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Research Article

Emotionally-loaded Visual Stimuli to Alter Brain Arousal: A Flicker Fusion Study

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Abstract

Background: Human brain performance and arousal are still challenging and critical, especially in environments such as power plants. Since different emotions are common in daily work life and have inevitable effects on cognitive performance, it is important to evaluate whether or not emotional interventions can, in any way, alter brain arousal, leading to mental fatigue in control room operators (CROs) and affecting their cognitive emotion regulation. To address this issue, flicker fusion frequency (FFF) was employed as a simple and reproducible surrogate index for mental fatigue.
Objectives: This study aimed to investigate whether or not emotionally loaded visual stimuli can alter brain arousal (brain fatigue) or is associated with cognitive emotion regulation (CER) ability.
Methods: Flicker fusion frequency was assessed by RT-961, and the International Affective Picture System (IAPS) was adopted as the picture database of stimuli. Additionally, the Cognitive Emotion Regulation Questionnaire (CERQ) was used to determine the participants' cognitive emotion CER ability. Twenty volunteer CROs from Fars Combined Cycle Power Plant participated in this study. They completed CERQ and then were assessed at two different time points, i.e., before and after presenting emotional stimuli. At each round, FFF was assessed 20 times, and the average frequency was recorded. Emotionally-loaded images were considered as stimuli. The stimuli sets were classified based on their arousal level and valence, yet they were presented in a random order. Subjects were exposed to each image for five seconds (30 minutes in total).
Results: The participants' mean age was 39.55 ± 7.02 years. The first and second FFFs were 42.15 ± 3.90 and 41.96 ± 3.98 in the appropriate group and 42.82 ± 3.59 and 42.26 ± 4.07 in the inappropriate group, respectively. Based on the statistical tests, there were no significant relationships between the measurements ($P > 0.05$).
Conclusions: Our findings suggest that CROs may positively maintain their brain arousal during specific emotional stimuli when the intervention lasts less than 30 minutes. Considering the prolonged working hours in such industries (roughly over eight hours a day) and the importance of cognitive aptitude in preventing work-related errors, we propose this line of research to gain momentum.

Keywords: Flicker Fusion, IAPS, Emotional Stimuli, Cognitive Performance, Cognitive Emotion Regulation (CER)

1.Background

It is obvious that the human brain is the command center of the human nervous system, receiving signals from the body's sensory organs and directs information to the feedback system. However, many aspects of cognitive performance and emotion (i.e., inner feelings such as fear, anger, shame, etc. (1)), which affect brain arousal and cognition, are still unclear. Emotion is also connected to cognitive processes (2). It is generally accepted that emotions influence the capability of a person to perform a given task (3). In physical activities, for example, emotion plays a major role in the quality of the athlete's performance (3). Physiologically and psychologically, emotions influence the health status of humans (4). Moreover, emotions are strong determinants of behavior, thinking, and experience and can be regulated in different ways (5). The memory of both positive and negative emotional stimuli, for instance, appears to be more effective than neutrals (6). In addition, attention seems to be captured by emotional stimuli (3), and cognitive performance can further be affected by the perception of emotional stimuli (7). The defective recruitment of predominantly prefrontal emotion regulatory networks causes failure to effectively down-regulate negative emotions (8). It is evident that in mental and cognitive tasks, emotions have inevitable and distinct effects on performance, contributing to possible errors. This is still challenging to know when facing emotions can limit performance through reducing brain arousal.

Furthermore, emotions encompass every second of our life and the world (4), so separating emotions from our behavior and activities is somehow impossible, especially when emotions can cause different changes and deeply affect our cognitive performance. So, the role of emotions in our life cannot be denied. A fundamental need in our daily life, accounting for psychological functioning and mental well-being, is the capacity to deal with emotional circumstances using cognitive emotion control (8).

One of the most common ways for experiencing emotions is the visual sense, so visual-loaded emotional stimuli can be considered a good choice for assessing emotional alterations. The effects of emotionally-loaded stimuli on different features of cognitive performance have been investigated in several studies (3). Another important item is the effect of emotions on brain arousal and brain fatigue (or cognitive fatigue), which can increase human errors and decrease cognitive performance, a matter that needs to be further investigated.

