Combined Effect on Accident Risk of a Dual Task and Higher Driving Speed: A Simulator Study

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Abstract. A study was conducted on a dynamic driving simulator aiming to examine whether the effect of mental effort due to an auditory detection task on accident risk is additive to the effect of higher speed. Two levels of the driving task were employed, a low-demanding and a high-demanding one. Twenty drivers were asked to drive two rounds on a rural road with normal traffic, with unexpected traffic events along the second round. In half of the cases an auditory detection task had to be performed in parallel. The analysis of results showed that higher speed or higher mental effort due to the secondary task lead to more accidents and the effects should be considered as additive. These effects should not be considered as the mere effect of attentional resource availability but as depending on the drivers' skill to manage their attentional control.

Keywords: accident risk, driving simulator, mental effort, secondary task.

1 Introduction

Several studies report that an increase in average speed results to an increase in the risk of an accident of any type [1,2]. Other driving studies have focused on the effect of mental workload on driving performance [3,4] often in an attempt to evaluate potential interference of specific in-vehicle systems into the primary driving task. Studies relevant to mobile phones report a decrement in some aspects of driving performance when a mobile phone is used –e.g. in visual search behavior [5,6], braking reaction time [7,8], visual processing and decision making [9-11] that vary according to the level of difficulty or intensity of the primary task. Studies of using visual route guidance systems and performing a secondary auditory task while driving [12,13] report that drivers tend to reduce their driving speed as well as to neglect subsidiary

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tasks (e.g. mirror-checking) when task demand increases but this does not imply that accident risk is equally reduced. However, the linkage that has been made so far between the relation of mental workload and accident risk is rather weak. It was reported [14] that the speed reduction while looking at a visual display can be interpreted as an indication of drivers' inattention to the primary task. On the other hand, a simulator study [15] reported that a primary task of lower demand does not improve the performance on the secondary task.

If task performance was solely dependent on attentional resource availability, then the lower the demand of the primary task, the better the performance on the secondary task should be. Still according to the attentional management theory [16] - describing dual task performance as a skill of attention management -drivers can achieve a high level of performance when performing a number of tasks concurrently because they prioritise their tasks with respect to the main task goal (namely to arrive safely at the destination), in such a way that it is possible to manage to attend different tasks (e.g. by expecting when an event will take place).

The objective of this experiment, performed within the framework of AIDE Integrated Project, was to study whether the effects on accident risk of increased speed and increased mental workload due to the parallel conduct of a secondary task should be considered as additive or interacting.

2 Method

2.1 Participants

20 persons, 13 males and 7 females, participated in this experiment. Participants were recruited via announcements at the announcement board of the Hellenic Institute of Transport. Participants' age ranged from 24-40 years old (mean: 30.8, standard deviation: 4.06 years). They held a driving licence for an average duration of 10.75 years (standard deviation 4.31 years).

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.

The secondary task employed was an auditory detection task with beeps randomly generated every 3 to 5 s, each one lasting for 1 s or until the participant had pressed the response button. Signal intensity was adjusted for each participant so that it was easily perceptible. Participants were asked to push the response button, as soon as a signal was noticed by them.

2.3 Experimental Design

Participants were allocated in two groups and two conditions. In the No pressure group, participants were asked to drive normally, and in the Pressure group, participants were given a short time limit within which they should have completed the simulator scenario, so as to urge them to drive at higher speeds. The two conditions were, Driving only (DO) and Driving while conducting in parallel an auditory detection task (DT). The order of presentation of conditions was counter-balanced.

The simulator scenario was built using a circuit rural route with one lane per direction, no central border and a total length of 6.2 km. There were 2 signalised and 1 non-signalised intersection along the route. Each participant was asked to drive two rounds of the circuit continuously. There were oncoming vehicles and lead vehicles in front of the ego vehicle, some of them driving at low speed. Overtaking in general was possible but risky.

