iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** V **Month of publication:** May 2023

DOI: https://doi.org/10.22214/ijraset.2023.48563

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue V May 2023- Available at www.ijraset.com

Cognitive Information Processing Speed

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Abstract: Using visual learning and meditation based techniques to develop brain training apps that can significantly improve cognitive performance. This paper seeks to understand what causes slow cognitive processing speed and designs an application to diagnose it in early stages and provide support to people having slow processing speed. Moreover, significant primary data is collected to validate the hypothesis that visual learning techniques presented through mobile applications can improve cognitive performance. Secondary data based on 100 sessions in 12,000 subjects is also analyzed to understand the improvement of brain functioning. The study also points to the option of including meditation training in schools to help children focus and concentrate better. The goal of this paper is to test the efficiency of CogniBuddy's program offered through app.

A comprehensive study of cognitive processing speed and how slow processing speeds affect students. The solution focuses on an entropy based way of calculating information processing speed in the brain to understand it better and an app, CogniBuddy, for brain training based on meditation and visual perception amelioration.

Link to the Application
https://drive.google.com/file/d/18VnWa7y0U0lIWx-WtGRQg4tPGEUEKW9U/view

I. INTRODUCTION

Processing speed is an essential component of the cognitive process, and as such is among the most important skills in learning, academic performance, intellectual development, reasoning and experience.
Processing speed is a cognitive ability that can be defined as the amount of time it takes a person to perform a task. It relates to the speed with which a person can perceive and react, whether it is visual (letters and numbers), auditory (language), or movement. In other words, processing speed is the time between receiving and responding to a stimulus.
Slow processing speed is not related to intelligence, which means that one does not necessarily predict the other. Slow processing speed means that some certain tasks will be more challenging than others, such as reading, math, listening, taking notes or having a conversation. It can also interfere with executive functions, as a person with a slow processing speed will have a more difficult time planning, setting goals, making decisions, initiating tasks, paying attention, etc.
Processing speed refers to a greater ability to perform tasks that are simple or already easily learned. It refers to the ability to process information automatically, which means to process information quickly and without doing it consciously. The faster the processing, the quicker your ability to think, react or learn.

II. SOLUTION

Over the last decade, the accessibility and use of smartphones and mobile internet has quickly expanded around the globe. In parallel to this rapid growth, the industry of mobile apps is exploding.
Brain training is a program of regular activities purported to maintain or improve one's cognitive abilities. The phrase "cognitive ability" usually refers to components of fluid intelligence such as executive function and working memory.
Therefore, the main objective is the development of CogniBuddy, an application that provides a blend of visual tasks related to response time, comprehension skills, and analytical thinking to improve cognitive performance. CogniBuddy was designed to be used by students between the ages 12-17 directly, enabling rapid statistical analysis to be conducted on the results. Brain processing speed was tracked through performance on different tasks, time taken to process complex tasks, and the accuracy, precision, and recall on different cognitive challenges.

III. MEDITATION

Mounting evidence suggests that cognitive training programs may have the ability to counteract this decline in cognitive processing speed in students. Based on a growing body of research showing that meditation has positive effects on cognition in younger and middle-aged adults, meditation may be able to offset age-related cognitive decline or even enhance cognitive function in older adults. In this paper, we review studies investigating the effects of meditation on cognitive speeds.

In general, the studies reviewed suggested a positive effect of meditation techniques, especially in the area of attention, as well as memory, verbal fluency, and cognitive flexibility. Meditation could be a potentially appropriate non-pharmacological intervention aimed at improving a student's performance in a multitude of tasks.

Although research has found that practicing long-term mindfulness meditation enhances executive functioning and the ability to maintain attention, the effects of short mindfulness training have not been fully explored. Therefore, we examined whether short meditation training affects cognition and mood when compared to an active control group. After two sessions of meditation training or listening to a recorded book, participants with no prior meditation experience were assessed by measures of mood, verbal fluency, visual coding, and working memory.

Both interventions were effective in improving mood but only short meditation exercises reduced fatigue and anxiety, improved cognitive speed, and increased alertness.

Furthermore, brief wakefulness training significantly improved visuospatial processing, working memory, and executive performance. Meditation training can enhance the ability to maintain attention; Meditation was a key motivation for a solution to this problem since scientific research has seen benefits reported with long-term meditators.