Mental fatigue is a very common experience, which is also known as cognitive fatigue or mental work-related fatigue (9). Moreover, fatigue is normal enough to be easily ignored (9), especially after performing ordinary duties, such as analyzing work-related data, preparing task requirements, planning actions, or other similar activities causing us feel fatigued (9). Despite many examples of this type of fatigue in our daily life, it is still poorly understood (9).

Flicker Fusion Frequency (FFF) has been used in fatigue research (10). Reduction in the FFF score is followed by fatigue development (10). It is believed that FFF can represent the fundamental temporal characteristics of the visual system and is, therefore, a proportional measure of its performance (11), for which strong test-retest repeatability has been achieved based on FFF measurements (11).

Cognitive emotion regulation (CER) ability is another important issue experienced after facing stressful and uncomfortable situations. This ability is defined as a set of cognitive processes through which people can deviate from the spontaneous direction of emotions to align their experimental, behavioral, and physiological responses. Besides being crucial in the field of mental health, this ability is also essential in terms of cognitive performance (12). As a result, improper management of emotions, stress, anxiety, and worries can affect executive functions, leading to a chain of wrong decisions, unsafe and incorrect actions, errors, and, finally, poor performance (13).

One of the most important tasks that has a high mental load is the control of power plants. Control room operators (CROs) experience a huge mental workload as their job demands multitasking, which can exert much pressure on them, even when reporting tasks (14, 15). Because of the complexity of systems and the importance of human-machine interactions in such workplaces, a simple mistake may lead to a big disaster. Therefore, the regulation of brain arousal and avoidance of brain fatigue are necessary to reduce human error.

2. Objectives

Based on the above-mentioned, this study aimed to investigate whether emotionally-loaded visual stimuli can alter brain arousal (brain fatigue) or not. This question was examined by FFF to test brain arousal before and after facing emotionally-loaded stimuli.

3. Methods

3.1. Cognitive Emotion Regulation Questionnaire

The Cognitive Emotion Regulation Questionnaire (CERQ) is one of the valuable tools for assessing CER ability. This tool was developed to highlight CER strategies when encountering stressful life events. The short form of this questionnaire has 18 questions, assessing nine subscales, each of which is assessed by two questions.

These subscales include self-blame, other-blame, focus on thought/rumination, catastrophizing, putting into perspective, positive refocusing, positive reappraisal, acceptance, and refocus on planning. While the subscales of positive refocusing, positive reappraisal, acceptance, and refocusing on planning are more adaptable coping strategies, self-blame, other-blame, focus on thought/rumination, and catastrophizing are less adaptable (16).

Responses to these nine subscales are scored based on a five-point Likert scale ranging from 1 (never) to 5 (always). The lowest and highest scores in each subscale are 2 and 10, respectively. Based on the number of questions, a higher score indicates that the individual uses the cognitive strategy more effectively. Because no cut-off point has been defined for this questionnaire, the difference between the scores of adapted strategies (appropriate) and non-adapted strategies (inappropriate) was used to distinguish appropriate and inappropriate groups in terms of CER ability. Higher scores were used to determine the dominant strategy (17).

3.2. International Affective Picture System

The International Affective Picture System (IAPS) is used to provide the ratings of effects for a large set of emotionally-evocative, internationally-accessible, color photographs including content across a wide range of semantic categories (18). This system is a pool of pictures whose arousal and valence are defined, so researchers can select the desired pictures that represent joy, fear, etc. In this study, different blocks of pictures were used to trigger emotions. There were five emotional blocks that were repeated twice, so a total of 10 emotional blocks with neutral blocks were obtained. Each block contained 13 pictures taken from IAPS. The characteristics of each block were defined as (1) high arousal and positive valence; (2) high arousal and negative valence; (3) low arousal and positive valence; (4) low arousal and negative valence; and (5) medium arousal and neutral valence, as emotionally-loaded stimuli; and (6) low arousal and neutral valence as neutral stimuli. In total, 164 pictures were selected from IAPS to induce emotions. For each emotional picture, five seconds, and for each neutral picture, 10 seconds were dedicated, so the total time of display was 1500 seconds (25 minutes).

