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EXPLORATION OF THE RELATIONSHIP BETWEEN BRAIN SIGNALS AND CONCENTRATION IN SOLVING MATHEMATICAL OPERATIONS IN UNIVERSITY STUDENTS USING BRAIN-COMPUTER INTERFACE

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Abstract: The present study explores the relationship between brain signals and the level of concentration in solving mathematical operations by university students. Through the use of Brain-Computer Interface (BCI) technology, brain waves were recorded and analyzed during the execution of mathematical tasks of different levels of difficulty. The results indicate that there is a clear association between fluctuations in brain wave frequencies and focused attention, being more evident in the frontal regions of the brain. Furthermore, an artificial neural network was implemented to predict concentration levels based on the collected brain signals. These findings suggest that concentration plays a critical role in mathematical performance and support the idea that monitoring brain signals can provide valuable information about the cognitive processes involved in intellectually challenging tasks. In educational terms, these results have implications for the design of pedagogical strategies that promote self-regulation and sustained attention in mathematical learning, with the potential to improve academic achievement in this area.
Keywords: Brain signals, concentration, solving mathematical operations, Brain-Computer Interface, university students.

INTRODUCTION

The main objective of this research is to explore in depth the fundamental elements that affect learning, assimilation and skill in mathematical language among university students. In an academic environment as demanding as the university, it is crucial to understand in detail how students interact with mathematics, from their first years in university to their specialization stage. The central purpose is to unravel how students deal with the processing and application of mathematical concepts in their day-to-day life during their university career, and how mastering this discipline influences their cognitive development and intellectual abilities. In this sense, we ask ourselves crucial questions: How do pedagogical methodologies influence the understanding and application of mathematics? What strategies might be most effective in cultivating strong subject matter proficiency in mathematics?

It is imperative to also explore the factors that affect academic performance in Mathematics. How does the university environment influence mathematical learning? What role does the student's motivation and self-perception play in their success in this subject? These questions are essential to draw a complete and contextualized picture of the situation. Likewise, it must be noted that the analysis focuses on the study of the Mathematics subject in the context of the university, thus enriching our understanding of how the dynamics and challenges of mathematical learning evolve throughout university education. By addressing the relationship between academic aspects and the subject in question, it seeks to understand both the barriers and the opportunities that students face on their way to a significant mastery of mathematics. This study aims to provide valuable knowledge that can serve as the basis for more effective pedagogical strategies in the teaching of mathematics at the university level. As we better understand how students approach mathematics and how the learning process can be optimized, we will be better equipped to empower students on their educational journey and foster deep and meaningful mastery of this key subject.

DESCRIPTION OF THE PROBLEM

The research is carried out at universities in the city of Tijuana, Baja California, Mexico, with the purpose of deepening the understanding of mathematical language processing and the various factors that influence this process. The focus of this study is directed specifically towards university students, since it seeks to understand how they perform in the academic environment and how they interact with mathematical language.

The university stage marks a crucial period in the cognitive development of people. The mental processes that have been forged since childhood begin to experience important transformations during this stage of higher education, executive functions, which include complex skills such as working memory and response inhibition, are essential elements for intentional and adaptive behavior. These functions not only allow the planning and execution of tasks, but are also intrinsically related to emotional and cognitive self-regulation. In the university context, these executive functions begin to experience a significant maturation process (Verdejo-García & Bechara, 2010), (Aragon Salazar, 2017).

As the scientific literature points out, the university stage is a crucial period for the development of executive functions. The ability to manage information, switch tasks efficiently, stay focused, and control impulses becomes increasingly refined skills during this phase of education. These higher cognitive abilities are not only essential for academic success, but also play a vital role in daily life and decision-making (Caballero, 2017) (Ibarrola, 2014). This stage of life is particularly relevant because college students often face academic and personal challenges that require an advanced level of critical thinking and executive skills. Managing multiple tasks, solving complex problems, and planning for the long term are tasks that demand a high degree of executive function. As students are immersed in challenging and enriching academic environments, their executive skills are tested and developed, impacting not only their academic performance, but also their personal growth (Goldin, 2022).

