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Prefrontal Cortex Activation during Diaphragmatic Breathing in Women with Fibromyalgia: An fNIRS Case Report

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Objective: The present study is designed to delve deeper into the realm of fibromyalgia (FM) symptom management by investigating the effects of diaphragmatic breathing on the prefrontal cortex (PFC) in women diagnosed with FM. Using functional near-infrared spectroscopy (fNIRS), the study aims to capture real-time PFC activation patterns during the practice of diaphragmatic breathing. The overarching objective is to identify and understand the underlying neural mechanisms that may contribute to the observed clinical benefits of this relaxation technique.

Design: A case report

Methods: To achieve this, a twofold approach was adopted: First, the patient's breathing patterns were meticulously examined to detect any aberrations. Following this, fNIRS was employed, focusing on the activation dynamics within the PFC.

Results: Our examination unveiled a notable breathing pattern disorder inherent to the FM patient. More intriguingly, the fNIRS analysis offered compelling insights: the ventrolateral prefrontal cortex (VLPFC) displayed increased activation. In stark contrast, regions of the anterior prefrontal cortex (aPFC) and orbitofrontal cortex (OFC) manifested decreased activity, especially when benchmarked against typical activations seen in healthy adults.

Conclusions: These findings, derived from a nuanced examination of FM, underscore the condition's multifaceted nature. They highlight the imperative to look beyond conventional symptomatology and appreciate the profound neurological and physiological intricacies that define FM.

Key Words: Fibromyalgia, Hyperventilation, Near-infrared spectroscopy, Prefrontal cortex

Introduction

Fibromyalgia (FM) is a complex and incapacitating chronic pain disorder marked by widespread pain, fatigue, and disruptions in pain processing [1]. Individuals grappling with FM confront an array of distressing symptoms that frequently culminate in a compromised quality of life [2]. The multifaceted nature of this condition necessitates innovative approaches to mitigate its impact on affected individuals [3]. One emerging avenue to address FM symptoms involves the exploration of relaxation techniques, with diaphragmatic breathing emerging as a particularly promising intervention [4].

Diaphragmatic breathing, often referred to as deep or abdominal breathing, involves deliberate and unhurried inhalations and exhalations while emphasizing the engagement of the diaphragm muscle [5]. This technique fosters a transition from shallow chest breathing to a more profound and controlled breathing pattern, promoting relaxation, mitigating stress, and augmenting oxygenation [6, 7]. By fostering a state of physiological equilibrium, diaphragmatic breathing holds the potential to alleviate

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FM symptoms, particularly those related to pain perception and emotional distress [8, 9].

The prefrontal cortex (PFC), positioned prominently at the anterior aspect of the brain, assumes a pivotal role in executive functions such as cognitive control, decision-making, emotional regulation, and pain modulation [10]. Given the intricate interplay between psychological and physiological factors in FM, the PFC emerges as a central player in mediating the effects of interventions like diaphragmatic breathing on symptom management [11].

Recent strides in neuroimaging techniques have facilitated the examination of real-time neural responses during specific interventions. Functional near-infrared spectroscopy (fNIRS), a non-invasive neuroimaging tool, permits the measurement of alterations in hemoglobin concentrations in the cerebral cortex, thus providing valuable insights into regional brain activation [12-14]. The fusion of diaphragmatic breathing with fNIRS presents an exceptional opportunity to investigate the neural mechanisms associated with this relaxation technique within the context of FM.

The present study aims to enrich our comprehension of FM symptom management by scrutinizing the patterns of PFC activation during diaphragmatic breathing among women diagnosed with FM. Leveraging fNIRS, our objective is to unveil potential neural mechanisms underpinning the effects of diaphragmatic breathing and their implications for FM symptomatology. Through this exploration, we aspire to bridge the gap between clinical observations and neurophysiological processes, thereby illuminating the therapeutic potential of diaphragmatic breathing as a strategy for managing FM.

