ORIGINAL ARTICLE

Predicting Posttraumatic Growth in COVID-19 Patients Using Electroencephalogram Signals

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Abstract

Purpose: The present study aimed to investigate the quantitative pattern of brain waves with post-traumatic growth dimensions in patients admitted due to Coronavirus Disease (COVID-19). Post-traumatic growth is the mental experience of positive psychological changes caused by the individual as a result of coping with challenging situations.

Materials and Methods: In this study, 66 individuals with COVID-19 who were admitted to Baharloo Hospital in Tehran as a stressful event were selected by convenience sampling and completed a post-traumatic growth inventory (PTGI) and their brain waves in rest were recorded.

Results: The results showed that brain components are a good predictor of post-traumatic growth dimensions. Alpha-parietal, F3-Sensorimotor Rhythm (F3-SMR) and alpha asymmetry predicted new possibilities component, alpha-F3 and alpha asymmetry predicted relating to others component, F4-SMR predicted spiritual change component and alpha asymmetry significantly predicted the total post-traumatic growth score. Also, Quantitative Electroencephalogram (QEEG) components did not significantly predict the appreciation of life and personal strength component.

Conclusion: According to the results, it can be said that more objective instruments such as Electroencephalogram (EEG) have good predictive power in complex psychological and multidimensional cases such as post-traumatic growth. The results of this study confirm the hypothesis that post-traumatic growth may reflect a process of active struggle to achieve new goals and perspectives. Accordingly, especially the more guided dimensions of post-traumatic growth (e.g., the new possibilities dimension) may be associated with the asymmetry of the frontal lobe of the brain. In contrast, the dimensions of appreciation of life and personal strength were not predicted by the brain component; these two components were slightly more abstract than the others and may lead to more / less neural network activity in Functional Magnetic Resonance Imaging (fMRI) that is more observable.

Keywords: Electroencephalogram; Posttraumatic Growth; Trauma; COVID-19.

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1. Introduction

Undergoing trauma can have various pathological effects such as anxiety, Posttraumatic Stress Disorder (PTSD), insomnia, and behavioral problems such as suicide [1]. It is, therefore, the time to understand the situation of this crisis as a traumatic event. Although the majority are not affected, media coverage and the possibility of infection cause immense stress and anxiety [2, 3]. People are divided into four groups after experiencing a traumatic event. One group develops PTSD and shows disturbing symptoms following trauma, avoidance of trauma-related stimuli, and increased spontaneous arousal. The other group shows the same symptoms for less than a month and is diagnosed with acute stress disorder. Another group only shows the symptoms of post-traumatic stress, and the last group is the people who take a step further, psychologically speaking, and report the symptoms now known as Post-Traumatic Growth (PTG) [4, 5]. PTG is the experience of a positive personal change resulting from coping with a crisis or traumatic event; this does not neutralize the psychological experience of the trauma but allows the individual to find new meaning in life despite it. Achieve positive personal change in areas such as improved self-concept, interpersonal relationships, and philosophy of life. Overall, PTG happens in five areas: new possibilities (finding opportunities to do things I could not do), relating to others (understanding how people might be useful), personal strength (I can handle big problems), appreciation of life (I enjoy each day more than the day before), and spiritual change (I believe in God more) [6, 7]. The oldest study examined was that of people with advanced cancer, which considered their psychological responses in general and did not directly address post-traumatic growth. The onset of interest and research on PTG dates back to the mid-1980s and early 1990s, focusing on the psychological development of people with cancer [8].