The app has a built-in meditation section that contains interventions for effective sleep and focus during studies. Study participants' progress was tracked and secondary data sources were pooled to determine the effectiveness of meditation in general and application in particular to improve the cognitive performance of the participants involved without any pharmacological interventions.

IV. SOCIETAL EFFECTS

However, research has shown that processing speed is linked to reading development and reading performance. Specifically, processing speed may be a factor in these situations:

Reading disorders such as dyslexia: A subset of reading disorders in which individuals display marked difficulties with verbal and visual processing speed.

Grapho-motor problems (dysgraphia): Individuals with dysgraphia have serious trouble forming letters and numbers; their handwriting is slow and labored; they may have trouble with spacing between words; they mix upper- and lower-case letters; etc. Because neatness only comes with their taking much time, their written work can be very strained and painful.

In addition to cognitive and attentional variables, a number of emotional factors can increase how much time it takes for students to complete work. When students are anxious, their processing speed can slow due to self-doubt, uncertainty, second-guessing, and self-consciousness.

Obsessive-compulsive disorder (OCD) can cause even more slowing. Here are some examples of how children with OCD might behave in this context:

One child has developed a “rule” that if he hesitates when reading, he “has to” reread the entire passage.

Another child spends an inordinate time when writing, laboring to form letters and numbers so that they are “perfect.”

Regardless of the category of services for which the gifted student qualifies, it’s important to prevent slow processing from interfering with a child’s success. Teachers should be aware of how slow processing speed can affect the performance of bright students and strive to differentiate their instruction. Gifted students with slow work pace should not be denied gifted education opportunities.

Because some very bright students with slow processing speed do not see themselves as smart, it’s important to help them understand the nature and pattern of their abilities. It may help to remind them that all people have strengths and weaknesses and that having a slower pace does not mean one is not smart. One student loved that I referred to him as an intellectual tank — not very fast, but extremely powerful.

Some students make good use of timers and alarms to help them track time. A teenager I worked with began using an alarm clock in the bathroom to remind him to get out of the shower. It can also help to conduct a time study. Teaching and training the students with SPS with good time management skills will help them perform better.

Parents can use a stopwatch to determine how much time it takes the child to complete routine tasks like doing a chore or getting dressed for school. These times can be used as goals to work toward and rewards can be provided when the student completes a task within the allotted time. Parents too should be counseled to set realistic goals for younger children who otherwise will feel frustrated with repeated failures.

V. A NEW METHOD TO ANALYZE THE BRAIN'S PROCESSING SPEED

For more than a century, psychologists have used reaction time as a window into the brain. The thinking is that information processing takes time, so the average amount of time taken to begin or complete a task reflects the duration of the cognitive processes involved in it.

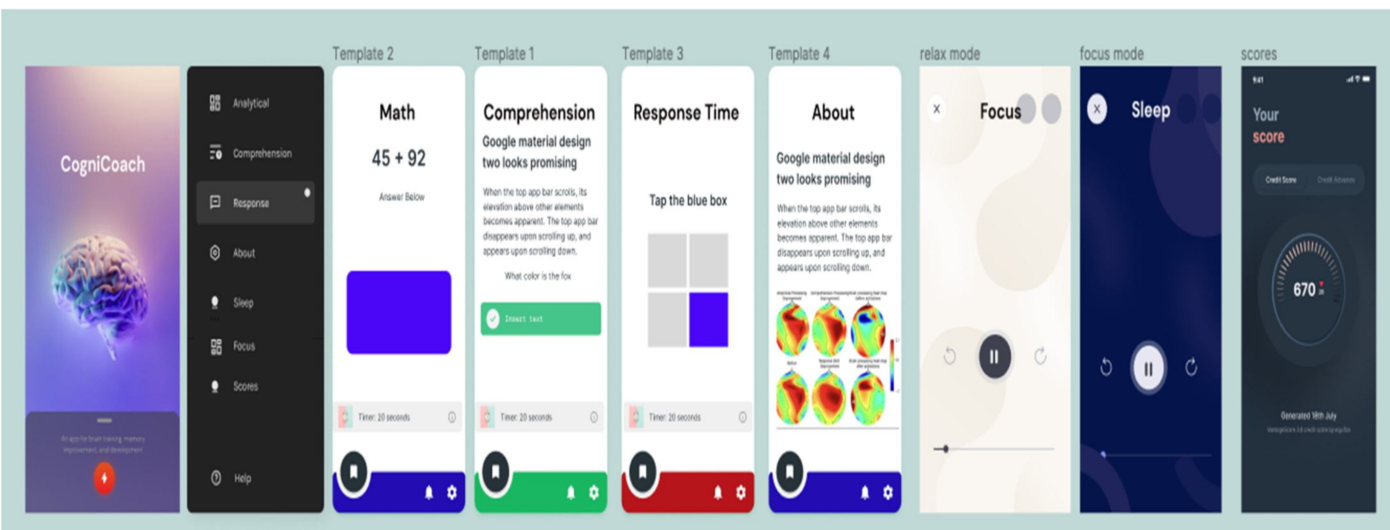
For example, a typical reaction-time experiment might ask a subject to classify a sequence of letters as a word or a nonword, by pressing a button. This kind of experiment is called a visual lexical decision task.

