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Persistent effects of mobile phone conversation while driving after disconnect: Physiological evidence and driving performance

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ABSTRACT

Cognitive workload has been known as a key factor in traffic accidents, which can be highly increased by talking on the phone while driving. A wide range of studies around the world investigated the effects of mobile phone conversations on driving performance and traffic accidents. But less noticed is the durability of cognitive effects of mobile phone conversations. This study aimed to determine the effects of different types of mobile phone conversations on physiological response and driving performance during and after the conversation. Heart rate, heart rate variability (physiological response), Standard deviation of lane position (SDLP), and the relative distance between two cars (driving performance) of 34 samples (male and female) in the driving simulator were recorded. In this study, three types of conversations (neutral, cognitive, and arousal) were used. Neutral conversation did not pursue specific purpose questions. Cognitive conversations were simple mathematical problem-solving questions and arousal conversations aimed at arousing participant emotions. Each conversation was used as a secondary task in a condition. The study had three conditions; in each condition the participant drove for 15 min. Each condition consisted of 5 min of driving (Background), 5 min of driving and conversation (dual tasks) and 5 min of driving after conversation to trace the effects of the conversation. Vehicle speed was 110 km/h in each of the three conditions using car-following scenario. The results showed that neutral conversations had no significant effects on physiological response. Though, arousal conversations had significant effects on physiological responsiveness and driving performance during conversations, where it was even more significant after disconnection. Therefore, the content of the conversation determines the amount of cognitive load imposed on the driver. Considering the persistence of cognitive effects caused by conversation, the risk of traffic accidents is still high even after disconnection.

1. Introduction

The high rates of traffic accidents in many countries made it essential to do extensive research on traffic safety and the factors

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influencing them [1]. Gicquel et al. believe that two categories of factors are related to traffic accidents, First, traffic environmental factors and vehicles, second, human-related factors [2]. It seems human factors plays a major role in preventing traffic accident [2,3]. Cognitive abilities like attention, decision making, and problem-solving are among the human factors that play an important role in safe driving. Therefore, any internal and external factor that reduces the cognitive functioning of individuals may lead to traffic accidents. Secondary tasks while driving increase the risk of accidents based on the attention resources they occupy [4]. From a resource-based perspective, the attention resources required to respond to a given set of perceived and functional demands are defined as cognitive workload. Therefore, in tasks such as driving, the interaction between cognitive workload in dual-task conditions and human capabilities is of high importance.

Cognitive workload is a key factor affecting human performance and human error, especially in high-risk conditions [5]. Changing speed and direction, reaction time, and decision-making in hazardous conditions make driving a task with high cognitive demand. The increase in the cognitive workload of task demand, such as dual tasks (driving and a secondary task simultaneously) increases the risk of traffic accidents [6]. Therefore, the driver's acceptable performance depends to a significant degree on the total cognitive demand while driving [3,7].

Previous studies made use of various methods to measure the level of driver performance variation or cognitive workload applied to drivers [8–15]. In measuring workload, approaches are generally grouped into subjective (self-report or observer ratings), performance, or physiological methods [16–19].

Although several approaches have been used to measure cognitive workload, most methods can be classified into one of four main categories: (1) subjective method (2) performance-based, (3) physiological, and (4) analytic [20]. In this study, physiological methods were used due to its advantages such as sensitivity to variations over time, objective measurement and recording of physiological variation while driving [21]. Physiological parameters such as heart rate, heart rate variability (HRV), electroencephalography, and the electrical conductivity of the skin are among the objective methods of cognitive workload measurements that are sensitive to changes in mental workload. Thayer et al. and Hess and Thomas (2014) proposed HRV measurements as an indicator of mental processing changes [22,23]. Many studies showed that HRV decreases with increasing mental processing during task execution [24–27]. Hjortskov et al. suggested that mental activity may inhibit parasympathetic activity, and may lead to increased HR and decreased HRV [28]. Heine et al. perceived function criteria showed that as the complexity of the task increased, the SDNN index also decreased [29]. Numerous studies have shown that both positive and negative emotions affect the parasympathetic activity and increase heart rate [30–34]. Therefore, HRV and HR can be used as indicators for assessing cognitive workload and determining the effects of different types of conversations on the risk of traffic accidents [35–37].

Many studies show that different functions of the driver are impaired while using a mobile phone [38–40]. Increased reaction time [41], the relative distance between two vehicles, mismatch with leader vehicle speed changes [42], and reduced environmental information processing [43] are observed during mobile phone conversations while driving. Studies show a reduction in driving performance in conjunction with the increase in the complexity of the conversation. In different forms of mobile phone usage, performance is effected differently, for example, the deviation of lane position when texting is more than conversing [6,44,45]. Researchers have used various variables such as reaction time, speed variations, time headway, and lateral position to evaluate driver behavior under dual-task conditions (mobile phone conversation while driving). A review of the studies shows that time headway and SDLP are the most causes of traffic accidents in Iran. For this reason, in this study, we selected headway time and SDLP as behavioral performance factors. A review of the literature shows that the effects of dual-task conditions on driving performance and physiological responses during the overt engagement have been the primary focus of most researchers and less attention has been paid to their potential lasting effects.

The main factor in the cognitive workload of mobile phone use while driving is the processing of conversation information and content [35,46–49]. Consequently, increasing the complexity and difficulty of the conversation increases the mental workload [50]. Various studies have used a variety of "conversation" content. These have included mathematical questions [8,51–53], spatial visualization questions [54,55] and arousal content [35,50] as subjects in conversations; other work does not characterize the content of conversations conducted [9,56–58]. The added cognitive load of conversations can negatively affect driver's performance, which can appear in reduced speed, increased longitudinal spacing, increased reaction time, increased standard deviation of lane position (SDLP), etc. [41,59–63]. The content of mobile phone conversations while driving is very diverse and this has challenged researchers in stimulating conversations. Thus, these studies have focused on the physiological and behavioral effects of conversation, and fewer types of conversation have been compared.

The questions/hypotheses of the present study include:
Does the load remain after the call is disconnected?
Is the persistence of cognitive effects different in different conversations?
Is the persistence of effects different in physiological and behavioral responses?

The present study was conducted in a driving simulator, providing a safe environment for studying phone conversations. Participants engaged in conversations using a mobile phone while driving and the effects of the conversations on physiological arousal (heart rate and HRV) and driving performance were measured both during the call as well as following to explore any persistent effects of the conversations.