Methods

In accordance with the Declaration of Helsinki, this case report was conducted after sufficient explanation of the study was given to the patient and consent was obtained.

Patient history and systems review

A 38-year-old woman with FM symptoms had been receiving outpatient treatment at a rehabilitation clinic for chronic neck and shoulder pain, recurrent back pain, insomnia, and muscle stiffness. She had increased generalized fatigue and stiffness, which are characteristic symptoms of fibromyalgia. She also had increased pain sensitivity, not just localized tenderness. She was diagnosed with inter-exercise breathing pattern disorder (BPD) and referred to the Sahmyook University laboratory to determine the underlying cause. The patient was found to have no other neurological or cardiorespiratory problems.

Examination

In this case report, a functional near-infrared spectroscopy instrument, NIRSIT Lite (OBELAB Inc., Seoul, Republic of Korea), was used to measure PFC activity [15](Figure 1). The instrument consists of 15 channels with a distance of 30 mm between each pair. The Broadman mapping of each channel is shown in Figure 2. NIRSIT Lite is a functional near-infrared spectroscopy (fNIRS), a non-invasive vascular-based neuroimaging technique. It is a tool that uses a light source and a photoreceiver to measure changes in oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (HbR) in cortical regions due to modulation of neural activity [16, 17]. HbO change was measured during a 30-second rest period after zeroing the device before performing the task, and during the 20-second task [17].

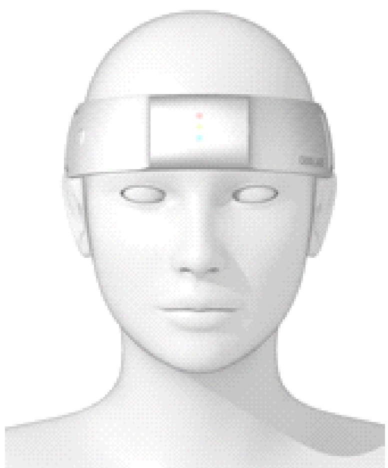

Figure 1. Schematic image of NIRSIT Lite.

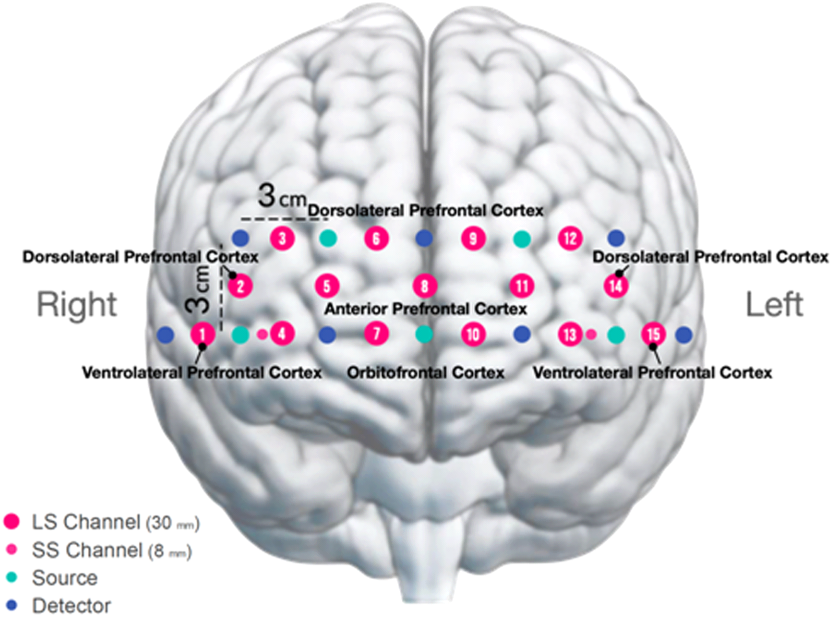

Figure 2. Broadman mapping of NIRSIT lite channels.