This information-centric approach is clearly ripe for an information-theoretic treatment. And sure enough, no sooner had Claude Shannon published his theory of information in the 1940s, than psychologists began to apply it to the exchange of information between the environment and the brain that goes on during reaction-time experiments.

Their approach eventually led to Hick's Law, one of the few laws of experimental psychology. It states that the time it takes to make a choice is linearly related to the entropy of the possible alternatives. The results from various reaction-time experiments seem to show that this is the case. Although one byproduct of this approach is that the results are intimately linked to the type of experiment used to measure the reaction time. And that makes each study peculiarly vulnerable to the idiosyncrasies of the experimental approach. Therefore, a better method is to study reaction times by analyzing the entropy of their distribution rather than in the manner of thermodynamics. Entropy is an estimate of the amount of information needed to specify the state of the system. The entropy of the distribution of reaction times is independent of the type of experiment and so provides a better measure of the cognitive processes involved. That's important, not least because it provides a way to more easily compare the results from different types of experiment.

This allows us to determine how much information the brain can process during lexical decision tasks - which is a maximum of 60 bits per second. However, it must be noted that this does not refer to the information processing capacity of the entire brain but is instead a measure of input/output capacity during a single task.

VI. THE COGNIBUDDY APP



The app uses Shannon's entropy to process results and has multiple sections focusing on everything from visual skill improvement and meditation - with the goal of improving and understanding cognitive processing speeds. It is an android application with a splash screen, home page, menu, and options to perform a wide variety of tasks. There is an emphasis on user interface design to make it easily accessible by students and those who need it. All the primary data and research done for the study was collected through the app. A beta test was conducted for students between the ages of 11-17 along with a survey to understand their background.

Moreover, using the section and formulae above, the app has an About section that computes the brain's efforts while doing the tasks and measures improvement in the form of a heatmap. Screenshots of the visual and result sections are below.

