The Influence of Workload on Attention during the Driving Task

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Abstract: This experiment analyses the effect that mental and visual workload have on the driver. The aim of this experiment is to induce both mental and visual workload to the participants, while they are solving an attention test on the computer; the difficulty has been manipulated by combining two types of items. Thirty students at different colleges in Iaşi participated in this study. Their ages varied between 22 and 24 years old, they were all males and had little experience as drivers. Each participant had to go through all the experimental conditions: without workload, mental workload and visual workload. The results indicate that mental workload mitigates task performance at the attention test, while visual workload doesn't. These results reinforce those studies which suggest that there are no differences between hand-held cell phones and hands-free phones, concerning mental workload. Another finding is that mental workload is much more dangerous than visual workload, because it can lead to the appearance of the 'looked, but failed to see' phenomenon.
Keywords: mental workload; visual workload; attention test.

Introduction

The number of new devices installed inside vehicles nowadays is rising continuously. This phenomenon has led to an increased probability that these devices would be used during driving. This represents a real problem for safety, because these devices compete with the driving task over the limited resources of the driver (Wickens, 2002). It has been estimated that 25-37% of accidents imply some form of distraction or inattention of the driver, although these numbers also include distractions that are not caused by in-vehicle devices (Sussman, Bishop, Madnick & Walter, 1985; Wang, Knipling & Goodman, 1996). Others, however, (e.g. Neale et al., 2005) state that inattention plays a very important, even decisive role in more than 78% of accidents. Also, the increased rates of car crashes have been associated with road sections containing a large number of commercial banners on the side of the road (Wallace, 2003). McEvoy, Stevenson & Woodward (2007) revealed that over 10% of a sample of 1367 drivers that were hospitalized because of a car crash reported that, at the time of the accident, they had been distracted by stimuli considered as irrelevant for the driving task.

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According to the load theory of selective attention (Lavie et al., 2004), when the driver experiences cognitive overload because of the surrounding environment, he or she would not be able to process stimuli that are relevant for the primary driving task. When drivers deal with too much information that cannot be processed, they experience workload. Workload is defined as the amount of resources processing information used in a unit of time in performing a task (de Waard, 1996; Wickens & Hollands, 2000). This notion is based on a conception derived from the theory of information, which states that man functions as a channel with limited capacity in transmitting and processing information. Overloading this channel, when the task is already complex and demanding, results in the emergence of errors, omissions or larger reaction times (The Great Psychology Larousse, 2006). There are two types of cognitive workload: visual and mental. (1) Visual workload appears when the driver's visual span contains more visual stimuli than the driver can process, while (2) mental workload is produced when the driver's cognitive resources are overloaded by his actions. The studies carried out in order to discover the effects that visual workload has on drivers revealed that this particular type of workload leads to speed reduction (e.g. Antin et al., 1990; Curry, Hieatt & Wilde, 1975) and impairs peripheral detection (Olsson, 2000), as well as the capacity to detect critical events in traffic (Greenberg et al., 2003). Also, visual workload leads to a reduced lane keeping performance (Greenberg et al., 2003; Zwahlen, Adams & de Bald, 1988) and entropy of steering wheel movements (Boer, 2000). On the other hand, mental workload is consistent with an increased reaction time of the driver (Makishita & Matsunaga, 2008). Research by Recarte and Nunes (2003) showed that some mental workload inducing tasks, like word production and engaging in a complex conversation, led to the concentration of gaze towards the centre of the road. There have been many contradictions concerning lane keeping. Some studies show that mental workload impairs lane keeping performance (Strayer & Johnson, 2001), while others demonstrate that it has little or no influence (Horrey & Wickens, 2004) or that it actually increases lane keeping performance (Brookhuis, de Vries & de Ward, 1991). Like visual workload, mental workload also reduces the capacity of detecting critical events. One study shows that drivers are much more aware of the visual workload state than the mental workload one (Makishita & Matsunaga, 2008). Therefore, it can be stated that the mental workload phenomenon is much more dangerous and affects the driving task more than the visual workload. The purpose of this experiment is to investigate the visual and mental workload phenomenon in order to establish which of these two types of workload has a greater impact on the driver, more precisely on the ability to drive safely.

