistical analysis revealed that motor priming device had a significant effect on lane departure duration compared to control condition in straight lines as well as in curves. Nevertheless, the majority of drivers significantly rejected this device. The auditory warning also tends to decrease lane departure durations but not significantly. Furthermore, compared with other assistance devices, performance (duration of lateral excursions) was among the worst, although paradoxically, it was significantly preferred than motor priming. Combined mode allowed driver to be more successful with respect to other devices while subjective judgments were scattered. Moreover, effectiveness and preferences of vibratory warning on seat as well as on steering wheel presented scattered results and thus were hardly distinguishable.

4 DISCUSSION

In this paragraph, the results are interpreted with respect to the hypothesis and the general aim of this study. More specifically, integration of an acceptable and effective driving assistance device for safety applied to lateral control is discussed.

First, the experimental protocol was quite *ecological* and therefore relatively close to a real driving situation, thanks to methodological choices. Dynamic driving simulation has the particularity to immerse the driver in driving situation and thus to preserve most of his usual driving task, at least at the operational level considered here. Besides, simulated distraction task, defined as a punctual appearance of a reading task, is quite close to real distractions sources (navigation tasks, audio, inattention, etc.). Thus, in spite of the simulation bias, the representativeness of the experimental situation allows to access, to some extent, to the drivers subjective point of view.

Study of acceptability of driving assistance devices through the evocation of lived experience was particularly rich. In particular, the several dimensions of acceptability (*Feeling*/*Interpretation*/*Utility*/*Attitude*) underlined were useful to compare modalities in details. For example, the speech relative to *feeling* and *interpretation* were widely positive for sound, and negative for motor priming; while the perception of *utility* was lightly positive for both sound and motor priming.

Overall, assistance devices comparison shows the superiority in terms of acceptability of auditory warning with respect to motor priming. On one hand, *ideal* experimental conditions permitted to perceive the sound well and therefore auditory warning was ranked at the head of preferences. Nevertheless, participants had some doubts regarding "easy" perception of sound when driving in a real car, and in real conditions; this may explain why auditory warning appeared mainly in second choice (50 % in rank 2, fig.1.). On the other hand, reproduced sound, which reminded of noise induced by driving on rumble strips, strongly contributed to the acceptance of tested auditory warning. These findings confirm the influence of sound design on acceptability.

Nevertheless, asymmetric steering wheel vibration (motor priming), which was supposed to be more efficient was confirmed as it induced the best successful correction. However, this assistance was not fully accepted by drivers, due to the location of the stimulation. Indeed, most drivers believe that steering wheel represents a prominent component to control vehicle and they were not very confident in the use of this device in real driving conditions: in a real car, vibrations are transmitted to steering wheel, and their amplitude and frequency depend on road type, speed, vehicle, etc. This may induce unsafety feelings and discomfort when using motor priming because drivers could not only confuse whether vibrations are related to infrastructure or to assistance device, but also lose control of their car.

Concerning the combined device, results in terms of effectiveness are equivalent to those found with the motor priming device alone. In terms of acceptability, some subjects declared that auditory warning helped them to better interpret motor priming stimulation: “I do not know if it is the combination of sound and steering wheel, but it seemed for me easier to manage”; “maybe thanks to sound, I was able to distinguish the first priming vibration. I do not know why it was easier for me to feel it”. Nevertheless, for others, non-synchronization signals, bad lateralization of motor priming device and confusion risks influenced negatively their user’s representation.

To conclude, the initial hypothesis on the combined mode is still reliable because the association of a sound, accepted by the majority of drivers, with efficient asymmetric vibrations on the steering wheel, seems to be a good compromise to combine effectiveness and acceptability. Nevertheless, a better integration of these assistance devices (by improvement of the synchronization frequency between sound and haptic stimulation for example) is still necessary to improve acceptability with preservation of device effectiveness. It should be noted that this compromise is difficult to obtain.

Effectiveness, which has generally been considered as a fundamental criterion for acceptability and usability in the Human-Machine Interaction domain[1], appears not to be the most important factor for Human-Machine cooperation. Indeed, driver did not immediately perceive the beneficial effect of the assistance, and thus acceptability was not influenced. Besides, interferences management, one of the important criteria of Human-Machine cooperation, can induce annoyance even if performances are raised. However, this criterion of effectiveness is essential in conception choices. This paradox makes important to discuss where to place effectiveness in the user-centered conception loop. It could be overcome by a compromise between device effectiveness (performances measures for example) and acceptability criteria as defined in this study.

5 CONCLUSION

Evaluation of acceptability in mutual control modes, through the analysis of spontaneous and provoked verbalizations, evidenced which modality was preferred and which one was rejected. In addition, these data permitted to understand individual and collective reasons of these differences. None of all assessed modalities was found to make unanimity of preferences, and drivers’

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[1] Because of the narrow link between perceived and real effectiveness.

opinions were various. However, it clearly appeared that: (1) auditory warning device was preferred although classified as second choice and (2) motor priming device was massively rejected because of various reasons, such as the location of the stimulation. Assistance devices' effectiveness did not influence drivers' choices in terms of acceptability, and hence effectiveness could not constitute the only criterion to choose cooperation mode.

In this paper, we underlined the potential gap between acceptability and effectiveness. This point can be a crucial one for an *efficient* design of the assistance. Consequently, we have to find the best compromise between these criteria. In our study, the results of the combined device (sound and motor priming) could be a possible solution for such compromise: the result of effectiveness is good in terms of effectiveness and quite good in terms of acceptability.

Furthermore the detailed analysis of verbalizations showed that for a majority of subjects the combined device was not felt as a unified sensation but as two distinct ones. This is the main explanation for the relative poor result of the combined device in term of acceptability. Further studies should address this major point by improving the accuracy of the synchronization of those sensations.

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