sciendo

Transport and Telecommunication, 2023, volume 24, no. 4, 397–408
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2023-0031

DRIVERS' REACTION TIME AND MENTAL WORKLOAD: A DRIVING SIMULATION STUDY

Anna Pouliou[1], Fotini Kehagia[1], Georgios Poulios, Magdalini Pitsiava-Latinopoulou[1], Evangelos Bekiaris[2]

[1]Department of Civil Engineering, School of Engineering, Aristotle University of Thessaloniki
54124 Thessaloniki, Greece
apouliou@civil.auth.gr, fkehagia@civil.auth.gr, mpitsiav@civil.auth.gr
[2]Hellenic Institute of Transport
Thessaloniki, Greece
abek@certh.gr

Drivers play a significant role in causing serious accidents, which underscores the need for further investigating the human element in order to improve road safety. Given the predominance of the information processing approach in driver's behavior research field, an important psychological construct, Mental Workload (MWL), has been introduced to study the behavior of drivers. The objective of this paper is to investigate the impact of increased MWL on driver behavior and specifically the changes in driver's Reaction Time (RT) under increased MWL. The experiment conducted in the driving simulator of the Hellenic Institute of Transport which is part of the Centre for Research and Technology Hellas, with the participation of 56 subjects from all age groups. For the simulation of the increased MWL conditions during driving, a secondary task was employed. To this end, the MIT AgeLab Delayed Digit Recall Task in the 1-back version was adapted for the needs of the present research. The driving scenario included 4 unexpected events, which further increase driver's MWL. Driving performance was observed and relative parameters were measured as RT on the unexpected events, accidents occurred, and maneuvers performed. Appropriate statistical analysis was performed to examine the difference in the drivers' RT in the unexpected events. Results demonstrated that higher MWL increased drivers' RT in the majority of the participants. Furthermore, results also indicated a number of participants that probably employed adaptive control behaviors to counterbalance the increased MWL. Overall, variance on MWL proved to play an important role on driver performance, and thus further research on its consequences on driving performance, and the factors that influence its variance during driving, is imperative.

Keywords: road safety, driving performance, mental workload, accident occurrence, secondary task, unex-pected events

1. Introduction

Driving is considered a highly mental task as it is mainly an information processing task, although physical activity is needed for performing the driving task. Driver's capability of sufficiently performing the driving task depends not only to the amount of information needed to be perceived and processed, but, most significantly, in the rate at which this information can be processed. Thus, information processing requires driver's attention, perception, understanding and reaction. Since driving is a temporal task, the existing time to identify and process the important information for its successful implementation, is limited. Often the driver must make a decision in seconds or even fractions of a second. This fact highlights the importance of information processing in driving and driver's significant role in road safety (Shinar, 2007; Migliorini *et al.*, 2022; Pouliou *et al.*, 2022).

The limit of the processing capacity of the human mind is discussed since 1956. Miller (1956) argues that the range of the absolute judgment and the range of immediate memory, create limitations in the amount of information that human brain is able to receive, process and remember. The theory of limited processing capacity of human brain describes the existence of resources available for task implementation, known as human mind capability, which are limited and are activated voluntarily. Therefore, processing capacity is the upper limit of the human brain capability (De Waard, 1996). Given the predominance of the information processing approach in driver's behaviour research field, an important psychological construct, Mental Workload (MWL), has been introduced to study driver's behaviour. A review in the international literature proves that MWL has a highly intuitive appeal, and while it seems easy to be understood as a concept, it is rather difficult to define it, as no consensus is made on its definition. In general, an analogy is made between stress (task demands) and strain (impact on driver), which is widely used, and it appears even in the international standard on MWL (ISO 10075, 2000; Wiberg *et al.*, 2015). MWL, including both cognitive load and stress, describes the amount of mental resources required for performing a task (Wiberg *et al.*, 2015). Usually, workload is defined as the demand posed by an external source for the completion of a task. As demands are enlarged, task complexity, an objective concept, is increased too. Task difficulty, though, is a subjective perception, that refers to the effort (amount of resources used) required by a particular person and under given conditions, to perform a specific activity (Rubio *et al.*, 2004; Schneegass *et al.*, 2013; Young *et al.*, 2015). Having in mind the multidimensional nature of MWL, Young et al. suggest that MWL reflects "the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support, and past experience" (Young *et al.*, 2015).

MWL is an important factor influencing road accidents and it is directly related to driver performance. It is a multidimensional concept, as it is determined not only by the requirements of the activity performed, but also by the given, each time, conditions, and by the driver (Wilde, 1982; De Waard, 1996; Schneegass *et al.*, 2013; Borsos, Birth and Vollpracht, 2015; Young *et al.*, 2015). High or low MWL while driving is affected by many factors, for example it depends on driver state affecting factors, driver trait factors, and environmental factors. The correlation between the factors that affect driving behaviour and the MWL's variance is a significant parameter in the science of road safety. It is widely observed, that when demands begin to exceed driver's capacity, there is the possibility of either compensate by adjusting the strategy (e.g., lower speed, stop interacting with passengers) or else performance necessarily degrades, leading inevitably to an accident (Taylor, 1964; Wilde, 1982; De Waard, 1996; Fuller, 2005; Young *et al.*, 2015).

Consequently, when an activity performed by the driver requires a high MWL, it deprives the corresponding processing capacity of a second activity that the driver must perform concurrently with the first one. The decision-making process is based on sufficient information and its proper processing. Therefore, both situations, either the lack of information that may lead to incorrect choices, or the situation in which the available information exceeds the driver's processing capacity resulting in the rejection of the additional -potentially critical- information, may lead to a dangerous road safety situation (De Waard, 1996; Shinar, 2007; Misokefalou, 2014).