The question arises as to whether growth after experiencing a stressful situation similar to the original stressful event [9] can affect the four domains of psychological, behavioral, interpersonal, and cognitive functions. In this regard, many researchers have examined the psychological dimensions [6] and interpersonal [10] and cognitive processes involved in PTG [11], but few studies have examined the brain's neural connections in individuals experiencing PTG [12]. However, research shows that PTSD is associated with patterns of brain dysfunction and cognitive impairment [13, 14]. Evidence from these studies suggests that theta activity in the frontal lobe of the brain is involved in identifying and monitoring the conflict. Mid-frontal theta waves also reflect the activity of the middle cortex of the cingulate, which is involved in anxiety and behavioral adjustment problems [15]. In people with PTSD, in addition to the physiological arousal and constant monitoring of the environmental stimuli associated with the trauma, the balance of the nervous system is disturbed. Decreased activity of theta in the brain's frontal areas impairs the individual's ability to process adaptive information in the form of executive functions. This condition is the main reason for applying the alpha-theta training neurofeedback protocol in stress-related disorders, which seeks to improve a person's cognitive processing power by increasing the theta firing and subsequently adjusting the alpha-to-theta ratio. The evidence, however, suggests that by improving this processing ability, the state of relaxation in the arousal system improves [16, 17].

Despite the examples of the above evidence for brain function patterns and cognitive impairments following stress and PTSD, these dimensions of PTG have not yet been studied in detail. Accordingly, the present study intends to use Electroencephalogram (EEG) instruments to assess whether individuals' brain function is related to growth components? EEG tools have already been used in cases such as stress and anxiety, and the present study will seek to investigate its applicability in the PTG position. If, in line with the previous findings, stress is associated with an increased beta wave, decreased theta wave performance, and alpha-theta ratio irregularity in the frontal lobe [15], can PTG and its components be related to these waves and their possible changes? Finally, considering the shortcomings of questionnaires in measuring growth after trauma [18, 19], we used EEG as our research tool.

2. Materials and Methods

2.1. Participants

The present research is fundamental due to increasing the awareness and knowledge about the psychological development after exposure to stressful events. The statistical population of this study included people aged 25 to 75 years who had been hospitalized in Baharloo Hospital due to Coronavirus Disease (COVID-19) as a result of stressful events during the last 3 months. The sample

size was determined using the G-Power software in proportion to the number of variables in this study and based on alpha value 0.05, test power value of 0.8, and the effect size of 0.35 [20].

2.2. Instruments

Post-Traumatic Growth Inventory (PTGI): This tool was designed in 1996 to assess the concept of PTG by Tedeschi and Calhoun in the United States. The questionnaire consists of 21 Likert-scale terms with a range of zero (I do not see this change as a result of the crisis) to five (I know this change as a result of the crisis to a great extent). This questionnaire has 5 subscales: new possibilities (5 items), relating to others (7 items), personal strength (4 items), appreciation of life (3 items), and spiritual change (2 items). Scores range from 0 to 105. A higher score indicates more PTG and a lower score indicates lower PTG. Translation and evaluation of the validity and reliability of this tool in Iran have been studied [21]. In this study, the internal consistency for the whole instrument was 0.95, and the internal consistency for the five dimensions ranged from 0.67 to 0.87.

EEG: The universal arrangement of electrodes, known as the 10-20 standard, was used. The name of the device used to record brain waves in the present study was "NrSign3840" (NrSign Inc., Vancouver, Canada) with 19 channels, database-2 assembly type, notch filter 45-55, a sampling rate of 500 Hz, and recording conditions were also in the closed-eye and open-eye states for 5 minutes each. For the Quantitative Electroencephalogram (QEEG) analysis, after recording brain waves, relative power in the theta, alpha, and SMR bands, and asymmetry on the channels F3, F4, Fz (as frontal areas), Cz (as central areas), and Pz (as Parietal areas) were compared.