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, so as to get acquainted with it. Each subject then had to drive the whole simulator scenario, consisting of two rounds. At the end participants were asked to complete a mental effort questionnaire.

During the first round, the driving behaviour of the other road users was in compliance with traffic rules, whereas no other unexpected traffic events took place. During the second round, the following unexpected traffic events were scheduled: a sudden deceleration of the lead vehicle (twice), an animal suddenly crossing the road, a parked car sudden entrance into the lane in front of the ego vehicle, the door of a parked car suddenly opening in front of the ego vehicle.

2.5 Measures and Analysis Method

The simulator logged time, number of accidents, ego vehicle speed, distance to lead car, time when the participant started braking or initiated an evasive manoeuvre after the occurrence of a critical event. An evasive manoeuvre was defined as a sudden change in the steering angle, resulting in a change in the ego vehicle lateral position towards the edge of the road. The following indicators were calculated:

- Response time to a critical event (s). This was the time that the participant initiated a braking or evasive manoeuvre in response to one of the critical events minus the time that the critical event was initiated.

– Headway to lead car at the moment when the participant started braking or initiated the evasive manoeuvre in case of the lead vehicle sudden braking event.

As regards the performance in the auditory task the following indicators were calculated: the mean response time in s and the mean hit rate, the latter being the correct hits within the specified time limit per total beeps emitted.

At the end of each scenario, participants were asked to rate their mental effort, using the Rating Scale of Mental Effort (RSME) [17].

ANOVAs and t tests were used for statistical analysis of data.

3 Results

3.1 Participants' Performance on Primary and Secondary Task

There was an effect of Pressure on ego vehicle speed, on lane keeping and on the headway at which the participants initiated the evasive manoeuvre or started braking in the case of the second lead vehicle braking in both the DO and DT conditions. No effect of Pressure was found for the headway at which the participants initiated the evasive manoeuvre or started braking in the case of the first lead vehicle braking, on RSME ratings or on the performance on detection task (hit rate and response time).

There was an effect of Detection task on RSME ratings but on no other indicator.

No interaction effects were found between Pressure and Detection task.

Table 1. Participants' performance per condition and group

	No Pressure		Pressure		Effect pressure	Effect detection task
	DO	DT	DO	DT		
Mean ego vehicle speed (km/h)	65.5	61.3	86.6	85.4	< 0.05	ns
Headway start response 1st lead vehicle brake (s)	0.88	1.01	0.68	0.73	ns	ns
Headway start response 2nd lead vehicle brake (s)	1.29	3.13	0.77	0.78	< 0.05	ns
StDev lateral position (m)	0.63	0.59	0.76	0.77	< 0.05	ns
Mean hit rate		84.5%		83.7%	Ns	ns
Mean response time (s)		0.45		0.44	Ns	ns
RSME	38	65	47	59	Ns	< 0.05

3.2 Type of Accidents and Accident Risk

The total number of accidents for all participants was much higher in the Pressure group (19 accidents in condition DO and 17 in DT) than in the No pressure group (11 accidents in condition DO and 10 in condition DT).

In the No pressure group the number of accidents in the second run was always lower or equal to that of the first run while in the Pressure group the number of accidents was in some cases higher in the second run than in the first one, irrespectively of the order of presentation of the experimental conditions.

No effect of Pressure or of detection task was found on response time to critical events, except from the first case of sudden braking of the lead vehicle and this only between the No pressure-DO and the Pressure-DT conditions.

