International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Usage of Augmented Reality Glasses in Automotive Industry: Age-Related Effects on Cognitive Load

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Abstract*: With the development of technology, augmented reality (AR) devices were introduced in many areas. One of these devices, AR glasses, is more convenient and easy to fulfil and still continuing to evolve. The AR glasses, which are frequently used in sectors such as education, entertainment, construction and automotive, bring many research areas. In this article, the cognitive load that AR glasses bring to the users who is working on an assembly line has been investigated. Cognitive load refers to the resources used by working memory in the brain. This study was carried out with healthy participants in the assembly line of an automotive manufacturing factory and 60 tests were performed for measurement. Effect of the AR glasses for participants under 35 and over 35 years of age was measured by electroencephalography (EEG). EEG is a common objective technique used in cognitive load measurements. EEG data collected were examined and no significant difference was observed between participants of under and over 35 years of age. When compared with the data obtained in the experiments without glasses, it was seen that the use of the AR glasses in assembly lines of automotive manufacturing factories did not create an additional cognitive load. It can be seen from the article that AR glasses did not have an age-related effect and can be use in the automotive manufacturing industry.

Index Terms*: Cognitive Load, Augmented Reality Glasses, Electroencephalography, Neuroergonomics.

I. INTRODUCTION

Today, technological devices have an undeniable places in our lives. Advances in technology have made it possible to use Augmented Reality (AR) technology on learning [1]. The term of AR refers to increasing the user's sensory perception of the real world with a computer-based information layer [2]. In the early 1990s, AR technology was introduced by the US military in 1992 [3]. Nowadays, it is used in many fields such as construction and architecture, health, travel, education and entertainment [4].

Manuscript published on 30 September 2019
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Augmented reality and virtual reality (VR) are closely related; both are part of a Reality-Virtuality Continuum [5] . However, while the VR replaces the reality around the user, the AR completes the reality [2]. In addition, AR is defined as [6];

- Combine virtual and real objects in a real environment.
- Run interactively and in real time.
- Align virtual and real objects with each other.

One of the industries in which the use of AR technology has increased and strengthened is the automotive manufacturing sector [7]. Some of the areas where AR technology is used in the automotive manufacturing sector are given below;

- Evaluation of in-car design [8],
- Easier manufacturing with smart welding machines [9],
- Easier tracking of vehicles in production [10],
- Increasing the safety of the operator in hybrid systems where human and robot work together in production lines [11].

We see that AR technology is used in many areas of automotive manufacturing. However, it has not been measured how this technology creates a cognitive load on users in assembly line.

The cognitive load represents the load imposed on the cognitive system while performing a specific task [12]. The cognitive load is structurally divided into two dimensions: causal and assessment dimensions [13]. While the causal dimension reflects the relationship between task characteristics and learner characteristics, the assessment dimension reflects mental load, mental effort, and performance. Task characteristics such as task complexity, time pressure, multimedia usage, and teaching speed are used for cognitive load theory (CLT) research [14]. CLT is related to the development of methods of efficient use of limited capacity working memory in order to adapt the auditory and visual knowledge and skills to new situations [15].

Employees must always be careful and alert to the harsh and dangerous conditions in their work environment. This alertness occur with the brain on the alert. If the brain is loaded with less cognitive load, the employee can give so more attention to his work. Therefore, the effect of the use of AR glasses in the automobile manufacturing sector should be clarified. This evaluation was done on different age groups.

