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Tracking Cognitive and Emotional Functions with fNIRS and Existential Graphs. A Study in Progress.

Original Study

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"Thought is a thread of Melody running through the succession of our senses."

Charles S. Peirce, 1878, How to make our Ideas Clear.

Abstract: The main objective of the study is to assess the effectiveness of fNIRs in monitoring cognitive and emotional responses during a logical game activity. Additionally, the study explores the use of Existential Graphs as a tool for observing brain cognitive responses during problem-solving tasks. Through the fNIR device, the study measures oxygenation and deoxygenation levels in the frontal lobe while participants engage in cognitive activities such as attention, information processing, decision-making, and future planning. While the focus is on Existential Graphs, the study incorporates the block and puzzle game Tetris as a counter example to validate the findings.

For this purpose, our study has for the first time applied Peirce's Existential Graphs as a practical cognitive model to observe real time problem solving processing of the frontal lobe; the study is also the first to use fNIRs to study the brain activity while processing existential graphs.

Kewords: Emotional response, fNIRS, Existential Graphs, Charles S. Peirce.

APPLYING EXISTENTIAL GRAPHS FOR COGNITIVE STUDIES

Existential Graphs (EG) is a logical model conceived by Charles S. Peirce, that uses diagrammatic representations of the reasoning process evolving in a dialogical communication while solving a logical problem. Peirce designed it as a logical tool to train skills for scientific observation and critical thinking.

Two elements define the composition of such a graph:

- The sheet of assertion, the dialogical space that represents the universe of discourse, and,
- The inferences introduced to the sheet of assertion

The primary component of existential graphs is the dialogical space of assertion, called the sheet of assertion to insert and display our thoughts. As a general model, the universe or the sheet of assertion is an imaginary universe, a universe of discourse for the dialogue between the graphist and the interpreter.

As a logical tool, EG is designed to verify the truth of propositions or arguments throughout a reasoning process.The term "existential" highlights the relation of existence, the universe of all possible meaning. In EG, introducing a graph represents inferring that such a thing exists in the universe, which is represented by the sheet of assertion. Every graph (a letter or symbol, or the space between graphs) inserted on the sheet of assertion has an exactly defined meaning and expresses a proposition related to "any possible state of the universe."[1]

Here's an example of how to apply the model:

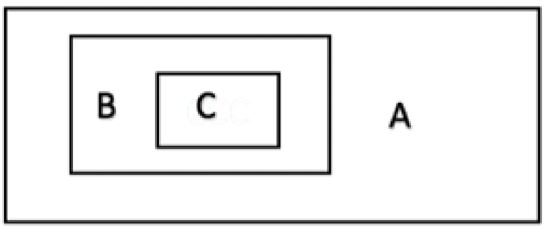
All horses (C) are mammals (B).
All mammals (B)are animals (A)
Therefore, all horses (C) are animals (A)

All C are B.
All B are A.
Therefore, all C are A

We will convert the above dialogue into a diagram by following two conventions:

Convention 1:
By introducing a field with an appropriate class name, along with an indication outside of the field for items that are not members of that class.

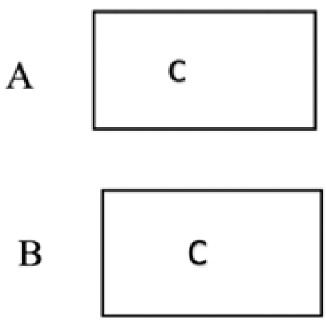
Therefore, if we mark a field and label it A (for the animals class as mentioned above), we are modeling that class:



Convention 1

Convention 2:
If we wish to show a particular negative proposition, "Some A is not C" or "Some B is not C" will be diagramed as:

Therefore, the graphs represent a space of interaction



Convention 2

to closely observe the joint assertion of both premisses of the argument. We can observe that the first premiss is represented as true because all the Cs are inside the B field; also, the second premiss is shown as true because all the Bs are inside the A field.

The above example is a demonstration of how EG allows us to observe and compare the evolution of thought, or, as Peirce writes: the moving picture of the mind or thought in action, and in all its essential details. EG explains the relation of thought to the reasoning process and to the graphs, while thought is in action.[2]

To summarize, the EG model helps establishing a space for observing a meaning process in action. Moreover, it allows us to train our skills how to verify truth in arguments and incorporate those into the active reasoning process.

The EG program used in this study is a digital adaptation of Peirce's initial EG model, designed as a logical computer game that follows Peirce's conceptualizations. It is structured around inferences and propositions governed by a predefined set of rules. At the conclusion of each problem, participants receive feedback indicating success or, in the event of a failure to solve, an auditory alert signaling an error. As a result, the EG exercise presents an ongoing series of intellectual challenges, prompting participants to resolve a variety of problems with intermittent breaks to advance to the next level of intensity or the subsequent puzzle.

