Adaptive Warning Strategies from Multiple Systems: A Simulator Study with Drivers with Different Reaction Times

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Abstract. Adaptive interfaces are being developed to avoid drivers' overload and distraction. 24 drivers, assigned in two groups according to their braking reaction time, participated in a driving simulator study experiencing incidents of concurrent warnings by two support systems. Warnings were provided either independently or via an adaptive interface in which one audio warning was intensified and the other was suppressed. The driving behaviour of the two groups was different, drivers with longer reaction times should be specifically considered when designing adaptive interfaces. The employed adaptive strategy caused changes in the driving behaviour of participants with shorter reaction time, another adaptive strategy, possibly generating warnings earlier, may be more appropriate for drivers with longer reaction times. The metrics that were more sensitive in identifying changes in driving behaviour are mean speed during incident, standard deviation of speed, standard deviation of lateral position and minimum time headway to lead vehicle.

Keywords: driving support systems, adaptive interfaces, driving behaviour, evaluation, metrics.

1 Introduction

Several driving support systems are being developed [1] aiming to enhance traffic safety. Such systems usually estimate the probability of a future crash and adequately warn the driver, if needed, so that the driver can take the appropriate averting actions. Due to the growing number of such driving support but also information systems available, an acute design problem is how to integrate all the potentially concurrent warnings and information messages in an adaptive user interface in order to avoid unnecessary drivers' overload and distraction [2]. One of the objectives of the AIDE Integrated Project was to develop a methodology for quantifying the behavioural effects of driving support and information systems and their relation to road safety.

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In this framework, a driving simulator experiment was performed aiming to identify which driving behaviour metrics are more sensitive for detecting changes in driving behaviour due to adaptive interfaces.

The need for adaptive interfaces to avoid overload and distraction is even bigger for drivers who are slower in perception, processing and reaction. For example, several studies report that older drivers are slower in all the facets of movement initiation and movement execution [3] and that reaction time increases with age [4]. The spare resources for a control process are related with the difference between the total time available and the total time needed to perform the control loop [5]. A thorough review of human perception-brake reaction time studies [6] conclude that factors such as age and cognitive load (either from driving or non-driving factors) are likely to reduce reaction time. Therefore, another objective of the present study was to evaluate whether drivers with longer reaction time would be equally benefited in terms of driving performance from an adaptive warning interface as drivers with shorter reaction time.

2 Method

2.1 Participants

24 persons participated in this experiment. Participants were selected among 57 people who were ranked according to their reaction time in a short test in a driving simulator. After familiarising with the simulator and while driving on a rural road, participants were asked to brake hard as soon as they would see a “STOP” message on the simulator screen. The 12 participants with the shortest reaction time were assigned in the “Early” group and the 12 participants with the longest reaction time were assigned in the “Late” group. The characteristics of the two groups are shown in Table 1.

Table 1. Characteristics of the two groups of participants

Group	Reaction time (s) mean (SD)	Gender	Age (years) mean (SD)	Annual mileage (km) mean (SD)
“Early”	0.8 (0.1)	8 males 4 females	29.8 (3.9)	19000 (9400)
“Late”	1.2 (0.2)	7 males 5 females	41.0 (17.8)	17500 (18000)

2.2 Apparatus

The experiment was performed on the dynamic driving simulator of the Hellenic Institute of Transport, built around a Smart cabin equipped with sensors. The position of all control levers, windshield wipers, blinker, ignition key and light switch is transmitted to the driving computer. All operational elements, steering wheel, accelerator pedal, brake pedal, gearshift lever and handbrake lever, provide nature-true force reactions. The gearshift functions like in the real car either as automatic or “softtip” with incrementing and decrementing the six gears and with reverse gear. The sight system includes five large-screens, each having a width of 2 m. There is on-screen projection with consumer video projectors with 2500 ANSI-lumen. The sound system generates original sounds according to the situation (starter, engine noise, horn, screeching of tires, drive wind, rain, etc.). The vibration device creates natural true vibrations of the car according to the revolvation of the simulated engine.

2.3 Experimental Design

Two support systems were simulated for the purpose of this experiment, a Forward Collision Warning (FCW) and a Blind Sport Warning (BSW) system.