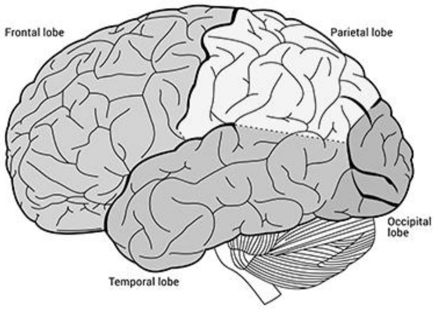

Fig. 1. Brain Lobes [40]

There are too many techniques for cognitive load measurements. The first is the subjective rating scale with techniques such as the NASA Task Load Index [16] or 9 point symmetric category mental effort rating scale [17]. The second is an objective cognitive load measurement technique that allows online assessment of cognitive load at all levels. These are physiological measurements such as heart rate variability [13], hormone levels [38] and eye movement data [18]. Other physiological techniques such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) used in neuroscience are also used in cognitive load measurement [19]. In contrast to other measurements (fMRI-limited position, PET- injection of harmful substances), the EEG can measure brain activity in real environments without interference. EEG is a common brain imaging technique that measures electrical activity by means of electrodes placed on the scalp [19]. It will also provide a good match between the system performance and participant's ability [20]. With the wireless EEG, data can be collected even more easily. Unlike to such good properties, EEG is affected by artifacts such as movement, eye blinking, and electrical cables in the work environment. The advanced recording and analyzing softwares in EEG systems not only make the amplification of the incoming signal possible but also get rid of the eye blink and movement artifacts.

Knowledge of the brain structure is important for EEG analysis. The brain is divided into four lobes (Fig. 1), frontal, parietal, temporal and occipital, and each lobe is characterized by its unique functions and those functions of brain lobes are given in Tab. 1.

When the EEG signals were examined it was observed that it contained several frequency bands. These waves are as follows and their wave shapes are given in Fig. 2;

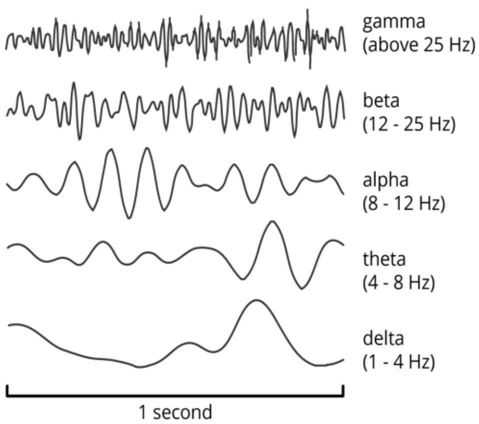

Fig. 2. Wave Shapes [41]

Tab. 1. Lobes Functions

Frontal Lobe	Decision-making, emotion control, problem solving
Parietal Lobe	Visual and tactile detection, recognition and orientation
Temporal Lobe	Hearing, long-term memory, speech
Occipital Lobe	Visual perception

- Delta wave: The term delta was first used by Walter [21]. The frequency range of these waves with high amplitude is 0.5 to 3.5 Hz. These waves appear instantly in deep sleep.
- Theta wave: The frequencies used by Walter and Dovey [22] for the first time have frequencies ranging from 4 to 7 Hz. It appears in moments with imagination, thinking and sleep.
- Alpha wave: The alpha wave named by Hans Berger [23; 24] has a frequency range of 8-13 Hz. The alpha wave appears in calmness but not asleep.
- Beta wave: The frequency has a range of 15 to 30 Hz and the amplitude values of beta waves are lower than the alpha waves [25]. It occurs when conscious focus or problem solving.
- Gamma wave: 30 Hz or higher. It is associated with high level cognitive processing tasks and is related to the ability to acquire new information.

Three main contributions to the use of EEG as a cognitive load measurement in the literature are given below;

- The event-related (De) synchronization measure for measuring oscillatory EEG dynamics [26].
- Basar's theory of neutral oscillations [27],
- Functional importance of alpha and theta oscillations [28],

Event-related (de) synchronization of changes in the alpha band were proposed as a measure of change rate for the oscillating EEG dynamics [26]. In the theory of neutral oscillations, Basar [27] explains how, in the theory of neutral oscillations, the EEG can be used to detect brainwave rhythms, and that these rhythms can be considered as an alphabet for brain functions. Klimesch [28], showed that functional topographies of alpha and theta oscillations related to cognitive performance should be examined. In another article, Klimesch, Schack and Sauseng [29] were stated that the localization of the recording regions was most prominent in the alpha parietal and theta frontal midline locations. Compared to a time interval before the stimulus, the percentage reduction in the band power in the time period in which the experimental task is studied reflects the event-related desynchronization (ERD) and the percentage increase reflects the event-related synchronization (ERS) [39]. García-Larrea and Cézanne-Bert [30] showed that, P3 amplitude change could be used to examine the working memory load. In the article, it is proved that the decrease in P3 amplitude shows the increase in the load in the working memory.