To contrast, the research incorporated the computer game Tetris as a means to validate the research inquiry and underscore the distinct characteristics of Existential Graphs. Tetris, known for its straightforward layout as a block and puzzle game, allows players to promptly experiment with solutions using five control keys for movement in various topological directions. Its visually expressive design captivates players' attention, requiring quick reactions without room for extended contemplation. Moreover, Tetris fosters habituation by perpetually presenting incomplete challenges, prompting players to introduce partial solutions and seamlessly progress to the next block, establishing a sequence of ongoing emotional engagement and satisfaction levels.

FNIRS AS MEASUREMENT INSTRUMENT

The importance of Functional near-infrared spectroscopy (fNIRS) studies has significantly increased in the fields of neuroscience and cognitive psychology. This imaging technique, which is non-invasive, enables researchers to track changes in brain activity by monitoring blood flow and oxygen levels.

In our study, we propose the use of fNIRS during gaming activities as a practical method to observe real-time brain function during cognitive training. Specifically, during EEG tasks, fNIRS can also provide insight into emotional responses triggered by success or failure

1 The following manuscripts provide a comprehensive overview of Peirce's Existential Graphs MSS: 694-464-478-425
2 Peirce: Phaneroscopy. In: The Monist , Bisanz. 2009. p. 352-365.

at each step of the game. This presents a unique opportunity to evaluate the capability of fNIRS in measuring emotional reactions in the brain.

Our FNIRS study focuses on the prefrontal cortex, which is recognized for its role in decision-making, emotional response, and cognitive reasoning in the brain. While FNIRS research has been established, there is a lack of literature on the emotional responses associated with gameplay. However, studies have shown specific changes in oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (HHb) during game tasks that increase in difficulty. Additionally, games involving mathematical challenges, such as those used in a pilot study by Baker et al. (2015), have demonstrated cortical activation in regions responsible for mathematical and number processing, such as the parietal and prefrontal regions. Therefore, FNIRS studies have the potential to enhance our understanding of how information is processed and stored, leading to more effective teaching methods and interventions.

Additionally, the application of fNIRS to observe hemodynamic responses linked specifically to emotional reactions during logical problem-solving presents a novel avenue for research. The complex and intricate relationship between emotion and cognition has long captivated researchers in psychology, neuroscience, and cognitive science. Emotions and cognition are deeply intertwined, mutually affecting each other and shaping our thoughts, choices, and behaviors. Studies have illustrated that emotions play a pivotal role in guiding cognitive functions, such as attention, memory, and analytical thinking.

Emotions possess the capability to either enhance or hinder cognitive performance based on the emotional context. Positive emotions like joy and gratitude have been shown to boost creativity, whereas negative emotions like fear and anxiety can restrict focus and impair decision-making. Moreover, emotions can impact memory retention, with emotionally-charged events often being more firmly ingrained in memory compared to neutral occurrences. This occurrence, termed the emotional memory enhancement effect, underscores the significant influence of emotions on our ability to process, retain, and recall information.

Conversely, cognitive responses are instrumental in shaping our emotional experiences. Our thoughts, beliefs, and interpretations of situations can shape the emotional reactions that follow. Cognitive processes, such as cognitive reappraisal and emotional regulation, enable us to reevaluate and manage emotions in constructive ways.

Thus, the dynamic interplay between emotion and cognition holds practical implications for various facets of human behavior and well-being. Understanding the interaction between emotions and cognition can aid in developing strategies for emotional regulation and enhancing decision-making processes.

THE STUDY: PROCEDURE, SETTING THE BASELINE, DATA ANALYSIS AND STATISTICS

The research study involved 105 individuals who were randomly selected to participate in either the Existential Graphs (EG) game or the Tetris game.

Examples of the screens used for each game are shown below.

In this study, an fNIRS Devices Model 2000S was utilized along with an 18-optode sensor pad and headband to secure the pad in place. Data collection in the study was conducted using Cobi Studio Modern software. Each participant was equipped with the fNIRS headband. Adjustments were made to the gain and LED current values based on the infrared penetration of the skin. Once the