To determine the dynamic changes in the PFC during diaphragmatic breathing, changes in the PFC of a 31-year-old man with no neuromusculoskeletal conditions and capable of diaphragmatic breathing were also measured.

Results

This case report is a comparison of the PFC of a patient with FM and a healthy adult. No statistical analysis was performed, and the results were interpreted through visual analysis and differences in HbO. When performed under the guidance of diaphragmatic breathing, no abdominal movements were found in FM patients only.

Visual analysis of the prefrontal cortex

A 3D activation map of the PFC during diaphragmatic breathing is shown in Figure 3.

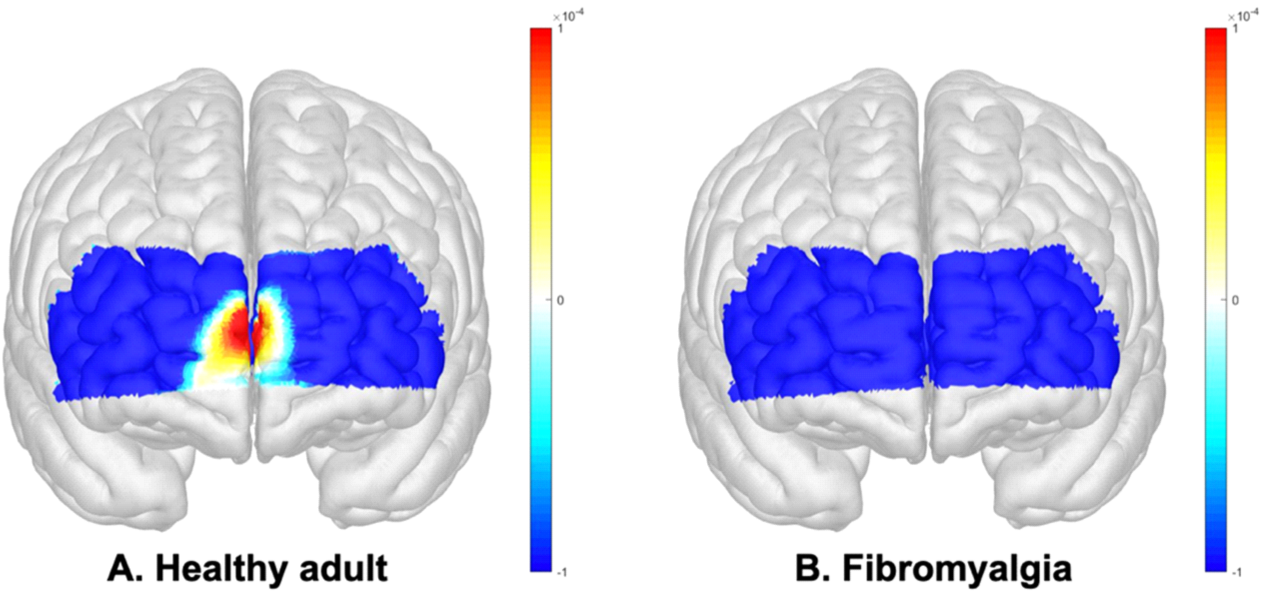

Figure 3. 3D activation map of the prefrontal cortex.

Table 1. Quantitative analysis of the prefrontal cortex.

x10,000	Right VLPFC	Right OFC	aPFC	Left OFC	Left VLPFC
Healthy adult	0.119	8.853	11.189	9.516	0.335
Fibromyalgia	2.968	1.047	0.101	0.668	5.814

aPFC: anterior prefrontal OFC: orbitofrontal cortex, VLPFC: ventrolateral prefrontal cortex.

Visually, the HbO of FM patients compared to healthy adults shows less activation of the anterior PFC (aPFC) and orbitofrontal cortex (OFC) during diaphragmatic breathing.

