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Review Article

Developing a Checklist for Cognitive Characteristics of Driving Scenarios in Dual-Task Studies: The Case of Cell Phone Use While Driving

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Abstract

Context: Recently, driving simulators have been widely used in various studies in the traffic safety domain, especially to investigate the effects of a mobile phone conversation on driving performance. As the characteristics of simulators and scenarios designed in previous studies were quite diverse, the cognitive workload resulting from scenarios in each study and their effects on the results varied significantly so that it made it difficult to compare the results. Therefore, the present study was conducted aiming at providing a checklist of cognitive specification control in this category of studies by investigating the methodological characteristics of previous studies.
Evidence Acquisition: The articles were searched in Springer, Elsevier, PubMed, and Google Scholar databases during 2002 - 2017. The author used mobile phone, cell phone, driving simulator, distraction, and mental workload keywords with the "and" and "or" operators. Based on certain criteria, 14 articles were selected among the retrieved articles.
Results: Methods and purposes of articles were evaluated in terms of factors affecting cognitive function. Based on reliable and valid scientific documents, a checklist of the cognitive profile of scenarios and simulators was designed and presented in three macro domains.
Conclusions: Considering various simulator designs the scenario design characteristics effective in cognitive workload, the studies were not convergent so that different aspects of the main variables were reported in various studies. Inattention to reporting these variables led to the incorrect estimation of the effects of a mobile phone conversation on driving performance.

Keywords: Cognitive, Workload, Driving, Cell Phone, Checklist

1. Context

In recent years, the high rate of road traffic accidents in most countries has led to a large body of research worldwide on the effects of mobile phone conversations on drivers' performance (1-3). Based on epidemiological studies, using mobile phones while driving is on the rise (4-7), which can cause an increased risk of traffic accidents. The effects of mobile phone conversations on driver performance were investigated by many scholars in driving simulators (8-10). A review of recent studies suggested that the used simulators and scenarios were designed based on the purpose of the given study. When the purpose is to study the road, the variables such as road geometry and road signs, surface properties and structural elements of the road, the visual texture, color, and the speed of the vehicle become significant in choosing the scenario and the simulator. When the behavior of the subjects is the purpose of the study, the variables of age, fatigue, mental and emotional states, personality aspects, and mental and physical disabilities are highlighted. That is why researchers in driver behavior studies under dual-task conditions reported insufficient information on the characteristics and parameters of scenario designs and simulators (9, 11, 12). A remarkable point in driver behavior stud-

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ies in the simulator environment is the attention to characteristics of the scenario design and the simulator environment because these characteristics can impose a different cognitive workload on the subject (driver). Dziuda et al. showed that changing the characteristics of the used simulator design in the study changed the characteristics of the subject's behavior. This change in behavior may be due to the difference in the design of a simulated driving environment resulting in a different cognitive workload imposition on the subject (driver); therefore, his behavior changed. In other words, in studies using a driving simulator, paying attention to the characteristics of the scenario design and the virtual driving environment were considered very important (8).

Since the lack of attention due to talking on a cell phone is known to be cognitive and changes to the cognitive capacity of a person while driving leads to traffic accidents, it seems essential to investigate influential variables of cognitive performance while designing studies in this field. Several factors were reported to be effective in designing simulator scenarios which may challenge cognitive processes, including more visual components in the scenario, driving environment (various types of roads, road topography, etc.), weather, so on. Also, characteristics of the experiment environment such as light, temperature, and sound could ban cognitive functioning and negatively affect the results of the study. The lack of a clear approach to design cognitive characteristics makes it impossible to compare and generalize the results of studies in the field.

Therefore, considering the role of scenario designs and simulator variables in driving cognitive workload, the present study was conducted aiming at providing a checklist of cognitive specification control in this category of studies by investigating the characteristics of equipment and scenarios used in previous studies. To achieve this purpose, the following steps were taken:

A) A review of previous studies based on keywords and screening them based on eligibility criteria.

B) A review of methodologies used with a focus on the cognitive characteristics of scenarios used in the studies.