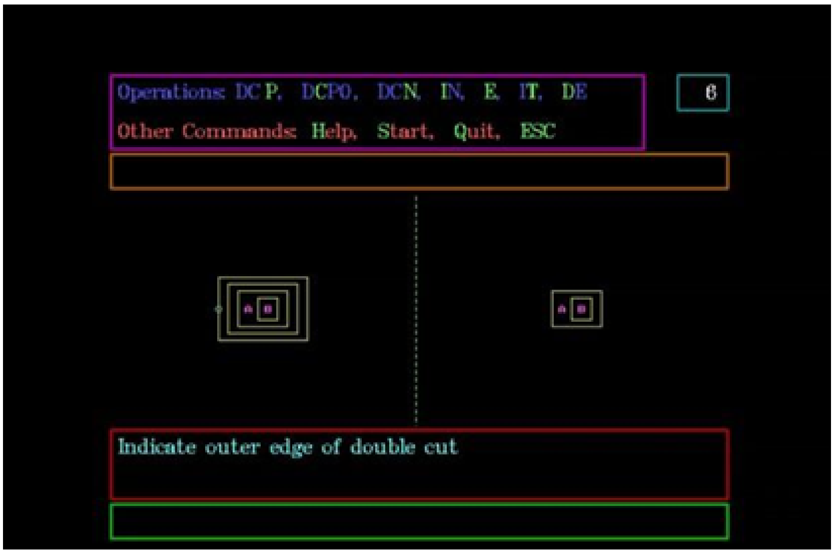


Figure 1. Example of what EG looked like to the participant. The objective of the game is to match the left side of the dashed line to the right side of the screen, following specific rules. Players can do this through a series of operations.

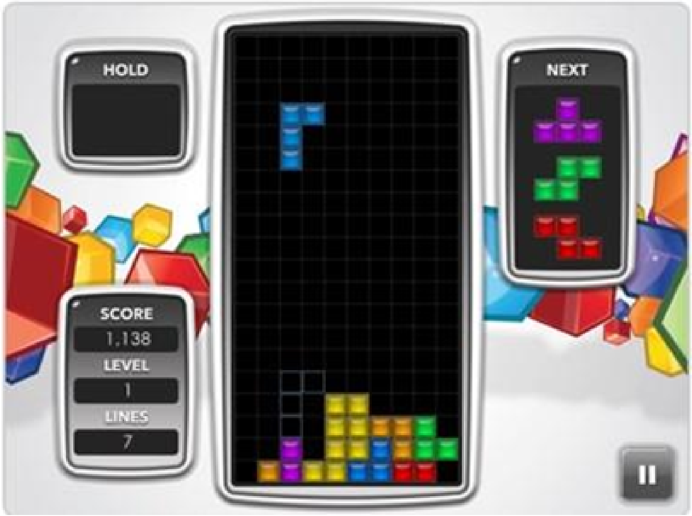


Figure 2. Web version of Tetris. The object of this game is to fit the blocks to fill each line. As the line fills up, blocks are moved down for more space. Players can rotate blocks using the arrow keys.

participants were fitted with the headband, they were informed about the game they would be playing and any necessary rules for success. After addressing participant questions, they played the assigned game for a total of 10 minutes.

The first step of the analysis involved establishing the participants' baseline by adjusting it with the software in the fNIRS device. This step was crucial in identifying when a participant might reach a peak cognitive response. Participants were directed to close their eyes and relax their minds, helping them to attain a state of relaxation and providing a baseline of their usual oxygenation levels.

The following markers were assigned to assess the cognitive and emotional responses during the play activity:

- Marker 1 for Opening or Closing EG App or Begin the Game
- Marker 2 for Completed Problem Successfully
- Marker 3 for Error or Mistake Made
- Marker 4 for Restart Problem
- Marker 5 for Opening the Help Menu

Once all raw data had been collected in COBI Studio Modern, we exported each file to the analysis software fNIR Soft. The initial step in analyzing the graphs involved assessing the consistency of oxygenation levels to determine the suitability of the data. We excluded graphs that showed significant spikes or lacked a consistent trend in oxygenation levels compared to a participant's baseline readings. Out of the 105 oxygenation graphs we collected, 37 showed inconsistency, so we evaluated 68 graphs in the study results.

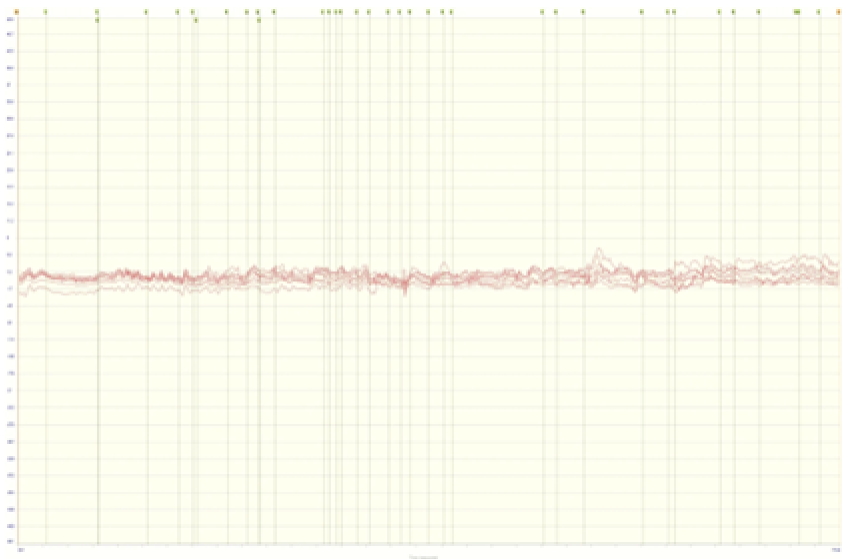


Figure 3. Graph showing consistency.

