Quantitative Electroencephalography and Balance Test Correlations in Patients with Chronic Patellofemoral Pain

Naghmeh Ebrahimi (PhD)[1], Amin Kordi Yoosefinejad (PhD)[2,3], Zahra Rojhani-Shirazi (PhD)[2,3]*, Mohammad Nami (MD, PhD)[4,5,6,7,8,9], Ali-Mohammad Kamali (PhD)[5,6]

[1]Student Research Committee, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[2]Department of Physical Therapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Rehabilitation Sciences Research Center, Shiraz University of Medical Sciences, Shiraz, Iran
[4]Neuroscience Center, Instituto de Investigaciones Cientificas y Servicios de Alta Tecnología (INDICASAT AIP), City of Knowledge 084301103, Panama
[5]Neuroscience Laboratory, NSL (Brain, Cognition and Behavior), Department of Neuroscience, School of Advanced Medical Sciences and Technologies, Shiraz University of Medical Sciences, Shiraz, Iran
[6]Dana Brain Health Institute, Iranian Neuroscience Society-Fars Chapter, Shiraz, Iran
[7]Academy of Health, Senses Cultural Foundation, Sacramento, CA 66006, USA
[8]Department of Cognitive Neuroscience, Institute for Cognitive Science Studies (ICSS), Pardis, Tehran, Iran
[9]Department of Neuroscience, School of Advanced Medical Sciences and Technologies, Shiraz University of Medical Sciences, Shiraz, Iran

ABSTRACT

Background: Quantitative Electroencephalography (QEEG) is a tool helping better understand the electrical activity of the brain and a non-invasive method to assess cortical activity. To date, the brain activity of patients with chronic patellofemoral pain (PFP) has not been investigated.

Objective: The current study aimed to investigate the effect of PFP on higher levels of the central nervous system by assessing the correlation between QEEG and modified excursion balance test (mSEBT) in patients with PFP.

Material and Methods: Twenty-two patients with chronic PFP participated in this observational study. Their cortical electrical activity was recorded in a resting state with their eyes open, via a 32-channel QEEG. C3, C4, and Cz were considered as regions of interest. In addition to QEEG, the balance performance of the participants was evaluated via mSEBT.

Results: The obtained findings revealed a negative and moderate to high correlation between theta absolute power and posteromedial direction of mSEBT in C4 (P: 0.000, r: -0.68), Cz (P: 0.001, r: -0.66), and C3 (P 0.000, r: -0.70). Additionally, a significantly close correlation is between alpha absolute power in C3 (P: 0.001, r: -0.70), C4 (P: 0.000, r: -0.71), and Cz (P: 0.000, r: -0.74) and the posteromedial direction of mSEBT. No significant correlations were between the other two directions of mSEBT, alpha, and theta.

Conclusion: According to our results, balance impairment in patients with chronic PFP correlated with their QEEG neurodynamics. Moreover, our findings demonstrated the efficiency of QEEG as a neuromodulation method for patients with PFP.

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Keywords
Electroencephalography; Postural Balance; Correlation; Patellofemoral Pain; Brain Waves; Cerebral Cortex

Introduction

Electroencephalography (EEG) shows the electrical activity of the brain, with a sinusoidal pattern consisting of four main waves: alpha, beta, theta, and delta. This electrical activity is beneficial and safe for frequently recording the electrical activity of the brain, regardless of the person's age or health status, without any adverse effects [1]. Three types of the electrode are used for recording EEG, namely

*Corresponding author:
Zahra Rojhani-Shirazi
Department of Physical Therapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
E-mail: zahrarojhani@gmail.com

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active, reference, and ground electrodes. In EEG, the alteration of action potential between active and reference electrodes is recorded. It can also represent normal and abnormal brain activity, leading to a good tool for assessing neurophysiological changes of the brain [1]. Quantitative EEG (QEEG) is a portable and non-invasive method and a type representing more detailed information about the source location of the electrical activity in the brain and its spatial components [1, 2]. Furthermore, QEEG is a powerful and efficient tool in clinical research, particularly in chronic pain conditions due to inexpensive cost without any complicated methodology and collecting reliable information. In addition, this tool does not have any limitations for patients with prosthetic devices or any metal implants [3].