C) Preparation of a checklist for the determination of cognitive characteristics of driving scenarios.

2. Evidence Acquisition

2.1. Search Strategy

To collect studies on the use of mobile phones while driving in the driving simulator environment, the author used engineering, medical, and transportation databases. The author searched in Springer, Elsevier, Web of Science, PubMed, and Google Scholar databases from 2002 to 2017 looking for terms and keywords of mobile phone, cell phone, driving simulator in combination with "distraction", and "mental workload". Moreover, Medical Subject Headings (MeSH) including headings "cognition driving", "perception" in combination with "information", visual, attention, processing, and "mental workload" were searched in combination with "driving" and "conversation".

Two authors (Mojtaba Zokaei and Mostafa Pouyakian) investigated all abstracts, titles, and keywords related to the articles. In the case they were not able to decide on the selection or rejection of abstracts, they evaluated the full text of articles. If they had opposing views, they asked for the opinion of other research team members.

2.2. Eligibility Criteria

Many studies investigated the effects of conversation and mobile phone use while driving and since it is one of the traffic safety problems in countries worldwide, it is studied as a research axis. Considering the research purpose, those studies were evaluated that investigated one of the modes of conversation on a mobile phone (holding in hands/hands-free or both) while driving with the simulator. The driver's performance during driving in the simulator (reaction time, speed variation, straight-line deviation, etc.) or the degree of the cognitive workload of the driver was measured in studies as the effect of conversation on a mobile phone. In this category of studies, the lack of use of a driving simulator or talking with a passenger were factors for exclusion from the investigation process. Therefore, those papers were selected that included the following three components simultaneously in the study: (1) conversation on a mobile phone; (2) using a driving simulator; and (3) assessing driving behavior and cognitive workload. Therefore, using this approach, the methodologies of the selected studies were evaluated. In the methodology section, the author collected the cognitive characteristics of driving simulator design and reported the scenario in supplementary file Appendix 1.

3. Results

In this study, the methodologies of 19 selected studies were carefully reviewed. The main objective was to examine the reported specifications of simulators and the scenarios used in the studies and the effects of the specifications on cognitive workload. Among the selected studies, five studies were published in the Transportation Research Part F Journal; six studies were published in the Journal of Accident Analysis and Prevention, and one in each of the following: Journal of Safety Research, Procedia- Social and Behavioral Sciences, and Traffic Injury Prevention. After investigating the driving simulator used in the selected studies, six variables, which were mentioned in most cases and showed cognitive effects on the subject, were selected. Of course, the quantity and quality of these variables were reported by researchers in none of the studies. Simulator specifications and scenarios such as vehicle speed were mentioned in 10 studies, the type of road in 11 studies, the number of lanes in nine studies, traffic load in four studies, path lengths in nine studies, and weather conditions in three studies.

The results of this study showed that many features of virtual environment design that could affect the cognitive capacity of the subject (driver) were not addressed by the researchers. There was also no integration and convergence in scenario design variables. Of course, some other scenario design features and laboratory environments that were effective in cognitive workload were referred to by case. Variables such as the subject's viewing angles and screen size, the frequency and resolution of the image provided, the complexity of the road used, the traffic events, the monitors used, the number of stimuli in the visual field, the subject's distance from the monitor, the fixed or movable simulator, the number of intersections, bends, traffic signs, computer specifications used, road effects (ups and downs), number and style of cars parked along the road, road lighting, audio systems for emitting the engine sound, road environments (without mentioning the sound pressure level), the existence of a motorcycle, and screen dimensions were also mentioned by case in the studies. The presence or absence of any of the features could be effective in cognitive workload and study results. All information on scenario design and its environment in the articles is summarized in supplementary file Appendix 2 and will be discussed further. As seen in supplementary file Appendix 2, it is noteworthy that there was no common variable reported in all the studies. Among the variables mentioned above, only the study by Dula et al. (13) referred to the specifications of the computer simulator system. The technical specifications of the computer used, in terms of the graphics required to run scenarios, and the display of non-slip scenarios were known as effective parameters on visual observation and the cognitive workload, which are significant in this category of studies.