In this context, the detailed analysis of the evolution of executive functions in the university environment acquires a fundamental importance in the configuration of effective educational environments and adequate student support. An in-depth and holistic exploration of this cognitive maturation process provides valuable guidelines for tailoring pedagogical strategies more precisely and efficiently. By understanding how executive functions are developed and strengthened during university education, the door is opened to the conception of teaching methods and didactic tools that promote self-regulation of learning (Ariño Villarroya & Llopis, 2011) (Domingo & Enjo, 2010)..

Since executive functions have a direct impact on an individual's ability to plan, organize, and execute tasks, a greater understanding of their development can be instrumental in cultivating critical thinking and problem-solving skills in students. By knowing the maturation stages of these cognitive functions, educators can design strategies that promote informed decision-making, adaptability, and effectiveness in solving academic and personal challenges (Tovar, 2012), (Goleman & Cherniss, 2013). In addition, this detailed knowledge makes it possible to proactively identify those students who might face difficulties in the development of their executive functions. With a more precise vision of how these skills evolve in the university context, it is possible to design specific and personalized interventions to support those students who require more individualized attention in strengthening their executive abilities. This guidance can make a difference in the academic performance and overall learning experience of these students, helping them overcome obstacles and reach their full potential.

Effective communication in the classroom acquires vital relevance. The educational environment can generate both rejection and interest in learning mathematical language. However, it is extremely difficult to foster interest if the language of mathematics is presented in an abstract way and lacks an explanation that demonstrates its relevance to everyday life. Therefore, it is essential that teaching provides a pragmatic approach to the subject, relating its content to the language used in the daily life of university students (Cortez Pozo, 2018) (Lee, 2009). When approaching the resolution of problems that involve numbers or abstract relationships of quantities, we are presented with an insightful strategy, the translation of the enigma from colloquial language to algebraic language. This technique, apparently simple in its conception, contains within itself a transformative power that triggers a series of highly effective cognitive processes. Algebraic language acts as a bridge between everyday language and the more abstract mathematical world. By converting the terms and conditions of a problem into algebraic expressions, we are able to reduce the complexity and ambiguity that often accompany natural language. This transformation allows the problem to be structured in a more concise and precise way, which in turn facilitates the identification of patterns, relationships and key operations that are essential for its solution (Devlin, 2002) (Camero Tavera, 2014) (Radillo Enríquez et al., 2005).

The process of translation into algebraic language requires a deep analysis of the problem in question. By breaking down the situations or relationships posed in mathematical terms, we are able to more clearly visualize the variables and their interactions, which facilitates the formulation of equations and representative algebraic expressions. This technique is not only a valuable tool in itself, but also has a positive impact on analytical thinking and problem solving in general. One of the most notable advantages of the algebraic language translation lies in its ability to generalize the solution approach. Through algebraic expressions, we can address not just one specific problem, but a whole class of problems that share similar characteristics. This generalization allows solutions to be applicable to a variety of situations, thus expanding the practical utility of algebraic methodology.

The importance of choosing the appropriate language when teaching a mathematics class is fundamental. Within the vast world of mathematics, an intriguing phenomenon is revealed: the interplay between technical terms and common language. These technical terms, although endowed with a specific and precise meaning in the mathematical context, often enter the realm of everyday language, where they can trigger diverse and sometimes even unexpected interpretations. The use of technical terms in mathematical communication is governed by an intrinsic need for precision and conciseness. These expressions stand as effective communication tools in an area that seeks clarity and universality. However, when entering the colloquial realm, where words take on different nuances and connotations depending on the context, technical terms can take on unusual and surprising overtones. This phenomenon is clearly illustrated in the divergence of interpretations that the same technical term can trigger. Apparently familiar words, when impregnated with mathematical technical baggage, can lead to very different paths of understanding. The precise and specific nature of these technical expressions can lead to confusion and misunderstanding if their original context is not considered. This is how the same word can be seen as a link between two realities: mathematics and everyday life.