Chronic conditions cause a maladaptation in brain activity and unpleasant plasticity in the cortex, leading to functional problems. Chronic conditions are accompanied by some other issues, like depression, discomfort, and distress. Depression, discomfort, and distress also inherently have the potential to trigger unfavorable plasticity and alteration of brain activity, and cognitive functions in patients. An example of these brain alterations is reducing brain gray matter due to various chronic pains. Evidence has shown that duration and intensity of a chronic condition correlated with reducing gray matter. Generally, chronic pain changes brain structures and functions. Each type of chronic pain affects a specific region in brain [4, 5]. Thus, chronic patellofemoral pain (PFP), as a type of chronic pain, can impair the brain activity.

Maintaining an upright posture is a complex motor skill that needs the integration of sensory systems, including visual, vestibular, and proprioception systems. Subcortical structures play an important role in regulating postural control. Meanwhile, certain studies have shown the role of cortical structures in this regulation [6, 7]. Patients with PFP are usually young and active. Balance impairment among these patients has been reported in previous studies [8, 9].

Previous research has shown that balance demands increased theta power in parietal and frontal regions [10, 11] and alpha oscillation plays a role in the attention aspects of balance control [12]. The correlation between EEG and balance performance was reported in studies evaluating the effect of different balance tasks among healthy people. Edwards et al. studied healthy people, recorded EEG during continuous balance task, and reported that "alpha power reduced as balance task difficulty increased and this reduction correlated with subjective difficulty rating" [12]. Hulsduker et al. investigated healthy men during balance tasks and showed significant correlations between theta and alpha waves with balance tasks [11]. Del Percio et al. also reported a correlation between alpha wave and body sway in athletes [13]. Sloubounove et al. reported a significant correlation between alpha suppression and increased center of pressure in patients with mild traumatic brain injury [14].

Some EEG studies were conducted on the cortical involvement in balance performance and maintenance of postural control [7, 10-14]. However, the majority of the studies on this topic are on healthy people [10-12] with less evidence about musculoskeletal disorders. As mentioned previously, PFP is more likely a musculoskeletal disorder, but its effects on the central nervous system and the correlation of this disorder with central structures have been studied limitedly with very simple methods [15]. A lack of QEEG studies is among patients with PFP. Thus, the current study aimed to investigate the effect of PFP on higher levels of the central nervous system by assessing the correlation between QEEG and mSEBT in patients with PFP. If a correlation between balance and QEEG was in patients with the PFP, the future "cause and effect studies" should be designed to assess all aspects and the details of this correlation. In fact, "cause and effect studies" a clear relationship between two phenomena in which one phenomenon is the reason behind the other. Although balance impairment is seen in patients with PFP, we could not find any research on the cortical activity of these patients. Therefore, the present study was conducted to investigate the brain activity of patients with PFP in correlation with the balance test.

Material and Methods

This observational study was conducted in the Rehabilitation Research Center, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran in November of 2020. The patients entered into the study based on inclusion criteria as follows: women between the age of 18 and 40 with the PFP by an expert physical therapist according to diagnostic criteria of PFP, more than six months of duration of symptoms, pain equal or more than 3 on the visual analog scale (VAS), right hand dominant (checked by Edinburgh Handedness Inventory [16]), and reporting pain during at least two of these activities: jumping, stair climbing, running, squatting, kneeling, and prolonged sitting with knee bending [17, 18]. The participants with neurological impairments, uncorrected visual impairments, history of knee surgery or knee osteoarthritis, pregnancy, situations were excluded affecting balance, such as drug use (sleeping drugs, antidepressant drugs,…), and knee pain due to trauma.

All the patients signed the written informed consent form before their participation in the study. Demographic information was collected prior to starting the study.

This study was approved by the Ethics Committee of Shiraz University of Medical Sciences, Iran.

Outcome measures: Outcome measures included balance and QEEG.

Balance: Balance was assessed using the modified excursion balance test (mSEBT). The patients were instructed to stand with their right leg in the center of a Y-shape drawn on the floor by three tapes and then touch each tape with the other leg without balance instability (Figure 1). Prior to the main recording, they performed six trials for familiarizing themselves with the test process [19]. Subsequently, three main recordings were performed and the maximum score was recorded. A modified excursion balance test was performed for the right lower extremities. The score of mSEBT was normalized to the leg length of each patient [20, 21].