Figure 4. Graph without consistency.

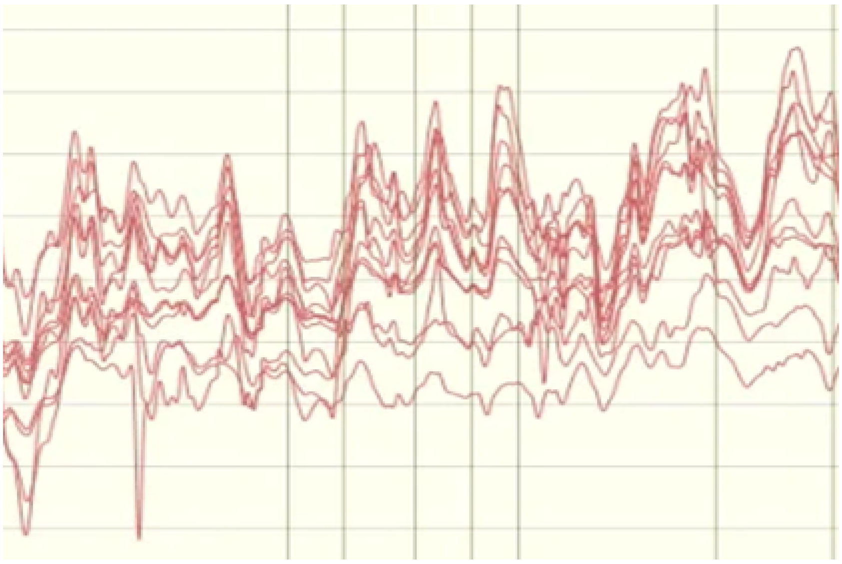


Figure 5. Spikes in oxygenation.

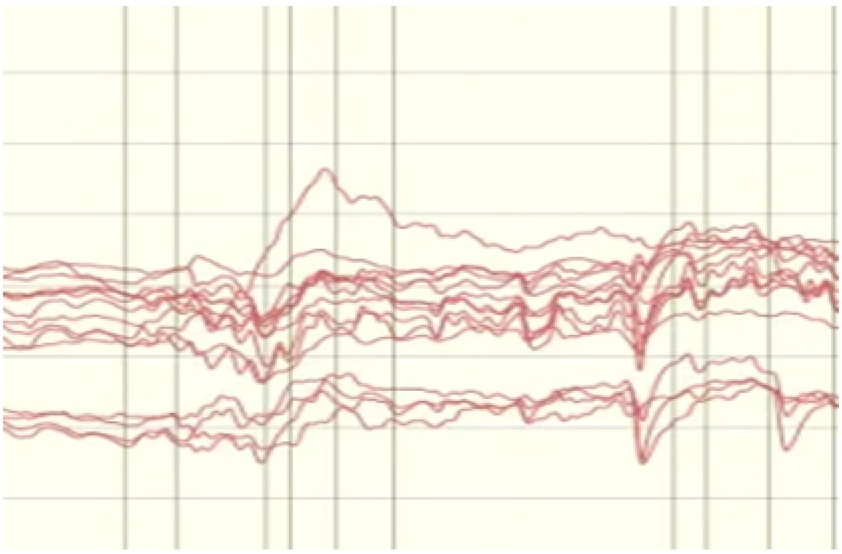


Figure 6. Gradual increase in oxygenation.

Examples of a clear oxygenation graph and one displaying inconsistency are provided below.

After identifying graphs with consistent oxygenation levels, we focused on instances of increased oxygenation levels within the graphs. When looking for spikes in cognitive response, these increases could appear in two ways: gradual increases over an extended period or sudden spikes. While gradual increases in oxygenation levels were more commonly observed in Tetris, they were also seen in EG as the problems became more challenging for participants to solve. Gradual increases were less likely to result from external factors and more indicative of the development of logical processes as participants navigated their way through problem-solving tasks.

FINDINGS/DISCUSSION

The analysis of the 68 graphs revealed that fNIR technology effectively captured the logical and cognitive processes participants engaged in as they tackled problem-solving tasks in EG. Initially, we examined the Tetris graphs, which depicted consistent oxygenation patterns across all participants. As players progressed through the game, their cognitive involvement heightened, resulting in a continuous rise in oxygenation levels throughout their gameplay. In contrast, the EG graphs displayed regular disruptions as individuals worked through various logical problem patterns.