2.3. Procedure

Sixty-six volunteer clients were randomly selected from patients admitted and recovered due to COVID-19 in Baharloo Hospital. After completing PTGI they became the second stage. Participation in the study did not incur any financial burden for the participants and the evaluation services were completely free. Also, this study did not contradict the religious and cultural norms of the subjects and society. This research with the code of ethics of IR.UT.PSYEDU.REC.1399.019 was approved by the ethics committee. Out of 66 volunteers admitted and recovered from COVID-19 in Baharloo Hospital who were selected in the first phase of the study, EEG recording was taken at rest. All EEG data were recorded from 19 channels using a special helmet placed on the head, while participants were asked to sit in a chair in a slightly dark room and not move or sleep while recording EEG. The duration of EEG was 15 minutes at a sampling rate of 500 Hz. Brain waves were recorded in two eyes-opened and eyes-closed positions for each of them at least five minutes. Considering that the EEG was recorded at the pandemic of COVID-19 disease, some points were considered; participants were evaluated for signs of COVID-19 before the EEG test. After installing the equipment, the distance between the technician and the participant was at least 2 meters. Participants were minimized, between each record, the room and various disinfectants and the room was ventilated for at least 10 minutes. According to the inclusion and exclusion criteria, the data of four participants were excluded from the study.

2.4. Data analysis

In the initial analysis of EEG data, preprocessing and signal processing were performed using MATLAB software. Then, descriptive statistics such as frequency, percentage, mean, and standard deviation were performed to investigate the objectives of the study, the method of ridge regression analysis was performed using R statistical software and SPSS version 20.

3. Results

The mean age of participants was 50.68 years (with a standard deviation of 11.65 and a minimum of 25 and a maximum of 75 years). None of the patients had a previous history of head trauma and an average of 4.76 weeks (with a standard deviation of 1.69 and a minimum of 3 and a maximum of 9 weeks) had passed since their recovery from COVID-19, the end of hospitalization, and a negative Polymerase Chain Reaction (PCR) test. The mean, standard deviation, minimum, and maximum age of the participants are presented in Table 1.

The mean, standard deviation, minimum, and maximum results of the subscales of the PTGI are shown in Table 2 . The results of quantitative analysis of patients' brain wave pattern (QEEG) can be seen in Table 3.

Table 1. Information on participants' demographic characteristics

Indicator	Level	Number	Percentage
Gender	women	29	46.8
	men	33	53.2
Marital status	single	12	19.4
	married	47	75.8
	divorced	3	4.8
Education	diploma	49	79
	bachelor	10	16.1
	master	3	4.8
Income	low and medium	55	88.7
	good	7	11.3
Dominant hand	right	56	90.3
	left	6	9.7
Physical illness	yes	30	48.4
	no	32	51.6
Mental illness	yes	11	17.7
	no	51	82.3
Substance use	yes	14	22.6
	no	48	77.4

It should be noted that the subjects' score on the QEEG refers to the relative power (amplitude) of a particular brain wave (frequency) in their EGG.

Table 2. Descriptive indicators of Post-Traumatic Growth Inventory (PTGI) subscales

Subscale	Mean	Standard Deviation	Minimum	Maximum
Personal strength	10.92	5.97	0	20
New possibilities	11.63	7.42	0	25
Relating to others	19.37	9.56	0	35
Appreciation of life	8.89	4.44	0	15
Spiritual change	5.84	3.65	0	10
Total	56.48	25.97	0	105

Due to the data conditions such as sample size limitation, high number of predictor variables and the existence of multiple alignments between predictor variables, ridge regression method was used to analyze the data. In this analysis, the data scores were standardized based on z

Table 3. Descriptive indicators of Quantitative Electroencephalogram (QEEG) subscales