The FCW was activated when the headway to the lead vehicle was less than 1.5 s. The warning was given visually in a simulated head-up display, projected on the central screen of the simulator and located under the central mirror, with a concurrent alarm sound.

The BSW was activated when the Time-To-Collision (TTC) between the rear vehicle at the left lane and the ego vehicle was less than 2 s, or when their distance was less than 5 m. This warning was given visually in a simulated visual display, projected on the left screen and located in the left external mirror, with a concurrent short beep sound.

The simulator scenario was built on a circuit route with a total length 8 km. The route consisted of a motorway with 2 lanes per direction (lane width 3.9 m), an emergency lane at the right and a central crash barrier. A lead vehicle in front of the ego vehicle was inserted at the right lane, at a steady speed of 60 km/h. If the driver overtook this, another lead vehicle was inserted at the right lane in front of the ego vehicle, at a headway of 2 s, driving also at 60 km/h. At the left lane there was a continuous flow of vehicles driving at 100 km/h with a random gap from 1 to 2 s.

The participants were instructed to closely follow the lead vehicle at the right lane.

Four times during the ride, if the TTC between the rear vehicle at the left lane and the ego vehicle was less than 3 s, in which case there would be soon a BSW activated, there was a sudden hard braking of the lead vehicle in the right lane. This would cause after a while a FCW to be generated, if the driver was indeed closely following the lead vehicle according to the instructions. In this way, there was a high chance of having concurrent warnings by the two systems. In these incidents, there were two possible reactions by the participants, either to brake in order to avoid the potential forward collision or to change lane in order to overtake the braking lead vehicle.

Two experimental conditions were used. In the “Non adaptive” condition, the two warnings were given independently of each other, namely in case of concurrent warning from the two systems, both visual warnings were displayed and both sounds were played. In the “Adaptive” condition, in case of concurrent warning from the two systems, an adaptation strategy was followed. The adaptation strategy was the extension of the duration of the audio warning of the FCW, while the audio warning of the BSW was suppressed. Both visual warnings were displayed.

2.4 Procedure

Upon arrival, participants were completing a background questionnaire with personal data and then they were asked to drive for 5 minutes the driving simulator in free traffic on a motorway, so as to get acquainted with it. The warning systems were active during the warm up scenario, so that drivers could get acquainted with their functionalities. Each subject then had to drive the whole simulator scenario in both conditions in counter-balanced order. The participants were asked to closely follow the lead vehicle and return quickly to the right lane, if they ever had to overtake.

2.5 Measures and Analysis Method

The simulator created a log file, where all dynamic variables, speed, vehicle lateral position, distance to lead vehicle, distance to cars in the left lane, brake force, lateral acceleration and other variables were stored with a frequency of 30 Hz. During post-processing of this log file, all incidents of concurrent activation of both systems were annotated. These incidents were not determined in advance; instead they were dependent on the dynamic behaviour of each participant. This is the reason why the number of incidents was not the same among participants.

From the logged data, we have calculated mean speed during the incident of concurrent activation, speed variation, lateral position variation, minimum time headway to lead car, reaction time, time headway to lead car when starting braking, time headway to side cars when initiating lane change, speed variation during lane change, maximum lateral acceleration during lane change. These were calculated for specific time windows around each incident of concurrent activation. Mean speed, standard deviation of speed and of lateral position and minimum headway to lead vehicle were calculated based on data collected in a time window starting 1.5 s before the incident and ending 4 s after the incident. The rest metrics were calculated based on data logged in a time window starting at the time of incident and ending 4 s after the incident. The reasoning for selecting the above time windows was to examine whether the adaptivity affected anticipatory driving behaviour.

Analysis of variance and t-tests were used to study effects of condition and group on the above metrics.

3 Results

In the “Early” group there were 149 incidents of concurrent warning in the “Non Adaptive” condition and 5 accidents. In 90 of the incidents the participants did not react at all, in 29 they reacted by braking, in 6 by changing lane and in 24 by exiting to the right. 20 of these reactions were early, namely they were initiated before the incident of concurrent warning. In the “Adaptive” condition there were 101 incidents of concurrent warnings, of which in 38 there was no reaction, there were 25 brakings, 10 lane changes, 28 right exists. 30 of these reactions were early. The Chi-square test has revealed that there were less cases of no reaction and more cases of early reaction in the “Adaptive” condition for the “Early” group ($p<0.01$). No difference in reactions was found between the two conditions for the “Late” group.