2. Methods

2.1. Participants

Thirty-six volunteers (17 men and 19 women) participated. Two of them left the study before the end of the experiment. 34 participants (18 men and 16 women) were present until the end of the study. In this study, ethics criteria in the research were considered and approved by the ethics committee of shahid Beheshti university of medical science (Ethical code: P/D/H/9296/11) and verbal informed consent was obtained from all participants. The mean age and driving experience of the participants are presented in Table 1. Participants were required to have a driver's license and at least 5 years of driving experience or 10,000 km of driving per year. Patients with a history of heart disease and untreated vision impairment were excluded from the study. Before starting the assessment, the study method was explained to the participants. They were compensated $12 for participating in the study.

2.2. Driving simulator and scenarios

The present study used a Pride vehicle simulator (Fig. 1). The simulator was designed and supported by the virtual reality lab of K. N. University of Technology. It was a class 2 simulator, with a car cabin with a driver's seat and an adjacent passenger seat, steering wheel, clutch, brake and gas pedals, and also a real dashboard. To display the scenario, three 19-inch monitors were used. The simulator structure was static and the distance between the driver and road screen was about 2 m (Fig. 2). The participant's horizontal view angle was 60°. The resolution provided by the simulator was 768 × 3072. The simulator was capable of producing starter and engine sounds, left and right signal indicators, flashers, and wiper blades. In this study, the sound of the engine, starter, and light switch was provided. This simulator was able to store car position and speed, and pedal interaction information in an Excel file.

The driving simulator used in this study included various components such as road type, speed, speed variation, cognitive components in the scenario, and type of road simulator. Road characteristics, road type, location of mirrors, number of cars, etc. are the cognitive components of the scenario.

In this study, freeways were considered with 3 lanes. The width of the road was 11 m and the width of the lane was 3.66 m. The number of curves was repeated twice a minute for each minute, the roadside environment and the dunes lacked vegetation. The environment around the road was sand dunes, and there was no other car on the road except for the leader car. The length of the road was considered indefinite; the mean speed considered in this study was 110 km/h. The duration of the condition in each scenario was considered to be 15 min. Considering the importance of maintaining continuous attention of samples during driving, the car-following scenario was selected as the main scenario in the study (Fig. 3). In this study, one scenario was used in all three conditions. The speed of the leader car fluctuated in order to prevent learning and to maintain the visual and auditory attention of the participant in the car following scenario. In this scenario, the participant follows the leader car and changes his/her speed as the leader car changes its speed.

The driving simulator was able to record position specifications data of leader and participant cars as well as pedals changes. This data was stored in an Excel file at a frequency of 30 Hz. After gathering the data in Matlab software, the following two variables were calculated: Standard deviation of lane position (SDLP) and time headway. SDLP is calculated by the standard deviation of the mean lateral position. Time headway was calculated by dividing the distance between the two cars by the speed of the participant car. SDLP and time headway is calculated individually.

2.3. Cognitive task

Mobile phone conversation and driving at the same time (dual task conditions) are inherently mental workload or cognitive demanding. This can be extended to all three types of conversation. The difference between their cognitive needs or mental workload is in the processing capacity used in different types of conversations.

Three types of mobile phone conversations were studied as secondary tasks: a neutral conversation, a puzzle or cognitive problem-solving task embedded in a conversation, and an arousal conversation. The structure and content were developed following [8,35,55], respectively. In the neutral conversation, questions were intended to be unambiguous and covered individual characteristics and interests with participants providing short answers to questions such as: what is your name? What is your favorite music? What is your favorite car? In the problem-solving or puzzle conversation (in this study defined as a cognitively loading conversation), participants

Table 1
Descriptive statistics of participants.

variables		mean	SD	Percentage
Age (years)	Men	29.7	5.38	–
	Women	27.3	4.2	–
Driving experience (years)	men	8.6	1.3	–
	women	6.2	.9	–
Annual Distance Driven (km/year)	<10000	–	–	32.35
	>10000	–	–	67.68
Mobile phone Use While Driving	do not use or at least once a week	–	–	23.53
	one to three times a week	–	–	64.87
	More than three times a week	–	–	11.77

Fig. 1. Pride simulator.

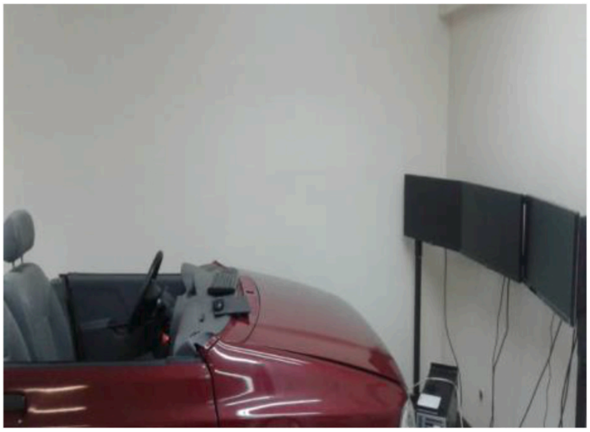

Fig. 2. Samples distance to monitors.

Fig. 3. Road scenario.

were required to perform one of four basic mathematical calculations. Questions in this type of conversation included: If Jane runs 6 miles in 54 min, how long does it take her to run one mile? How many hours will it take to run 21 miles at a rate of three miles per hour? The arousal conversation was designed to stimulate the emotions and tailored for each individual. Prior to the driving simulation, participants were interviewed on topics such as social, cultural, ethnic, religion, political, and women's rights and terrorism. From among these topical areas, participants' greater emotional investment and sensitivity were recorded to select the subject of conversation and opposing views were discussed to give rise to excitement during the conversation during the drive. Conversation methods in this category of studies include hand hold, hand free and passenger. This study the mobile phone conversation was hands-free and the researcher made contact with the participant.

2.4. Physiological measures

Heart rate is perhaps the most commonly used and reliable physiological index in mental workload studies [17,64–66]. In addition to considering mean heart rate, change in the degree of variability of the interval between successive heart beats (e.g. HRV) is also a sensitive indicator for evaluating operator workload. HRV metrics can be calculated in the time, frequency, and nonlinear domains (see the standardized descriptions in European Cardiovascular Association and American Electrophysiological Association guidelines [67]). A frequently the most commonly used HRV measurement method is the measurement of the standard deviation of heart rate intervals, hence considering the measurement time used in this study in each condition (5 min) and the variable SDNN representing the HRV overview, it seemed logical to measure HRV over a 5-min interval. The SDNN index was also used in this study. On the other hand, due to the arousal load of some conversations and the role of sympathetic and parasympathetic nerves in the arousal conversation of the LF/HF ratio, this index was calculated in frequency domain LF/HF ratio was calculated. The LF/HF ratio was obtained by dividing low-frequency power (LF power 0.04–0.15 Hz) by the high-frequency power (HF power, 0.15–1.00 Hz) values.