Site	Band	Mean	Minimum	Maximum	Standard Deviation
Frontal	**theta**	**19.00**	**4.96**	**60.30**	9.56
	alpha	**20.91**	**5.47**	**59.78**	11.35
	SMR	**6.39**	**1.82**	**13.14**	2.28
	Alpha/theta	**1.24**	**0.10**	**3.59**	0.70
Central	**theta**	**17.82**	**6.10**	**79.42**	12.38
	alpha	**29.40**	**5.37**	**69.53**	16.89
	SMR	**7.29**	**1.31**	**14.14**	2.94
	Alpha/theta	**2.23**	**0.06**	**9.68**	1.95
Parietal	**theta**	**16.14**	**4.17**	**82.92**	13.14
	alpha	**38.74**	**5.13**	**81.83**	20.75
	SMR	**8.36**	**1.08**	**23.27**	4.87
	Alpha/theta	**3.77**	**0.06**	**18.74**	3.72
F3	**theta**	**17.45**	**2.88**	**9.64**	10.59
	alpha	**20.64**	**4.28**	**57.14**	11.58
	SMR	**7.65**	**1.52**	**52.65**	6.37
	Alpha/theta	**1.45**	**0.10**	**4.83**	1.01
F4	**theta**	**17.19**	**5.29**	**70.11**	10.40
	alpha	**25.16**	**5.39**	**60.53**	14.16
	SMR	**6.71**	**1.48**	**16.36**	2.71
	Alpha/theta	**1.75**	**0.09**	**5.34**	1.19
Asymmetry	alpha	108.04	81.07	135.02	57.04

scores, the convergence threshold was 0.001 and the number of multiple validation blocks was 10, taking into account the significance level of 0.05. Alpha-parietal, F3-SMR and alpha asymmetry predicted new possibilities component, alpha-F3 and alpha asymmetry predicted relating to other components, F4-SMR predicted spiritual change component and alpha asymmetry significantly predicted the total PTG score. Also, QEEG components did not significantly predict appreciation of life and personal strength component. Complete regression tables came in Table 4-8.

4. Conclusion

Beta 1 band shows different behaviors at different frequencies in different parts of the brain, and power increases in beta waves under stress or mental work [15, 22]. Increased beta-1 (SMR) activity has been observed in patients with post-traumatic stress disorder, especially in the forehead areas in the F3 channel [23]. Relative success in increasing SMR is positively correlated with improving attention function, and SMR training leads to increased inhibitory activity in the thalamic nuclei that interact with the motor-sensory cortex and improve cognitive integration of sensory input [24]. In this regard, in the present study, SMR-F3 predicted the component of new possibilities and SMR-F4 predicted the component of spiritual change. Also, under stressful conditions, the power of alpha waves decreases, which indicates a change in response to stressful conditions, and the results of the present study showed that the alpha-parietal predicted the component of new possibilities and the alpha-F3 predicted the relating to others. Researchers have been searching for biological markers of psychological adjustment to stress and trauma. Frontal asymmetry is an extensively studied EEG biomarker, pointing to hemisphere differences in alpha power. Forehead hemisphere asymmetry may be related to vulnerability to psychological pathology and not to the disorders themselves [25]. Forehead asymmetry has long been considered a promising indicator of psychological resilience and vulnerability to psychological pathology. Psychological well-being has recently been introduced and has been described as understanding the engagement with existential challenges in life, such as pursuing meaningful goals, developing as an individual, and building quality relationships with others [26]. The tendencies of a purposeful approach (e.g., challenging oneself and striving to achieve it in the face of adversity) reflected by left frontal activation [27] may be important for achieving psychological well-being. PTG represents

Table 4. Ridge regression results of quantitative pattern of brain waves in predicting new possibilities

Variable	Subscale	B	Beta	Standard error	t	Significance level
Pz	alpha	0.006442	1.044100	0.513	2.033	0.04
F3	SMR	0.027833	1.385657	0.704	1.968	0.04
Asymmetry	alpha	-0.003553	-1.583189	0.690	2.291	0.02

Table 5. Ridge regression results of quantitative pattern of brain waves in predicting relating to others

Variable	Subscale	B	Beta	Standard error	t	Significance level
F3	alpha	-0.086419	-7.821632	3.817	2.049	0.04
Asymmetry	alpha	-0.025286	-11.266235	5.226	2.155	0.03

Table 6. Ridge regression results of quantitative pattern of brain waves in predicting spiritual change

