REDUNDANT HEAD-UP AND HEAD-DOWN DISPLAY CONFIGURATIONS AND DISTRACTION DUE TO COMMON SECONDARY AUTOMOBILE TASKS.

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ABSTRACT

This study was designed to investigate effects of using two different display designs for presenting information and managing secondary tasks while driving. Eighteen drivers completed a driving simulator study designed to resemble normal driving in a fixed base high fidelity simulator. Driving performance, glance behaviour, physiological measures, and task completion times were measured during the execution of common automobile secondary tasks. The main result was that a display design with redundant, and more centrally placed information, had less detrimental effects on driving performance and glance behaviour than a more spread out design.

KEYWORDS

Head up display, display design, distraction, driving performance

INTRODUCTION

Distraction is an emerging problem in today's traffic. Distraction can stem from several sources where one is the automobile interior since automobiles are becoming more and more technologically complex [1, 2] and with more and more built-in driver information systems [3]. With a higher amount of information presented to the driver, dynamic displays showing many types of information in one place has found its way into the automobile [1]. Visual distraction can be particularly detrimental on traffic safety since the driver is mainly guided by vision when driving [4] and the visual distracters compete with the same perceptual and cognitive resources as the task of driving [5]. There is also a risk that visual information can be lost in the quantity of information displayed to the driver [5].

Everything that can distract the driver from the driving task with eyes-on-the-road and hands-on-the-wheel must be investigated with regard to traffic safety [6]. The Alliance of Automobile Manufacturers (AAM) [7] state that the completion of an in-vehicle task should require less than 20 seconds of total glance time towards the vehicle interior. In-vehicle activities other than driving, so called secondary tasks, can increase glance durations and time spent looking away from the road, which might degrade the driving performance and increase the crash risk [3, 8]. Cognitive load, which can arise during a secondary task, is also a source for degraded driving performance and can, combined with frequent gazes away from the road, especially degrade driving performance [9].

If information is acquired from a display located close to the road view, e. g. a Head-Up Display (HUD), the driving performance is less degraded than for a distant display [10, 11]. Using a HUD can also result in reduced workload, decreased response times, and increased driving comfort [12]. The detection of signals is easiest near the line of sight and it decreases significantly for larger eccentricities, especially the vertical ones [11], however, a HUD can increase the time the eyes are kept on the road, but also deteriorate the reaction time for events on the road by increased visual clutter in the driver’s line of sight [13]. Redundant elements may aid in the interpretation of information [14], but other forms of redundancy may also deteriorate performance [15]. Physiological measures have been used in earlier traffic safety studies to study, for instance, stress reactions while it might be useful for also study workload in in-vehicle technology [16].

Research aim and research questions

This study is the second of two studies to explore possible distracting properties of centrally and redundantly displayed information, where the first study examined effects of simple warnings displayed to the driver [17]. The aim of the present study is to investigate the influence of two display configurations on driving performance and glance behaviour both while driving and while performing common automobile secondary tasks while driving. One display configuration had a four display design similar to those found in high-end automobiles of today (e.g. BMW 7-series) while the other presented information centrally and redundant in two different displays; a LCD display in a HUD position 15° from the drivers’ normal line of sight, that did not obstruct the drivers view of the road, and a regular instrument cluster head-down display (HDD). The following specific questions are addressed: Does redundantly displayed information placed in the driver’s line of sight differ with respect to driving performance, added distraction, and time spent looking away from the road? Is the driver’s stress level affected by having information displayed in the line of sight?

METHOD

Participants and equipment

Eighteen drivers (8 females and 10 males aged 24 to 60 years with a mean age of 37.8 years) conducted the study. All participants had a valid driver’s licence and normal, or corrected to normal, vision. None of the participants’ private vehicles were equipped with any type of HUD display. The experiment took place in Luleå University of Technology Designlab’s driving simulator, which is a fixed base Volvo XC90 cockpit where four LCD displays replaced the original instrumentation (Figure 1). The display in the centerstack (CS) position consisted of a programmable touch screen where common automobile functions such as, for example, climate control and audio functions are simulated. The simulator’s handling was configured to simulate a front-wheel drive SUV (e.g. Volvo XC90).