Method

Main goal

Although cognitive overload has been widely explored in mainstream cognitive psychology, in traffic psychology the distinction between mental and visual workload is a new topic. It is only recently since the two are assumed to have potentially distinct effects on performance. Therefore, the aim of this experiment is to induce both mental and visual workload to the participants, while they are solving an attention test on the computer. The difficulty level has been manipulated by combining two types of items. Thus, we tested which of these two phenomena impairs the ability of driving safely to a greater extent. We expected that (1) the mental workload will decrease performance on the attention test to a higher degree than the visual workload, and that (2) attractive visual stimuli will deteriorate the performance on the attention test to a higher degree than the neutral visual stimuli.

Participants

The initial sample consisted of 33 male participants, aged between 22 and 24 years and with little driving experience, meaning that they drove less than 50.000 km. Our sample fits the high-risk group pattern mentioned by the literature: young inexperienced male drivers. Three subjects did not pass the adaptation phase in order to be accepted in the testing phase. Thus, the final sample included 30 participants.

Procedure

<u>The computer-based attention test</u>

The attention test used in this experiment was given to the participants on a laptop with a 10.1 inch display, 1366 x 768 screen resolution as well as an active speaker. The participants were placed at approximately 40 cm away from the screen. The attention test includes a combination of items belonging to Posner's (1980) behavioral inhibition and attention mobility tests. Posner measured attention mobility through a series of items with a basic shape represented by a square with a fixation point ("X") in the center of the screen. On each side of this fixation point, numbers and capital letters can appear. Participants must press the Caps Lock key only when a letter is shown on the left side of the fixation point. Similarly, the Enter key must be pressed when a number is displayed on the right side of the fixation point. This means the item requires action only when (a) there is a letter on the left side of the fixation point and when (b) there is a number on the right side of the fixation point. The item is incorrect when (a) there is a number on the left side of the fixation point or (b) there is a letter on the right side of the fixation point (see the Appendix). In the last two situations no key should be pressed.

Behavioral inhibition refers to the possibility of repressing certain behaviors or reactions. It was measured with a different type of item. This time, two uppercase letters that are or are not followed by a sound, appear inside a slot. Participants must press the Space key only when the letters are the same and are followed by a sound (see the Appendix). This is the only situation that requires action. Otherwise no key should be pressed.

<u>Experimental stages</u>

The experiment consisted in three stages: initiation, adaptation and testing. In the initiation phase, participants were shown the different types of items, as well as the way they should react to them. The adaptation's goal is to let the subjects get familiar with the task by exercising on a set of sixteen demonstrative items. In order to get to the testing phase they must correctly solve at least eleven out of sixteen items. The first two items are not taken into account as they serve as practice for the subjects. The feedback regarding the participant's performance appears at the end of the series of items. If a participant solves less than 11 items correctly, he is asked to repeat the adaptation phase, but within the limit of 3 trials. If the participant still does not succeed in adapting, he will not be included in the testing phase. The items pertaining to the attention mobility and behavioral inhibition test sections are presented at constant time intervals that only differ depending on item type. Specifically, the items belonging to the attention mobility test are presented at 3000 ms intervals, and those belonging to the behavioral inhibition test are presented at 2000 ms intervals. This situation only applies when the subject does not press any key. If a key is pressed, regardless of it being a correct or incorrect reaction, the next item automatically appears. The testing phase contains a set of 125 items that unroll at a time interval of 2000 ms for attention mobility items and 1250 ms for behavioral inhibition items. Following a counterbalancing method, each participant must solve the set of items three times, in different experimental conditions. The set of 125 items is the same in each condition, meaning that there are the same items placed in the same order.

