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A Pattern of Brain Waves in Response to Induced Stress with Different Cognitive Readiness

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Abstract

Introduction: Many unpredictable situations require the use of cognitive and emotional resources, but stress prevents adaptation to the situation and cognitive readiness claims to create this adaptation. Therefore, the aim of this research is to compare the brain wave patterns with different cognitive readiness in two situations with and without stress.

Method: The present research is of a causal-comparative that the statistical population included military personnel, who volunteered to participate in the research. The participants included 42 people who were placed in two groups of low and high cognitive readiness. The level of cognitive readiness of all people was done using situation simulation and Virtual Reality. The electroencephalography of subjects was recorded in two situations. Data were analyzed using the MANCOVA test.

Results: Brain waves have significant differences between the two groups, and the intensity of the waves in the group with low cognitive readiness is more than the other group, which shows brain activity to react to stress in the group with low cognitive readiness is more than the other group ($p<0.01$).

Conclusion: Physiological and neurological indicators can be considered important for military applications. This is because finding physiological characteristics with sufficient accuracy can be reliable evidence for selecting military personnel or checking the effectiveness of psychological.

Keywords: Electroencephalography, Brain, Psychological Stress

Introduction

The world armies have a common saying that "the most predictable thing in military situations and operations is their unpredictability" [1]. The current military operational environment has become highly complicated, and this complexity has been created for various reasons, such as rapid developments and technology expansion, the dispersion and independence of military units, the interdependence and internal dependence of employees, and the existence of asymmetric threats [2]. The experience of stress has permeated our civilian and military workforce and is fueled by unrealistic expectations and incessant demands for optimal performance. The ability to maintain unit readiness and mission effectiveness in the midst of increasing technological demands ultimately depends on the skillful application of internal and external resources for coping with a variety of stressors. Therefore, in this regard, the most valuable skill or characteristic for human resources is cognitive readiness, which allows them to transfer their learning from one system or situation to another system or condition without the need for retraining [3]. Cognitive readiness is a mental preparation with skills, knowledge, abilities and motivations that can be created in a person so that the mentioned person can maintain his/her desired performance in the complex and unpredictable environment of modern military operations [4]. Cognitive readiness focuses on quick, realistic and satisfying decisions that are made in response to experienced transformation-based patterns in complex, critical and risky situations with uncertain and often multiple goals [3]. This state is achieved when all elements of cognitive readiness are used. Knowledge, skills and insights (KSA) are the high-level elements of cognitive readiness. These elements are assumed to cause individual differences in response to ambiguous situations [5].

On the other hand, many unpredictable and ambiguous situations that require adaptation have not only cognitive requirements (such as what is needed in decision-making) but also critical emotional requirements. Some conditions may need less cognitive resources and more emotional ones. In other words, although there are still some levels of cognitive requirements in such situations, the task process can include an emphasis on the individual's readiness to call on emotional resources. Therefore, one of the emotional states that people feel in these conditions is stress [6].

The performance of quality soldiers can be affected by various personal, situational, and organizational factors, particularly within dynamic and stressful environments. While there are certainly numerous societal contributors to military stress, such factors are not, for a multitude of reasons, directly amenable to change. Therefore, individuals must adapt to these diverse and often rapidly shifting environments by applying effective coping strategies to mitigate the effects of stress. Lazarus and Folkman have defined stress as a state that occurs when stressful factors (environmental or social) exceed a person's adaptive resources. According to their assessment, in addition to the variety of stressful factors (i.e. their type and intensity), some other factors such as individual differences in personality, stress perception, experience and environmental expectations are also considered important [7]. In this regard, the general research results indicate that the reaction to stress and its intensity can affect people's cognitive and skill performance; as with the increase in stress intensity, a weaker performance will be observed [8].

Since unpredictable situations can cause high stress and on the other hand, individual differences in reaction to perceived stress can cause different amounts and levels of stress. Therefore, it is possible that every person feels a certain intensity of stress in the same unforeseen circumstances and reacts to them [9]. In contrast, the Cognitive readiness theories claim that stress can be controlled with some solutions in the form of different cognitive and emotional dimensions, managing the emergency or crisis, maintaining emotional control and focusing on the current situation [6]. These preparations require some solutions that involve bearing a large amount of the cognitive and emotional reactions burden. In fact, cognitive readiness claims that stressful situations may require bearing more emotional burden than a cognitive burden, but people with high cognitive readiness can create different implicit meanings for the used characteristics and strategies of the situation, leading everything to a more predictable situation, and as a result, reduce the stress [10, 11].