The road view was projected by a NEC NP-1000 projector on a 1.8m high by 2.4m wide screen in front of the driver which subtends about 33.4° of the driver's forward view. Eye movements were monitored by a Seeing Machines FaceLab system (version 4.5). The minimum duration for a glance was in this study set to 100 ms [8]. Eye data calculations were based on fixations towards areas of interest (AOIs). Physiological measures were collected with a Mind Media Nexus-10 hardware and a BioTrace (version 1.20) software. EKG sensors in a Lead II chest position were used for measuring heart rate (HR). Galvanic skin resistance (GSR) sensors were mounted on the index and ring finger of the left hand. A temperature sensor was mounted on the middle finger on the left hand.

Driving environment

The driving environment was designed to simulate a realistic route with traffic, surroundings, and events that might occur in a realistic driving situation. A rural road generally gives the largest effect sizes for a driving simulator study [18]. In this study, an approximately 15 km long road with two lanes through rural areas and with a short four lane segment through a city environment was used. There were segments with 50 and 70 km/h speed limits. Throughout the study there was some oncoming traffic in the opposite lane and some in the same lane as the driver to simulate realistic driving. To keep the driver focused on the driving, some automobiles had to be overtaken, some made unexpected manoeuvres with abrupt brakes, and at one time a cyclist suddenly emerged from behind a parked truck.

Experimental design

The experiment was a 2 (driving condition) x 2 (display configuration) factorial design with repeated measures on the first factor. The driving conditions were "driving only" and "driving with a task". For the latter, ten short messages, consisting of a 15×15mm exclamation mark icon accompanied by a short text, were presented to the driver (Table 1). The participants were instructed to read the message when it popped up and perform a task according to the message. The two display configurations were "Redundant HUD" where vehicle speed and messages was presented to the driver redundant in the HUD and HDD, and "Spread out" where vehicle speed was presented in the HDD display and messages appeared in one of the four display positions (Figure 1). The order of displays the messages appeared in was: Infotainment display (IF), Centerstack (CS), HDD, IF, HUD, HDD, IF, HUD, HDD, and CS.

Table 1. Messages and placements.

Number	Placement	Message
1	Infotainment	Raise temperature to 22°C
2	Centerstack	Activate CD
3	Head-down display	Change to CD track 5
4	Infotainment	Lower volume to lowest perceptible
5	Head-up display	Activate MP3
6	Head-down display	Change to album "French pop"
7	Infotainment	Raise volume two steps
8	Head-up display	Dial xxx-xxxxxxx*
9	Head-down display	Raise fan speed two steps
10	Centerstack	Dial xxx-xxxxxxx*

Note: Messages translated from Swedish to English
*Actual phone number not displayed

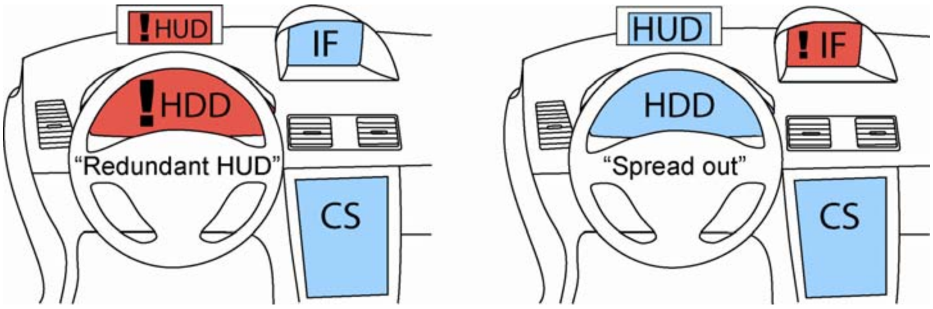

Figure 1. Display configurations. HUD – Head-up, HDD – Head-down, IF – Infotainment, CS – Centerstack

Procedure

The experimental session started with the participants being introduced to the simulator and given a five minute practice run to get familiar with handling the simulator. There were then two driving blocks of 15 minute each; a "driving only" block and a "driving and task" block. The order of these was balanced and both were made on the same road segment but in reverse directions in order to prevent the driver from getting too familiar with the road segment. The "driving only" block consisted only of driving through the road segment. The "driving and task" block consisted of driving with the addition of a task, where the drivers were asked to, while driving, perform tasks according to short messages displayed to the driver. The messages were displayed to the driver until the task was properly accomplished. All tasks were carried out on the CS touch screen. The participants were asked to drive as they normally would do with their own vehicles and to obey presented speed limits. Custom software was used to synchronize and reduce all data regarding the dependent measures (Table 2) to 10Hz, to analyze gaze data, driving data, and physiological data. Mann-Whitney's U-test was used for between subject analyzes, and Wilcoxon Signed Ranks Test for within subjects analyzes, due to the non-normally distributed data. Significance levels were set to .05.