4. Discussion

The present study was conducted aiming at providing a scenario quality control checklist and driving simulator components in terms of the characteristics of cognitive workload, especially through investigating research conducted on the effect of using a mobile phone on driving performance. It seems that the important issue in designing the methodology of such studies is the lack of attention to the participants' processing capacity and the designing characteristics of the virtual environment design in the simulator. Thus, since the brain is limited in the amount of information that can be considered at a time, the design of the road environment in the scenario is of great importance (14, 15). Therefore, with the assumption that the brain cannot process all input information, increasing the visual component in the scenario may lead to an increase in unwanted cognitive load. Various cognitive characteristics in the scenario lead to a different cognitive workload on the participant. When the cognitive components of the scenario increase, the cognitive workload of the conversation is overestimated, and with the simplicity of the scenario, the cognitive workload is underestimated (16, 17). Also, the existing variables in the simulator and the scenario can impose different cognitive workloads on the driver and consequently affect the driver's performance. Therefore, paying attention to the mechanism and the capacity for information processing in the brain and components existing in designing the methodology of such studies can be useful in increasing the accuracy of the results of such studies. In the following, seven important variables in the simulator design and scenario that can create cognitive workload are discussed.

4.1. Driving Simulator

In recent years, the use of driving simulators has shown an increase in the traffic research field (18). Driving simulators provide a safe, inexpensive, controllable, inter-personal repeatable environment for data collection and research on driver behavior (19). Driving simulators fall into three categories in terms of sophistication and advancement. In the first group, simulators are used for commercial and entertainment purposes. These simulators include a desk and a computer that is used for video games and have controlling equipment such as pedals and a steer. Mid-level simulators include a vehicle mock-up in front of which is a monitor with one or more projectors. High-level simulators usually provide a viewing angle of 180 - 360 degrees along with side mirrors and can move in several degrees of freedom (7). Driving simulators are very diverse in appearance and create new experiences for the driver, so the driver can expect to experience a variety of cognitive workloads. Design characteristics and parameters in the driver simulation environment can affect various levels of driver understanding and cognition. Therefore, it is a useful tool for assessing driver capability and testing cognitive processes, as well as standardization measures (7). The study of variables and reported specifications of simulators and scenarios used in previous studies indicated that there was no convergence among studies in these specifications. In Rasmussen's theory of human control and behavior models (behavior based on skill, knowledge, and rule) in driving tasks, Rasmussen suggested that behavior moves from knowledge or rule towards skill, which results in a reduction in cognitive needs for the performance of the task. Therefore, a large part of the attention or sources of attention could be devoted to other tasks. The driver's available level of attention at any given time is partly dependent on the driver's prioritization among various tasks, which is inherently related to distraction aspects (20). Accordingly, it is expected that the existence of multiple elements in the simulator and the scenario in terms of the subject's vision may require more processing capacity. Considering several studies mentioned in the previous section, we observed that researchers measured the quality or quantity of some variables, such as the number of road lanes, weather conditions, scenario number, and vehicle speed during the test, cognitive workload, path length, and the type of road in their studies. However, researchers not only lacked a unanimous trend in their reports on selecting and mentioning these variables, but also neglected many noteworthy variables. In recent years, extensive studies were conducted to investigate the effect of using a mobile phone on the driving performance in a simulator. These studies often addressed behavioral or physiological changes resulting from simultaneous implementation of two tasks. However, the results of these studies showed ambiguity about the role and effect of the type of the simulated environment on the subject's (driver's) mental workload. Thus, the allocation of processing capacity in the base state to such virtual environments should be considered since using different simulation environments in their designs and visual characteristics may lead to the induction of either more or less mental workload. Otherwise, the results of studies of the effect of mobile phones on the performance of drivers could be biased and it might be difficult for the researcher to judge the extent of changes in the driving performance due to conversation. Therefore, it is likely that due to the lack of specific standards in the design of the virtual environment and the disagreement in different studies, the effect of a mobile phone conversation on traffic safety was not properly estimated.