By monitoring the five markers indicating different events linked to cognitive response spikes, we pinpointed three significant occurrences with distinct oxygenation levels. These events occurred when participants successfully solved a problem (Marker 2), made an error (Marker 3), or accessed the help menu (Marker 5). Conversely, Markers 1 (Opening or Closing EG App or Beginning the Game) and 4 (Restart Problem) had minimal to negligible effects on participants' oxygenation levels.

The primary noteworthy marker is Marker 3, where participants' oxygenation levels decreased following an error response. Examples demonstrating how these markers appear and their impacts are illustrated below.

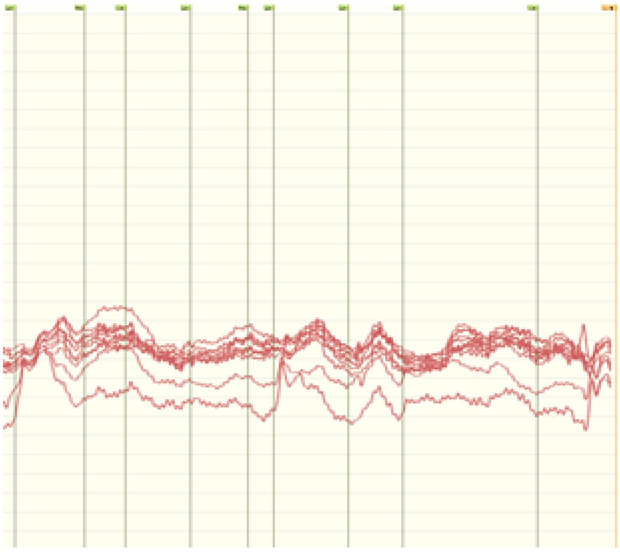


Figure 7. Spikes of marker 3.

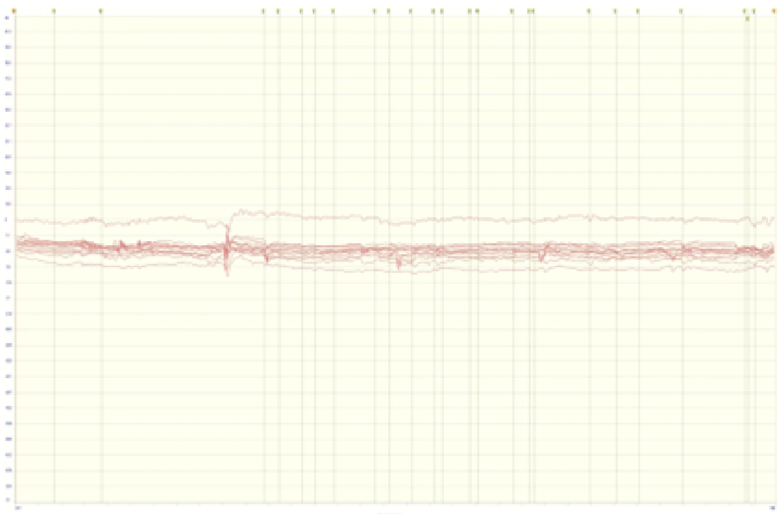


Figure 8.Spikes of marker 2.

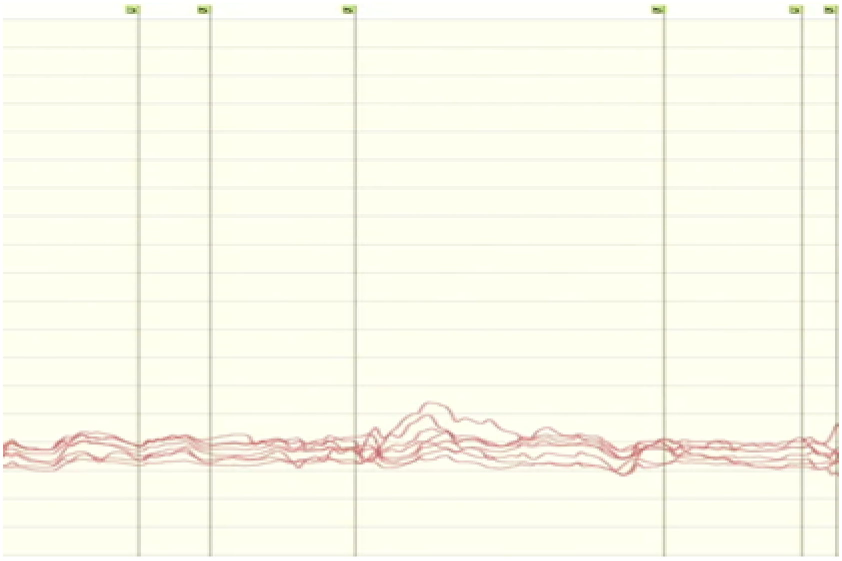


Figure 9. Spikes of marker 5.

The second noteworthy marker, Marker 2, emerged after a cognitive spike had already transpired. A noticeable contrast was observed among participants who smoothly solved problems, experiencing minimal to no cognitive response spikes. An illustration of one of these participants is provided below.