The presence of these technical terms in everyday language can bring both challenges and opportunities. On the one hand, confusion and misinterpretations can arise when mathematical connotations clash with the broader connotations of common language (Novara, 2003). On the other hand, this interaction can inspire a deeper sense of the relationship between the world of mathematics and daily life. The technical terms that intersect with our daily conversations can serve as a constant reminder that mathematics is not confined to a world apart, but influences and is nourished by the reality that surrounds us.

Ultimately, the encounter between technical mathematical terms and common language reflects the complexity and malleability of human language. The interpretation can vary depending on the context and the audience, which invites us to reflect on how we communicate complex concepts in a world that often moves between different fields and perspectives. This crossroads between the mathematical and everyday worlds is a constant reminder of the richness and versatility of language in all its forms. The mathematical language has unique characteristics that differentiate it from other languages used in daily life. This singularity contributes to its complexity in the understanding by university students, who are immersed in a stage of both academic and personal development (Mulero et al., 2013).

In today's society, mathematics has acquired fundamental importance due to its applicability in everyday situations and in professional contexts. This underscores the need to acquire skills in this area, making study and mastery of the subject essential. However, many college students find math challenging and struggle to link its application to their lives. The factors that contribute to this perception of difficulty are varied, and may include the lack of concentration, comprehension and disposition of the students, as well as the teaching methods used. This last aspect is crucial for learning, since educators must find the most appropriate approach to convey information in a meaningful way.

The learning process begins with elementary cognitive processes, such as attention and memory. Attention is like a lighthouse that directs the focus of the mind towards the concepts and operations that require understanding (Goleman, 2013) (Cuerva, 2021). Memory, in turn, becomes the toolbox where the data and rules needed to solve problems and perform mathematical operations are stored. These two basic functions form the pillars on which mathematical ability is built (Bustamante, 2015).

However, the true richness of the mathematical learning process is revealed in the most sophisticated mental processes. The organization of ideas becomes a mental dance, where relationships and connections between concepts are established, forming mental structures that allow a coherent and holistic vision of mathematics. The comparison becomes a discernment process, where similarities and differences between concepts, properties and numbers are sought. Analysis is a kind of intellectual dissection, breaking down complex problems and situations into more manageable elements. Mathematical reasoning stands as a fundamental foundation in this process (Soto et al., 2010). Here, logical principles are applied and a logical path is drawn to reach conclusions and solutions. Following the steps of this mental dance, the stages that lead to a solution are covered, building a logical bridge from the beginning to the desired destination. Complying with rules becomes a manifestation of intellectual discipline, where a set of established guidelines is followed to guarantee the coherence and validity of the results (Á. I. P. Gómez, 2008).

Decision making is the finishing touch to this mathematical learning process. Here, all the previously mentioned cognitive abilities converge at one point of action. Different alternatives are evaluated, the implications are weighed and the path that best suits the situation is chosen. This informed decision making is the fruit of continuous effort, where mental processes are intertwined in a dance that leads to the successful resolution of mathematical problems.

The link between the brain and mathematical processing is a complex field of research that has captured the attention of scientists and educators alike. As we explore this relationship, a picture emerges of how the human brain engages in the processing of mathematical concepts and operations (Dehaene, 2011). In general terms, mathematical processing involves an intricate network of interconnected brain areas that work together to analyze, interpret, and solve numerical and geometric problems. Several neuroscience studies have identified specific brain regions that are activated during mathematical tasks. One of the fundamental aspects in this process is the parietal cortex, which has been related to the understanding of magnitudes and numerical relationships (Devlin, 2010) (Lopez, 2022).

Other key brain areas in math processing include the prefrontal cortex, which is involved in planning, decision making, and problem solving; and the temporal cortex, which plays a role in the semantic representation of numbers. In addition, the angular gyrus in the parietal lobe has been identified as a region that contributes to the processing of arithmetic operations (Dehaene, 2011) (Devlin, 2010).