<u>Experimental conditions</u>

In the control condition the participants' task was to solve the items according to the rules presented in the initiation phase, without inducing them any type of workload ("no workload"). In the "mental workload" condition, participants were told to skip count by two, aloud, starting at "2", as fast and correct as possible, while solving the attention test. The speed at which the participants were counting was not considered as a variable in this study. They were asked to count as fast as they could in order to prevent them from concentrating on the primary task (the attention test) through a standardized mental task. In the “visual workload” condition, some items are accompanied by visual distracter stimuli, which have a circular shape and switch location on the screen from one item to the next. The attractive distracting stimuli are red, whilst the neutral ones are grey. The red color was chosen due to its significance for the drivers: most of the important traffic signs are red, such as the “Stop” sign, the traffic lights are red and so are the braking lights. The grey color was chosen because it could easily blend with the black background.

Dependent measures

The dependent measures analyzed in this experiment are: (1) the average total reaction time, (2) the average reaction time on the items measuring attention mobility, (3) the average reaction time on the items measuring attention mobility that were answered correctly, (4) the average reaction time on the items measuring attention mobility that were answered incorrectly, (5) the number of correct answers on the items measuring attention mobility, (6) the number of incorrect answers on the items measuring attention mobility, (7) the average reaction time on the items measuring behavioral inhibition, (8) the average reaction time on the items measuring behavioral inhibition that were solved correctly, (9) the average reaction time on the items measuring behavioral inhibition that were solved incorrectly, (10) the number of correct answers on the items measuring behavioral inhibition, (11) the number of incorrect answers on the items measuring behavioral inhibition, (12) the average reaction time on the items accompanied by attractive distracting visual stimuli and (13) the average reaction time on the items accompanied by neutral distracting visual stimuli.

Results

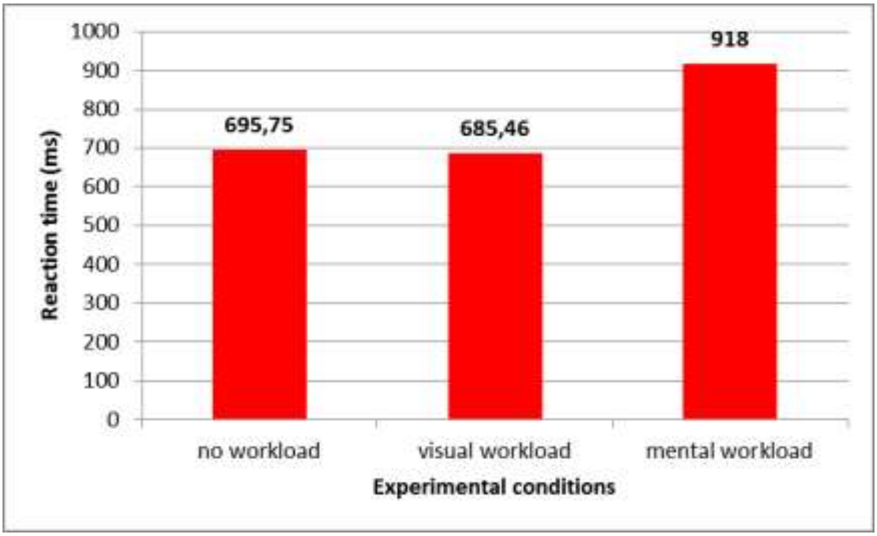
SPSS (Statistical Package for Social Sciences) v. 17.0 was used in the statistical analysis of data. Considering the fact that the measurements were within-subjects, the Paired-Sample T Test was used in order to see how the participants’ performance varies through the conditions.