Driving is a complex task as it is related to the driving environment, including both roadway and traffic conditions, that changes constantly as a vehicle moves, and the human behaviour that is highly complicated, too. Primary driving task consists of a series of actions that the driver performs in order to maintain the vehicle in a safe route, retaining the longitudinal and lateral control of the vehicle on the road (Brookhuis and De Waard, 2010; Gkemou, 2013). Every task performed by the driver is conscious, requires attention and gives feedback to the driver, through a controlled process. This process is time consuming and does not allow the driver to perform any other activity at the same time. When such tasks are repeated often, they begin to become more automated, as the course of their execution does not require close monitoring by the driver, and therefore are performed almost unconsciously. The attention devoted by the driver to perform non-automated, controlled tasks requires effort, and drivers tend to dedicate the least required attention to the driving task, where possible. While the driver engages to more automatic tasks, arises the danger of being absorbed in the automated driving, failing to perceive any emergency that may arise on the road (e.g., unexpected event), requiring an immediate reaction through a controlled action (De Waard, 1996; Shinar, 2007).

An unexpected situation demands priority, activating a compensation process to ensure safety (Michon, 1985; Schaap, van Arem and van den Horst, 2008; Edquist, Rudin-Brown and Lenné, 2012). Therefore, the presence of an unexpected event, forces the driver to change behavior, in order to safely maintain the trajectory of the vehicle within the lane limits. The way each driver handles an unexpected situation, depends on the nature of the event, and the driver characteristics, i.e., parameters related to the human factor. As regards the nature of the event, the driver's reaction is affected by the type of event, its expectancy, how urgent the situation is, but also how dangerous it is for the driver or other road users (Schaap, van Arem and van den Horst, 2008; Dozza, 2013; Briggs, Hole and Turner, 2018; Powelleit and Vollrath, 2019). Concerning the human factor, the influence of the driver's MWL is important, as drivers who are engaged in a secondary task, and therefore presenting higher MWL, react differently to an unexpected event (e.g., react to fewer events, record longer reaction times), compared to drivers who are focused exclusively on driving task (Briggs, Hole and Turner, 2018). Furthermore, dual tasking drivers present difficulties in detecting unexpected events based on their type (driving incongruent/congruent events) and even when these events are being detected, Reaction Time (RT) is significantly longer than RT of drivers not engaged in a secondary task. The two most common actions that the driver is required to take when an emergency is perceived, are to maneuver, if possible, the vehicle away from the obstacle, or to use the brake pedal to decelerate or stop the vehicle to avoid conflict. Relevant literature prove that the vast majority of drivers choose to brake, as initial response to an unexpected event, even when a steering maneuver is feasible (Adams, 1994; Powelleit and Vollrath, 2019). When studying the driver's reaction to external stimuli, it is observed that it does not follow a linear model, as time delays are recorded (Macadam, 2003). A significant percentage of road accidents are due to some delay related to the human factor, such as delay in risk perception, delay in decision making or implementation, etc. (Shinar, 2007; Borsos, Birth and Vollpracht, 2015).

Previous research proves that spare capacity of attention while driving changes with the road conditions, and RT seems to be a sensitive measure to evaluate the spare capacity of attention (Kontaxi, Ziakopoulos and Yannis, 2022). Moreover, the driver's perceptual ability to detect an unexpected event can be improved by upgrading road conditions through road and environmental interventions (Domenichini, Branzi and Meocci, 2018). Ruscio et al. (2015), stated that interaction of the driver with Advanced Driver-Assistance Systems (ADAS) generate different RT, and relevant influence is observed during speaking on a phone while driving, which increases the driver's RT and MWL, and changes driver's visual overview ability as well as understanding of the situation (Žuraulis *et al.*, 2018; Papantoniou *et al.*, 2019). Important influence of driving, MWL and age on RT is also proved by Makishita and Matsunaga, who demonstrated that 75% of drivers had a RT of less than or equal to 1 second, with the exception of older drivers while performing mental calculations. Their findings confirmed that with the increase of the difficulty of performing an activity, the difference in the RT related to age is also increased. The importance of drivers' awareness that additional MWL affects driving behavior is also highlighted, reporting drivers' decision for compensatory behavior, e.g., by reducing vehicle speed (Makishita and Matsunaga, 2008).

The study of driver behavior includes conditions and situations that considered dangerous, such as driving under high MWL, increasing the likelihood of an accident occurrence. For this reason, relevant researches regarding driver behavior are being implemented mainly with the use of a driving simulator (Makishita and Matsunaga, 2008; Papantoniou, 2015). The laboratory environment ensures the safety of the participants, which is of high importance when studying the condition of the driver (e.g., driving under high MWL, under fatigue, under the influence of drugs or alcohol), which in real driving conditions would not be ethically acceptable, due to the danger involved. Furthermore, the driving simulator allows the complete control of the studied conditions, eliminating any confusing variables that may affect the results. They also allow for the repeatability of the studied conditions, which increases the objectivity and reliability of the results. It is therefore possible to create scenarios that are likely to endanger the safety of road users (e.g., aggressive driving, driving in fog) and scenarios that cannot be predicted in the field (e.g., unexpected events possibly leading to an accident). In addition, it facilitates the use of measurement equipment, compared to the field study, where the relevant constraints are increased due to the use of a conventional vehicle for measurements (Blana, 2001; Shinar, 2007; Gkemou, 2013; Papantoniou, 2015). On the other hand, the researcher should always take into consideration that the actual driving conditions can be simulated only approximately, and especially the surrounding traffic and the behavior of other drivers is very difficult to be predicted and therefore to be represented in the simulator. Another issue for consideration is the challenge to ensure the realistic response of the driver, behaving in the same way as if driving on the road, despite the awareness that in the simulated environment there are no consequences for driving mistakes. Additionally, the researcher should always be alert for identifying simulator sickness indications observed while driving, which is particularly intense and common in older drivers, and may lead to impaired driving behavior altering research results, or even in the resignation of the driver, not being able to complete the experimental process (Vardaki, Yannis and Papageorgiou, 2014). Finally, it should be noted that the cost of the driving simulator is commensurate with its quality, which increases the cost of implementing a research on a simulator, and may lead to a reduction in the sample size and time of driving for each participant (Brookhuis and De Waard, 2010; Papantoniou, 2015). For this reason, the results of a research implemented in a driving simulator require cautious interpretation, based on preceding studies proving the usefulness of the simulator on comparative under study conditions (Healey and Picard, 2005; Gkemou, 2013; Young *et al.*, 2015).