Lastly, we address Marker 5, which signifies accessing the help menu. Among the 68 chosen graphs, Marker 5 displayed the utmost consistency. The majority of participants exhibited a cognitive response spike after utilizing the help menu. Marker 5 was consistently noted prior to both gradual and sudden increases in cognitive activity. A sample graph is presented below.

To comprehend why the 5th marker elicited a cognitive response, it is essential to understand the purpose of the help menu (Figure 10). The help menu provides different functionalities and rules how to add layers or letters to a graph in EG. These actions heighten participants' cognitive engagement as they interact with the help menu to find solutions. Participants who did not require the help menu exhibited oxygenation graphs with stable levels, indicating no variations in oxygenation levels.

Below is the list of essential functions displayed on the players' screen from which participants can select to address the problem.

PROBLEM SOLVING SAMPLES

To understand the connection between a participant's cognitive responses and emotional reactions, it

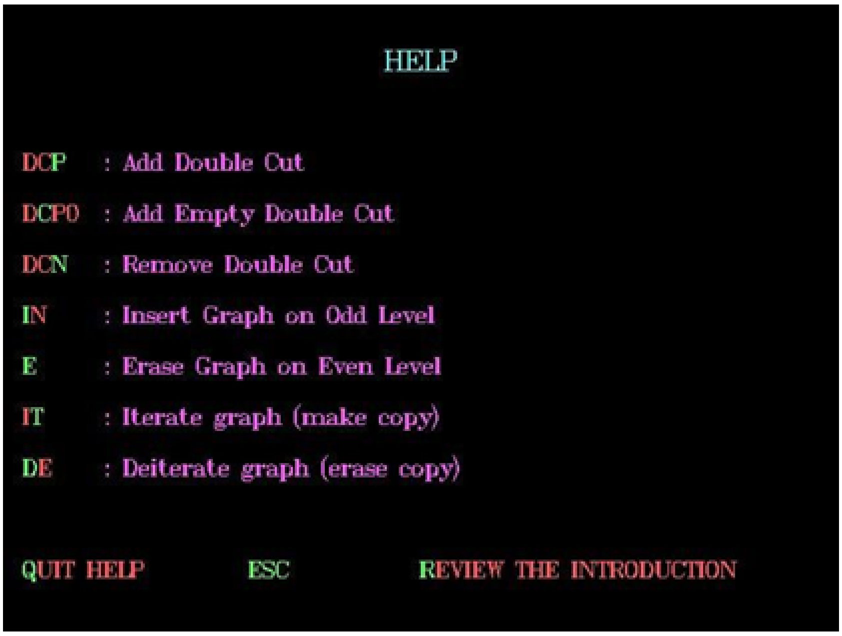


Figure 10. Help Menu

is necessary to delve into how they tackled the problems they encountered. Below are examples of two problems (problems 5 and 8 in EG) that participants had to solve during EG (Figures 11 and 12). The objective is to determine the correct moves, adhering to the given rules, to transform the graph on the left side of the field into the graph displayed on the right side.

Problem number 5 necessitates participants to apply the rules they have previously learned, utilizing operations they have employed in previous problems. When

Figure 11. EG problem 5 & Figure 12. EG problem 8.

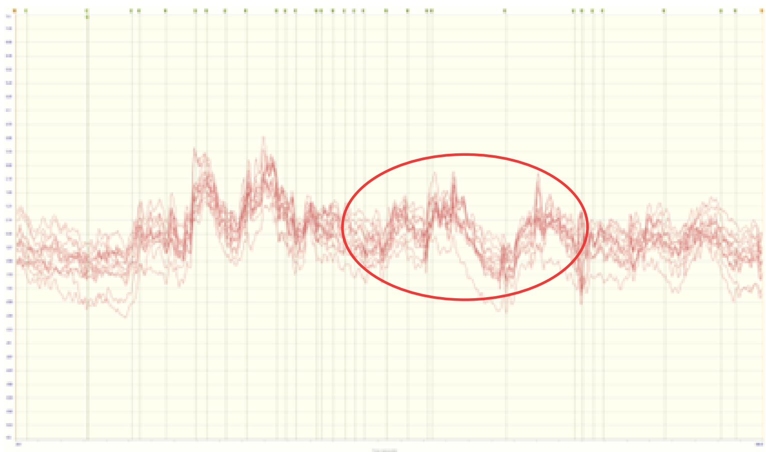


Figure 13. Cognitive spikes as a participant works through EG problem 5.