Table 2. Results´ overview

Events	**Early**		**Late**	
	Adaptive	*Non-adaptive*	*Adaptive*	*Non-adaptive*
Conflicts	**101**	**149**	**146**	**144**
Accidents	**14**	**5**	**24**	**15**
No reaction at all	38	90	52	64
Braking	25	29	46	34
Lane change	10	6	9	10
Exit in right	28	24	39	36
of which early reactions	30	20	42	36

In the “Non-adaptive” condition, the ”Early” group was driving at higher speed during the incidents compared to the “Late” group (p<0.01).

In the “Adaptive” condition, participants in the “Early” group were driving at lower speeds during the incident than in the “Non-adaptive” condition (p<0.05). The same trend can be seen for the “Late” group, but the difference is not significant.

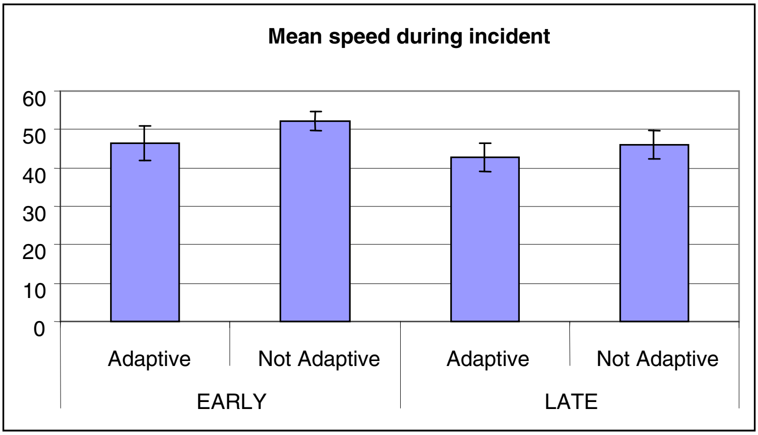

Fig. 1. Mean speed during incidents of concurrent warnings

In the “Non-adaptive” condition the standard deviation of speed of the “Early” group was lower than that of the “Late” group (p<0.05).

In the “Adaptive” condition, the standard deviation of speed in the “Early” group during the incident was higher than in the “Non-adaptive” condition (p<0.01). The same trend can be seen for the “Late” group, but the difference is not significant.

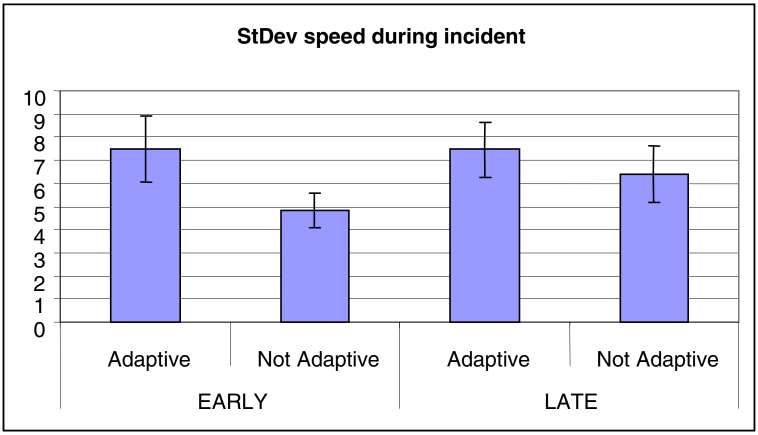

Fig. 2. Standard deviation of speed during incidents of concurrent warnings

No difference as regards the standard deviation of lateral position during the incident was found between groups in the "Non-adaptive" condition.

The standard deviation of lateral position during the incident was higher in the "Adaptive" condition than in the "Non-adaptive" condition for the "Early" group ($p<0.01$).