Relevant literature regarding experiments performed in driving simulators, highlights also the significance of the validity of the simulator employed (Blana, 2001; Gkemou, 2013; Misokefalou, 2014; Papantoniou, 2015), while, up to date, the majority of relevant researches uses simulators of limited validity, such as fixed base or seat simulators (Makishita and Matsunaga, 2008; Schaap, van Arem and van den Horst, 2008; Mehler, Reimer and Dusek, 2011; Pasetto and Barbati, 2011; Powelleit and Vollrath, 2019). Other limitations of relevant literature that the present research attempts to address are the often absent or inadequate trial drive for the familiarization of the subjects with the driving simulator, and limitations regarding the sample, such as limited sample or age representation and increased proportion of male drivers in the sample (Healey and Picard, 2005; Reimer and Mehler, 2011; Marinescu *et al.*, 2016, 2018; Heine *et al.*, 2017). Furthermore, since unexpected events play a crucial role in road safety, especially while driving under high MWL, the current research examines, apart from driver's reaction time, also driver's reaction manner to the unexpected events. The study of the way the driver reacts to an unexpected event on high MWL is promising and can provide important insights to optimize driver's reaction time to unexpected events. To this end, further study of the driver's reaction in different conditions and environments is needed. Another novel aspect of the current research is the development of a dedicated driving simulator scenario that succeeds to create the desired under study conditions of unexpected events, engaging the driver in a secondary task while driving, as well as a custom software for the communication of the independent devices (driving simulator, camera) and for editing of raw data.

Based on the above, the objective of the current paper is the investigation of the effect of increased MWL on driver behavior and specifically the changes in driver's RT while driving under increased MWL (1-back digit recall task). To this end, a driving simulator experiment took place, as this environment, provides the ability to study repetitive conditions, as well as the safety needed, to create the desirable - possibly dangerous-conditions, of high MWL. Through the statistical analysis performed, driving performance was analyzed based on relevant parameters (RT, accident occurrence, maneuver performance). The RT of drivers on the unexpected events and the changes in drivers' RT that occurred due to the increased MWL were analyzed, as well as drivers' way of reaction as affected by the parameters under study. The present study is part of a wider research that takes place in the context of a doctoral dissertation concerning the study of out-of-the-vehicle factors that influence driving behavior. The approach focuses on Greek drivers, emphasizing driver's reactions to visual stimuli.

2. Materials and Methods

2.1. Analysis of the problem

The first step of the methodology is to clarify the MWL concept based on a literature review. In this context, a better understanding on the relationship between MWL and other processes, including those that are cognitive in nature e.g. attention/effort, helps to identify the needs per driver (driving performance and drivers' behavior) under different scenarios of incidents tested. Moreover, an extended literature review carried out to investigate in a comprehensive way the research topics examined the combined problem of task demand, MWL and driving performance, as it is graphically depicted in Figure 1.

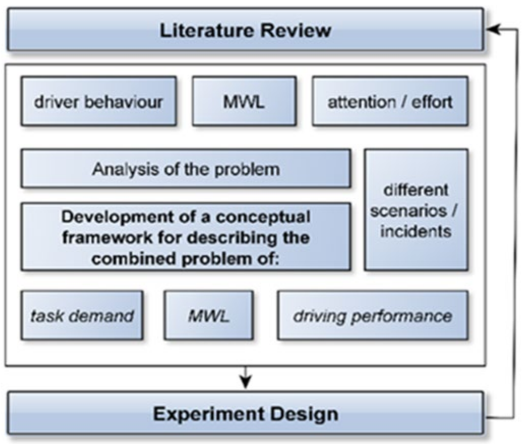

Figure 1. Framework research design

2.2. Experiment Design

The experiment conducted in the Driving Simulator of the Hellenic Institute of Transport which is part of the Centre for Research and Technology Hellas (Figure 2). The dynamic simulator employed for the experiment is based on a real vehicle (Mercedes-Benz Smart) moving on a dynamic platform. The driving wheel, the throttle and brake pedals, and the handbrake are connected to a feedback system including sound and vibration to provide realistic feel while driving. A wide field of vision of 180º is ensured through five (5) large screens projecting the driving environment. Driving took place under the supervision of a researcher, who passively observed the driver, also ensuring the proper function of the systems.

Figure 2. The Driving Simulator of the Hellenic Institute of Transport

2.3. Driving Scenario

The driving scenario developed for the present research consisted of a 6 km drive in a rural environment. The road had two directions, with a 3 m. lane per direction, mild horizontal curves, and no gradient. Other vehicles were driving in both directions, interacting with the participating driver. A graphic illustration of the road map of the specific driving scenario is depicted in Figure 3.