Variable	Subscale	B	Beta	Standard error	t	Significance level
F4	SMR	0.017281	0.367022	0.179	2.045	0.04

Table 7. Ridge regression results of quantitative pattern of brain waves in predicting total Post-Traumatic Growth Inventory (PTGI) score

Variable	Subscale	B	Beta	Standard error	t	Significance level
Asymmetry	alpha	-0.004553	-2.028889	0.964	2.104	0.03

Table 8. Significant levels of Pearson's Correlation between the components of post-traumatic growth and brain waves

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1. personal strength																											
2. new possibilities	0.00																										
3. relating to others	0.00	0.00																									
4. appreciation of life	0.00	0.00	0.00																								
5. spiritual change	0.00	0.00	0.00	0.00																							
6. total PTGI	0.00	0.00	0.00	0.00	0.00																						
7. theta F3	0.95	0.39	0.99	0.21	0.46	0.56																					
8. alpha F3	0.31	0.32	0.16	0.07	0.52	0.15	0.70																				
9. SMR F3	0.66	0.04	0.17	0.19	0.36	0.77	0.01	0.53																			
10. alpha/theta F3	0.33	0.82	0.23	0.61	0.47	0.36	0.00	0.00	0.00																		
11. theta F4	0.52	0.41	0.46	0.17	0.17	0.28	0.00	0.71	0.23	0.00																	
12. alpha F4	0.88	0.23	0.82	0.82	0.93	0.85	0.90	0.00	0.37	0.00	0.86																
13. SMR F4	0.16	0.34	0.15	0.36	0.04	0.11	0.00	0.88	0.31	0.40	0.00	0.41															
14. alpha/theta F4	0.61	0.36	0.40	0.60	0.33	0.37	0.01	0.00	0.36	0.00	0.00	0.00	0.00														
15. asymmetry	0.20	0.02	0.01	0.29	0.35	0.03	0.68	0.59	0.08	0.33	0.18	0.00	0.16	0.00													
16. theta Fz	0.81	0.67	0.52	0.18	0.13	0.39	0.00	0.46	0.26	0.00	0.00	0.54	0.00	0.00	0.55												
17. alpha Fz	0.96	0.93	0.35	0.33	0.66	0.54	0.44	0.00	0.66	0.00	0.58	0.00	0.62	0.00	0.03	0.35											
18. SMR Fz	0.07	0.10	0.16	0.53	0.05	0.07	0.03	0.50	0.18	0.44	0.00	0.11	0.00	0.00	0.08	0.01	0.23										
19. alpha/theta Fz	0.86	0.88	0.90	0.65	0.62	0.99	0.00	0.00	0.97	0.00	0.00	0.00	0.01	0.00	0.05	0.00	0.00	0.01									
20. theta Cz	0.63	0.41	0.65	0.21	0.25	0.37	0.00	0.82	0.16	0.00	0.00	0.46	0.00	0.00	0.16	0.00	0.99	0.00	0.00								
21. alpha Cz	0.85	0.32	0.82	0.72	0.91	0.88	0.80	0.00	0.80	0.00	0.52	0.00	0.54	0.00	0.00	0.92	0.00	0.13	0.00	0.14							
22. SMR Cz	0.29	0.90	0.62	0.78	0.29	0.53	0.00	0.53	0.27	0.50	0.00	0.61	0.00	0.11	0.68	0.00	0.65	0.00	0.10	0.00	0.74						
23. alpha/theta Cz	0.84	0.45	0.68	0.80	0.42	0.63	0.04	0.00	0.58	0.00	0.00	0.00	0.08	0.00	0.01	0.04	0.00	0.02	0.00	0.00	0.00	0.24					
24. theta Pz	0.41	0.20	0.59	0.11	0.28	0.24	0.00	0.54	0.07	0.00	0.00	0.16	0.00	0.00	0.13	0.00	0.62	0.00	0.00	0.00	0.04	0.00	0.00				
25. alpha Pz	0.80	0.09	0.82	0.88	0.72	0.71	0.36	0.00	0.13	0.00	0.35	0.00	0.76	0.00	0.00	0.85	0.00	0.25	0.00	0.07	0.00	0.69	0.00	0.01			
26. SMR Pz	0.22	0.30	0.65	0.95	0.67	0.81	0.00	0.22	0.44	0.81	0.00	0.09	0.00	0.72	0.50	0.00	0.18	0.00	0.52	0.00	0.15	0.00	0.88	0.00	0.17		
27. alpha/theta Pz	0.81	0.26	0.94	0.97	0.89	0.68	0.04	0.00	0.13	0.00	0.01	0.00	0.14	0.00	0.08	0.10	0.00	0.06	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.70	