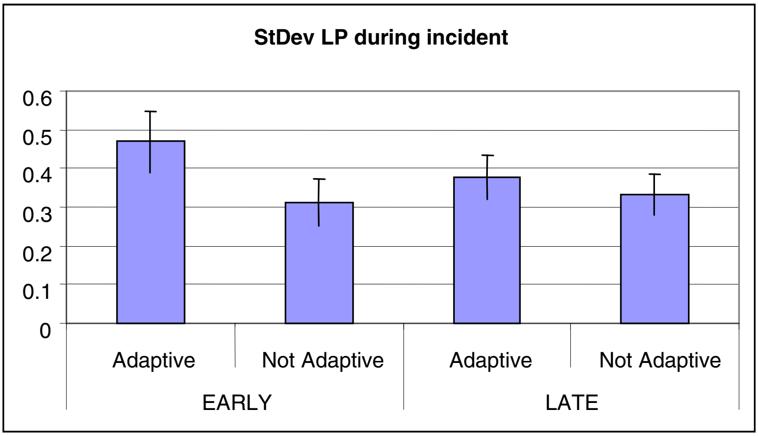

Fig. 3. Standard deviation of lane position during incidents

In the "Non-adaptive" condition the minimum time headway to the lead vehicle during the incident was longer in the "Early" than in the "Late" group ($p<0.01$).

The minimum time headway during the incident was lower in the "Adaptive" condition than in the "Non-adaptive" condition for the "Early" group ($p<0.01$).

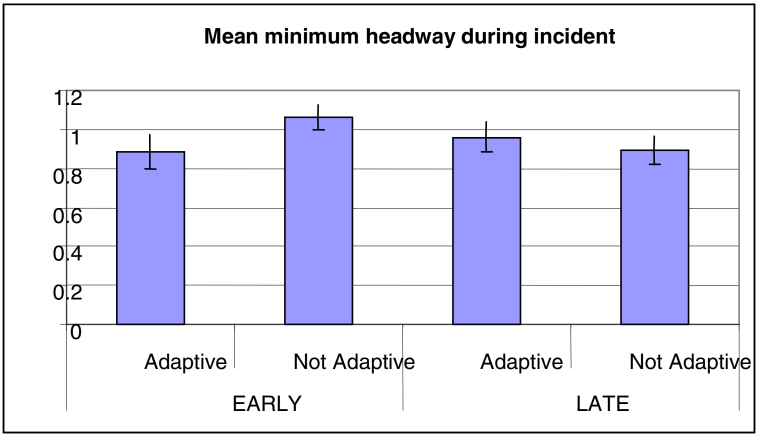

Fig. 4. Minimum headway to lead car during incidents

No difference was found either between groups or conditions as regards reaction time after an incident of concurrent warning and headway to lead car at which a reaction was initiated after such an incident.

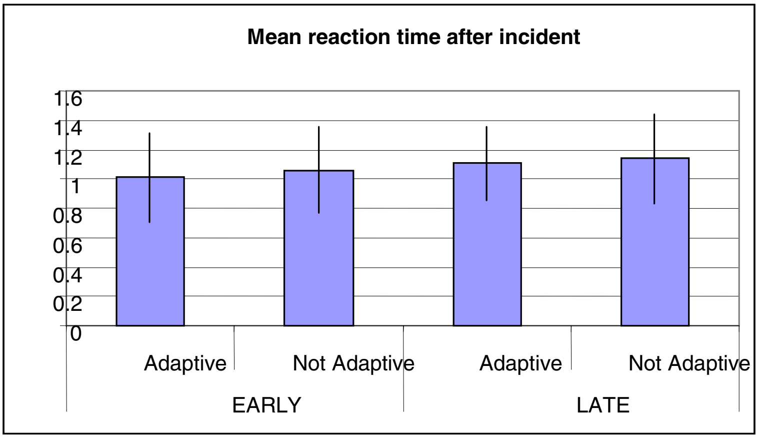

Fig. 5. Reaction time after an incident of concurrent warning

No difference was found between groups or conditions as regards the headway to the vehicle forwards or backwards in the left lane at the time point when a lane change manoeuvre was initiated.

No difference was found between groups or conditions as regards the standard deviation of speed during a lane change.

In the "Non-adaptive" condition, the maximum lateral acceleration after a lane change initiation was higher in the "Early" than in the "Late" group ($p<0.05$).