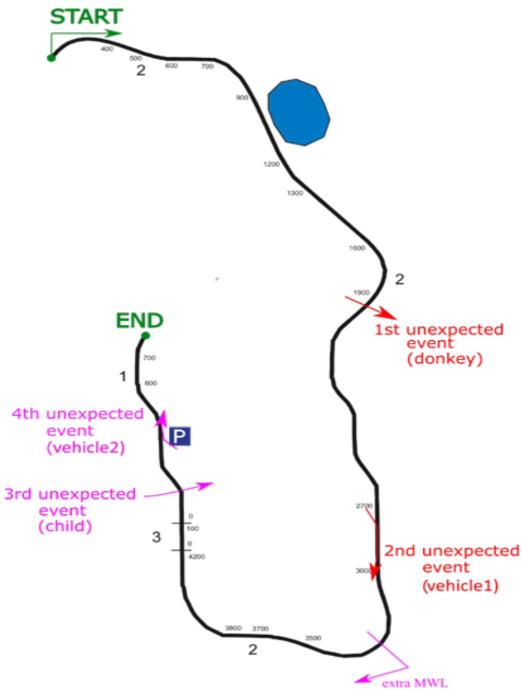

Figure 3. The scenario's road map

During this drive, four (4) unexpected events occurred, which took place with the following order:

- 1st unexpected event (donkey): A donkey stands behind a bush and crosses the road when the driver approaches (Figure 4a);
- 2nd unexpected event (vehicle1): A parked vehicle behind another parked vehicle at the side of the road, leaves its parking slot, drives in front of driver and parks again later at the side of the road (Figure 4b);

- 3rd unexpected event (child): Opposite a farmhouse, behind a parked vehicle, a red ball runs in the road and a child follows crossing the road (Figure 4c);
- 4th unexpected event (vehicle2): Beside a parking, there are a lot of parked vehicles, the last one -in the row- leaves its parking slot, drives in front of driver and parks again later at the side of the road (Figure 4d).

2.4. DDRT secondary task

For the simulation of the increased MWL conditions during driving, a secondary task was employed. To this end, the MIT AgeLab Delayed Digit Recall Task (n-back) (DDRT) *(Mehler* et al*., 2009)* in the 1-back version was adapted to current research needs. The DDRT increases driver's MWL by employing his/her short memory while driving. It is implemented via recorded auditory stimuli, in which drivers respond verbally. A soundtrack of 10 single digits (0-9) presented in random order, at an interval of 2.25 seconds between each digit, initiated during the drive asking of the driver, each time, to recall the 1-back digit. The DDRT commenced after the first two unexpected events, so as to let happen in 2 events in each state (No MWL/With MWL).

2.5. Questionnaire

Along with the driving procedure, the participants filled in an online questionnaire, which was divided in two parts. The first part, including demographic and driving data, was filled before driving, and the second part, including data regarding the driving experience during the measurement process and the Rating Scale of Mental Effort (RSME), without and with the DDRT, was filled afterwards. Driving simulator experiment was designed so as not to last more than 20-30 minutes, since this is the maximum time given in literature for filling self-reporting tools without significant information loss (De Waard, 1996).

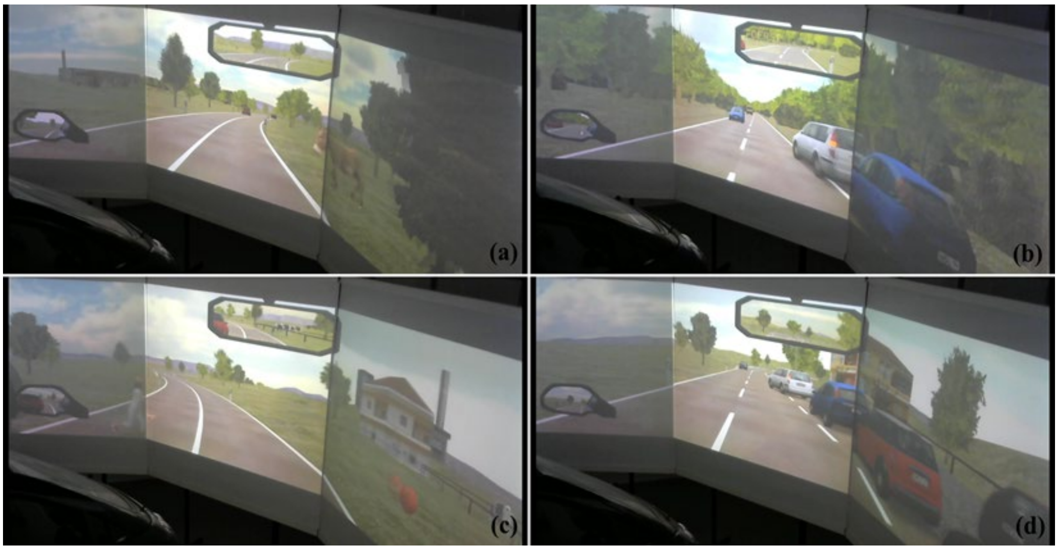

Figure 4. Implementation of the four (4) unexpected events: (a) 1st unexpected event (donkey), (b) 2nd unexpected event (vehic1e1), (c) 3rd unexpected event (child), (d) 4th unexpected event (vehicle2)

2.6. Experimental protocol

The experimental protocol followed during all trials included the subsequent steps:

1. The researcher welcomed the participating driver and informed him/her orally about the experimental procedure.
2. The participant was informed about the excluding criteria (orally and written).
3. A consent form was signed by both the participant and the researcher. The researcher assigned a unique 4-digit code to the participant, valid for the whole experiment (questionnaire, simulator's files, video recording, custom software for synchronization), so as the participation to be anonymous.
4. The participant was given full written instructions for the experimental procedure.