On the other hand, it should be mentioned that most neuroimaging studies determine the brain's cognitive roles by performing statistical analysis among people and identifying common areas of activity. Understanding the differences in how to perform cognitive tasks is essential for armies and is often used to understand the responsiveness of individuals and describe the mental characteristics of efficient soldiers and officers [12].

In this regard, it should be mentioned that the brain's electrical activity (which is measured by Electroencephalography (EEG) signals) indicates an asynchronous pattern during stress and strong emotional emotions (such as fear) and the frequency of beta waves. In a state of calmness without any fear, the EEG waves include the activity of alpha waves. Although the basic mechanisms of EEG generation are not fully understood, the interaction between thalamic networks and the brain cortex plays a crucial role in various EEG activities [13]. Also, the thalamus is especially mentioned as a critical factor in producing alpha and beta waves. Likewise, the interaction between cortico-cortical and thalamocortical nerves during information processing has been assumed to include the production and creation of higher frequency vibrations and beta waves. In particular, the thalamus also consists of the production of delta waves (frequency 1-4 Hz), which may be caused by the interaction between the deep layers of the cortex (cortex) and the thalamus, which are usually inhibited by afferent nerves from the ascending network activation system. It should also be mentioned that the hippocampal system and different limbic system areas include the production of theta vibrations [14]. Therefore, it can be seen that brain waves during stress are different from normal conditions in terms of frequency and place of production.

According to what was said, cognitive readiness can control stress and ambiguity levels so that a person can perform at an optimal level, and on the other hand, the frequency of brain waves is different in different conditions. Therefore, the current research question is: what pattern of brain waves do people with different cognitive readiness show in response to the same perceived stress?

Method

The current study has used a comparative causal method, and its statistical population is one of Tehran's military organs' personnel who volunteered to participate in this research in early May 2022. The participants included 42 people in two low and high cognitive readiness groups (23 and 19 people, respectively) [15]. In this cognitive readiness study, the participants must have been between 30 and 40 years old (to control the factors of experience, educational qualification and military rank). Also, the self-report form and a clinical interview confirmed participants' mental and physical health. In addition, not using psychiatric drugs such as antidepressants, anti-anxiety medications, barbiturates, and antiepileptic drugs were among the other criteria which led to participants' exclusion from the study.

The subjects were informed about the purpose, the result and the output of the research and a written consent were obtained from each of them.

The tools used in this study were as follows:

Cognitive Readiness Test: This test is based on O'Neill et al. The cognitive readiness theory [16] has been developed by Muñoz et al. [17] in 2021. This computer test measures a person's cognitive abilities in simulated situations. To do so, Virtual Reality (VR) is used, and a software examines the person's performance in a simulated military situation and reports their cognitive readiness level. This test has been reported to have construct validity between 0.63 and 0.79 and test-retest reliability of 0.89. Cronbach's alpha in the present study was equal to 0.71.

Recording of EEG signals: EEG is a mathematical and quantitative method that is used to process electroencephalograph signals. Fourier transforms used in this method to analyze the signals and compare normative data to estimate the functioning level of each wave or frequency at each point of the brain. In this study, a 19-channel, 250 Hz sampling rate and a frequency range of 0.5 to 70 Hz made In Russia by Medicom Company was used to record EEG. NeuroGuide software (version 2.9.2; 2017) was used for artefact removal and EEG data analysis. The obtained EEG waves from this study were calculated as theta (4-8 Hz), alpha (8-13 Hz) and beta2 (20-30 Hz), delta (4-0.5 Hz) and SMR (13-15 Hz). The brain's frontal, temporal and temporal regions were used to record the waves.

Creating Stress: Four stages were considered to develop stress. First, the person is asked to talk about the stressful event that he/she experienced in his/her life. In the second stage, stressful cognitive tasks are used because the induction of stress does not have harmful side effects, and it has been proven that they are psychologically stressful [18]. While talking, the participants' skin conductance and diastolic blood pressure were measured every three seconds to check the reliability and validity of this set of assignments regarding skin conductance level and blood pressure compared to baseline. According to the calculations of the MANOVA matrix, there was a meaningful difference in the measurements of skin conductance level and blood pressure compared to the baseline values. The mental analysis is provided after a 10-minute rest period to perform this test. At first, the sentence association stage begins. In this process, three categories of five sentences with threatening content (aggressive, dependent and competitive) were shown to the participant; each sentence was written on a card. The subject was told: "I will show you some cards with a printed sentence on each one. Please read each sentence aloud, then say the first thing that comes to mind. After showing each category, the next stage, i.e., the subject acceptance test, is presented. The cards numbered GF18, GF8, BM8, 10, 15 and 2 were shown separately and based on the test instructions, the subjects had to make a story for each card. In the end, the matter must subtract 13 by 13 consecutively from the number 609 within a minute. This assignment emphasizes the speed and accuracy of the performance and is described as a mental ability test for the subject. The subject was asked to do his/her best. Regardless of the subject's performance, after 15 seconds, he was asked to perform faster [19].