Table 1: *Comparison between the average total reaction time from the three experimental conditions.*

Source	Mean	SD	t	df
no workload – visual workload	695.75 685.46	119.06 92.88	0.662	29
no workload – mental workload	695.75 918	119.06 129.16	-9.345*	29
visual workload – mental workload	685.46 918	92.88 129.16	-10.944*	29

*p<.05

Figure 1: *Comparison between the average total reaction time from the three experimental conditions.*



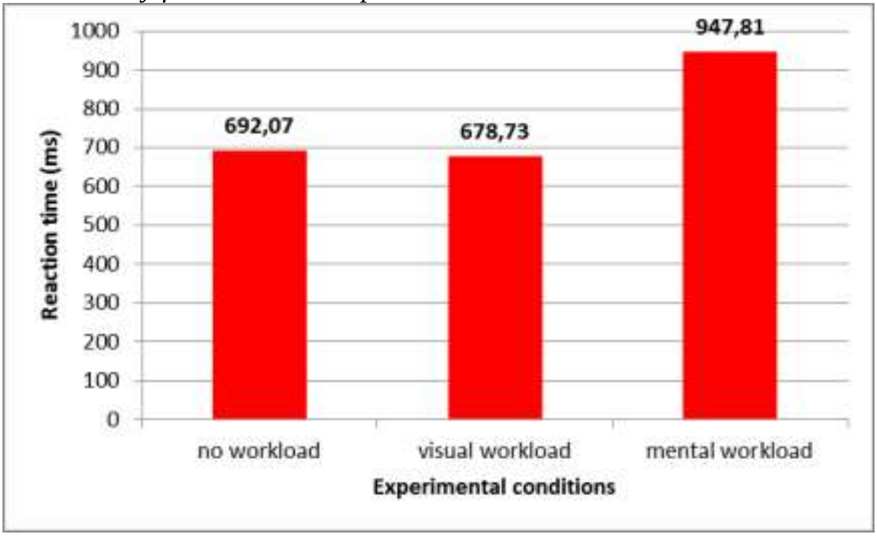
Concerning the total reaction time, the only significant differences were those between the mental workload and the other experimental conditions. More precisely, the average total reaction time was significantly higher in the mental workload condition than in the other two conditions.

Table 2: *Comparison between the average reaction time on the items measuring attention mobility from the three experimental conditions.*

Source	Mean	SD	t	df
no workload – visual workload	692.07 678.73	137.23 109.03	0.730	29
no workload – mental workload	692.07 947.81	137.23 143.20	-9.612*	29
visual workload – mental workload	678.73 947.81	109.03 143.20	-11.349*	29

*p<.05

Figure 2: *Comparison between the average reaction time on the items measuring attention mobility from the three experimental conditions.*



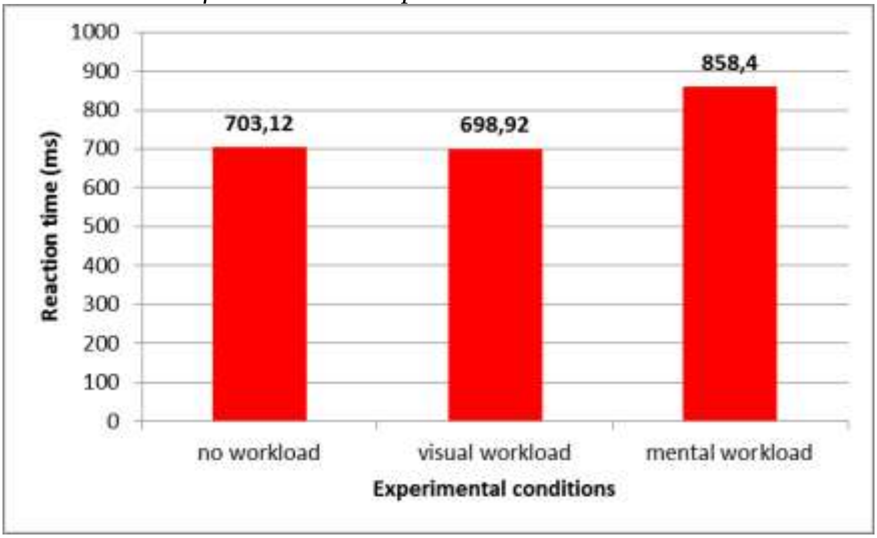
When we compared the average reaction time on the items measuring attention mobility, we found significant differences between the two types of workload and between the mental workload and no workload. The average reaction time on the items measuring the attention mobility from the mental workload condition is significantly larger than those from the other two conditions. These differences emerge when it comes to both correctly and incorrectly solved items. When it comes to the number of errors, the ones from the mental workload condition are significantly more frequent than the ones from the visual workload condition [$t_{(29)} = 5.403$; $p < .05$], as well as from those in the without workload condition [$t_{(29)} = 4.215$; $p < .05$].