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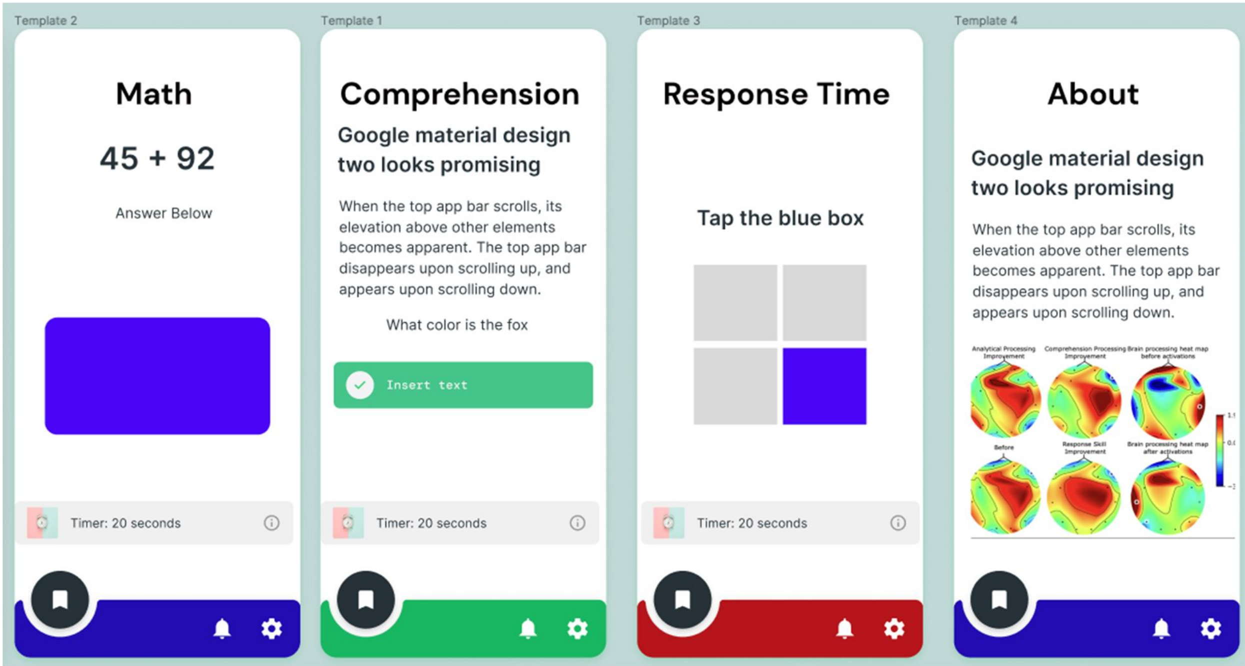
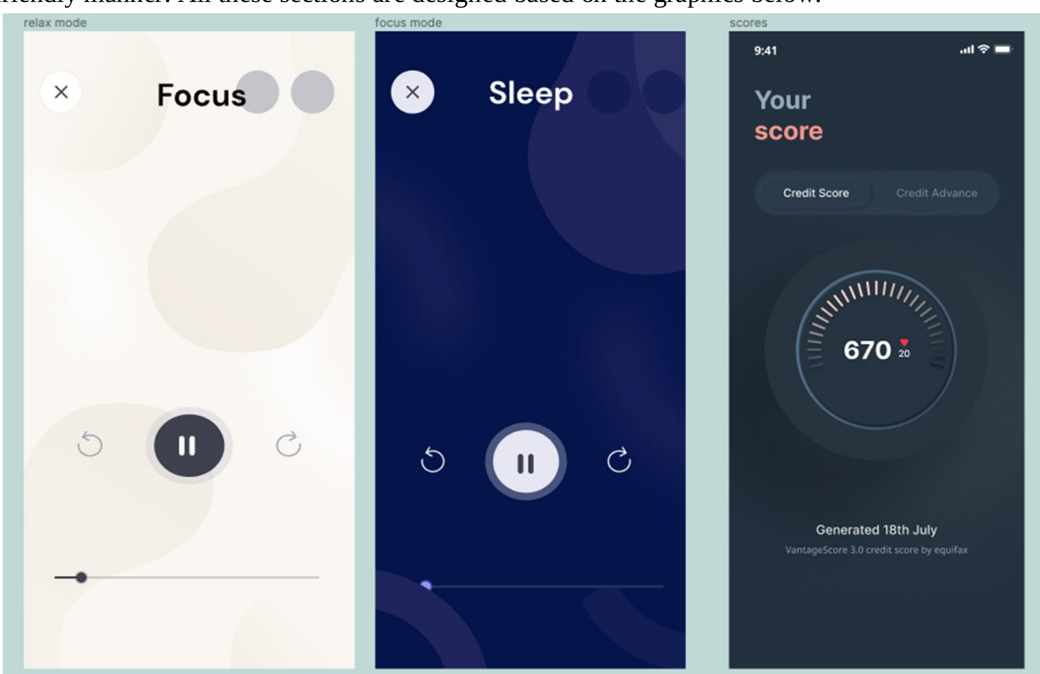


Moreover, the app also has a guided meditation section for both sleep and focus. It presents the scores for students in an easily accessible, user-friendly manner. All these sections are designed based on the graphics below.



VII. INFORMATION CAPACITY

The surface frequency of a word can be expressed by Shannon's amount of information, that is, the minimum number of bits that would be necessary to encode the word in an optimal binary coding of all the words in the lexicon.

In this way the amount of information (Is(w)) of a surface form w; with a frequency F(w) in a corpus of size N is given by:

$$Is(w) = -log_2 \frac{F(w)}{N}$$

Where p(w) = (F(w))/N is the probability of encountering w in a corpus.

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Note that, according to Eq. (1), the amount of information is inversely proportional to the log frequency of the word. As it has been established that logarithmic frequency correlates negatively with lexical decision latencies, the amount of information of a word should show a positive correlation with lexical decision latencies. This technique went into developing the comprehension section and response time section of the app since it was vital to measure the amount of information going into the brain and the speed at which it was being processed.