Table 2. Response time (s) for the various events among groups and conditions

	No Pressure		Pressure	
	DO	DT	DO	DT
Response time 1st lead vehicle brake (s)	0,70	0,52	0,42	0,18
Response time 2nd lead vehicle brake (s)	0,54	1,38	0,43	0,40
Response time animal (s)	1.44	1.39	1.52	1.40

3.3 Combined Effect on Number of Accidents

Speed, headway at which a braking or evasive manoeuvre was initiated, standard deviation of lateral position, RSME ratings, accuracy on detection task (*AccuDet*) and mean reaction time on detection task (*RTDet*) were normalised into a range 0 to 1 and the following regression model was used.

$$\text{Number of accidents} = \exp(\beta_o + \beta_1 \text{ Speed} + \beta_2 \text{ RSME} + \beta_3 \text{ Headway} + \beta 4 \text{ LatPos} + \beta_5 \text{ AccuDet} + \beta_6 \text{ RTDet}) \quad (1)$$

According to the data collected, the speed, RSME rating and accuracy on the detection task were found to have an effect on number of accidents. No other effect was found and no interaction was found between speed, RSME ratings and accuracy on detection task.

Table 3. Regression results for the data collected

Variable	Coefficient	StdError	T Stat	Significance
Speed	3.788	1.326	2.858	< 0.05
RSME	2.228	0.852	2.615	< 0.05
Headway	-2.107	2.865	-0.736	ns
LatPos	-1.307	0.950	-1.375	ns
AccuDet	-3.576	0.985	-3.631	< 0.05
RTDet	0.217	0.802	0.270	ns

4 Discussion

Although the number of participants in this study was low and interpersonal differences between participants should be kept in mind, results allow to derive some

indications, which however should be validated in future studies with higher number of participants using a within-subjects design.

The time pressure was found to increase mean speed, as expected, and to deteriorate the lane keeping performance of participants, the latter may be due to their more frequent attempts to overtake slower lead vehicles.

The time pressure was also found to reduce the time headway at which participants initiated an evasive manouevre but only for the second occurrence of the sudden braking lead vehicle, not for the first occurrence neither for any other event. This may be due to the participants' attempt to finish the scenario within the set time, which urged them to drive more closely to lead vehicles, especially as time passed by.

The concurrent performance of the secondary task was not found to have an effect on the studied indicators of driving performance or on indicators of the secondary task performance, still it resulted in higher RSME ratings by participants. This may explain why performance on the secondary task did not deteriorate with time pressure. Despite the secondary task, participants may have always maintained their focus on driving and managed to adequately perform both the primary and secondary task, although with an increased mental workload.

As regards accident risk, more accidents occurred in the Pressure than in the No pressure group, which indicates that speed increases accident risk, as expected. In the Pressure group a lot of accidents were related to loss of vehicle control, that is road departure, which may be attributed to these participants driving at higher speeds. In the No pressure group accidents in the second run were less or equal than in the first run, which may indicate that these participants traded-off increasing situational demands due to the unexpected events by shifting attention to traffic dangers while driving at lower speed. In the Pressure group accidents in the second run were more than in the first, possibly due to the participants' attempt to finish the scenario within the set time.

No effect of Pressure or detection task on the response time to a critical event was found, that is the higher speed or the concurrent conduct of the detection task did not prohibit participants from paying full attention to traffic risks and timely reacting to them. Although this may be attributed to inter-personal differences, the lower (although not significantly) response times to critical events of the Pressure compared to the No pressure group may indicate that participants in the Pressure group attempted to trade-off increased speed by increasing their alertness to traffic dangers.

Supported by the results of the regression analysis, higher speed was found to lead to more accidents, the same holds true for the RSME ratings, while the increase in accuracy in detection task was found to relate with less accidents. The latter may be due to interpersonal differences, indicating that participants who performed better in driving performed also better in the secondary task. Moreover, these results are in accordance with the attentional management theory [16]; meaning that the effect of speed and mental workload on accident risk should not be considered as the mere effect of attentional resource availability but as depending on the drivers' skill to manage their attentional control.

No interaction effects of speed, RSME rating and accuracy on the detection task on number of accidents were found. This means that if it is found that a new driving

support system results in an increase of driving speed and of mental effort, these effects should be clearly considered as additive in order to estimate the total system effect on accident risk.

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