4.2. Visual Attention and Processing in Driving

It seems that although the human brain has a high level of parallel processing, there are still limitations in the processing of information. The overlapping of some information in the brain is known as the model of the psychological refractory period. This pattern refers to the existence of two simultaneous stimuli. When a person faces two stimuli, the processing of one of the stimuli is affected by another stimulus processing, which creates a delay in the processing of the second stimulus (21). Based on this model, the visual attention in driving is crucial (22). Identifying and understanding the movements and activities during driving are of basic characteristics of visual perception and attention that is of great importance in interacting and communicating with the environment and people. Attention plays a role in various stages of processing activities (23). An increase in the visual components associated with driving leads to a limitation and reduction of the available processing resources for the purpose of proper processing and implementation of the main tasks. Still, the biological nature related to the limitations of the processing resources is not known and there may be difficulties in controlling the application of driving skills in dangerous situations while speaking on a phone (24). One of the significant issues in driving simulators is the visual stimuli displayed by the simulator during the tests. The number and type of visual stimuli determine the degree of cognitive workload, and hence the changes in driver's performance (8, 21). The perception-decision-making mechanism of the driver to optimally react at the right time is influenced by the driver's perception of the characteristics and specifications of the road, as well as obtaining the essential information from the external environment. Patten et al. showed that the choice of visual strategy was based on the complexity and road traffic environment (20, 25). As human cognitive resources are limited, the allocation of mental resources (attention) depends on different levels of the cognitive workload of the driver. An increase in the complexity of the driving simulator scenarios leads to a reduction in driver's available processing capacity. The human cognitive system has a limited capacity and continuously supports a small amount of visual information. Stelzel et al. asserted that visual attention occurred instantaneously in a fraction of time and the identification of visual images happens in terms of size, color, and direction in a fraction of a second. When information leads to a multi-purpose understanding, the response becomes increasingly selective, and when the driving environment has multiple goals, the cognitive resources available become limited for the visual information processing stages. Hence, the purposes compete for selecting and accessing the processing resources (21). Therefore, the processing resources have to attend to multiple purposes for achieving continuous cognition. The study of the perceived workload and visuocortical process shows that the increase of target points in a simulated environment (e.g., driving in crowded environments such as traffics, intersections, children, etc.) increases the visual workload, too (20).

Over 90% of the information is visually received by the brain and the internal processing mechanism of visual information is based on semantic or symbolic inference (26), i.e. the brain, thinks, reasons and infers in interaction with visual stimuli and the image in an abstract approach, and processes all visual information as visual-conceptual objects or direct images in the long-term memory (25). Thus, in driving simulators, the visual stimuli presented in the context of driving scenarios are known as significant in visual processing and cognitive workload. There are limited processing resources to simultaneously process the information received through auditory, visual, and tactile sensations (14). Based on previous studies, the type of task determines using multiple resources or one common pool of resources (14). According to Arrighi et al., when a person has to do multi-objective tasks (MOT) and simultaneously has separate visual and auditory stimuli, the multiple sources of attention are used distinctly and the individual needs supportive attention (27). Hochberg believes that "vision is not everywhere dense" and attention lies behind this phenomenon. Therefore, considering the limitation in the attention sources, the more is the attention, the better will be the vision. In some tasks that require target search, selective attention is used in processing visual field information, leading to slower information processing. Pre-attentive tasks do not require attention resources, and information processing is done in parallel and at a high speed (28). Using efficient encoding strategies in the peripheral vision is another constraint that the visual system faces. Thus, the visual system cannot simultaneously perform multi-visual tasks due to brain limitations (11, 28). Gerhard et al. and Minin et al. believe that an increase in task visual requirements increases cognitive workload. Accordingly, everything that increases the need for visual perception increases mental workload (6, 29).