5. Questionnaire (first part) was filled online and anonymously, using the 4-digit code.
6. The participant was informed, in writing, about the DDRT and was trained in the task following the training protocol of MIT AgeLab, adapted to the Greek language. When the participant succeeded in the training, proceeded to the next step.
7. The participant entered the simulator's vehicle, and a free driving scenario was initiated at the simulator, enabling the participant to familiarize with the driving in the simulator.
8. When the participant stated that he/she got accustomed to the driving simulator, the researcher commenced the rural road scenario of the present research and enabled the recording of measurements in all systems (operating parameters of the vehicle and visual field of the driver). Throughout the driving procedure, the researcher ensured that the participant was feeling well and that the experiment could proceed.
9. With the completion of the experimental drive in the simulator, the researcher stopped the recording of measurements, and the participant exited the vehicle.
10. The participant filled the second part of the questionnaire, within 30 minutes from the completion of the driving experimental process.

It is important to mention that along with the instructions for the experimental procedure, the participants were asked to try to approach their everyday driving style by reacting to situations encountered in the driving scenario as they would react if they happened on a real road. They were also encouraged to quit from the experiment at any time they may feel unwell, or they do not wish to continue the experiment for any reason.

3. Results

3.1. Sample

In the present study, 60 drivers participated in the experiment, with 4 of them encountering serious difficulties in driving task due to simulator sickness, not managing to properly complete the drive. Thus, the final sample of the present study is 56 drivers, with 48% of them female and 52% male. As regards age distribution, four age groups were created [(18 – 25), (26 – 40), (41 – 55), (> 56)], and the distribution of the participants covered all age groups, as depicted in Table 1. The sample was selected to be representative of the Greek drivers, in terms of age and gender. The excluding criteria applied in the sample are:

- health reasons or medication that may affect driving: if yes, the subject is excluded,
- any kind of nausea (simulator nausea, traveling nausea etc.): if yes, the subject is excluded,
- class B driver's license in force: if no, the subject is excluded,
- year of obtaining driver's license: if 2019, 2020, the subject is excluded,
- kilometers driven since the day the driver's license was obtained: if 0 - 2,000 km, the subject is excluded.

Table 1. Gender and age distribution of sample

				Male		Female	
Age group	**N**	**Mean**	**SD**	**N**	**%**	**N**	**%**
18 - 25	6	0.500	0.548	3	10%	3	11%
26 - 40	19	0.470	0.513	10	34%	9	33%
41 - 55	17	0.470	0.514	9	31%	8	30%
> 56	14	0.500	0.519	7	24%	7	26%
Total	56	0.480	0.504	29	100%	27	100%

3.2. Data processing

According to the experimental protocol (par. 2.6), all subjects drove the experimental scenario once, while all relevant systems were recording the data. Thus, with the completion of the experiment, the researcher saved the data collected from the driving simulator, the camera recording driver's field of vision, and the online questionnaire. The driving simulator data was further edited via custom software that was developed for the research's needs and finally extracted in a *.csv type of file. The camera produced an *.mkv type of file, which was used for the quality control of the simulator data, and the collection of data regarding drivers' reaction. The online questionnaire was created and published on EU Survey online survey-management system and the content was automatically extracted in a *.xls type of file. Finally, all data was analysed with the IBM SPSS software for the production of results and conclusions.

3.3. Statistical analysis

Appropriate statistical analysis was performed to examine the RT of drivers on the unexpected events and the changes in driving performance that occurred due to the increased MWL (DDRT). The statistical analysis methodology included an Analysis of Variance and two binary logistic regressions. A two-way Analysis of Variance (ANOVA) was performed to investigate the effect of MWL and unexpected events on driver's RT. Binary logistic regressions were employed to examine the effect of MWL on maneuver execution, as well as on accident occurrence. All analysis performed with the software IBM SPSS Statistics v.27. A two-way ANOVA was applied to investigate how the presence of additional MWL (No MWL/With MWL) and the source of the unexpected event, affect the RT of drivers to the unexpected events. The statistical significance level was set at 0.050 and the analysis showed that MWL ($F = 83.635$, $p < 0.010$, $Eta = 0.282$) and the source of event ($F = 37.167$, $p < 0.010$, $Eta = 0.149$) are statistically significant (Table 2).

In general, drivers reacted slower in the presence of additional MWL, with 80 % of them demonstrating higher RT in higher MWL conditions, i.e. during the 3rd and 4th unexpected event. Furthermore, drivers showed higher RT in the 2nd and 4th unexpected event (vehicle1, vehicle2), as it is depicted in Figure 5. More specifically, in the case of the unexpected events caused by the donkey and the child, 75% of the drivers demonstrated higher RT in higher MWL conditions, while in unexpected events caused by vehicle1 and vehicle2), 80% of the drivers demonstrated higher RT in higher MWL. The remaining percentage of drivers (25% and 20% respectively) probably employed adaptive control behaviors to counterbalance the increased MWL.