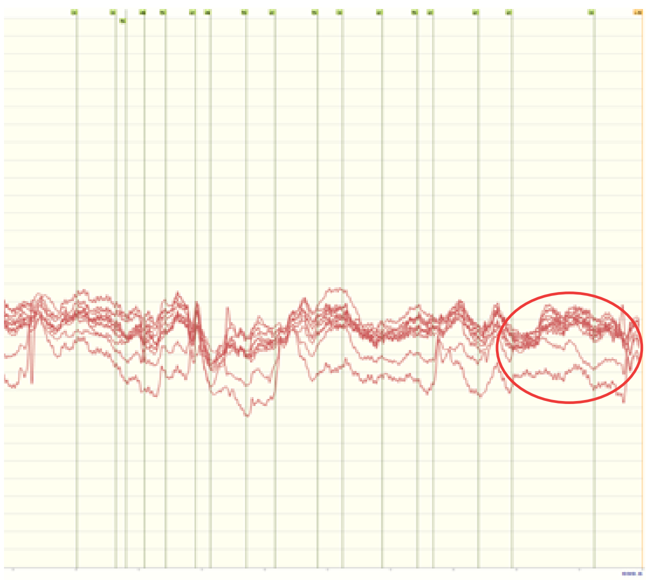


Figure 14. Cognitive spikes as a participant works through EG problem 8.

observing the participants' oxygenation levels during this problem, we notice a cognitive response spike or an initial increase in oxygenation as they commence their cognitive problem-solving skills and progress through the first step. Subsequently, as they realize they are nearing the solution and complete the problem with the second step, another cognitive response spike or a continued rise in oxygenation is observed. Following the resolution of the problem, the slope returns to the participant's baseline oxygenation levels (Figure 13).

Moving on to problem number 8, participants need to revisit the help menu upon recognizing the necessity of applying a rule that has not been utilized in previous steps. Similar to the cognitive response spikes witnessed in problem number 5, the participants' oxygenation levels increase as they undertake the operations needed to solve the problem. The response spikes exhibit variance as they navigate through the new problem scenario (Figure 14).

Connecting these cognitive response spikes to specific emotions may pose a challenge; however, considering the game structure, it is apparent that these spikes correspond to an emotional response, reflecting the effort, anticipation, and hope for successful problem-solving.

Moreover, examining the topography can offer further insight into the problem-solving process and events triggering cognitive response spikes. Analyzing participants' brain activity in the frontal cortex reveals the impact of different occurrences on various regions of the frontal cortex. Upon using Marker 5, a near-complete activation of the frontal cortex is observed. Furthermore, compared to events like Marker 3 and Marker 2, Marker 5 exhibits a higher level of activation across multiple segments of a participant's frontal cortex.

In summary, utilizing fNIRS allows us to observe evident disparities in cognitive responses between the two logical games, Tetris and EG. When examining Tetris, we note consistent increases in oxygenation levels, indicating that participants are consistently engaged in problem-solving efforts (Figure 18). This varies from EG, where participants tackle problems sequentially. By scrutinizing the oxygenation graphs in EG, we identify specific junctures where participants initiate and conclude their cognitive endeavors to solve the problems. In the case of EG, we can outline the impacts of various events on participants' cognitive processes (Figure 19).

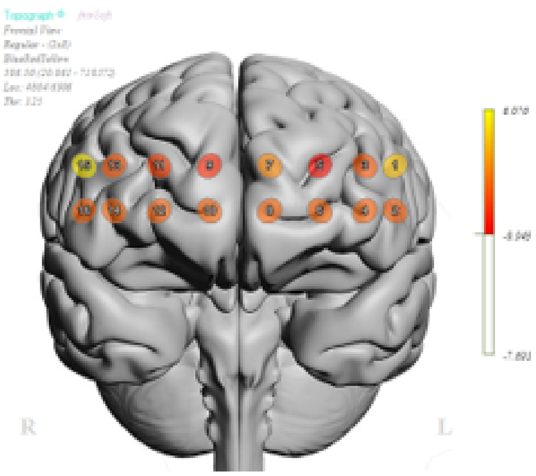


Figure 15. Participant is looking at the help menu.

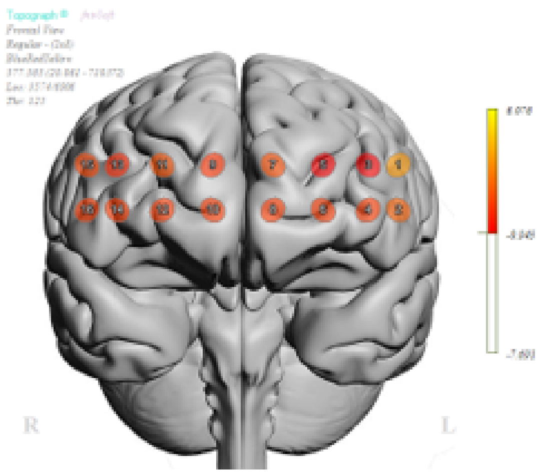


Figure 15. Participant problem-solving using the help menu.