The use of EEG for cognitive load measurement has been the subject of many articles. Kumar and Kumar [20] proposed the use of an EEG power spectrum for the measurement of cognitive load in complex computerized human interaction. Causse, Fabre, Giraudet, Gonzalez, and Peysakhovich [31] investigated the effect of cognitive load on the processing of visual instructions during the dynamic piloting task. Dan and Reiner [32] examined the cognitive load of the participants whom connected to EEG system, on the learning of origami, which includes simple and complex tasks in 2D and 3D screens. Mazher, Abd Aziz, Malik and Ullah Amin [33] measured the cognitive load using EEG to understand the complexity of the multimedia learning task in their article. Zhang, Zhao, Bai and Tian [34] examined the functional connection in the brain when the working memory reached its capacity when participants performed a visual working memory with increasing loads from 1 to 6. Yang, Ma, Zhang, Guan and Jiang [35], aimed to gather driving behavior data with EEG and create a driving behavior recognition system.

In previous studies, the cognitive effect of the use of AR technology in the automobile manufacturing sector has not been investigated in previous studies of English literature. In order to fill this gap, the cognitive load of the AR glasses, which is designed for use in assembly lines, has been investigated in this study. The cognitive load of the participants was compared according to age (under 35 years and over 35 years).

The article is organized as follows; Section 2 describes the experimental setup and how the experiment is performed; the results are presented in Section 3; and the discussion is presented in Section 4.

II. MATERIALS AND METHOD

A. *Participants*

Volunteers who signed the volunteering forms required by the Uludag University Faculty of Medicine Clinical Research Ethics Committee participated in the experimental study. Two participants were younger than 35 years, while two were over 35 years. The general health status of the participants was good and they had no history of illness or medicine use. Hamilton Depression Rating Scale [36] and Hamilton Anxiety Scale [37] were applied before each experiment to determine the presence of depression and/or anxiety. Participants were asked not to take alcohol and caffeine 24 hours before the experiment. After the experiment, participants were asked to fill in the NASA-TLX [16] to assess their workload subjectively.

B. *Procedures*

The experiments were carried out in the real environment in the assembly line of an automobile manufacturing factory. The participants were selected from the assembly line. There is a standard assembly work at the factory. The parts to be installed are taken from the main warehouse to the intermediate storage and this process is called diffusion. Depending on the number of vehicles produced and the number of products, the number of parts in the diffusion area is very high. In the current structure, the installation operator prepares the necessary parts of the vehicle in the diffusion area and leads to the installation. This is done with the light warning system called SAG or PicToLight. In this system, the installation operator must perform the control of the SAG / PicToLight system simultaneously with the diffusion paper on which the part and chassis numbers are located, so that the operator can select the correct part. The workflow of the SAG / PicToLight system is defined as follows;

- Receive the part from the rack which the warning light on,
- Pressing the button to turn off the light,
- Compare the part number with diffusion paper,
- Place the part in the diffusion trolley.

The EEG recording of the first three trials was taken according to the standard work procedure. Subsequent trials were performed with AR glasses. The procedure with the AR glasses is as follows;

- Go to the box where the part number is written, according to the part code coming from the AR glasses' screen,
- Read the QR code on the front of the box with the AR glasses,
- Place the part in the diffusion trolley.

The AR glasses used in the experiment is the 'SmartEyeglass SED-E1' produced by Sony and is shown in Fig. 3.