Participants were exposed to emotional stimuli in a room with a computer workstation that was perpendicular to a window. The participants were asked to sit in front of the monitor and try to focus on each picture.

3.3. Flicker

The flicker fusion frequency, also known as critical flicker fusion or flicker fusion threshold, is defined as the frequency at which an intermittent light stimulus appears to be completely steady to an average human observer.

The frequency at which flickering light can be perceived as continuous is known as the critical flicker fusion frequency (CFFF), which is used to evaluate how well temporal vision is processed. The crucial flicker fusion threshold (or threshold for flicker fusion (TFF)) represents the maximum speed of flickering light that can be perceived by the visual system as the upper limit of one's visual processing ability. Accordingly, TFF is used as a functional index of cerebral nervous system (CNS), which is described as alertness and cortical arousal in humans due to its effectiveness in detecting rapid changes (19). Based on its relation to the CNS system, TFF can be a measure of brain fatigue or brain arousal, which is a very important factor linked with human error and performance in industries.

Also, RT-961 was used to assess participants' FFT. This part of the study was conducted in a completely dark room. The subjects were asked to sit in front of the machine. When the subjects were ready to start, the test was run by the researcher. The subjects were then asked to inform the researcher whenever they perceived a change in the light source. The frequency of the device was changed, and when the subjects verbally gave feedback on understanding the change under light, the response frequency was recorded. This test was repeated 20 times, and the average of the highest scores was reported as the final result.

3.4. Participants

Twenty CROs from Fars Combined Cycle Power Plant were recruited in this study. In this plant, operators in the central control room work in four equally long shifts (A, B, C, and D). The operators had to work in a 12/48 work/rest schedule. Having at least 24 years of age and four years of work experience was the inclusion criterion. Self-reported psychological disorders (drug users) and history of neurosurgical operations were the exclusion criteria. The participants took part in the research voluntarily. Over nearly 20 years, IAPS has been used as a collection of emotional pictures and one of the most commonly used pools for visual stimulations worldwide (2).

3.5. Procedure

The purpose of the study was explained to CROs, and they voluntarily participated in this research. Furthermore, the participants were informed that they could leave the study at any time they wanted. On the same day, the questionnaires were given to the CROs in their workplace and then were collected. Only this phase of the study was conducted in the control room. The other phases of the study were conducted at the DANA brain health institute. All participants completed a consent form after attending the laboratory. Also, this study was approved under the ethical codes of IR.TUMS.SPH.REC.1398.003 (link: www.tums.ac.ir/ IR.TUMS.SPH.REC.1398.003) by Tehran University of Medical Sciences and IR.SUMS.REC.1398.1026 (link: www.sums.ac.ir/ IR.SUMS.REC.1398.1026) by Shiraz University of Medical Sciences. The participants should have slept well the night before attending the laboratory and avoided consumption of alcohol, coffee, and tea and smoking cigarette. All the experiments were performed between 9 and 12 a.m. First, brain arousal via FFF was recorded in a dark room, as described before. Next, the participants were admitted to the room with a computer workstation to face emotional stimuli. Finally, after demonstrating the pictures, the brain arousal of the participants was recorded again.

Finally, SPSS 16 software was used for statistical analysis. In this regard, the Shapiro-Wilk test was used for assessing the normality of data. A significance level of less than 0.05 was considered, and the results were reported as mean and standard deviation for quantitative variables using tables. Correlation between variables was also investigated using Pearson's test.

4. Results

A total of 20 male subjects were selected and included in the experiment, whose age and work experience (both in years) were 39.55 ± 7.02 and 14.85 ± 6.77, respectively. The mean of sleep hours at the night before the test was 6.9 ± 1.51. Moreover, 30% of the participants were selected from shifts A, C, and D, and 10% from shift B. Table 1 presents the demographic data of the subjects.

Table 1. Demographic Parameters

Parameters	Mean ± SD
Age (y)	39.55 ± 7.02
Work experience (y)	14.85 ± 6.77
Hours after shift	40.36 ± 22.79
Sleep the night before the test (h)	6.9 ± 1.51

The first recorded FFF was 42.48 ± 3.66, and the second one was 42.10 ± 3.91. The comparison of these two mean values indicated no significant difference (P = 0.34).