QEEG: QEEG was recorded in resting state, at sitting position, with eyes open for 3 mins. NrSign device (The NrSign Inc.,Vancouver, Canada) was utilized for EEG recording; sampling rate was 500 Hz and bandpass filter was

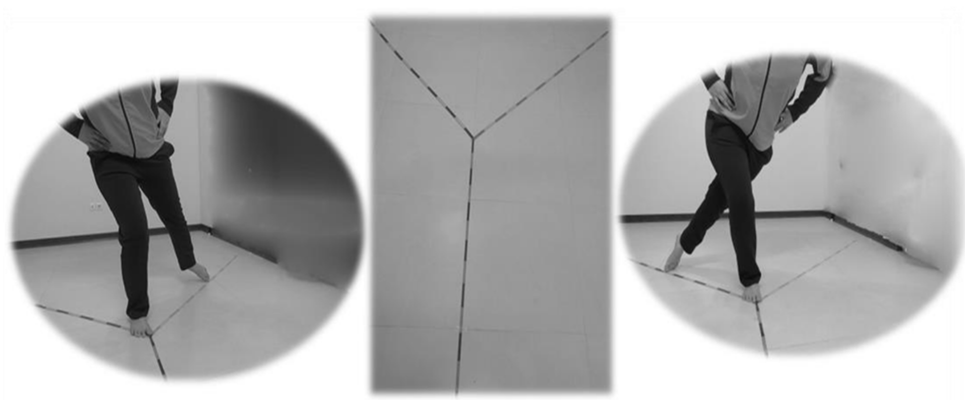

Figure 1: Modified star excursion balance test, composed of three directions (anterior, posterolateral, and posteromedial direction)

selected at 2-120 Hz. Electrode placement was according to 10/20 international system and 24 electrodes were placed on the scalp. Since all the participants were female, they were asked to take a bath and wash their hair thoroughly to reduce the risk of noise. The conductive gel was used for impedance reduction in the site of electrodes and impedance was set under 5 K-Ohm. The linked ear was selected as the reference electrodes.

Data analysis

Statistical analysis was conducted using the statistical package SPSS version 16.0 (SPSS Inc, Chicago, IL, USA) for Windows. The descriptive statistics were reported as mean ± SD, minimum, and maximum. Normal distribution of the data was confirmed via the Kolmogorov-Smirnov test and then Pearson's correlation was employed for investigating the association between balance and QEEG. P-values less than 0.05 were considered significant.

EEG data were analyzed with Neuroguide software and an expert of EEG visually followed raw QEEH and denoised the recorded signals. Afterward, automatic denoising was applied with Neuroguide on the signals. The absolute power of theta and alpha waves were analyzed and their correlation with balance was calculated.

Results

Twenty-two patients with chronic PFP participated in the study. The youngest participant was 19 years old and the oldest was 40 years old. Table 1 depicts the demographic data, measurements of mSEBT, and the power of brain waves of the participants.

According to Table 1, the mean age of the subjects was 30 years old and a modified excursion balance test was reported as a percentage due to normalizing to a leg length of the participants.

The correlation between QEEG and mSEBT was calculated via Pearson's correlation. Information about the correlation between these two variables is visible in Table 2.

Based on Table 2, the correlation between posterolateral and anterior directions of mSEBT with alpha and theta waves was not significant.

Table 1: Demographic data of participants and baseline measures of modified star excursion balance test (mSEBT), alpha, and theta absolute power (N=22)

Variable		Minimum	Maximum	Mean	Std. Deviation
Demographic data	Age (y)	19.00	40.00	30.59	5.63
	Height (cm)	153.00	175.00	163.68	5.11
	Weight (kg)	47.00	103.00	68.54	12.52
mSEBT data	Anterior mSEBT (%)	52.69	102.03	73.12	11.47
	Posterolateral mSEBT (%)	59.17	98.06	76.08	11.13
	Posteromedial mSEBT (%)	48.78	112.59	88.27	13.71
Alpha and theta absolute power	Theta absolute power in C3	-3.07	5.71	-0.68	1.75
	Alpha absolute power in C3	-1.32	3.69	0.11	1.20
	Theta absolute power in C4	-3.57	4.71	-0.82	1.67
	Alpha absolute power in C4	-1.70	3.12	0.12	1.14
	Theta absolute power in Cz	-3.61	4.30	-1.36	1.62
	Alpha absolute power in Cz	-2.09	2.70	-0.67	1.03

mSEBT: modified Star Excursion Balance Test, C3: Left Central, C4: Right Central, Cz: Midline Central