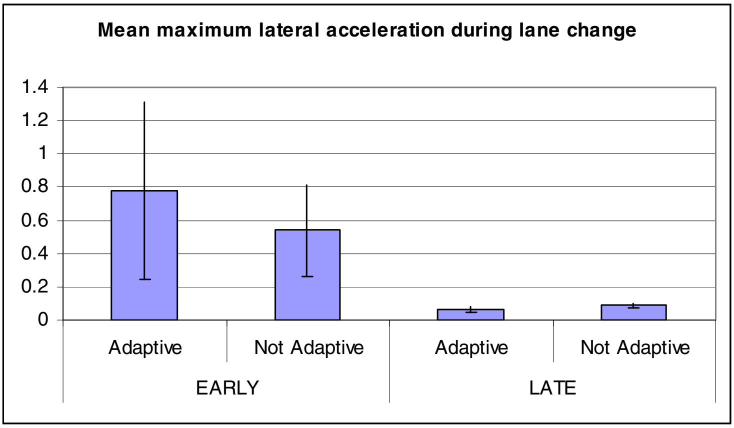

Fig. 6. Maximum lateral acceleration after a lane change initiation due to an incident of concurrent warning

4 Discussion

The results of this work will be discussed in respect to the following questions: (a) whether drivers with longer reaction time were equally benefited in terms of driving performance, from an adaptive warning interface as drivers with shorter reaction time and (b) which driving behaviour metrics are more sensitive for detecting changes in driving behaviour due to adaptive interfaces.

The two groups of drivers, which were formed according to the participants' measured reaction time in a driving simulator test, were found to differ as regards several driving behaviour parameters. Findings reveal that drivers with shorter reaction times, the "Early" group, in the "Non-adaptive" condition, were driving at higher mean speed during incidents, with lower standard deviation of speed, longer minimum time headway to lead vehicle and higher maximum lateral acceleration after a lane change initiation, than the "Late" group. No difference was found between the two groups in the "Non-adaptive" condition as regards standard deviation of lateral position during the incident, reaction time after the incident, headway to lead vehicle at which a reaction was initiated, distances to vehicles in the left lane at the start of a lane change and standard deviation of speed during a lane change. This may indicate that the brake reaction time is indicative of drivers with different driving behaviour during incidents of multiple risk. Such differences in driving behaviour should be separately studied when designing driving support systems.

Furthermore, the findings show that the adaptive interface did not affect the driving behaviour of drivers in the "Late" group. On the contrary, there were effects of the adaptive interface on the driving behaviour of participants in the "Early" group, lower mean speed during incidents, higher standard deviation of speed, higher standard deviation of lateral position, shorter minimum time headway to lead vehicle, less cases of no reaction and more cases of early reaction. These effects are contradictory as regards expected impact on traffic safety, therefore the chosen adaptivity strategy should be further examined. Since no effects of the adaptive strategy on the driving behaviour of the "Late" group were found, it seems that the chosen adaptivity strategy, namely the prolongation of one auditory warning and the suppression of the second, was not adequate for the "Late" group. Considering that the groups were formed according to braking reaction times, and that there should be a difference between the total time needed to perform the control loop [5], it seems that the chosen strategy was not appropriate for drivers with longer reaction time, since it did not increase the total time possibly needed by drivers in the "Late" group. It would have been probably better to employ an adaptivity strategy, which would provide earlier warnings to the "Late" group. Instead, in the "Early" group there is evidence that the adaptive interface induced drivers to be more alert for an anticipated multiple risk, as shown by the higher cases of early reactions.

From the studied metrics, those that were sensitive to detect changes in driving behaviour due to the adaptivity strategy were mean speed during incident, standard deviation of speed, standard deviation of lateral position and minimum time headway to lead vehicle. The metrics that were not sensitive to show changes in driving behaviour were reaction time after an incident, distance to lead vehicle at which a reaction was initiated, distances to vehicles in the adjacent lane at start of a lane change, standard deviation of speed and maximum lateral acceleration during lane change. Although our findings should be confirmed by more data and by experiments in other traffic scenarios and conditions, future studies and methodologies to evaluate the effect of adaptive interfaces on driving behaviour could focus on the more sensitive metrics.

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