These measures were obtained from electrocardiographic (ECG) recordings using the eWave device (Parto Danesh). The signal was recorded at a rate 1000 Hz with a band pass filter of 1–40 Hz. In making the recordings, the skin of the chest was cleaned with alcohol for the placement of the chest leads (male participants were advised to shave the area before coming for the condition). Two electrodes were placed in the left and right chest regions, just below than the clavicle bone and the mastoid was used for the ground/reference placement. The fundamental signal extracted from the ECG for analysis was the interval between successive normal-to-normal QRS intervals in the ECG wave-form, specifically the interval between successive R-wave peaks (RR intervals). The more familiar metric, heart rate (HR), is calculated from the RR interval (HR in beats per minute = 60,000/IBI in milliseconds). These procedures were in line with the European Cardiovascular Association and American Electrophysiological Association guidelines cited previously.

The Kubios software package (v.7) (www.kubios.com) was used for data cleaning and calculating the heart rate variability (HRV) metrics. Kubios software has the ability to remove possible artifacts in a detected heart-beat interval series. The artifact correction option was set at the moderate level.

2.5. Procedure

One day before the condition, participants were informed about compliance requirements and conditions of the study. Training provided the study prior to the implementation of conditions (How to work with the simulator and the steps of the study). Participants were then asked to complete a demographic questionnaire. In order to adapt to the driving simulator, all participants drove the simulator for at least 5 min (Fig. 4). After adaption with simulator, ECG electrodes were prepared and installed (Fig. 4). The total duration of the experimental driving simulation lasted 45 min, consisting of three 15-min conditions, each condition consisted of three parts (5-min) but continuously (Fig. 4). The study design was within-subject and all participants completed all three conditions. In order to perform the conditions counter-balanced between the participants, the order of the three types of phone conversation was randomized across the sample.

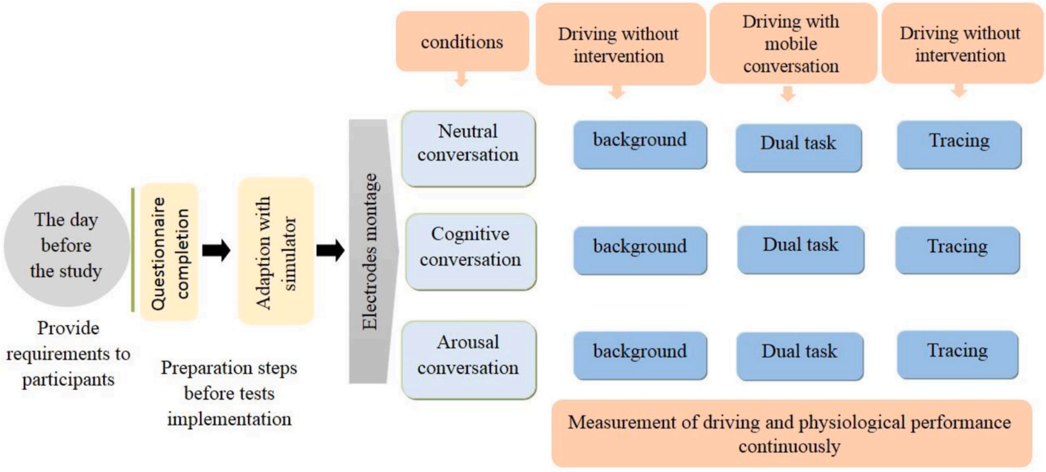

Fig. 4. Procedure of study.

2.6. Data-analysis

All statistical analyzes were performed using SPSS software (v. 20). Normality of data was assessed by Kolmogorov-Smirnov condition. As outlined in the objectives of this study, physiological (HR, RR, SDNN, LF/HF) and driving performance (time headway, SDLP) metrics were compared across the Background, dual-task, and Tracing conditions for driving segments containing each of the three different types of conversations (neutral, cognitive, arousal). Repeated Measures One Way ANOVAs were conducted to condition for the presence of differences in driving performance and cardiac activity.

3. Results

3.1. Physiological data

As outlined above, physiological and driving performance data were collected and analyzed across three 5-min intervals: Background single task driving, driving and engaging in a mobile phone conversation (dual task), and a Tracing period post-conversation for each of the three conversation types. Mean and standard deviation values for each of the data collection periods are shown in Table 2. No significant changes in physiological arousal (Tables 2 and 3) were observed relative to Background during the neutral conversation (HR, $p = 0.2$; RR, $p = 0.95$; SDNN, $p = 0.4$; LF/HF ratio, $p = 0.89$). RR interval in the cognitive conversation condition, showed no statistically significant changes, while heart rate, LF/HF ratio and SDNN, showed significant changes (dual task condition, HR, $p = 0.038$; RR, $p = 0.47$; SDNN, $p = 0.003$; LF/HF ratio, $p = 0.00$). Conversely, in arousal conversations, the heart rate and LF/HF significantly increased, and RR, SDNN significantly decreased (dual task condition, HR, $p = 0.00$; RR, $p = 0.69$; SDNN, $p = 0.003$; LF/HF ratio, $p = 0.01$). The results showed that neutral conversation had no persistent effects. (Tracing condition, HR, $p = 0.27$; RR, $p = 0.97$; SDNN, $p = 0.7$; LF/HF ratio, $p = 0.9$).

However, cognitive conversation (Tracing condition, HR, $p = 0.43$; RR, $p = 0.68$; SDNN, $p = 0.041$; LF/HF ratio, $p = 0.04$) and arousal conversation (Tracing condition, HR, $p = 0.32$; RR, $p = 0.86$; SDNN, $p = 0.016$; LF/HF ratio, $p = 0.014$), SDNN, LF/HF parameters showed significant changes, while RR showed no significant changes. HR, though, experienced a significant and meaningful change due to arousal conversation (Dual task condition), while it was not significant in cognitive conversation. Considering the significant changes in the three above mentioned variables, these results indicated persistent effects of arousal conversation on heart function even after call disconnection (Table 2). The results of the one-way ANOVA test show that the heart rate in the dual task state shows a significant difference between groups and within group, and also the LF/HF ratio of shows a significant difference in the conditions of cognitive and arousal conversation (Tables 3 and 4).