Table 2. Dependent measures and their definitions

	Measure	Definition
Driving performance	Mean speed	Vehicle's mean speed
	Standard deviation of speed	How much the vehicle's speed deviates
	Maximum speed	Maximum speed reached
	Standard deviation from speed limit	How much the vehicle's speed deviates from the posted speed limit
	Standard deviation of lane position	How much the driver's lateral control of the vehicle deviates
	Number of lane exceedences	The number of times more than half of the vehicle is exceeds the lane
Physiological measures	Mean GSR	Difference in Galvanic Skin Resistance while relaxed and while driving
	Mean temp	Difference in mean hand temperature while relaxed and while driving
	Mean HR	Difference in drivers mean Heart Rate while relaxed and while driving
Glance measures	Time to notice	Time from a message appears until gaze is directed towards display
	Glance frequency	Number of glances to the message while it is displayed
	Total glance duration	Total time the message display is gazed upon
	Mean glance duration	Mean time the message display is gazed upon
	Gaze duration off road scene ahead	Time the gaze is not directed towards the road scene ahead
	HUD duration	Total time spent viewing the Head-up display
	HDD duration	Total time spent viewing the Head-down display
	Task completion time	The time from a message appears until the task is completed

RESULTS

Differences between driving tasks for "Redundant HUD". Adding secondary visual-manual tasks to the driving task actually improved the speed maintenance with significantly decreased standard deviation of speed (z=-2.521, p=0.012) and decreased standard deviation from the speed limit (z=-2.521, p=0.012) while the time spent looking away from the road significantly increased (z=-2.380, p=0.017). No significant differences were found regarding the physiological measures.

Differences between driving tasks for "Spread out". The "driving only" condition showed significantly lower means for mean speed, (z=-1.988, p=0.047), and higher means for standard deviation of speed, (z=-2.395, p=0.017), compared to "driving with task". The time spent looking away from the road significantly increased, (z=-2.803, p=0.005), during "driving with task". No significant differences were found regarding the driving performance or physiological measures.

Differences between display configurations for "driving only". When comparing "driving only" data for the two display configurations, the "Redundant HUD" showed a significantly lower mean for standard deviation of lane position, (U=13.000, p=0.016). "Redundant HUD" also showed a lower mean for HDD duration, (U=13.000, p=0.016), and a higher mean for HUD duration, (U=18.000, p=0.051), caused by the HUD-speedometer. There were no significant differences between the display configurations for the time spent looking away from the road or for any of the physiological measures.

Differences between display configurations for "driving and task". Data was analyzed for every separate task from the time the message displaying the task appeared until 15s after the task was properly accomplished. This time interval was chosen because the driving performance and the physiological measures were thought to also be affected a short while after the completion of the secondary task. When analyzing all tasks together, the "Redundant HUD" showed better driving performance in the form of a significantly lower mean for standard deviation of lane position, (U=16.000, p=0.034). There was no significant difference in major lane exceedences, but in total 113 lane exceedences occurred for the "Redundant HUD" and 176 for the "Spread out". The glance measures showed lower means for "Redundant HUD" for time to notice, (U=3.000, p=0.000) and HDD duration, (U=8.000, p=0.003). "Redundant HUD" showed a higher mean for HUD duration, (U=0.000, p=0.000). There were no significant differences in secondary task performance or any physiological measure between "Redundant HUD" and "Spread out".

Detection times were analysed for each separate message occurrence in order to study if these pop-up messages are distinguished from other in-vehicle information (Table 3). Some message occurrences yielded significantly higher detection times for "Spread out"; namely message 1, (U=13.000, p=0.046), message 2, (U=10.000, p=0.019), message 3, (U=18.000, p=0.049), message 4, (U=13.000, p=0.016), and message 10, (U=7.500, p=0.017).