There was a significant positive correlation between the first and second FFTs (r = 0.891, P = 0.000). Moreover, age had a negative correlation with the first and second FFTs (-0.125 and -0.066, respectively), but these values were not significant (P = 0.601 and P = 0.789). The same was true for job experience and sleep hours at the night before the test. Table 2 shows the results of correlation analysis.

Moreover, the data were analyzed using CERQ scores and according to the characteristics obtained via CERQ. Then the independent sample t-test was used to compare the FFF results between the appropriate and inappropriate groups, showing no significant differences between these groups (Table 3).

The results of correlation between the variables in the appropriate and inappropriate groups have been presented in Tables 4 and 5, respectively.

5. Discussion

Flicker fusion frequency has rarely been used to explore brain arousal after facing emotionally-loaded visual stimuli in CROs and individuals with appropriate and inappropriate abilities in CER. When CROs are in the workplace, many different types of emotional stimuli may make them happy, sad, angry, etc. All of the emotional stimuli can have an inevitable effect on performance in the workplace. Therefore, the ability to maintain optimal performance despite different emotional stimuli is a matter of concern, especially in workplaces with a high mental demand. Of course, emotional stimuli can lead to higher performance levels (20), but the extent and scope, diversity, and some other parameters are not clear. In this study, a mixture of positive, negative, and neutral pictures with different arousal levels was used as emotional stimuli. Moreover, the total exposure time was about half an hour. In real life, there might be a mixture of stimuli with a variety of exposure time intervals. However, the results of this study indicated that CROs could maintain their brain arousal at an appropriate level.

It is common knowledge that emotions affect a person's capability to perform a particular task (3). However, regardless of whether an emotion is pleasant or unpleasant, the human amygdala appears to alter the intensity of the conscious recall of experiences with emotional relevance (6). Furthermore, we did not observe any significant difference in FFF before and after facing emotional stimuli, neither in the appropriate and inappropriate groups nor in general (without considering the differentiation factor). Some studies have reported opposite results regarding the link between stimuli and FFF, indicating that intermittent sounds with varying frequencies have an intersensory effect on CFFF (21), which is different from the results of the present research. This discrepancy may be because of CROs' cognitive abilities that enable them to enhance their skills to cope with difficult situations. Moreover, it should be helpful to expand this research based on CER ability and emotionally-loaded visual stimuli in the period when the subjects are exposed to pictures or any other stimuli.

The findings of previous studies suggest that different cognitive abilities are negatively impacted by sleep deprivation, suggesting a role for sleep in emotional regulation. Overall, sleep deprivation for one night makes it more likely for healthy participants to perceive emotionally neutral stimuli as unpleasant (22). However, in our research, there was no significant correlation between FFF results and sleep hours at the night before the test and hours after shift. The only significant link was the negative correlation of "hours after the shift" with age and work experience.

Our results demonstrated that CROs with appropriate or inappropriate CER abilities could properly manage their brain arousal and mental fatigue. Based on the results of previous studies, emotion regulation is crucial for coping

Table 2. Correlation Between the First and Second Flicker Fusion Frequency and Demographic Data

Parameters	1	2	3	4	5
1. Age (y)					
2. Work experience (y)	0.937 [a]				
3. Hours after shift	-0.359	-0.403			
4. Sleep the night before the test (h)	0.218	0.331	-0.103		
5. First flicker fusion frequency	-0.125	-0.109	-0.187	-0.191	
6. Second flicker fusion frequency	-0.066	-0.091	-0.286	-0.062	0.892 [a]

[a] Correlation is significant at 0.01 level.