3.2. Driving performance data

Mean and standard deviation values for the driving performance metrics are shown in Table 5. Time headway in arousal and cognitive conversations increased significantly. Unlike, neutral conversation caused no significant change in time headway of two cars (Fig. 5, Table 6). The results from SDLP at the speed of 110 km/h, while dual tasking, suggested significant changes relative to the types of conversations (Fig. 6).

Table 6 shows the results of driver's performance in tracing condition under different conversations at a speed of 110 km/h. Considering tracing condition in arousal conversation, there was significant increase in both time headway between two car and SDLP compared to Background condition, while after Tracing condition in cognitive conversation, only SDLP was influenced by persistent effects of conversation and no significant change was observed in time headway. Also, in neutral conversation, no significant change was reported for both driving performance variables. The results of the one-way ANOVA test show that the SDLP and Time headway a significant difference between groups and within group in all state (Table 6). The results of Multiple Comparisons in ANOVA test show that Time headway a significant difference in dual task and tracing state (Table 7).

Table 2

Physiological performance in three types of conversation.

Feature			Neutral	P_{valu}	Cognitive	P_{valu}	Arousal	P_{valu}
			mean ± SD		mean ± SD		mean ± SD	
Heart Rate (beat/min)		Background	76.4 ± 9.1		76.97 ± 9.4		78.76 ± 7.8	
		Dual task	80.1 ± 7.31	0.067	82.07 ± 7.4	0.013	86.05 ± 5.6	0.01
		Tracing	79.6 ± 8.4	0.18	79.45 ± 7.8	0.22	81.27 ± 6	0.02
Heart Rate Variability	**RR (ms)**	Background	709 ± 123		716 ± 67		705 ± 125	
		Dual task	100 ± 700	0.99	93 ± 690	0.91	681 ± 115	0.001
		Tracing	702 ± 116	0.9	699 ± 93	0.71	691 ± 92	0.32
	SDNN (ms)	Background	77.7 ± 14.7		79.8 ± 11.4		78.7 ± 10.1	
		Dual task	10.7 ± 73.73	0.21	10.4 ± 70.69	0.01	70.3 ± 7.2	0.004
		Tracing	75.09 ± 12.5	0.88	73.58 ± 9.09	0.01	71.9 ± 8.15	0.001
	LF/HF ratio	Background	1.6 ± 0.92		1.65 ± 0.86		1.57 ± 0.73	
		Dual task	0.69 ± 1.78	0.44	1.07 ± 2.84	0.001	3.22 ± 1.3	0.001
		Tracing	1.64 ± 0.71	0.99	2.22 ± 0.81	0.01	2.33 ± 1	0.01

Table 3
Significant level of physiological performance in ANOVA condition.

Variables	Condition	Mean Square		F	Sig.
Heart Rate (beat/min)	Background	Between Groups	70.900	.961	.386
		Within Groups	73.805		
	Dual task	Between Groups	331.846	7.308	**.001**
		Within Groups	45.410		
	Tracing	Between Groups	26.065	.474	.624
		Within Groups	55.010		
LF/HF ratio	Background	Between Groups	.193	.05	.995
		Within Groups	.661		
	Dual task	Between Groups	19.476	17.356	**.001**
		Within Groups	1.122		
	Tracing	Between Groups	4.816	6.672	**.002**
		Within Groups	.722		

Other variables of physiological performance, including RR and SDNN, had no significant correlation between the different conditions studied, and due to the limitation of the pages of the article, they were not expressed in this table.

Table 4
Multiple Comparisons in ANOVA **test**.

Variable			conversation	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Heart Rate	background	neutral	cognitive	2.068	.966	−5.892	4.156
			arousal	2.099	.446	−7.941	2.256
	Dual task		cognitive	1.622	.387	−6.291	1.590
			arousal	1.646	.001	−10.237	−2.238
	tracing		cognitive	1.785	1.000	−4.267	4.408
			arousal	1.812	.797	−5.893	2.911
LF.HF Ration	background	Neutral	cognitive	.19582	0.99	−.492	.458
			arousal	.19872	0.99	−.484	.480
	Dual task		cognitive	.25508	.001	−1.656	−.417
			arousal	.25886	.001	−2.110	−.853
	tracing		cognitive	.20460	.026	−1.044	−.050
			arousal	.20763	.002	−1.2292	−.2206

Other variables of physiological performance, including RR and SDNN, had no significant correlation between the different conditions studied, and due to the limitation of the pages of the article, they were not expressed in this table.

Table 5
Driving performance in three types of conversation.

Feature		Neutral mean ± SD	Cognitive mean ± SD	Arousal mean ± SD
Time headway (s)	Background	7.44 ± 0.41	7.42 ± 0.46	7.33 ± 0.4
	Dual task	7.51 ± 0.4	8.10 ± 0.71	8.11 ± 0.46
	Tracing	7.46 ± 0.39	7.68 ± 0.82	7.75 ± 0.53
SDLP (m)	Background	0.41 ± 0.11	0.9 ± 39.0	0.36 ± 0.09
	Dual task	0.76 ± 0.14	0.76 ± 0.53	0.84 ± 0.1
	Tracing	0.41 ± 0.16	0.83 ± 0.19	0.82 ± 0.12

Background: Background condition Dual task: Dual task condition

4. Discussion

The present study aimed to investigate the cognitive effects of conversations on physiological and driving performance after disconnecting the conversation. Physiological data and driving performance measures were used as direct readings in a simulated environment to measure the effects of cognitive workload. Although [25] suggested that simulation environments do not create the true sense and fear of an accident in participants; it can create mental workload in a person. The results of this study showed that both physiological and driving performance indices significant changes in dual task condition. As stated, each of the parameters measured and evaluated at different condition conditions reported various changes relative to mental workload. Arousal conversation in dual-task condition showed significant changes in the measured parameters, and in the tracing conditions, only RR variable did not show significant changes. In cognitive conversation, changes in cardiac parameters were not the same as applied workload, so that SDNN and LF/HF ratios changed significantly during and after a conversation, while heart rate and RR parameters remained without any significant changes. In Neutral conversation, no significant changes were observed in variables, which can be due to two factors: first, lack of sensitivity in evaluated variables; and the use of a compensatory mechanism in information processing, which ultimately leads to a tolerable mental workload through this mechanism. Based on these results, it can be said that cardiac parameters were more

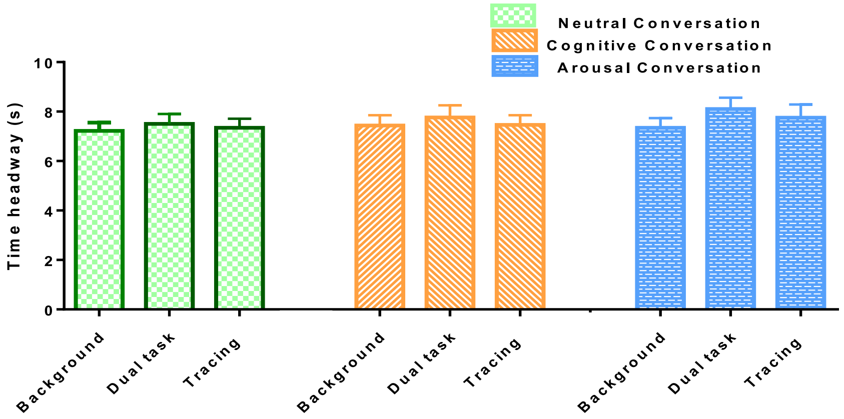

Fig. 5. Comparison of time headway of a driver at types conversation.