Table 2. Tests of between-subjects effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	17.363a	4	4.341	33.674	0.000	0.387
Intercept	13.416	1	13.416	104.077	0.000	0.328
MWL	10.781	1	10.781	83.635	<0.001	0.282
Source of event	4.791	1	4.791	37.167	<0.001	0.149
MWL * Source of event	1.240	1	1.240	9.617	0.002	0.043
Error	0.386	1	0.386			
Total	27.457	213	0.129			
Corrected Total	555.013	218				

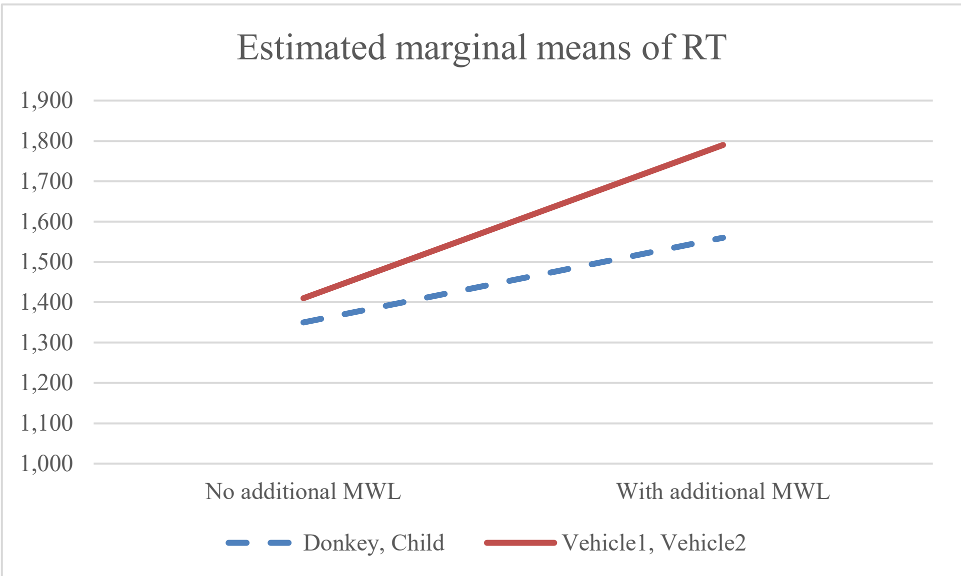

Figure 5. Estimated marginal means of RT

3.4. Effect of MWL and source of the unexpected event, on maneuver execution

Regarding the way drivers reacted to the unexpected events, the vast majority of the drivers (92%) employed the brake pedal, while only 30 % of them performed a maneuver. More analytically, 69 % of the drivers used only the brake, with 5 % performing only a maneuver, and 23 % employing both ways of reaction. Furthermore, in total of 224 unexpected events occurred during all drives, there were 6 cases (3 %) where there was no reaction at all, leading inevitably to accident. Overall, 33 accidents occurred (15 % of all 224 events), most of which happened in events caused by the donkey and the child (61 % of accidents happened at the donkey and child events, 39 % of accidents happened at the vehicles events). A binary logistic regression proved that only MWL (B = 1.032, p = 0.001, Exp(B) = 2.807), and not the source of event (B = -0.137, p = 0.650, Exp(B) = 0.872) significantly affects the execution of a maneuver, apart from or along with braking, as a reaction of the driver to the unexpected event (Table 3).

Table 3. Binary logistic regression on maneuver execution - Variables in the equation: MWL, Source of event

							95% C.I.for EXP(B)	
	B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**Lower**	**Upper**
MWL	1.032	0.310	11.077	1	0.001	2.807	1.528	5.154
Source of event	-0.137	0.303	0.205	1	0.650	0.872	0.482	1.578
Constant	-1.399	0.282	24.591	1	0.000	0.247		

3.5. Effect of MWL and source of the unexpected event, on accident occurence

A second binary logistic regression performed to estimate the effect of MWL and source of the unexpected event, to accident occurrence. In this case, nor MWL (B = 0.407, p = 0.349, Exp(B) = 1.503) or source of event (B = 0.340, p = 0.415, Exp(B) = 1.405) significantly affected the realization of an accident (Table 4).

Table 4. Binary logistic regression on maneuver execution - Variables in the equation: MWL, Type of event

							95% C.I.for EXP(B)	
	B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**Lower**	**Upper**
MWL	0.407	0.435	0.877	1	0.349	1.503	0.641	3.526
Source of event	0.340	0.417	0.664	1	0.415	1.405	0.620	3.181
Constant	0.644	0.478	1.815	1	0.178	1.904	0.746	4.857

4. Conclusions

Results prove that higher MWL increases drivers' RT, deteriorating driving performance in the majority of the participants, confirming the literature (Blana, 2001; Makishita and Matsunaga, 2008; Brookhuis and De Waard, 2010). Furthermore, the number of participants showing lower RT in the presence of high MWL, could be attributed to the fact that they may be employing adaptive control behaviors to counterbalance the increased MWL. The source of the unexpected event, seems to play also a significant role in driver's reaction, but contrary to the findings of Briggs *et al.* (2018) pertaining that dual tasking drivers present more difficulties in detecting items that are driving incongruent, current research's findings demonstrate that most drivers show higher RT in events that derive from the two vehicles leaving their parking slots, entering suddenly the road. This may be ascribed to the fact that drivers do not perceive the parking vehicles as possible hazard, since they are frequently encountered in the driving environment, and thus drivers are accustomed to them. On the contrary, at the two unexpected events caused by the donkey crossing the road and the child following her ball on the road, drivers are probably more alerted, once becoming aware of the donkey or the ball/child besides the road, demonstrating lower RT.

Regarding the way drivers react to the unexpected events, results reveal a significant dominance of the brake use, alone or along with the execution of a maneuver. With the latter being significantly affected by the presence of high MWL, since drivers tend to "forget" to maneuver in conditions of high MWL. The process of automation of the driving task during which the driver devotes the minimum effort on driving, driving almost unconsciously, may shed light to the driver's choice of braking on a critical situation, failing to opt for a steering maneuver, even when this choice would be more efficient.