Table 3. The First and Second Flicker Fusion Frequency in the Appropriate and Inappropriate Groups

Flicker Fusion Frequency	Mean ± SD	P-Value
First Flicker Fusion Frequency		
App. [a]	42.15 ± 3.90	0.694
Inapp. [b]	42.82 ± 3.59	0.695
Second Flicker Fusion Frequency		
App.	41.96 ± 3.98	0.870
Inapp.	42.26 ± 4.07	0.871

[a] Appropriate group (cognitive emotion regulation)
[b] Inappropriate group (cognitive emotion regulation)

with stressors and can also be influenced by stress. Additionally, mixed evidence shows that stress can positively or negatively affect CER depending on stress timing, sex, or emotion regulation strategies. Stressed men have better cognitive regulatory engagement, which ultimately may lead to better emotion regulation outcomes (8). These notions can explain our results since all CROs studied here were men and, therefore, able to manage the situation properly.

In this study, we did not find any significant link between FFF and age, which is in line with other studies that suggest although adults of different ages exhibit various responses to negative stimuli, similar responses to various emotions can be found in each age group (23).

Physical fatigue has a significant impact on decision-making, especially when doing effortful tasks. Previous studies have shed light on how fatigue increases the subjective value of effort (i.e., making it more costly) (24). Contrary to the complicated situation faced in control rooms, no significant relationship between FFFs in our participants after their encountering stimuli can be due to the fact that they had proper resting before taking part in this study.

5.1. Limitations

The recruitment of only male participants can be mentioned as a limitation of this study. In fact, we could not recruit female participants in this research. Moreover, because of special circumstances, performing all the tests in the control room was impossible, so we had to invite operators to our brain health institute.

5.2. Conclusions

In summary, CROs seemed to be able to maintain their brain arousal appropriately after facing emotional stimuli, especially when the intervention was no longer than 30 minutes. Considering the prolonged working hours in such industries (roughly over eight hours a day) and the importance of cognitive aptitude in preventing work-related errors, we propose this line of research to gain momentum. Although improving CER and maintaining brain arousal at a proper level are crucial, CROs working at Fars Combined Cycle Power Plant were able to manage emotional stimuli during their work shifts, at least when the duration of exposure to stimuli was about half an hour.

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Footnotes

Authors' Contribution: Zahra Ghanbari: Data acquisition, data analysis, and data interpretation, drafting of the manuscript; Seyyed Abolfazl Zakerian: Study supervision, critical revision of the manuscript for important intellectual content; Alireza Choobine: Study supervision, critical revision of the manuscript for important intellectual content; Mohammad Nami: Concept and design, administrative, technical, and material support; Faramarz Gharagozlou: Statistical analysis

Table 4. Correlation Between the First and Second Flicker Fusion Frequency in the Appropriate Group

Flicker Fusion Frequency	1	2	3	4	5
1. Age (y)					
2. Work experience	0.912 [a]				
3. Hours after shift	0.179	0.76			
4. Sleep the night before the test (h)	-0.064	0.069	-0.359		
5. First flicker fusion frequency	-0.294	-0.220	-0.052	0.216	
6. Second flicker fusion frequency	-0.095	-0.070	-0.285	0.494	0.881 [a]

[a] Correlation is significant at 0.01 level.

Table 5. Correlation Between the First and Second Flicker Fusion Frequency in the Inappropriate Group

Flicker Fusion Frequency	1	2	3	4	5
1. Age (y)					
2. Work experience (y)	0.959 [a]				
3. Hours after shift	-0.685 [a]	-0.705 [a]			
4. Sleep the night before the test (h)	0.419	0.508	0.284		
5. First flicker fusion frequency	-0.011	-0.006	-0.349	-0.591	
6. Second flicker fusion frequency	-0.044	-0.102	-0.304	-0.619	0.905 [a]

[a] Correlation is significant at 0.01 level.

Conflict of Interests: None was declared by the authors.

Data Reproducibility: The dataset presented in the study is available on request from the corresponding author during submission or after publication. The data are not publicly available due to ethical issues and privacy.

Ethical Approval: This study was approved by the ethics committee of Tehran University of Medical Sciences under the ethical code IR.TUMS.SPH.REC.1398.003 (www.sums.ac.ir/IR.TUMS.SPH.REC.1398.003) and Shiraz University of Medical Sciences under the ethical code IR.SUMS.REC.1398.1026 (webpage: IR.SUMS.REC.1398.1026).

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Informed Consent: All participants completed a consent form after attending the laboratory.

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