Table 6

Significant level of driving performance in ANOVA condition.

Variables	Condition		Mean Square	F	sig
SDLP	Background	Between Groups	80	0.61	**0.54**
		Within Groups	132		
	Dual task	Between Groups	1629	7	0.001
		Within Groups	210		
	Tracing	Between Groups	1475	7.07	0.001
		Within Groups	208		
Time Headway	Background	Between Groups	.89	31.8	.08
		Within Groups	2.81		
	Dual task	Between Groups	13.897	101.2	.001
		Within Groups	.137		
	Tracing	Between Groups	5.415	40.4	.001
		Within Groups	.134		

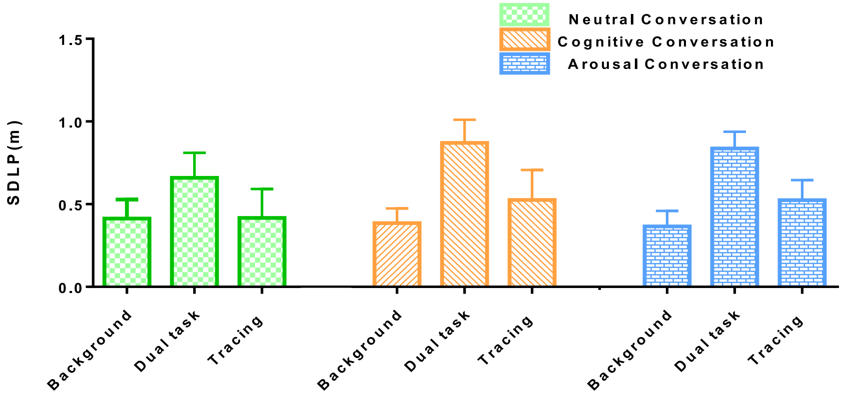

Fig. 6. Comparison of time headway of a driver at types conversation.

sensitive to mental workload from arousal conversations compared to cognitive and neutral conversations, and also a persistent effect of arousal conversation after the discontinuation of the conversation was reported by several parameters.

Since determining excessive mental workload is a cue for the development of adaptive systems and is shown to improve interactions between humans and machines [68,69], if Autonomic Nervous System (ANS) and central nervous system (CNS) reach the maximum or "saturation level" of mental workload, workload is found to be more than mental capacity. Therefore, the difference between results from various conversations may suggest that saturation level for mental workload is not met under neutral conversation. Also, low mental workload of driving scenarios may be a reason to insignificant effect on neutral conversation on cardiac parameters, which does not impose excessive mental workload from conversation load.

On the other hand, some researchers such as [70] claimed that mental capacity is similar to U shape curve in the opposite direction. However, this important issue was rarely taken into account from the neurophysical point of view and human factors. The Autonomic

Table 7
Multiple Comparisons in ANOVA test.

Condition		Conversation		Std. Error	Sig.	Lower Bound	Upper Bound
SDLP	Background	neutral	cognitive	2.76936	.655	−3.8313	9.6212
			arousal	2.81040	.995	−6.2297	7.4222
	Dual task		cognitive	3.48969	.034	−17.4749	−.5234
			arousal	3.54141	.001	−22.2993	−5.0965
	tracing		cognitive	3.47789	.003	−20.3774	−3.4832
			arousal	3.52943	.009	−19.3432	−2.1986
Time headway	background	neutral	cognitive	.07166	.071	.3364	.6845
			arousal	.07273	.958	−.1438	.2095
	Dual task		cognitive	.08922	.002	.1027	.5361
			arousal	.09054	.000	−1.1378	−.6980
	tracing		cognitive	.08808	.014	.0418	.4697
			arousal	.08938	.000	−.7466	−.3125

Nervous System (ANS) is a control system that acts largely unconsciously and regulates bodily functions such as the heart rate, digestion, respiratory rate, pupillary response, urination. Therefore, changes in mental workload may be related to changes in ANS activity and can be associated with changes in heart rate and other time and frequency variables. ANS activity is influenced by sympathetic and parasympathetic nervous systems. Kamat et al. (2000) believed that low-frequency heart rate variability (LF) associated with blood pressure; In other words, this happens with the involvement of sympathetic activity; and the variability of heart rate in the high-frequency region (HF) is associated with sinus respiration arrhythmia, i. e parasympathetic activity. As the results show, the LF/HF ratio index is one of the most reliable indicators for measuring mental workload. For example, in cognitive conversational condition conditions, it can be identified as an indicator with sufficient sensitivity to detect the persistent effects of mental workload [5]. also suggested LF/HF ratio index as a reliable indicator in additional mental workload conditions, which confirms the results of the present study. Mandrick et al. (2016) reported the effects of emotions on HR [71]. However, to support this research and other researchers such as Heine et al. (2017), heart rate was influenced by the secondary task cognitive requirements and rapidly responded and increased at higher complexity [29]. As the results showed, HRV components under the influence of workload stress did not improve performance. To interpret these results, we may refer to Patel et al. (2016) describing the interaction between cognition and emotions at work. Induction of stimulations on work-related memory dependent to work complications has various influences, and a mutual increase of cognitive requirements improves the physiological responses associated with anxiety [72]. Though, this does not prove to be true for HRV parameters studied. Therefore, this argument confirms the results of the present study.

The purpose of this study was to detect the persistent effects of mental workload. Measurement of HRV indexes and driving performance indicated the persistent effects of mental workload after a conversation. The results showed that cognitive and arousal conversations had persistent effects on physiological and driving performance parameters. Among the parameters monitored, SDNN, and LF/HF ratio and SDLP (behavioral performance) showed persistence effects for cognitive conversations. In arousal conversation, with the exception of RR, all the measured variables confirmed the persistent effects of mental workload. Since the neutral of mobile phone conversation is associated with mental workload, it seems like an arousal conversation, and the arousal aspect of the conversation and the excitement of the participants are likely to have more persistent effects on this type of conversation. Therefore, arousal conversations have a significant effect on physiological parameters such as SDNN and LF/HF ratio. Miyake et al. (2009) and Cinaz et al. (2013) believed that the LF/HF ratio was a well measure of productivity and confirms this study [73,74].