Limitations of the present study derive mainly from the research environment of the driving simulator in which the study took place, which affect both the driving conditions and the reaction of the drivers. The researcher should always interpret the results, considering these limitations and preceding studies proving the validity of simulator results on relevant conditions.

Bearing in mind the driver's significant role in road safety, the need for further investigation of the human element for the improvement of road safety is emphasized. Overall, MWL proved to play an important role on driver performance, and thus further research on its consequences on driving performance, and the factors that influence its variance during driving, is imperative. Additionally, during the study of critical situations created by unexpected events, the source creating the unexpected event should be taken into consideration as it constitutes an important influencing factor of driver's RT. Finally, drivers' opt for braking or steering maneuver should be further investigated, aiming to a better understanding of this mechanism, to increase effective performance of steering maneuver when feasible. Ultimate goal of relevant research is the enhancement of road safety.

The present study is part of the ongoing doctoral research on driver behavior. Next steps include further research on more type of roads (rural and urban/suburban) and on different visibility conditions (good weather/fog), examining the influence of under study parameters on driving behavior (RT, way of reaction, accident occurrence). Moreover, drivers' physiological parameters are being recorded (HR, skin conductance, skin temperature) to further investigate the role of MWL on driver behavior. Along with the aforementioned data analysis, the online questionnaire data is being evaluated to further elaborate on research's results. The combined analysis of objective and subjective data is anticipated to provide valuable insights on driving behavior.

Acknowledgments

Acknowledgments given to the Hellenic Institute of Transport which is part of the Centre for Research and Technology Hellas for allowing the implementation of the current experiment in the Driving Simulator of the Hellenic Institute of Transport.

References

1. Adams, L. (1994) 'Review of the literature on obstacle avoidance maneuvers: Braking versus steering', (August), p. 22. Available at: http://dev.todaystrucking.com/images/BrakeVsSteeringUMTRI86649.0001.001.pdf.
2. Blana, E. (2001) *The Behavioural Validation of Driving Simulators as Research Tools: A Case Study Based on the Leeds Driving Simulator*, *University of Leeds*. Doctoral Thesis. University of Leeds.
3. Borsos, A., Birth, S. and Vollpracht, H.-J. (2015) The role of human factors in road design. In: *6th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, 363–367.
4. Briggs, G.F., Hole, G.J. and Turner, J.A.J. (2018) The impact of attentional set and situation awareness on dual tasking driving performance. *Transportation Research Part F: Traffic Psychology and Behaviour*, 57, 36–47. Available at: https://doi.org/10.1016/j.trf.2017.08.007.
5. Brookhuis, K. and De Waard, D. (2010) Monitoring drivers' mental workload in driving simulators using physiological measures. *Accident; analysis and prevention*, 42(3), 898–903. Available at: https://doi.org/10.1016/j.aap.2009.06.001.
6. Domenichini, L., Branzi, V. and Meocci, M. (2018) Virtual testing of speed reduction schemes on urban collector roads. *Accident Analysis and Prevention*, 110(November 2017), 38–51. Available at: https://doi.org/10.1016/j.aap.2017.09.020.
7. Dozza, M. (2013) What factors influence drivers' response time for evasive maneuvers in real traffic? *Accident Analysis and Prevention*, 58, 299–308. Available at: https://doi.org/10.1016/j.aap.2012.06.003.
8. Edquist, J., Rudin-Brown, C.M. and Lenné, M.G. (2012) The effects of on-street parking and road environment visual complexity on travel speed and reaction time. *Accident Analysis and Prevention*, 45, 759–765. Available at: https://doi.org/10.1016/j.aap.2011.10.001.
9. Fuller, R. (2005) Towards a general theory of driver behaviour. *Accident Analysis and Prevention*, 37(3), 461–472. Available at: https://doi.org/10.1016/j.aap.2004.11.003.
10. Gkemou, M. (2013) *Modeling of driving behaviour in driving simulator and correlation with real traffic conditions*. Aristotle University of Thessaloniki.
11. Healey, J. and Picard, R. (2005) Detecting Stress During Real-World Driving Tasks Using Physiological Sensors. *IEEE Transactions on Intelligent Transportation Systems*, 6(2), 156–166.