an element of psychological well-being [28]. This positive psychological change in response to very challenging life events is characterized by an active change in personal plans, beliefs, goals, and relationships. Its mental affirmation requires separation from unattainable goals and orientation towards new goals [6]. Based on previous findings, it can be assumed that PTG (as an element of psychological well-being) is associated with relative asymmetry of the left frontal lobe. Therefore, in the present study, it was observed that the relative asymmetry of the brain predicts well the components of new possibilities, relating to others, and the total score PTGI. People with more active left areas may organize more limited resources to support approximate behaviors and thoughts [29]. This may enhance the mental recognition of the positive changes experienced in the aftermath of traumatic events such as severe COVID-19 disease. The results of this study confirm the hypothesis that PTG may reflect a process of active struggle to achieve new goals and perspectives. Accordingly, especially the more guided dimensions of PTG (e.g., the new possibilities dimension) may be associated with the asymmetry of the frontal lobe of the brain. In contrast, the dimensions of appreciation of life and personal strength were not predicted by the brain component; these two components were slightly more abstract than the others and may lead to more /less neural network activity in functional Magnetic Resonance Imaging (fMRI) is more observable.

Further studies are needed to discover the possible underlying mechanisms of brain asymmetry of the forehead with PTG. For this purpose, two potential directions are conceivable: first, the evaluation of PTG and the individual difference variables associated with anterior asymmetry (behavioral approach, emotional response, coping or repression, and psychological well-being measures); second, assessing the important role that individual differences in anterior brain asymmetry may play in regulating emotions and stress. Relative left anterior activity is more associated with biological indicators of response to stressful events such as better recovery after a negative event [30] and greater cell activity in response to stress [31]. Given the association between anterior brain asymmetry and PTG found in this study, it was suggested that the focus for further research be on how biological indicators related to stress and health related to PTG. There is only one study of this type in which PTG is associated with a stress-adapted cortisol response and there is evidence for flexibility in emotion regulation circuits [32]. EEGs are restricted to record activity in areas that are said to be involved in emotion regulation and pathophysiology of PTSD, such as the amygdala, hippocampus, and inner frontal cortex. Studies using better spatial resolution neural imaging techniques are needed to better understand the brain structures involved in PTG. This was the first study to measure brain function in relation to PTG in Iran and patients with COVID-19. Relative activation of the left frontal cortex with higher growth rates after trauma was shown to occur in a sample of COVID-19 survivors. We hypothesize that the left hemisphere's self-regulatory system, which mediates the approach and positive effect, facilitates growth. The results showed that alpha EEG asymmetry may be useful in differentiating different dimensions of PTG. In this study, the effect of aging on the brain was not considered. In fact, one of the sub-objectives of this study was to generalize the findings to all sections of society regardless of age and therefore the age variable was not controlled and it seems better in future research in several groups considering different age groups and examine brain components and PTG in them. Due to the pandemic conditions and the choice of COVID-19 as trauma, this study has some limitations, including the fact that according to COVID-19 studies, it affects the nervous system, especially the brain in a percentage of people. Structural tests of the brain, including Computed Tomography (CT) scans, were used alongside this functional EEG test to evaluate the brain effects of the disease was useful.

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