The results of the driving performance data from the present study show that mobile phone conversation led to an increase in the time headway (cognitive and arousal conversation) and SDLP (In three types of conversation). These results showed that the mobile phone conversation while driving led to increased mental workload and reduced driver processing capacity. Thus, the driver understood the greater risk of an accident. And the driver tried to increase the safety margin by increasing the time headway. In addition, depending on the type of conversation on the mobile phone, it could cause lasting effects on participants' driving performance which still carried the risk of accidents due to distractions even after disconnection. Based on the results of this study, arousal conversions affected the driver's performance functioning for 5 min after disconnecting. These results indicated a significant increase in SDLP at three levels of conversation and the headway between cognitive and arousal conversations. Following changes in performance functions at all three levels of conversations suggested that changes in arousal conversations were significantly affected by conversation, and after disconnecting, time headway between two vehicles and the SDLP was significantly more than the background condition. Since information about mobile phone use is not included in accidents, some traffic accidents may be the result of the persistent effects of mobile phone conversations. Oviedo-Trespalacios et al. and Briggs et al. [50,75] believed when the task is finished, the cognitive effects of the conversation would be persistent and confirmed the results from our studies.

The Multiple Sources theory in human information processing should be sought in the "single-channel bottlenecks" concept, indicating limitations in simultaneous performance of dual tasks [4]. Some studies have shown that increasing the complexity of the conversation and the difficulty of the secondary task reduces the rate of road and environment scanning by the driver and causes the driver to focus more on the center of the road [46]. 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 information in the brain is known as the model of the psychological refractory period [76]. As such, the content of the various conversations can have different processing levels and make it more difficult for the driver to handle the tasks. Therefore, the difference in processing level of cognitive and arousal type of conversation is the cause of different changes in performance parameters.

According to Horrey and Wickens (2004), driver performance during driving may depend on various cognitive resources; for example, a number of driver's responses to environmental stimuli require decision making, and some are dependent on the choice of response. Therefore, each of these two variables of time headway and SDLP occupies different processing resources [43]. In other words, driving performance and driver's subjective workload were interconnected and could act independently under compensatory conditions. In fact, if the complexity of the task increases, the driver may maintain a stable performance to a certain extent through increasing effort [77]. For this reason, in neutral conversation in a dual-tasking condition, the relative time headway between two vehicles was not affected, but the position of the vehicle in the middle of the road significantly changed. Therefore, when the conversation is at a low processing level and the sources required to process the conversation and maintain driver's performance are different, no significant change in performance is reported, such as no significant change in vehicle time headway and the neutral conversation. However, in arousal, and cognitive conversations, that make the conversation more complicated, compensatory mechanisms cannot maintain performance [78].

Most contemporary theoretical models show that drivers can impose a number of active controls for the allocation of attention resources, in order to avoid passive distraction. According to the Michan [79] operational-tactical-strategic driving model and Reagan et al. [80], when drivers are faced with driving challenges, they can apply three different controls to maintain their performance. Controlling feedback differs from the resources allocated to the "goal" and the current situation helps the driver change his behavior based on past results. In driver nutrition control, the driver changes his behavior in predicting future events or challenges.

Failure at any level of control can lead to errors at other levels, which in turn results in the breakdown of the entire system (called "the cascading effects"). At the operational level, a driver responding to a phone call can reduce demand by reducing the number of gear changes. At the tactical level, this is achieved by slowing down and staying in the same lane (adaptive control); at the strategic level, this is achieved by choosing a safer route and avoiding crowded intersections (default feeding control) the demand level is reduced. The results of this study show that by reducing speed and increasing the distance between two cars, the driver tries to reduce the demand level.

Accordingly, the results of driving and physiological performance confirm the lasting effects of conversation after disconnection. Cognitive effects may last stronger if it comes to arousal conversations or requires greater utilization of processing capacity, and this concern traffic accidents happening.

4.1. Study limitations

One of the limitations to the study was the type of arousal conversation, as the choice of challenging subjects varies from one person to another and the amount of stimulation in the arousal conversation may vary from person to person. Also, the amount of driving experience with the simulator could affect the results. For example, if people are more skilled, they may suffer less degree of cognitive workload compared to others.

5. Conclusion

The results from the present study indicated that the workload applied to individuals may cause lasting effects, and these lasting effects subsequently reduced the level of immunity and increased potential human error and accidents even if the workload was ceased. This study provided evidence on effects and duration of such effects of conversation on mobile phone while driving and after that. In this study, three cardiac indexes, each representing HRV, were used along with heart rate as physiological measurements. Based on the results, the LF/HF ratio index was shown to be a better indicator of work load. Also, the results of this research can be of interest to the field of cognitive workload to define broad studies on durable effects of cognitive workload in high-risk jobs.

Author contribution statement

Mostafa Pouyakia: Conceived and designed the experiments.
Mojtaba Zokaei: Conceived and designed the experiments; Performed the experiments.
Milad Abbasi: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Mohsen Falahati: Analyzed and interpreted the data.
Ali Nahvi: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e17501.