The results of a study conducted by Kunstler et al. suggested a reduction in processing capacity in dual-task activities. Also, this study supported the hypothesis that the implementation of a relatively simple task could affect central attention and make it difficult to obtain visual information (30). Multiple resource theory and prediction of its performance pertain to the concepts of attention and cognitive workload. The multiple sources theory in processing human information should be sought in the "single-channel bottlenecks" concept, indicating limitations in the simultaneous performance of two tasks. Considering the limited processing resources available, it can be inferred that performing tasks faces difficulty known as workload. Visual processing has two central and environmental aspects. Focal vision is solely used for processing details and pattern recognition (e.g., reading the text, identifying small objects). On the contrary, the peripheral vision includes environmental vision used to measure one's orientation and movement (the direction and speed that move through the environment) (31). Therefore, considering that driving conditions use both these processes, if the processing uses common resources, it can impose more cognitive workload on the individual. Thus, various visual stimuli in the driving simulator are capable of increasing the cognitive workload, which requires researchers to especially consider the visual components in designed scenarios.

4.3. Road Characteristics

In this category of studies, the driving environment refers to the driving scenario designed for driving in the virtual environment. The type of roads used in virtual environments includes rural and urban roads (urban and suburban).

4.3.1. Road Environment

According to the central bottleneck model, when the number of stimuli to the brain increases, the processing of some stimuli in the brain does not take place inevitably. Based on this model, the landscape around the road, such as natural landscapes, can account for part of the processing capacity in suburban and rural roads or the homes and shops along urban roads.

The road environment is considered an important factor in both rural and urban roads. Investigations in the literature show that driving on repeated roads or routes leads to learning, where less cognitive requirements are needed for performing driving tasks and the driver often overlooks the repetitive scenes; however, in simulator studies, the paths, i.e. visual components of the defined scenarios, are of visual appeal for participants (32, 33), leading to paying attention and allocating processing capacity to the existing components around the road; as a result, the increased use of processing capacity takes place while driving (in single-task conditions). The increase of the driver's cognitive workload in single-task conditions is crucial since conversations with a low level of processing can deteriorate the driver's performance if the cognitive workload increases in such cases. Therefore, if the workload of the scenario is reduced, a mobile phone conversation with a low level of processing may not have a damaging effect on the performance of the driver. Thus, it can be said that by creating the cognitive workload obtained from the road, such as the number of stimuli, the existing components in the scenario, and the surrounding landscapes, the amount of incurred cognitive workload can change and affect the results of the study.

4.3.2. Road Width

Road width is one of the main characteristics of a road. The road width or the number of lanes available to the driver can affect the selective speed. Since, in most studies, the researchers select limit speeds of 60 - 80 km/h, the difference in the width of the selected road speed can change the ability of the subject to process information. Therefore, in studies aimed at determining the effect of conversation on mobile phones on driver performance, the failure to pay attention to this cognitive workload can lead to results with an estimation that is either more or less than the reality regarding mobile phone intervention in driver performance.

4.3.3. Traffic Signs

Considering the amount of information available on traffic signs and billboards along roads, they are among the variables that can impose a cognitive workload on the driver. Increasing the information on traffic signs can lead to an increase in the time required for information processing (34). Toornros et al. (2006) and Briggs et al. (35) used billboards and signs in their studied scenarios. The point that should be taken into consideration is the amount of information the billboards and the amount of attention that these boards take. In these studies, the difference in the drivers' rates of attention to these signs was not considered.

4.4. Weather Conditions

Weather conditions are other environmental variables that affect cognitive workload while driving (36). Rainy conditions and less light may require more attention by drivers and take more cognitive capacity to process information. Therefore, it is recommended that researchers pay more attention to this environmental component in future studies in this field because it may influence the results of studies.

4.5. Complexity of the Road

Specifications and complexities of roads are of great importance in laboratory studies of the effects of using mobile phones while driving. Based on the results of studies conducted using driving simulators, driver performance varies when performing dual tasks on difficult (twisty) roads and simple (straight) roads (37). Driving is a task that does not require high cognitive capacity in normal conditions and is done automatically. However, twisty roads require further cognitive needs and the driver needs more time for information processing (38-40). These facts indicate that a dual-task activity during driving may result in the involvement of part of the cognitive ability of the driver, which is followed by changes in driver performance, whether on simple or on difficult roads. Therefore, very difficult roads or roads that have many bends and the simultaneous accomplishment of dual tasks require more attention to the road and stimuli in the viewing angle.