12. Heine, T., Lenis, G., Reichensperger, P., Beran, T., Doessel, O., Deml, B. (2017) Electrocardiographic features for the measurement of drivers' mental workload. *Applied Ergonomics*, 61, 31–43. Available at: https://doi.org/10.1016/j.apergo.2016.12.015.
13. ISO 10075 (2000) Ergonomic Principles Related to Mental Work-Load. Brussels: CEN.
14. Kontaxi, A., Ziakopoulos, A. and Yannis, G. (2022) *Discovering the influence of feedback on driver behavior through a multiphase experiment based on a smartphone application*. Available at: www.oseven.io.
15. Macadam, C.C. (2003) Understanding and Modeling the Human Driver. *Vehicle System Dynamics*, 40(1–3), 101–134. Available at: https://doi.org/10.1076/vesd.40.1.101.15875.
16. Makishita, H. and Matsunaga, K. (2008) Differences of drivers' reaction times according to age and mental workload. *Accident Analysis and Prevention*, 40(2), 567–575. Available at: https://doi.org/10.1016/j.aap.2007.08.012.
17. Marinescu, A., Sharples, S., Ritchie, A.C., Sánchez López, T., McDowell, M., Morvan, H. (2016) Exploring the Relationship between Mental Workload, Variation in Performance and Physiological Parameters, *IFAC-PapersOnLine*, 49(19), 591–596. Available at: https://doi.org/10.1016/j.ifacol.2016.10.618.
18. Marinescu, A., Sharples, S., Ritchie, A. C., Sánchez López, T., McDowell, M., Morvan, H. P. (2018) Physiological Parameter Response to Variation of Mental Workload. *Human Factors*, 60(1), 31–56. Available at: https://doi.org/10.1177/0018720817733101.
19. Mehler, B., Reimer, B., Coughlin, J. F., Dusek, J. A. (2009) Impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Transportation Research Record*, (2138), 6–12. Available at: https://doi.org/10.3141/2138-02.
20. Mehler, B., Reimer, B. and Dusek, J.A. (2011) *MIT AgeLab Delayed Digit Recall Task (n-back)*. Massachusetts.
21. Michon, J. (1985) A critical view of driver behavior models: what do we know, what should we do? *Human behavior and traffic safety*, 485–520. Available at: https://doi.org/10.1007/978-1-4613-2173-6.
22. Migliorini, Y., Imbert, J.-P., Roy, R. N., Lafont, A., Dehais, F. (2022) Degraded States of Engagement in Air Traffic Control, *Safety*, 8(1). Available at: https://doi.org/10.3390/safety8010019.
23. Miller, G.A. (1956) The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63(2), 81–97.
24. Misokefalou, E. (2014) *Investigation into and modeling of factors influencing drivers' attention and impacts on road safety*. University of Thessaly.
25. Papantoniou, P. (2015) *Risk factors, driver behaviour and accident probability. The case of distracted driving.*
26. Papantoniou, P., Antoniou, C., Yannis, G., Pavlou, D. (2019) Which factors affect accident probability at unexpected incidents? A structural equation model approach. *Journal of Transportation Safety and Security*, 11(5), 544–561. Available at: https://doi.org/10.1080/19439962.2018.1447523.
27. Pasetto, M. and Barbati, S.D. (2011) How the interpretation of drivers' behavior in virtual environment can become a road design tool: A case study. *Advances in Human-Computer Interaction*, 2011, 1–11. Available at: https://doi.org/10.1155/2011/673585.
28. Pouliou, A., Kehagia, F., Bekiaris, E., Pitsiava-Latinopoulou, M., Poulios, G. (2022) Mental Workload Influence of Drivers Reaction Time on Unexpected Events: A Driving Simulation Study, in *Road Safety and Simulation Conference*. Athens.
29. Powelleit, M. and Vollrath, M. (2019) Situational influences on response time and maneuver choice: Development of time-critical scenarios. *Accident Analysis and Prevention*, 122(October 2018), 48–62. Available at: https://doi.org/10.1016/j.aap.2018.09.021.
30. Reimer, B. and Mehler, B. (2011) The impact of cognitive workload on physiological arousal in young adult drivers: a field study and simulation validation. *Ergonomics*, 54(10), 932–942. Available at: https://doi.org/10.1080/00140139.2011.604431.
31. Rubio, S. Díaz, E., Martín, J., Puente, J. M. (2004) Evaluation of Subjective Mental Workload: A Comparison of SWAT, NASA-TLX, and Workload Profile Methods. *Applied Psychology*, 53(1), 61–86. Available at: https://doi.org/10.1111/j.1464-0597.2004.00161.x.
32. Ruscio, D., Ciceri, M.R. and Biassoni, F. (2015) How does a collision warning system shape driver's brake response time? The influence of expectancy and automation complacency on real-life emergency braking. *Accident Analysis and Prevention*, 77, 72–81.
33. Schaap, N., van Arem, B. and van den Horst, R. (2008) Drivers' behavioural reactions to unexpected events. *October* [Preprint].

34. Schneegass, S., Pfleging, B., Broy, N., Heinrich, F., Schmidt, A._(2013) A data set of real world driving to assess driver workload. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '13*, 150–157. Available at: https://doi.org/10.1145/2516540.2516561.
35. Shinar, D. (2007) *Traffic safety and human behavior*. Edited by Elsevier. Oxford: Emerald Group Publishing Ltd. Available at: https://www.dawsonera.com:443/abstract/9780080555874.
36. Taylor, D.H. (1964) Drivers' galvanic skin response and the risk of accident. *Ergonomics*, 7(4), 439–451. Available at: https://doi.org/10.1080/00140136408930761.
37. Vardaki, S., Yannis, G. and Papageorgiou, S.G. (2014) Assessing selected cognitive impairments using a driving simulator: A focused review. *Advances in Transportation Studies*, 34, 105–128.
38. De Waard, D. (1996) *The Measurement of Drivers ' Mental Workload*, *Groningen University*. Doctoral thesis. Groningen University. Available at: https://doi.org/10.1016/j.apergo.2003.11.009.
39. Wiberg, H., Nilsson, E., Lindén, P., Svanberg, B., Poom, L. (2015) Physiological responses related to moderate mental load during car driving in field conditions. *Biological Psychology*, 108, pp. 115–125. Available at: https://doi.org/10.1016/j.biopsycho.2015.03.017.
40. Wilde, G.J.S. (1982) The Theory of Risk Homeostasis: Implications for Safety and Health. *Risk Analysis*, 2, 209–225.
41. Young, M.S., Brookhuis, K., Wickens, C., Hancock, P. (2015) State of science: mental workload in ergonomics. *Ergonomics*. Taylor & Francis, 1–17. Available at: https://doi.org/10.1080/00140139.2014.956151.
42. Žuraulis, V., Nagurnas, S., Pečeliūnas, R., Pumputis, V., Skačkauskas, P. (2018) The analysis of drivers' reaction time using cell phone In the case of vehicle stabilization task. *International Journal of Occupational Medicine and Environmental Health*, 31(5), 633–648. Available at: https://doi.org/10.13075/ijomeh.1896.01264.