The conducting method of the present research is that, at first, each subject takes the cognitive readiness test and is placed in one of the four categories according to the acquired score. After that, a 15-minute rest time was given to each person, and the baseline EEG was recorded during the rest of the time. Then the cognitive stress induction process was performed, and while the person had reached the last stage of stress induction, the EEG was recorded under stress.

Brain activity was compared before and after stress induction by using the installed NeuroStat toolkit on NeuroGuide (version 2.3.8; 2007) and multivariate analysis of variance (MANOVA) test.

Results

The participants included 42 people who were placed in two groups of low and high cognitive readiness (23 and 19 people, respectively) by the cognitive readiness test. The mean and standard deviation of their ages were 37.76 (6.9) and 37 (5.72), and no significant difference was observed in this respect. The following table shows the average absolute power of the frequency ranges in microvolts:

Table 1 shows that there is a difference in the average absolute power of the frequency ranges, which MANCOVA will be used for further investigation. In order to check the assumptions of the research, the correlation of the variables of the QEEG scale in the pre-test and post-test showed that all the correlations had values less than 0.85, and as a result, the existence of a multiple common linear relationship between the scales is not confirmed. Also, in order to check the assumptions of homogeneity of the regression lines of the interaction between the group and the covariate variable, the results showed that this interaction is not significant for any of the variables and the considered assumptions were confirmed. Levine's test was used to check the homogeneity of variance of the two groups, which was not significant in any case, and the hypothesis was confirmed. As a result, MANCOVA can be used. The effect of the group was statistically significant, which shows that there is a significant difference between the groups (Wilks Lambda=0.38; F=5.96; p=0.001).

The above table shows that regardless of covariate variable, only SMR waves in all areas haven't significant difference. On the other hand, by controlling the pre-test scores, it was seen that delta waves in all brain lobes, alpha waves in the frontal and beta waves in the temporal lobe show a significant difference. Meanwhile, the changes in brain waves in the comparison between the two groups show that delta waves in all lobes, theta waves in the temporal lobe, alpha waves in the frontal and parietal lobes, and SMR waves in the frontal and temporal lobes have significant differences. According to Table 1, it can be stated that the intensity of waves in the group with low cognitive readiness is more than the group with high cognitive readiness.

Table 1. Average Absolute Power of Frequency Ranges in Microvolts

			High cognitive Reediness		Low cognitive Reediness	
Location	Variable	Phase	M	SD	M	SD
Frontal	Delta	rest	17.37	9.22	16.52	11.63
		stress	20.02	6.97	37.07	17.06
	theta	rest	14.16	17.18	12.51	15
		stress	14.32	9.12	27.54	12.02
	Alpha	rest	19.19	16.24	17.28	19.63
		stress	22.23	15.8	31.92	18.48
	SMR	rest	4.09	2.03	5.5	3.45
		stress	5.38	2.18	4.27	1.44
	Beta2	rest	2.59	1.68	2.12	1.48
		stress	2.27	1.41	1.63	0.58
Temporal	Delta	rest	19.35	11.39	16.22	6.52
		stress	16.81	6.33	36.53	13.29
	theta	rest	14.78	13.15	16.67	13.83
		stress	14.88	8.34	30.36	12.26
	Alpha	rest	24.71	19.53	26.81	13.55
		stress	24.74	16.28	38.21	19.33
	SMR	rest	5.62	2.84	6.81	3.55
		stress	6.94	2.93	4.79	1.65
	Beta2	rest	4.58	5.04	3.44	3.47
		stress	3.72	4.94	1.98	1.04
Parietal	Delta	rest	19.57	10.11	13.91	20.94
		stress	20.85	13.19	39.83	12.49
	theta	rest	15.89	12.48	16.56	14
		stress	16.78	11.55	34.59	17.05
	Alpha	rest	46.59	38.59	42.40	17.3
		stress	50.73	36.82	61.79	23.2
	SMR	rest	6.68	2.98	6.98	3.79
		stress	8.17	5.35	5.42	1.95
	Beta2	rest	3.22	2.02	2.14	1.61
		stress	2.12	1.17	1.93	1.23

Discussion

The present study was conducted to investigate the changes in the brain wave pattern of people with different cognitive readiness in two situations rest time and under stress. The results indicated that delta, theta, and SMR waves have significant differences between the two groups in the two considered situations and the wave intensity of the group with low cognitive readiness is more than the group with high cognitive readiness, which shows that the brain activity and pressure react more to stress in the group with low cognitive readiness. To explain the present findings, it should be stated that reactivity to stress is considered a characteristic that includes the basis of individual differences in physiological and psychological responses to stress. In other words, the biological-psychological concept of reactivity to stress explains the unique differences between stress and performance. In general, in line with the findings of previous studies, it shows that there is a negative relationship between perceived stress and cognitive performance [3, 8].