Table 3. Comparison between the average reaction time on the items measuring behavioral inhibition from the three experimental conditions.

Source	Mean	SD	t	df
no workload – visual workload	703.12 698.92	120.17 108.98	0,311	29
no workload – mental workload	703.12 858.40	120.17 127.95	-6.641*	29
visual workload – mental workload	698.92 858.40	108.98 127.95	-7.188*	29

*p<.05

Figure 3. *Comparison between the average reaction time on the items measuring behavioral inhibition from the three experimental conditions.*



When comparing the average reaction time on the items measuring behavioral inhibition, significant differences were found between the mental workload condition and the other two experimental conditions, namely visual workload and no workload. Specifically, the average reaction time on the items measuring behavioral inhibition is significantly larger in the mental workload condition than in the other two conditions. Also, these differences emerge when it comes to both correctly and incorrectly solved items. Moreover, in what the number of errors is concerned, the ones from the mental workload condition are significantly more frequent than the ones from the visual workload condition [$t(29) = 7.367$; $p < .05$] and from the ones in the without workload condition [$t(29) = 6.633$; $p < .05$].

Table 4: *Comparison between the average reaction time on the items accompanied by attractive distracting visual stimuli and the average reaction time on the items accompanied by neutral distracting visual stimuli.*

Source	Mean	SD	t	df
attractive stimuli – neutral stimuli	429.45 388.64	61.56 53.06	7.840*	29

*p<.05

It emerges that the average reaction time on the items accompanied by attractive distracting visual stimuli is significantly bigger than the one obtained on the items accompanied by neutral distracting visual stimuli.

Generally, the data reveals that the performances obtained by participants in the "no workload" and "visual workload" conditions are not statistically different. This means that the distracting visual stimuli did not deteriorate the participants' results in a significant way. However, when comparing the average reaction times on the items with attractive distracting visual stimuli with those on the items with neutral distracting visual stimuli, it turned out that participants' ability to respond correctly and quickly was considerably diminished by the attractive distracting visual stimuli.

The values obtained in the "mental workload" condition differ in a significant way from those obtained in the other two conditions. This means that the participants' performance is considerably diminished when they experience mental workload, unlike visual workload or lack of workload.