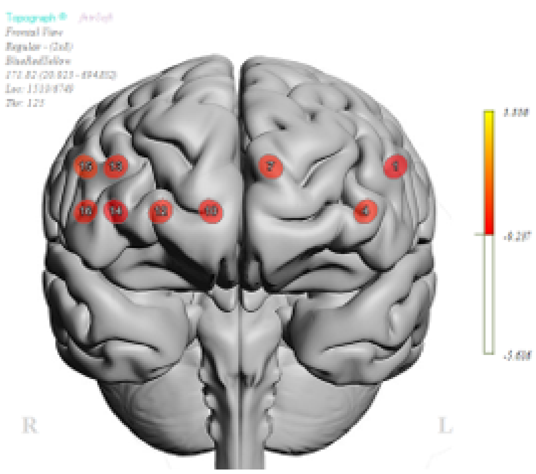


Figure 16. After solving problem (Marker 2).

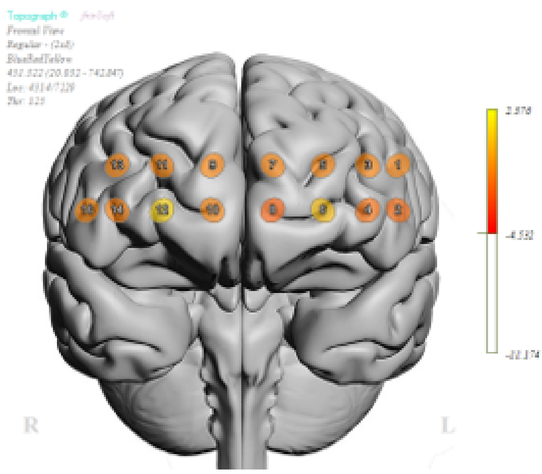


Figure 17. After an error was made (Marker 3).

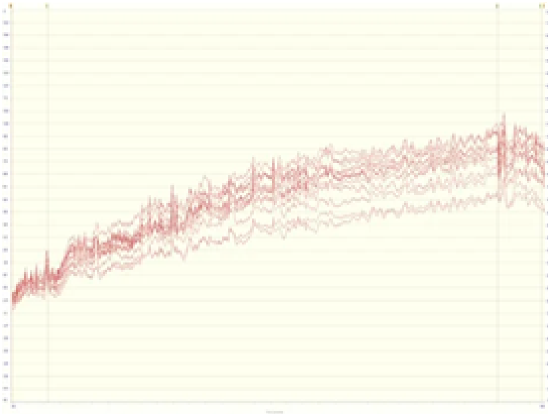


Figure 18. Cognitive spikes of Marker 2.

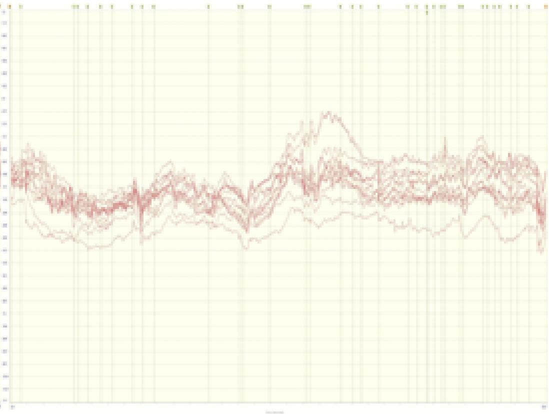


Figure 19. Cognitive spikes of Marker 3.

CONCLUSION

This study showcases the robust capability of fNIRS to assess emotional responses correlated with brain activity, particularly changes in oxy and deoxy-hemoglobin levels in the prefrontal, temporal, and parietal cortices. Furthermore, the study highlights computer-based logical games as valuable tools for observing and evaluating the cognitive responses of the brain.

Building upon the findings from marker 3, we deduce that the decrease in oxygenation following an error response may be linked to either preceding or subsequent emotional engagement. In both scenarios, it is evident that emotional involvement influences the oxygenation levels. This assertion is reinforced by marker 2, which signifies task completion. Successful participants displayed minimal to no cognitive response spikes, underscoring their minimal cognitive processing required to solve the problems.

Additionally, the study reveals that the majority of participants experienced significant cognitive responses during the problem-solving processes indicated by marker 5. The activation of more areas in the frontal cortex and the rise in oxygenation levels in the fNIR further demonstrate participants' utilization of logical and cognitive abilities to tackle the given problems.

Notably, the results from Tetris validate the hypothesis regarding the correlation between heightened emotional responses and increased cognitive effort.

Lastly, the utilization of fNIRS in conjunction with the diagrammatic model, Existential Graphs, for quantifying and assessing cognitive responses during a reasoning activity unveils new perspectives on comprehending the impact of Existential Graphs as a logical tool for enhancing relational reasoning skills.

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