Quantitative analysis of the prefrontal cortex

The results for the MAX values for each channel during diaphragmatic breathing are shown in Table 1. Values with relatively large differences were categorized according to Broadman mapping. Compared to healthy adults, FM patient showed higher activity in the ventrolateral prefrontal cortex (VLPFC). In contrast, healthy adult showed high activity in the aPFC and OFC.

Discussion

FM has traditionally been viewed through the lens of widespread chronic pain and associated symptoms such as fatigue and cognitive disturbances [18]. Our study has ventured into uncharted territories of FM by establishing a correlation between BPDs and PFC activation. This intricate link offers a nuanced perspective on FM's multifaceted nature, bringing forth valuable insights into potential treatment approaches.

Differential PFC Activation in FM

The observed heightened activity in the VLPFC and the subdued activation in the aPFC and OFC in FM patients, compared to healthy adults, pave the way for a deeper exploration of the neural pathways involved in FM. The hyperactivity in the VLPFC suggests an intrinsic cerebral response aiming to modulate pervasive pain sensations, hinting at a compensatory mechanism [19, 20]. In contrast, the diminished activity in the aPFC and OFC might be reflective of cognitive challenges and emotional dysregulation, a common thread in FM narratives [21, 22].

Understanding BPDs in FM

Our findings pertaining to BPDs offer a novel avenue to understand the physiological intricacies in FM. It's plausible that these altered breathing patterns stem from heightened sympathetic activity, a phenomenon often reported in FM [4, 23, 24]. This maladaptation might be the body's response to chronic pain, where shallow, rapid breathing serves as a protective mechanism [25]. However, this approach could paradoxically accentuate pain due to diminished muscular oxygenation [26].

Decoding the neural signatures in the PFC

Enhanced activation in the VLPFC

The observed hyperactivity in the VLPFC might be a manifestation of the brain's attempt to modulate or even suppress the pervasive pain sensation in FM [27]. This area's involvement in pain perception and modulation is well-documented, and its heightened activity could indicate a compensatory mechanism at play [28].

Subdued activation in the aPFC and OFC

A suppressed anterior PFC activity might hint at challenges related to decision-making and cognitive flexibility, potentially accounting for the so-called 'fibro fog' [29]. Meanwhile, the reduced OFC activation, a region pivotal for emotional processing and reward evaluation, may underscore emotional dysregulation observed in many FM patients [30].

Bridging the neural and respiratory findings

There's potential interplay between PFC dysregulation and BPDs. Chronic hyperventilation, stemming from altered breathing patterns, may result in diminished cerebral perfusion, influencing PFC activity [31, 32]. Conversely, the cognitive stressors and emotional challenges arising from PFC imbalances might precipitate breathing abnormalities.

Towards a holistic treatment approach

These observations hint at the possibility of multi-faceted interventions for FM. Techniques to recalibrate breathing, combined with cognitive interventions targeting PFC dysregulation, might yield synergistic benefits. Exploring non-invasive neural modulation of the identified PFC regions could also present promising therapeutic avenues.

Navigating through Limitations and Future Directions

While our study's insights are illuminating, the cross-sectional design necessitates interpretive caution, and future studies with longitudinal designs are pivotal for elucidating causal relationships. Diving deeper into the exploration of additional neural networks and understanding their interaction with cognitive and respiratory parameters will further refine our understanding of FM's complexities. Moreover, given that the study focuses on a single case comparison with a male healthy adult, further research encompassing diverse demographic variables is essential for generalization of our findings.

Conclusion

In this case report, we examined the neurological and physiological features of a patient with FM. In conclusion, a distinctive breathing pattern disorder was observed in the FM patient. Analysis via fNIRS revealed that the activation of the VLPFC was elevated compared to healthy adults, whereas the activation of the aPFC and OFC was diminished. These observations provide a more lucid understanding of the intricate characteristics of FM.

Conflicts of interest

The authors declare no conflict of interest.

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