Discussion

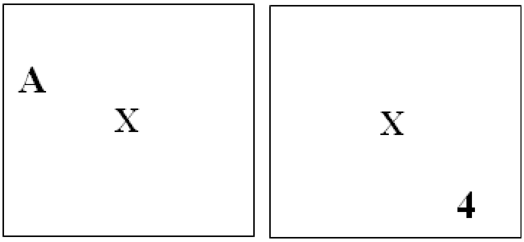
The results of the experiment support the first hypothesis, which stated that a mental workload deteriorates the attention test performance in a greater extent compared to a visual workload. Our data suggests that a mental workload has powerful and significant effects on driving performance, in the sense that the participants' reaction times and correct answers were considerably diminished compared to the other two experimental conditions. On the other hand, the visual workload did not provoke a similar effect. On the contrary, the average reaction times obtained in the visual workload condition were smaller than the ones in the "no workload" condition. This phenomenon can be due to the fact that the participants got used to the task and therefore improved their performance. This may also mean that the visual stimuli did not distract the participants' attention and thus did not fulfill the purpose for which they were introduced. Considering this conclusion, it can be stated that a visual workload does not have a powerful impact on attention or that the distracting visual stimuli used were not able to have a significant effect. Although it seems like the distracting visual stimuli did not have a strong impact on the participants, the reaction times on the attractive visual stimuli were significantly larger compared to the neutral visual stimuli. Therefore, the deterioration of the performance at the attention test does not appear between conditions, but within the same (i.e. visual) condition. All of this considered, it cannot be stated that the difference in the reaction times obtained at the red stimuli and the grey stimuli is due to the fact that the participants perceived the red stimuli as more attractive than the grey ones. One should also consider that the stimuli selected for both workload conditions constitute only a small range of possibilities. The outcome could have been different if the visual stimuli had other characteristics (e.g. ego-threatening, more salient etc.).

The most important practical implication of these results is that they indirectly reinforce those researches that have discovered that there are no differences between mobile phones and hands free devices in what concerns a mental workload (e.g. Alm & Nilsson, 1995; Consiglio et al., 2003; Lamble et al., 1999; Törnros & Bolling, 2005, 2006). Although using hands free while driving is permitted by law, these devices are as prejudicial as mobile phones because they induce a mental workload. Another practical implication of this research is that a mental workload is much more dangerous than a visual workload. This conclusion is not shared by most drivers because they tend to consider that they can observe potential threats and act in order to avoid them as long as they keep their eyes on the road. In spite of these beliefs, the results of this experiment show that the state of one's mental workload has a significant negative impact on attention. It may be the cause of the "looked-but-failed-to-see" phenomenon.

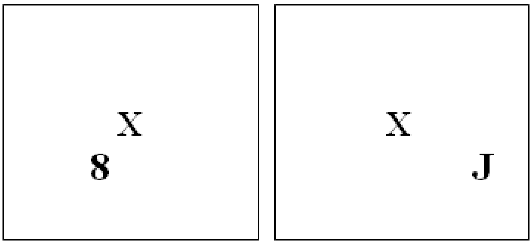
One should be aware that the attention test used represents a simulation of the mental and visual workload phenomena, without any certainty that they develop in exactly the same way in real life. The same thing can be said about the concepts of attention mobility and behavioral inhibition, measured by Posner (1980) and transposed into the two types of items introduced into the attention test. In addition, the number of participants who took part in this experiment is relatively small. Although we tried to control the variables that could have interfered with our results, it is possible that some of the participants had more experience in typing and therefore they would have found the useful keys more quickly in order to react to the items, thus obtaining shorter reaction times. Also, there is a chance that certain participants were more familiarized with the size and the shape of the laptop that was used in this experiment. Another possible issue is that the induction of the mental workload state depended on the participants' mathematical abilities, namely on the ability to operate with numbers. It is possible that some of the subjects obtained a smaller reaction time due to their ability to operate with numbers easier and faster than others. Besides, there can be additional confounding variables that may explain the differences observed in the results.

As far as further research is concerned, this experiment could be improved by introducing more relevant distracting visual stimuli that would probably lead to the appearance of significant effects.

Appendix

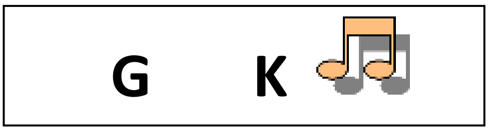


Two examples of correct attention mobility items. In the first case the left key must be pressed. In the second case the participant must press the right key.



Two examples of incorrect attention mobility items (no key should be pressed).

Example of correct behavioral inhibition item (the space key must de pressed).



Example of incorrect behavioral inhibition item (no key should be pressed).

A A

Example of incorrect behavioral inhibition item (no key should be pressed).

P R

Example of incorrect behavioral inhibition item (no key should be pressed).

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