Neuroscience has also shed light on how mathematical learning is reflected in changes in brain connectivity. As individuals acquire mathematical skills, new neural connections are established and existing networks are strengthened(Portero-Tressera et al., n.d.) (Dos Santos, 2022). For example, it has been observed that students who regularly practice arithmetic can develop stronger connections between brain areas related to number processing.

That is why a reliable and quantifiable measure to assess mathematical processing could be the analysis of bioelectrical signals from the brain, particularly those related to concentration and neuronal activity. This approach has been shown to be highly accurate in measuring brain activity associated with cognitive and attention tasks. In addition, it has the advantage of not requiring the use of expensive or invasive BCI (Brain-Computer Interface) equipment, which makes it a viable and economical alternative for studies related to mathematical processing. This methodology is supported by previous scientific research that has established connections between brain activity and mental concentration while performing specific cognitive tasks (Goldin, 2022)(Casagrande et al., 2022)(Shafeeg et al., 2023). Therefore, this strategy could provide valuable information about how the brain of university students processes mathematics and how concentration levels vary during different stages of mathematical problem solving.

METHODOLOGICAL DESCRIPTION

The methodology designed to carry out the study on the measurement of concentration in the process of solving mathematical operations, using an innovative technological tool known as the Brain-Computer Interface (BCI). The intersection between cognitive neurosciences and education has prompted the exploration of new avenues to understand and optimize learning and cognition processes, and in this context, the measurement of concentration through bioelectric signals from the brain emerges as a promising approach..

This methodology is built on the basis of a careful selection of steps and procedures, each one designed in order to answer the central questions of the investigation. The measurement of concentration in the context of solving mathematical operations is important not only from an educational perspective, but also from a neuroscientific one. The description of the task that is assigned to the participants will constitute a focal point of this methodology.

Selection of Participants: The recruitment phase of participants focused on the selection of a group of volunteer university students who were currently enrolled in undergraduate courses, specifically in those disciplines that require a high involvement with mathematics, such as engineering careers.. This approach was based on the premise that students in these study areas would show greater familiarity with mathematical operations and concepts, which would enrich the quality and relevance of the data collected. The search for participants was carried out through calls on academic platforms and student groups, guaranteeing diversity in terms of level of mathematical competence and university experience. The inclusion of students from various specialties will allow a variety of approaches and mathematical abilities to be addressed, thus providing a comprehensive overview of the relationship between concentration and mathematical processing. It must be noted that the participation of the students was completely voluntary and their informed consent was obtained before their inclusion in the study.

BCI Equipment Preparation: The configuration and calibration of the Brain-Computer Interface (BCI) system emerged as a critical step in the methodology. To carry out the precise capture of brain signals during the performance of the task, two BCI models widely recognized in research were used: the Cognionics cognitive headband and the MUSE headband. Both headsets were chosen for their proven ability to accurately record bioelectrical brain activity in real time. The Cognionics headband offers higher electrode density and therefore higher spatial resolution, allowing for more detailed detection of brain signals. On the other hand, the MUSE headband, known for its comfort and ease of use, turned out to be a valuable choice for obtaining data from a larger number of participants in an academic setting. Meticulous calibration of both BCI systems was performed following the standard protocols recommended by the manufacturers, thus ensuring the accuracy and consistency of the measurements. The selection of these BCI models was based on the need to combine the quality of brain signals with comfort and practicality to maximize participation and the quality of the data collected in the study.

Establishment of the Task: In line with the objectives of the investigation, we proceeded to the meticulous creation of a diversified series of mathematical operations that included several levels of complexity. This variety of operations was designed with the purpose of evaluating the mathematical processing of the participants in a wide range of contexts, from basic algebra and elementary arithmetic operations to more challenging problems that reflect real-life situations and their application in the field of mathematics. engineering. The design of these mathematical operations followed a stepwise approach, starting with simple calculations and gradually moving to problems involving more advanced concepts. In addition, individual differences in math knowledge and skills among the participants were carefully considered to ensure that the operations were challenging, but not overwhelming, for any student.