Table 3. Mean detection times for each message. (in seconds)

Message number	1	2	3	4	5	6	7	8	9	10
Time to notice "Redundant HUD"	1.24	0.50	0.91	0.74	2.01	4.18	2.64	1.85	3.00	0.66
Time to notice "Spread out"	9.25	12.13	5.56	11.04	8.52	4.33	8.99	1.52	3.80	9.07

For “Redundant HUD”, the participants had the opportunity to choose which one of the HUD and HDD displays to consult to recognize a message. Nine out of ten participants chose to exclusively consult the HUD, and one participant checked the HDD for only one single presented message, namely message number two.

DISCUSSION

As in a previous study [17], the results did show some differences between the two display configurations in line with earlier research, namely that the display configuration with more centralized information resulted in better driving as well as task performance than the spread out display configuration [10],[11].

The addition of a secondary task while driving can significantly impair the driving performance [3], however, Normark et al. [17] could not confirm these results possibly due to the simplicity of the task. The present study did not find any effects on driving performance in terms of decreased lane keeping ability even though more time was spent looking away from the road for the both display configurations. However, the speed maintaining ability differed between the display configurations in that the “Redundant HUD” showed less deviating speed and a better adaptation to the posted speed limit during the secondary tasks. This could be explained by the fact that the drivers were forced to look more frequently on the HUD in order to read the instruction messages and thereby also more frequently monitored the HUD-speedometer. The “Spread out” showed more deviating and lower speed probably caused by less frequently monitoring of the speedometer since eight out of the ten instructing messages were displayed in other displays than the one with the speedometer.

For both driving tasks, the “Redundant HUD” yielded better driving performance in the form better lane keeping ability compared to “Spread out”. Even though more time was spent looking at the highly salient HUD close to the driver’s field of view for the “Redundant HUD”, this display configuration did not seem to be distracting. There should be some safety benefits by being able to quickly shift the attention from a display to the road and the closeness to the road of this display configuration simplifies road monitoring and improves the driver’s lane keeping abilities. Looking down at the HDD and the other display positions simply takes too much effort compared to looking at the HUD.

In general, the messages were discovered faster with the “Redundant HUD” then the “Spread out” (Table 3). Especially the messages appearing in the IF and SC positions of the “Spread out” were difficult to detect. The CS position should clearly be avoided for pop-up information since the messages were difficult to detect and took much attention away from the road when they were read. It is noticeable that the messages displayed in the IF position were hard to detect despite the display’s salient position close to the road view. One possible explanation could be that the drivers were shifting focus only between the road and completing the tasks carried out in the centerstack (CS), which led to a delayed detection of the IF messages. The CS touch screen might have been more visually demanding than a regular automotive centerstack with physical buttons as the drivers were only guided by visual cues when performing the tasks.

The HUD was the preferred display to observe in the “Redundant HUD” for nearly all message presentations. Since none of the participants had a HUD in their own personal vehicle, the novelty of seeking information in this position might have attracted more glances than necessary, however, not so much that it caused distraction.

Even though the secondary tasks were more advanced and longer lasting than the task used in an earlier study [17], the physiological measures did not imply any differences in stress levels between the two display configurations or between the driving tasks. However, just the novelty of driving a simulator could have been stressful enough for the respondents and, hence, overshadowed the stress specifically caused by the display configuration and/or the task. The ten messages were all different with respect to their content from each other, but of similar complicity so the detection times should not have been effected of the content differences. However, the participants seemed to remain highly vigilant during the driving blocks and in some cases repeatedly scanned the vehicle interior for new messages, which, on the other hand, could have effected the time it took to notice a message, but, if so, it should have affected both display configurations equally. The ten tasks did, however, differ both regarding comprehension and complexity of executing the task, which means that a direct comparison between tasks is difficult. However, in spite of these differences it was shown that they still can be used to reveal decreased driving- or task performance caused by in-vehicle technologies or vehicle interior design.

It can be interesting to further study possible interaction effects of differences in task and traffic complexity and how these might affect driving performance and physiological measures.

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