One of the variables considered in the scenarios designed in such studies is the traffic load. When the quantity of information available in the environment is considerably high to process, the visual field is reduced (41). Increased traffic load allows the driver to spend more time to receive information and observe the road conditions; in such conditions, more processing resources are needed (42, 43). It is expected that when the traffic load increases, information processing required for attention increases as well (17). Out of 14 studies, only four reported the specification of the traffic load in their used simulators. Also, another variable that required more time on the road was the bends on the tested route. On the other hand, moving in a straight lane could not challenge the perception of task simultaneity (44).

The presence of a junction on the driveway can take some part of the driver's processing capacity. Hakamies-Blomqvist et al. believe that the existence of junctions leads to a momentous increase in cognitive workload and an increase in the junction complexity could increase the cognitive workload (33, 45). The driver's selective attention and visual strategy are partly affected by the junction because the presence of pedestrians is probable in junctions and the number of junctions and the awareness/lack of awareness of the subject of the presence or absence of a stimulus or pedestrian at the junction can affect the subject's visual attention (38).

4.6. Speed

Regarding the effect of speed on visual comprehension, contradictory results were obtained. According to some researchers, the visual perception of field decreases with acceleration while others reject this claim based on evidence-based results (46). Among the studies investigated, 10 studies mentioned the vehicle speed during the test and 11 studies described the urban or rural road type. The reported speed was often approximately 60 - 80 km/h, which has some degrees of convergence. In addition to increasing the risk of accidents, the speeds over 80 km reduce the driver's performance in the dual-task mode and the increase in speed leads to the tunnel vision phenomenon, which reduces the visual field (47). Doori et al. (2014) held that visual information should be controlled by the driver due to the fact that driving speed increases the rate of visual information for processing (48); therefore, it is expected that future studies obtain more reliable results concerning different levels of cognitive workload in dual-task conditions at various speeds.

4.7. Environment Condition and Cognitive Workload

4.7.1. Temperature

The work environment or lab temperature characteristics can affect cognitive function. Past studies indicated that heat (49-52) and cold (5, 16, 53, 54) could lead to the destruction of cognitive processes in humans (55). The meta-analysis results of the heat cognitive effects also indicated a decline in the individuals' performance in high-temperature conditions (56). In the opinion of Hancock et al., thermal stress leaves a negative effect on psychomotor capacities and information processing of individuals (57). Therefore, performing a task under conditions of lacking thermal comfort could increase the error rate and reduce work efficiency. The response to the environment temperature was reported to vary with tasks (13, 58) and exposure to heat over duty requirements could lead to the degradation of cognitive function (57, 58). Also, complex tasks were more affected by these factors than simple tasks (13, 59). There will be almost no negative effects of the workplace or the lab temperature in the temperature range of 17°C - 23°C (58). Based on the Arousal theory, an increase and decrease in temperature in this range may lead to the degradation of cognitive function (57). Therefore, the temperature conditions of the study location are considered in this category of cognitive research. Thus, it is suggested that, while observing the comfortable temperature during the study implementation, environmental temperature specifications should first be kept constant during the study and for all participants, and second, this characteristic should be also mentioned in the study methodology.

4.7.2. Noise

Sound leaves a variety of effects on cognitive function. Based on some studies, sound can lead to arousal at low levels and improve cognitive function. Some studies indicated that sound cannot affect function in simple tasks though it can damage short-term memory (35). In complex activities, sound shows further efficiency loss; therefore, it significantly increases in cognitive workload dual tasks that can leave synergistic negative effects (60, 61). Sound affects the proper job function by reducing the available cognitive resources, and interferes with the choice of response to environmental stimuli (62, 63). The prefrontal cortex in the brain is responsible for cognitive function, which is damaged by the presence of sound and the resulting physiological responses (increased secretion levels of noradrenaline and dopamine in the hypothalamus). Among the studies investigated, Stavrinos et al. (54), Saifuzzaman et al. (16), and Leung et al. (62) mentioned the engine sound in the cabin in their studies. Since sound also follows the Arousal theory, the level of sound pressure in the car cabin or the lab environment could be important as it may increase or decrease the effect of cognitive function. Therefore, it is suggested that the researchers in this area consider the environmental sound characteristics, in addition to controlling the laboratory conditions.