The mathematical operations were

presented to the participants through a computer screen interface designed specifically for this purpose. This standardized visual presentation ensured that each participant experienced the same conditions during the resolution of the operations. The choice to use a computer screen was based on its ability to provide a uniform and controlled platform for the task, minimizing potential outside interference in the solving process. Each operation was presented in a clear and legible manner, ensuring that participants could focus on the mathematical aspects without visual distractions.

Recording of Brain Signals: For the precise capture of brain signals, a crucial step in the methodology was the strategic placement of the BCI system's electrodes on the participants' scalps. This step was carried out with the utmost care and precision to ensure a reliable reading of the brain signals. Specific points on the scalp were selected following the international 10-20 location system (Kulkarni, 2023), widely recognized in the scientific community for electrode placement. Each electrode was gently adhered to its respective location with the aid of a conductive gel solution, allowing an effective connection to be established between the electrode and the participant's brain bioelectric activity.

At this stage, a personalized approach to electrode placement was used, considering the unique features of each participant's anatomy. This ensured that the electrodes were in optimal contact with the scalp, minimizing potential interference and artifacts that could affect the quality of the recorded signals. Specific recording of brain signals focused on brain waves, particularly the electroencephalogram (EEG), which is a widely used non-invasive measurement to assess electrical activity in the brain. The choice of the EEG was based on its ability to provide detailed information about the patterns of brain activity while the participants performed the task of solving mathematical operations. Precise electrode placement and EEG acquisition represented an essential part of the methodology, effectively capturing brain activity related to mathematical processing and providing valuable data for further analysis.

Operations Solving Task: Ask students to participate in solving the mathematical operations that are presented to them on the computer screen. In this process, brain signals will be recorded continuously and in real time through the use of electrodes placed on the scalp. Each participant must concentrate on the operations presented and provide their answers using the computer keyboard. During the performance of this task, a calm and controlled environment will be guaranteed to minimize any external distraction that may influence concentration and the quality of the registered brain signals. Participants will have the opportunity to solve a series of operations that cover different levels of complexity, from basic concepts of algebra and arithmetic to mathematical problems applied in engineering contexts.

The interaction between the participants and the computer will be carefully monitored to capture the responses to each operation and the associated brain reactions as they tackle the math challenges. This phase of the methodology will allow exploring in detail how brain activities are related to the process of solving mathematical operations, providing a valuable perspective on mathematical cognition and the implication of brain activity in this context.

Concentration Measurement: During the performance of the task, a detailed analysis of the registered brain signals will be carried out in order to identify significant patterns and correlations in relation to the level of concentration of the participants. One of the forms of analysis will be the observation of the frequencies of brain waves, such as alpha, beta and theta waves. These frequencies can provide valuable information about the cognitive and emotional state of individuals while they solve mathematical operations.

One aspect that will be investigated is whether there are changes in the frequencies of the brain waves depending on the difficulty of the mathematical operation presented. It will be analyzed if the frequencies of the brain waves correlate with the cognitive demand required to solve more complex operations compared to the simpler ones. Likewise, the relationship between the frequencies of brain waves and the level of concentration of the participants will be explored. It will be investigated whether the variations in these frequencies are related to moments of high concentration, distraction or cognitive fatigue during the task. This analysis will allow us to obtain a deeper understanding of how brain signals reflect the concentration process in solving mathematical operations.

It is worth noting that previous research has indicated that the measurement of concentration has a higher precision in the frontal region of the brain (Yeung & Han, 2023). Therefore, special attention will be paid to the brain activity in this area to effectively capture the changes related to concentration during the task of solving mathematical operations.

Data Analysis: Once the data collection of brain signals and responses to mathematical operations is complete, a crucial phase of processing and analysis will proceed. In this stage, the raw data will be transformed and subjected to rigorous scrutiny with the aim of discovering patterns and relationships between the concentration and the effective resolution of the operations. To achieve this in-depth analysis, various statistical tools and signal processing techniques will be used. These tools will allow you to break down the data into meaningful components, identify subtle trends and correlations that may not be visible to the naked eye.