Table 2: Pearson's correlation between absolute power of brain waves in C3, C4, Cz regions and three directions of modified star excursion balance test (mSEBT) (N=22)

Variable		Anterior mSEBT	Posterolateral mSEBT	Posteromedial mSEBT
Theta wave absolute power in C3	Correlation	-0.27	0.03	*-0.70
	P-value	0.22	0.89	0.000
Alpha wave absolute power in C3	Correlation	-0.33	-0.05	*-0.67
	P-value	0.12	0.79	0.001
Theta wave absolute power in C4	Correlation	-0.26	-0.02	*-0.68
	P-value	0.24	0.89	0.000
Alpha wave absolute power in C4	Correlation	-0.30	-0.05	*-0.71
	P-value	0.17	0.79	0.000
Theta wave absolute power in Cz	Correlation	-0.22	-0.03	*-0.66
	P-value	0.32	0.87	0.001
Alpha wave absolute power in Cz	Correlation	-0.35	-0.08	*-0.74
	P-value	0.10	0.69	0.000

*Correlation is significant at the 0.01 level (2-tailed).

mSEBT: modified Star Excursion Balance Test, C3: Left Central, C4: Right Central, Cz: Midline Central

Discussion

This work was the first study to investigate the correlation between alpha and theta power with balance performance among patients with chronic PFP. A negative and moderate to high correlation was between the sensorimotor cortex (C3, C4, Cz) and the posteromedial direction of mSEBT. Based on the obtained results, chronic PFP affected brain activity.

Previous studies have focused on healthy people or patients with neurological disorders [10-12, 14].

Theta is a wave effective on error detection, increasing higher balance demands [11, 22]. According to our results, a negative correlation ($r= -0.66$ - -0.70) was between theta power and balance performance. According to the aforementioned points, if balance is impaired, theta activity will increase and vice versa. On the other hand, since the posteromedial direction of mSEBT is more difficult than the anterior direction [23], the increased theta activity indicates a further need for error detection in the cortex. Hence, in patients with PFP with balance issues, theta power activity rises, i.e. more need for error detection and error processing [11]. This mechanism of error detection is visible in our study; because the posteromedial direction of mSEBT is more difficult than anterior direction, the error detection mechanism is presented as a correlation between theta power and posteromedial direction of mSEBT.

Based on previous research, increasing alpha results in a cognitive task with high challenging conditions, i.e. more information processing in the cortex [11]. In posteromedial direction, visual feedback decreased and the participants had to use other systems (such as proprioception and vestibular) and remember the location of the tape [24], leading to increasing alpha activity.

Based on our findings, a correlation was between balance and QEEG in patients with the PFP; however, future "cause and effect studies" should be designed to assess the details of this correlation for clarification that one event (the cause) leads to another event (the effect). Modified star excursion balance test is to assess dynamic aspect of balance performance [25]. The correlation between static balance performance and brain activity among patients with PFP may be different from the results of the present study. Our participants were women, thus our findings could not be generalized to all male individuals with PFP which is considered a potential limitation of the present study. Future investigations could assess the correlation between balance function and brain activity in patients with acute PFP.

Conclusion

Balance performance among patients with chronic PFP was negatively correlated with sensory-motor cortex activity, showing the role of structures of the cortex in addition to the subcortical region, in balance function. Furthermore, QEEG can be used as a neuromodulation, neurorehabilitative, and physical therapy method to assess patients with PFP. However, further research is required in this area.

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Authors' Contribution

N. Ebrahimi, Z. Rojhani-Shirazi, A. Kordi Yoosefinejad, and M. Nami participated in the conception and design of the study. N. Ebrahimi was responsible for the acquisition of data. N. Ebrahimi, Z. Rojhani-Shirazi, A. Kordi Yoosefinejad, M. Nami and AM. Kamali analyzed and interpreted the data. N. Ebrahimi drafted the manuscript and Z. Rojhani-Shirazi, A. Kordi Yoosefinejad, M. Nami and AM. Kamali critically revised the manuscript for important intellectual content. All authors confirmed the final version of manuscript.

Ethical Approval

An ethical approval code was provided by the Ethics committee of research in Shiraz University of Medical Sciences, Shiraz, Iran (IR.SUMS.REHAB.REC.1398.027).

Informed Consent

All the patients signed the written informed consent form before their participation in the study.

Conflict of Interest

None

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