Fig. 3. Sony SmartEyeglass SED-E1 [42]

C. *EEG Recording*

EasyCap (Brain Products, Munich, Germany) electrode cap and Smarting EEG amplifier (mBrainTrain, Belgrade, Serbia) were used to collect EEG signals. The reference electrode of the 24-channel electrode cap was placed between Cz and CPz, the center of the scalp based on the international 10-20 system. Electrode cap and channel position on the scalp is shown in Fig. 4. Smarting has Bluetooth and records were taken without limiting movements. EEG signals were recorded at 500 Hz sampling rate. The impedances were reduced below 10 kΩ.

(a) (b)

Fig. 4. (a) Electrode cap and (b) channels position

Five different EEG recordings were obtained for each participant. These records consist of three repetitions. A total of 60 tests were performed for 3 repeats, 5 records and 4 subjects. Between each experiment, the participants worked without taking two

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DOI:10.35940/ijrte.C3853.098319
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working days of measurement so that the participants could get used to the system. The first EEG recording was performed while the participant was working with the standard work procedure, and the other four EEG recordings were taken while the participant was working with the AR glasses. Fig. 5 shows a participant working with AR glasses and Tab. 2 shows an experimental plan for each participant.

Fig. 5. An example of an experimental study

D. *Analysis*

EEG analysis was performed with BrainVision Analyzer 2 (Brain Products, Munich, Germany). When the characteristics of the waves were examined, beta and gamma waves were used in the analysis because the participants were in a focus and they would perform the experiment while learning a new knowledge.

The data were filtered according to the wavelengths of the beta and gamma waves and the filtered data was divided into segments. After the artifacts such as line noise and movement were purified, the segments were averaged. Fig. 6 shows an average data received from channel T_7.

According to functions of the brain lobes; frontal, temporal and occipital channels (Fp_1, Fp_2, F_3, F_4, F_7, F_8, O_1, O_2, T_7, and T_8) were used for analysis. Different from the studies, where the participants were sitting calmly, participants were working on standard work procedure while they were using the AR glasses in this study. Comparisons were made according to the area under the average graph.

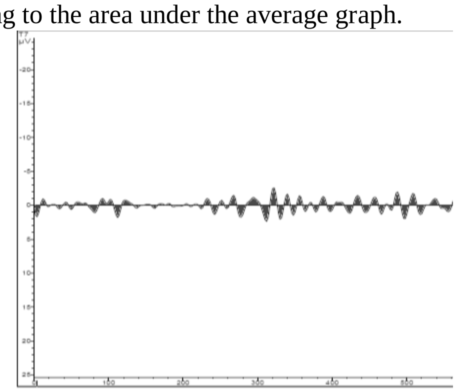

Fig. 6. An average chart from T_7 channel

According to García-Larrea and Cézanne-Bert's [30] article, it is assumed that the cognitive load is higher in the measurements where the absolute value of the area is lower.

Tab. 2. Experimental plan

Days	1	2	3	4	5	6	7	8	9	10	11
EEG	✓	✓	✕	✕	✓	✕	✕	✓	✕	✕	✓
AR Glasses	✕	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Experiment Number	1	2			3			4			5

III. RESULTS AND DISCUSSION

The EEG data collected from participants were eliminated from the artifacts with the BrainVision Analyzer 2 (Brain Products, Munich, Germany) software and averaged. When the three replicates were examined for each experiment, the data set with the least artifacts was used for comparison. With the Analyzer, the area below the average graph is calculated. The results of the experiment with glasses were taken from the last experiment where the participants worked with glasses.

Firstly, 200 samples (from 4 subjects, 5 experiments, 10 channels) were examined for compatibility with normal distribution. It was observed that the data fit the normal distribution (mean 15.84). The values calculated from the area under the graph of the experiments with and without glasses were analyzed by using one-way ANOVA (analysis of variance) with a confidence level of 95%. There was a significant difference ($p < 0.05$, $p = 0.00$) between experiments without glasses (mean 5.24) and experiments with glasses (mean 18.96).

As can be seen in Fig. 7, area values of the experiments with glasses were higher than area values of the experiments without glasses. It was found that cognitive load was lower in experiments with glasses.