It should be noted that in this study the outputs were extracted. In the case of subjects with high cognitive experience, the EEG result was normal on alpha while they were mentally calm enough to cope with situations. However, these same people are in danger. Their focus was on the stage as their stress levels rose, shifting them from alpha to beta. In low diagnostic test subjects, their EEG results showed alpha for normal conditions but beta for stress. In other words, they can adapt to predictable conditions, but are unable to show beta in critical conditions. Also, their beta frequency was higher than the baseline frequency in some situations. In the case of low-level subjects, the EEG results show that if stress increases, it is probably due to frustration, or information processing disorders. Since unpredictable situations can cause high stress, and on the other hand, individual differences in reacting to perceived stress can cause different amounts and levels of stress, it is possible that every person in the same unforeseen circumstances understands a certain intensity of stress and reacts to it. On the other hand, cognitive readiness can control situational stress by providing solutions in the form of different cognitive and emotional dimensions, managing emergency or crisis situations, maintaining emotional control, maintaining objectivity during crisis conditions, and maintaining focus on the current situation [6]. Such preparation requires providing solutions that bear many cognitive and emotional burdens. In fact, cognitive readiness claims that although stressful situations may require bearing more emotional burden than a cognitive burden, people with high cognitive readiness can create different implicit meanings for the characteristics and strategies of the situation and move the situation towards a more predictable one so that the stress can be reduced [3].

Table 2. Result of MANCOVA

	Variable	SS	df	MS	F	P	η^2
Intercept	frontal delta	1797.74	4	449.43	2.96	0.06	0.47
	temporal Delta	2098.14	4	524.53	5.96	0.006	0.64
	parietal delta	2226.94	4	556.73	3.56	0.036	0.52
	frontal theta	1360.66	4	340.16	3.7	0.03	0.53
	temporal Theta	1634.81	4	408.7	3.75	0.01	0.59
	parietal theta	2961.21	4	740.3	5.7	0.007	0.63
	frontal Alpha	4179.28	4	1044.82	15.49	0.001	0.82
	temporal Alpha	4409.79	4	1102.44	10.21	0.002	0.75
	parietal alpha	11962	4	2990.5	10.07	0.001	0.75
	frontal SMR	38.7	4	9.67	5.14	0.1	0.61
	Temporal SMR	53.41	4	13.35	2.72	0.076	0.45
	parietal SMR	134.96	4	33.73	2.38	0.1	0.42
	Frontal beta	15.53	4	3.88	7.38	0.002	0.69
	Temporal beta	200.41	4	50.1	16.01	0.001	0.83
	parietal beta	10.62	4	2.65	2.7	0.07	0.45
Covariate	frontal delta	44.54	1	44.54	50.02	0.001	0.86
	temporal Delta	413.25	1	413.25	14.7	0.001	0.15
	parietal delta	256.86	1	256.86	1.74	0.001	0.21
	frontal theta	16.857	1	16.857	0.18	0.67	0.01
	temporal Theta	31.08	1	31.08	0.36	0.55	0.02
	parietal theta	3.72	1	3.72	0.03	0.68	0.002
	frontal Alpha	1458.49	1	1458.49	21.62	0.001	0.62
	temporal Alpha	9.92	1	9.92	0.09	0.76	0.001
	parietal alpha	1820.99	1	1820.99	6.13	0.02	0.32
	frontal SMR	2.16	1	2.16	1.15	0.3	0.08
	Temporal SMR	4.59	1	4.59	0.93	0.35	0.06
	parietal SMR	27.41	1	27.41	1.94	0.18	0.13
	Frontal beta	1.47	1	1.47	2.8	0.11	0.17
	Temporal beta	129.68	1	129.68	41.45	0.001	0.76
	parietal beta	1.54	1	1.54	1.57	0.23	0.1
Group	frontal delta	1647.83	1	1647.83	10.78	0.006**	0.38
	temporal Delta	1817.55	1	1817.55	20.67	0.001**	0.66
	parietal delta	1947.52	1	1947.52	12.45	0.004**	0.41
	frontal theta	174.81	1	174.81	1.92	0.18	0.12
	temporal Theta	275.2	1	275.2	3.22	0.04*	0.09
	parietal theta	182.3	1	182.3	1.4	0.25	0.32
	frontal Alpha	428.83	1	428.83	6.35	0.02*	0.11
	temporal Alpha	182.49	1	182.49	1.69	0.21	0.35
	parietal alpha	2094.02	1	2094.02	7.05	0.02*	0.18
	frontal SMR	9.43	1	9.43	5.01	0.04*	0.27
	Temporal SMR	24.2	1	24.2	4.93	0.04*	0.27
	parietal SMR	40.29	1	40.29	2.85	0.11	0.18
	Frontal beta	0.263	1	0.263	0.5	0.49	0.03
	Temporal beta	3.94	1	3.94	1.25	0.28	0.08
	parietal beta	0.13	1	0.13	0.13	0.72	0.01