References

[1] Y.-K. Wang, S.-A. Chen, C.-T. Lin, An EEG-based brain–computer interface for dual task driving detection, Neurocomputing 129 (2014) 85–93.
[2] L. Gicquel, et al., Description of various factors contributing to traffic accidents in youth and measures proposed to alleviate recurrence, Front. Psychiatr. 8 (2017) 94.
[3] K. Young, M. Regan, M. Hammer, Driver Distraction: A Review of the Literature, 2007, pp. 379–405. Distracted driving.
[4] C.D. Wickens, Multiple resources and performance prediction, Theor. Issues Ergon. Sci. 3 (2) (2002) 159–177.
[5] G. Durantin, et al., Using near infrared spectroscopy and heart rate variability to detect mental overload, Behav. Brain Res. 259 (2014) 16–23.
[6] M. Papadakaki, et al., Driving performance while using a mobile phone: a simulation study of Greek professional drivers, Transport. Res. F Traffic Psychol. Behav. 38 (2016) 164–170.
[7] M.A. Just, T.A. Keller, J. Cynkar, A decrease in brain activation associated with driving when listening to someone speak, Brain Res. 1205 (2008) 70–80.
[8] M. Saifuzzaman, et al., Impact of mobile phone use on car-following behaviour of young drivers, Accid. Anal. Prev. 82 (2015) 10–19.
[9] T.C. Lansdown, A.N. Stephens, Couples, contentious conversations, mobile telephone use and driving, Accid. Anal. Prev. 50 (2013) 416–422.
[10] C. Dijksterhuis, et al., Classifying visuomotor workload in a driving simulator using subject specific spatial brain patterns, Front. Neurosci. 7 (2013) 149.
[11] T.A. Schweizer, et al., Brain activity during driving with distraction: an immersive fMRI study, Front. Hum. Neurosci. 7 (2013) 53.
[12] B. Reimer, B. Mehler, The impact of cognitive workload on physiological arousal in young adult drivers: a field study and simulation validation, Ergonomics 54 (10) (2011) 932–942.
[13] M. Pouya Kian, et al., Using mobile phone while driving: a simulator study of a dualtask condition, Iranian Rehabilit. J. 10 (2012) 31–36.
[14] I. Alimohammadi, M. Zokaei, S. Sandrock, The effect of road traffic noise on reaction time, Health Promot. Perspect. 5 (3) (2015) 207.
[15] I. Alimohammadi, et al., The effects of road traffic noise on the students' errors in movement time anticipation the role of introversion, Iran. Occup. Health 9 (3) (2012) 52–59.
[16] P.A. Hancock, P.A. Desmond, Stress, Workload, and Fatigue, 2001 (Lawrence Erlbaum Associates Publishers).
[17] B. Mehler, B. Reimer, J.F. Coughlin, Sensitivity of physiological measures for detecting systematic variations in cognitive demand from a working memory task: an on-road study across three age groups, Hum. Factors 54 (3) (2012) 396–412.
[18] K. Brookhuis, D. De Waard, Assessment of Drivers'workload: Performance and Subjective and Physiological Indexes, workload and fatigue, Stress, 2001.
[19] C. Wickens, J. Hollands, Stress and Human Error. Engineering Psychology and Human Performance, third ed., Prentice Hall, Upper Saddle River, NJ, 2000.
[20] N. Moray, Mental Workload: its Theory and Measurement, 2013. Vol. 8 Springer Science & Business Media.
[21] R.D. Dias, et al., Systematic review of measurement tools to assess surgeons' intraoperative cognitive workload, J. British Surgery 105 (5) (2018) 491–501.
[22] J.F. Thayer, et al., Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health, Ann. Behav. Med. 37 (2) (2009) 141–153.
[23] T.M. Hess, Selective engagement of cognitive resources: motivational influences on older adults' cognitive functioning, Perspect. Psychol. Sci. 9 (4) (2014) 388–407.
[24] M. Fallahi, et al., Analysis of the mental workload of city traffic control operators while monitoring traffic density: a field study, Int. J. Ind. Ergon. 54 (2016) 170–177.
[25] H. Mansikka, et al., Fighter pilots' heart rate, heart rate variation and performance during an instrument flight rules proficiency test, Appl. Ergon. 56 (2016) 213–219.
[26] D.M. Pendleton, et al., Mental engagement during cognitive and psychomotor tasks: effects of task type, processing demands, and practice, Int. J. Psychophysiol. 109 (2016) 124–131.
[27] M. Causse, et al., Monitoring cognitive and emotional processes through pupil and cardiac response during dynamic versus logical task, Appl. Psychophysiol. Biofeedback 35 (2) (2010) 115–123.
[28] N. Hjortskov, et al., The effect of mental stress on heart rate variability and blood pressure during computer work, Eur. J. Appl. Physiol. 92 (1–2) (2004) 84–89.
[29] T. Heine, et al., Electrocardiographic features for the measurement of drivers' mental workload, Appl. Ergon. 61 (2017) 31–43.
[30] A. Uusitalo, et al., Heart rate variability related to effort at work, Appl. Ergon. 42 (6) (2011) 830–838.
[31] S. Pieper, et al., Cardiac effects of momentary assessed worry episodes and stressful events, Psychosom. Med. 69 (9) (2007) 901–909.
[32] C.S. Weber, et al., Emotional irritation before mental stress is associated with enhanced peripheral norepinephrine, Scand. J. Psychol. 48 (6) (2007) 459–466.
[33] R. McCraty, M. Atkinson, D. Tomasino, Impact of a workplace stress reduction program on blood pressure and emotional health in hypertensive employees, J. Alternative Compl. Med. 9 (3) (2003) 355–369.
[34] E.A. Butler, F.H. Wilhelm, J.J. Gross, Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction, Psychophysiology 43 (6) (2006) 612–622.
[35] C.S. Dula, et al., Differing types of cellular phone conversations and dangerous driving, Accid. Anal. Prev. 43 (1) (2011) 187–193.
[36] J. Son, H. Oh, M. Park, Identification of driver cognitive workload using support vector machines with driving performance, physiology and eye movement in a driving simulator, Int. J. Precis. Eng. Manuf. 14 (8) (2013) 1321–1327.
[37] K. Knaepen, et al., Psychophysiological response to cognitive workload during symmetrical, asymmetrical and dual-task walking, Hum. Mov. Sci. 40 (2015) 248–263.
[38] S. Leung, et al., A comparison of the effect of mobile phone use and alcohol consumption on driving simulation performance, Traffic Inj. Prev. 13 (6) (2012) 566–574.
[39] K. Lipovac, et al., Mobile phone use while driving-literary review, Transport. Res. F Traffic Psychol. Behav. 47 (2017) 132–142.
[40] C. Collet, et al., Physiological and behavioural changes associated to the management of secondary tasks while driving, Appl. Ergon. 40 (6) (2009) 1041–1046.
[41] P. Choudhary, N.R. Velaga, Modelling driver distraction effects due to mobile phone use on reaction time, Transport. Res. C Emerg. Technol. 77 (2017) 351–365.
[42] S.G. Hosking, K.L. Young, M.A. Regan, The effects of text messaging on young drivers, Hum. Factors 51 (4) (2009) 582–592.
[43] W.J. Horrey, C.D. Wickens, Examining the impact of cell phone conversations on driving using meta-analytic techniques, Hum. Factors 48 (1) (2006) 196–205.
[44] A. Cuenen, et al., Does attention capacity moderate the effect of driver distraction in older drivers? Accid. Anal. Prev. 77 (2015) 12–20.
[45] O. Oviedo-Trespalacios, et al., Driving behaviour while self-regulating mobile phone interactions: a human-machine system approach, Accid. Anal. Prev. 118 (2018) 253–262.
[46] J.L. Harbluk, Y.I. Noy, M. Eizenman, The Impact of Cognitive Distraction on Driver Visual Behaviour and Vehicle Control, 2002.
[47] D. Shinar, N. Tractinsky, R. Compton, Effects of practice, age, and task demands, on interference from a phone task while driving, Accid. Anal. Prev. 37 (2) (2005) 315–326.
[48] L. García-Larrea, et al., Interference of cellular phone conversations with visuomotor tasks: an ERP study, J. Psychophysiol. 15 (1) (2001) 14.
[49] D.L. Strayer, W.A. Johnston, Driven to distraction: dual-task studies of simulated driving and conversing on a cellular telephone, Psychol. Sci. 12 (6) (2001) 462–466.