Age comparison was performed only for the experiments with glasses. The area values for the participants aged under (mean 19.30) and over 35 (mean 17.69) years were analyzed using one-way ANOVA with a confidence level of 95%.

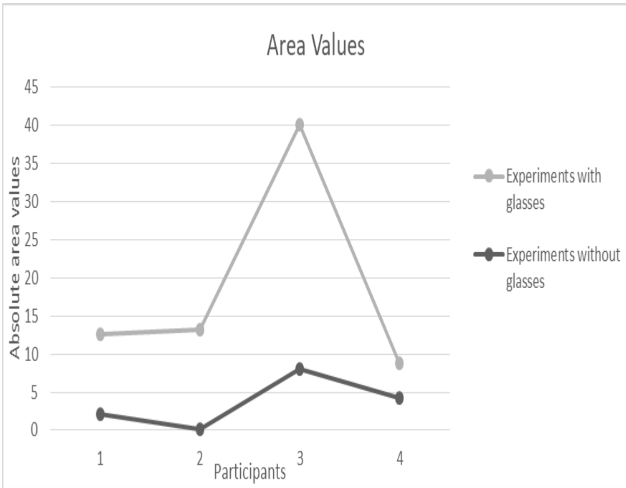

Fig. 7. Absolute Area Values

There was no significant difference ($p > 0.05$ i.e. $p = 0.533$) between the area values of the participants aged under and over 35 years. Organizations often use cutoffs such as 40, 45, or 50 years. So age 35 might have been an inappropriate cutoff to study the effect of age on cognitive load with new devices. Fig 8. shows comparison between under and over 35 years of age and can be seen area values of under 35 years of age were higher than area values of over 35 years of age.

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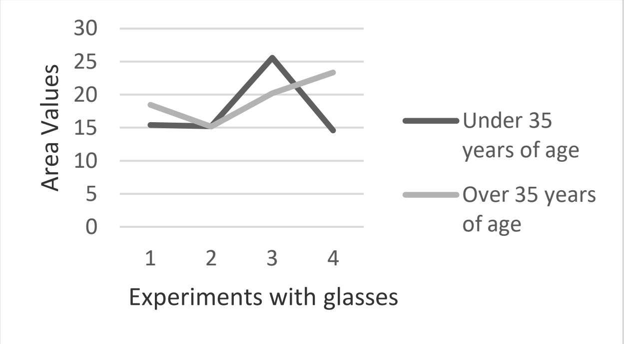

Fig. 8. Age comparison

The Hamilton Depression and Anxiety scores rule out any depression and/or anxiety. NASA-TLX results were consistent with EEG findings of the experiments showing less cognitive load in the participants using glasses.

In this study, presence of additional cognitive load with the use of AR glasses in the assembly line of the automotive manufacturing factory in two different age groups was tested. EEG and NASA-TLX were used to measure the cognitive load objectively and subjectively, respectively. The experiments were performed on a real assembly line. Age produced no significant difference on cognitive load. According to these results, cognitive load with the use of AR glasses in the assembly line did not have an age-related effect.

IV. CONCLUSION

Through the innovations in AR technology, it is now easy to reach and use AR devices. The use of these devices in many sectors has increased attention from different research fields. One of these devices, AR glasses, has also been the subject of many articles. However, impact of the use of AR glasses on cognitive load has not been investigated on a real assembly line.

The present study examined the effect of using AR glasses on cognitive load. Participants first worked with the standard work procedure and then worked with AR glasses. The data collected by EEG were compared according to the age status of the participants.

The results of this study confirmed no additional cognitive load of using AR glasses in the assembly line and no difference in terms of ages of the participants being 35 as the cut-off. This is the first study to investigate the effect of AR glasses of cognitive load on a real assembly line in an automotive manufacturing sector.

ACKNOWLEDGMENT

This study is an output of the TUBITAK project “An investigation of cognitive load effect of using augmented reality glasses in automotive manufacturing”, project number 217M505.

We thank Tofaş Turkish Automobile Factory Inc. for their contributions.

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