In addition, individual sensitivities to threats at any time determine how a person perceives a potential threat and affects the actions he takes to defend against that threat. Since each person has different psychological characteristics, stressful situations may be perceived differently; therefore, if the brain perceives that event as a threat, the brain reacts automatically and defensively. Despite these individual differences, exposure to this uncertainty and other threats in a complex environment may lead to chronic stress for several team members. In chronic stress, the amygdala is strengthened, and as a result, the fear reaction and emotional reaction increase and the rate of false answers increases. If this was not enough, the activities of the prefrontal cortex, which plays a role in modulating the amygdala excesses, are slowed down, resulting in poorer decision-making, cognitive deficits, memory deficits and attention, and adversely affect the integrity and flexibility of the brain network, its ability to change and learn, and also physical and mental health [3].

It should be added that the alpha-theta protocol is used as an indicator of patients' stress and tension. Therefore, based on the conducted studies, it was expected to show a higher level of stress, tension, and restlessness after the stress induction of the alpha-theta protocol. However, the basis of the formation of cognitive readiness is to deal with the stress caused by an ambiguous situation, and through direct exposure to stressful experiences. Actually, a person tries to be in a state of theta dominance (a brain wave related to creative thinking) and to reduce the negative emotional load. A person with high cognitive readiness experiences the link between stressful experiences and a state of relaxation and uses crisis management skills by trying to cope with problems in the theta state. These steps are actually done by the brain first, and then the person becomes aware of it at higher stages. In more advanced stages, this process can reach unconscious experiences and solve conflicts and stressful experiences in the unconscious, similar to the process that occurs in psychotherapy [8]. The other dimension however is the changes observed in the SMR brain wave. The brain wave that neuropsychologists consider to be the motivational basis of the human psyche. This wave has a special role in physical relaxation, sensory-motor coordination, motivation and hope for life, and coordination and regulation of emotions [9].

Therefore, the increase in cognitive readiness and its activity becomes essential because it expresses the readiness to act at two levels of performance. The first level refers to the "routine" cognitive aspects of difficult situations. Therefore, this type of preparation can express an individual readiness to participate in evaluating the situation, analyzing it and problem-solving in familiar and routine missions. The second level of cognitive readiness is based on the first level, but it expresses the readiness to participate in cognitive processes under stress, which is more specific to adaptive performance contexts. This training shows the possibility of using this content in distinguishing between "normal" and "adaptive" expertise. Standard expertise refers to having the skill to recognize and apply the known rules, trends, and solutions to common problems. Adaptive expertise refers to the ability to understand when and why existing processes are no longer applicable to solving problems and that one must know how to adapt problem-solving strategies to new situations. This problem appears when a person does not know his/her duties to carry out orders in a stressful situation, and they may suffer human error, resulting in many costs.

It should be added that one of the limitations of the present study was the selection of participants among those who had job duties with moderate stress, but some job duties will have high stress, so the generalization of the present findings to that group should be made with caution. In this regard, it is suggested to choose people with different job duties for future research. Also, according to the research findings, it should be mentioned that military personnel will have specific responsibilities and tasks and must remain free from stress so that their services can be used for the benefit of the society. Thus, it is suggested to use different techniques and training to increase cognitive readiness to reduce stress.

Conclusion

According to the findings of the present study it can be stated that biomarkers and EEG can assess the relationship between cognitive readiness and performance in a critical situation. Also, these biological indicators are useful in evaluating individual diversity and their readiness in the field of education and research.

Conflict of Interest

The authors declare no conflicts of interest.

Ethical Approval

The present study has fully adhered to the standard ethical rules in research. Accordingly, an informed letter of consent was signed by all participants. They were ensured of the confidentiality of the information they provided.

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