[50] G.F. Briggs, G.J. Hole, M.F. Land, Emotionally involving telephone conversations lead to driver error and visual tunnelling, Transport. Res. F Traffic Psychol. Behav. 14 (4) (2011) 313–323.
[51] S. Amado, P. Ulupınar, The effects of conversation on attention and peripheral detection: is talking with a passenger and talking on the cell phone different? Transport. Res. F Traffic Psychol. Behav. 8 (6) (2005) 383–395.
[52] M.M. Haque, S. Washington, A parametric duration model of the reaction times of drivers distracted by mobile phone conversations, Accid. Anal. Prev. 62 (2014) 42–53.
[53] Y.-K. Wang, T.-P. Jung, C.-T. Lin, EEG-based attention tracking during distracted driving, IEEE Trans. Neural Syst. Rehabil. Eng. 23 (6) (2015) 1085–1094.
[54] M.E. Rakauskas, L.J. Gugerty, N.J. Ward, Effects of naturalistic cell phone conversations on driving performance, J. Saf. Res. 35 (4) (2004) 453–464.
[55] S.a.C. Leung, J. Rodney, Melinda L. Jackson, Mark E. Howard, Raymond J. McKenzie, A comparison of the effect of mobile phone use and alcohol consumption on driving simulation performance, Traffic Inj. Prev. 15 (6) (2012) 566–574.
[56] J. Törnros, A. Bolling, Mobile phone use–effects of conversation on mental workload and driving speed in rural and urban environments, Transport. Res. F Traffic Psychol. Behav. 9 (4) (2006) 298–306.
[57] R. Matthews, S. Legg, S. Charlton, The effect of cell phone type on drivers subjective workload during concurrent driving and conversing, Accid. Anal. Prev. 35 (4) (2003) 451–457.
[58] J. Maciej, M. Nitsch, M. Vollrath, Conversing while driving: the importance of visual information for conversation modulation, Transport. Res. F Traffic Psychol. Behav. 14 (6) (2011) 512–524.
[59] G. Tillman, et al., Modeling cognitive load effects of conversation between a passenger and driver, Attention Percept. Psychophysics 79 (6) (2017) 1795–1803.
[60] M.M. Haque, S. Washington, The impact of mobile phone distraction on the braking behaviour of young drivers: a hazard-based duration model, Transport. Res. C Emerg. Technol. 50 (2015) 13–27.
[61] P. Choudhary, N.R. Velaga, Analysis of vehicle-based lateral performance measures during distracted driving due to phone use, Transport. Res. F Traffic Psychol. Behav. 44 (2017) 120–133.
[62] C.M. Farmer, et al., Secondary behavior of drivers on cell phones, Traffic Inj. Prev. 16 (8) (2015) 801–808.
[63] P. Choudhary, N.R. Velaga, Mobile phone use during driving: effects on speed and effectiveness of driver compensatory behaviour, Accid. Anal. Prev. 106 (2017) 370–378.
[64] M. Fallahi, et al., Assessment of operators' mental workload using physiological and subjective measures in cement, city traffic and power plant control centers, Health Promot. Perspect. 6 (2) (2016) 96.
[65] F. Schneider, et al., The validity of linear and non-linear heart rate metrics as workload indicators of emergency physicians, PLoS One 12 (11) (2017), e0188635.
[66] M. Mather, J.F. Thayer, How heart rate variability affects emotion regulation brain networks, Current Opinion Behav. Sci. 19 (2018) 98–104.
[67] A. Camm, et al., Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, Circulation 93 (5) (1996) 1043–1065.
[68] P.A. Hancock, W.B. Verwey, Fatigue, workload and adaptive driver systems, Accid. Anal. Prev. 29 (4) (1997) 495–506.
[69] F. Dehais, M. Causse, S. Tremblay, Mitigation of conflicts with automation: use of cognitive countermeasures, Hum. Factors 53 (5) (2011) 448–460.
[70] S. Miyake, Multivariate workload evaluation combining physiological and subjective measures, Int. J. Psychophysiol. 40 (3) (2001) 233–238.
[71] K. Mandrick, et al., Neural and psychophysiological correlates of human performance under stress and high mental workload, Biol. Psychol. 121 (2016) 62–73.
[72] N. Patel, et al., Interaction of threat and verbal working memory in adolescents, Psychophysiology 53 (4) (2016) 518–526.
[73] B. Cinaz, et al., Monitoring of mental workload levels during an everyday life office-work scenario, Personal Ubiquitous Comput. 17 (2) (2013) 229–239.
[74] S. Miyake, et al., Physiological responses to workload change. A test/retest examination, Appl. Ergon. 40 (6) (2009) 987–996.
[75] O. Oviedo-Trespalacios, et al., Risk factors of mobile phone use while driving in Queensland: prevalence, attitudes, crash risk perception, and task-management strategies, PLoS One 12 (9) (2017), e0183361.
[76] C. Stelzel, S.A. Brandt, T. Schubert, Neural mechanisms of concurrent stimulus processing in dual tasks, Neuroimage 48 (1) (2009) 237–248.
[77] Y.-Y. Yeh, C.D. Wickens, Dissociation of performance and subjective measures of workload, Hum. Factors 30 (1) (1988) 111–120.
[78] F.A. Drews, M. Pasupathi, D.L. Strayer, Passenger and cell phone conversations in simulated driving, J. Exp. Psychol. Appl. 14 (4) (2008) 392.
[79] J.A. Michon, A critical view of driver behavior models: what do we know, what should we do?, in: Human Behavior and Traffic Safety Springer, 1985, pp. 485–524.
[80] M. Doppelmayr, T. Finkenzeller, P. Sauseng, Frontal midline theta in the pre-shot phase of rifle shooting: differences between experts and novices, Neuropsychologia 46 (5) (2008) 1463–1467.