4.8. Subject Characteristics

One of the components of this type of study is the specifications of subjects, including physical and mental health, age, and cognitive and processing capacity of subjects. In all the investigated studies, physical and mental health dimensions were evaluated using questionnaires; people with no qualifications were excluded from the study. The most significant screening factors in these studies were psychiatric disorders, drug misuse, neural disorders, head injury or loss of consciousness, right-handedness, and uncorrected visual impairment. The age range of the subjects in these studies was often 20 - 30 years. Indeed, in all the investigated studies, driving experience was also taken into consideration. However, some studies also selected an age range of approximately 20 to 60 years. The age of subjects is among the parameters that are significant in terms of the cognitive aspects and the viewing angle. Horberry et al. (2006) concluded that people over 60 would be more cautious to reduce the distraction effects on the driver. Cuenen et al. showed that with increasing age, the capacity of attention decreases and distraction during driving leads to a degradation of the driver's performance (5). Therefore, it can be said that as the age increases, the driver's viewing angle decreases and some of the elements on the road may be neglected (41). As an increase in age reduces the processing capacity and attention, and with the mean values of complexity and cognitive workload, performance degradation can be observed. Thus, choosing the age of subjects (drivers) in a certain category (age-specificity among the subjects in the study) leads to more accurate results. As a result, it is proposed to select the subjects' (drivers') age in such studies, in a specific age group (age proportion among participants) to yield more accurate results.

Investigating the method of conducting laboratory studies in the field of talking on a mobile phone while driving indicates that this type of research deals with several axes in its methodology. Participants' specifications, driving simulators and scenarios, and mobile phone interferences were the three main topics in the methodology. Considering the purpose of the present study, supplementary file Appendix 3 indicates the checklist of the main variables considered in designing studies on the effect of conversation on a mobile phone on driving performance.

This checklist consists of three major parts. It helps researchers in the field of transportation, cognitive ergonomics, and psychologists. It also contributes to the uniformity and convergence of studies, to compare the results of different studies and to determine the level of workload more precisely. This checklist is compiled through (1) Reviewing previous studies of the effect of mobile phone on driver performance and (2) Fundamentals and scientific theories (referenced in the results section). Sections 1 and 3 show the similarity of the driving simulator to real driving. The use of advanced equipment and simulators can make the results more realistic. Section 2 refers to the virtual environment of the designed scenario. The characteristics of the road environment include the number of road lines, the type of road, vehicles parked on the route, traffic signs, the length of the route, weather conditions, and so on. It is important to understand the level of cognitive workload that should be taken into consideration. Accordingly, this checklist can be considered an essential tool for continuing relative studies.

5. Conclusions

Driving simulators have been used to study the cognitive workload of using a mobile phone while driving. However, the effects of virtual driving environment design on overall cognitive workload are not addressed in designing such studies. In other words, there is no integration in the design of the virtual driving environment in these studies. This can lead to inaccurate estimates of the effect of mobile conversation on driving performance. Non-convergence is evident in the design specifications of the simulators used in this study. In this paper, the importance and necessity of considering the design of the virtual driving environment in simulators were discussed and a framework was proposed for virtual design requirements in simulators. This framework can be a guide for criticizing studies and designing new research.

Key points:

- Much information about scenarios in simulator studies investigating the effect of talking on a phone while driving was not reported.

- It seems that not paying attention to the design and cognitive aspects of scenarios results in the unrealistic estimation of workload imposed by a conversation on a phone while driving.

- A framework including important scenario design parameters affecting cognitive performance in driving simulator studies was proposed.

Supplementary Material

Supplementary material(s) is available here [To read supplementary materials, please refer to the journal website and open PDF/HTML].

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Footnotes

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