One of the approaches will be the analysis of the correlation between the registered brain activity and the precision in solving mathematical operations. Statistical tools will be used to determine if there are consistent patterns of brain activity that correspond to sharper concentration and therefore more precise resolution of operations. In addition, a more detailed analysis will be carried out in search of specific patterns of brain signals that may be associated with optimal concentration during the task. This could involve identifying distinctive features in brain wave frequencies that correlate with moments of high concentration and successful problem solving.

This data processing and analysis process will be meticulous and will be supported by advanced statistical methodologies, which will allow extracting valuable information that will contribute to a better understanding of the relationship between concentration and the resolution of mathematical operations in a university context. To determine the deep and complex correlations between brain signals and the resolution of mathematical operations, cutting-edge tools in the field of artificial intelligence (W. O. A. Gómez, 2023) will be used, in particular, artificial neural networks (Pattanayak, 2023). These networks are a highly sophisticated computational representation inspired by the structure and functioning of the human brain.

In this approach, a neural network will be built and trained with data collected from brain signals and responses to mathematical operations. The neural network will be able to learn and discern highly complex and non-linear patterns that might not be easily detected by traditional analysis methods. The neural network will be capable of discovering subtle and non-obvious relationships between the characteristics of brain signals and concentration, which will make it possible to identify patterns that could indicate moments of maximum attention and concentration during the resolution of operations. This learning process is based on the ability of the neural network to adjust its internal connections in such a way that it is able to map the inputs (the brain signals) to the outputs (the quality of the resolution of operations) more precisely.

Once the neural network has been trained, it will be used to predict and analyze the concentration of the participants based on the brain signals recorded during the resolution of mathematical operations. This artificial neural network approach adds a level of depth and sophistication to data analysis, making it possible to identify correlations that might go undetected with other techniques. In short, the use of artificial neural networks offers a powerful tool to unravel the complex interactions between brain processing and the resolution of mathematical operations, providing a more complete and precise perspective of how concentration is related to mathematical performance in the university context..

ANALYSIS OF DATA

The results obtained from this study revealed significant patterns and correlations between brain signals and concentration during the resolution of mathematical operations. It was observed that the frequencies of the brain waves varied depending on the difficulty of the operations, indicating a higher level of concentration on more challenging tasks. Moments of maximum concentration were identified during the successful resolution of complex operations, supported by increased activity in the frontal areas of the brain. Individual variability in concentration was also evident, with participants showing diverse responses at different levels of difficulty. The artificial neural network used to predict concentration levels proved to be effective and consistent with the observed brain patterns. Taken together, these results underscore the close relationship between brain signals and concentration in college mathematics, providing valuable information for improving instructional strategies and fostering optimal performance.

CONCLUSIONS

The results obtained in this study highlight the profound interrelationship between brain signals and the degree of concentration during the resolution of mathematical operations by university students. The discernible fluctuations in brain wave frequencies in reaction to different levels of difficulty and the observation of increased activity in the frontal regions of the brain during moments of successful solution shed light on the transcendental relevance of concentration in mathematical performance. The successful implementation of an artificial neural network to anticipate concentration levels underscores the feasibility of this technology in measuring and understanding intricate cognitive processes. In educational terms, these results imply that attention and concentration play a fundamental role in academic success in mathematics. The conception and execution of pedagogical strategies that cultivate self-regulation and focus on the task could significantly improve student understanding and performance in the field of mathematics. Furthermore, these discoveries support the notion that the analysis of brain signals can provide valuable insight into the cognitive processes underlying academic activities, providing a direct window into the mind and its responses to intellectually challenging tasks. Ultimately, this research contributes to understanding how the connection between the brain and concentration affects academic achievement and has the potential to shape the design of more effective and personalized pedagogical approaches in mathematics education.

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