The average amount of information of an inflectional paradigm (e.g. feminine nouns) is inversely related to the processing speed of the individual inflected forms that constitute the paradigm—high average amounts of information are paralleled by shorter processing speed per one bit in a given experiment. We can consider the inflectional paradigm of a word to be a random variable whose possible values are the different inflected forms that a base word can take. Hence, we can calculate the entropy of the inflectional paradigm, its inflectional entropy.

$$H(P) = -\sum_{x \epsilon P} p(x|P) log_2 p(x|P) \simeq -\sum_{x \epsilon P} \frac{F(x)}{F(P)} log_2 \frac{F(x)}{F(P)}$$

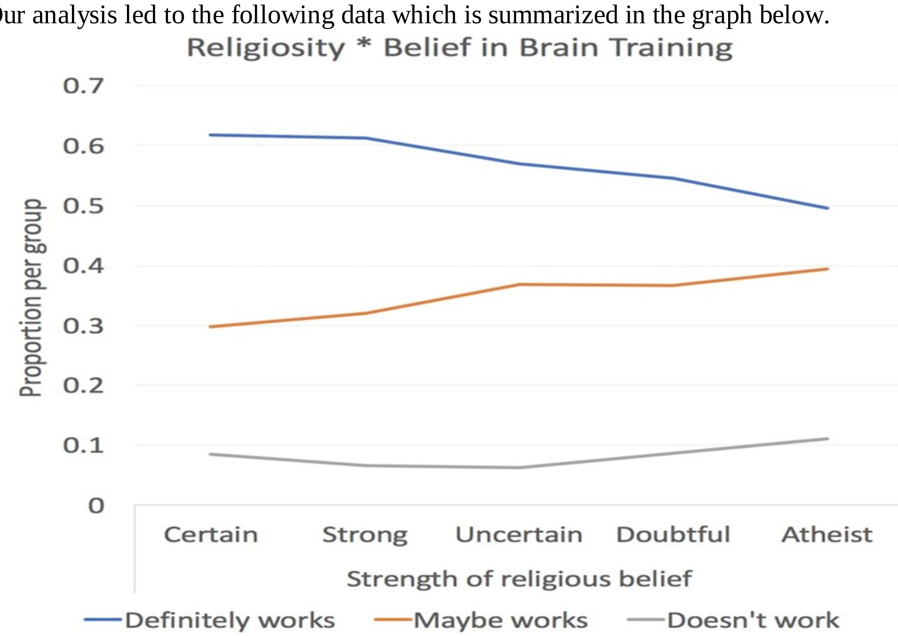
For example, the inflectional paradigm of the base form car consists of the forms "car" and "cars" with surface frequencies F("car") and F("cars"). The base frequency of the inflectional paradigm car is F(car) = F("car") + F("cars") and the probabilities of the inflected form being "car" or "cars" within the inflectional paradigm of car are p("car") = F("car")/F(car) and p("cars") = F("cars")/F(car). The entropy of the inflectional paradigm of car will then be H(car) = -p("car")log2p("car") - p("cars")log2p("cars")

VIII. STATISTICAL ANALYSIS

We conducted our analysis on primary and secondary data for the app and the concept of brain training in general. Secondary data analysis was guided by prior work in the field and primary data analysis was done through a survey and a randomized control trial of improvement of participants cognitive processing speed as they used the app and the meditation section.

We sent out a survey to a number of private and government schools in India where we analyzed data to get a background on students suffering from slow cognitive processing speed. Once we had a large list of students suffering from this issue, we contacted teachers to get more background about the students and see if they fit the criteria for the study and were valid candidates. After this, the next step for data collection was conducting training for the selected students - over 150 of whom completed the study. We taught them how to use the app and collected data over a span of one month and have analyzed all the collected data below. We followed a month-long schedule with bi-weekly follow ups and weekly data collection to ensure that the study was accurate and fair and did not put pressure on the students. After the study, we had objective data in the form of numbers and results and also reports from students where they talked about the direct benefits of the study and how they had improved after using the app.

It's important to understand people's belief in brain training since it directly affects the improvement that they get and how involved they are in the study. Our analysis led to the following data which is summarized in the graph below.



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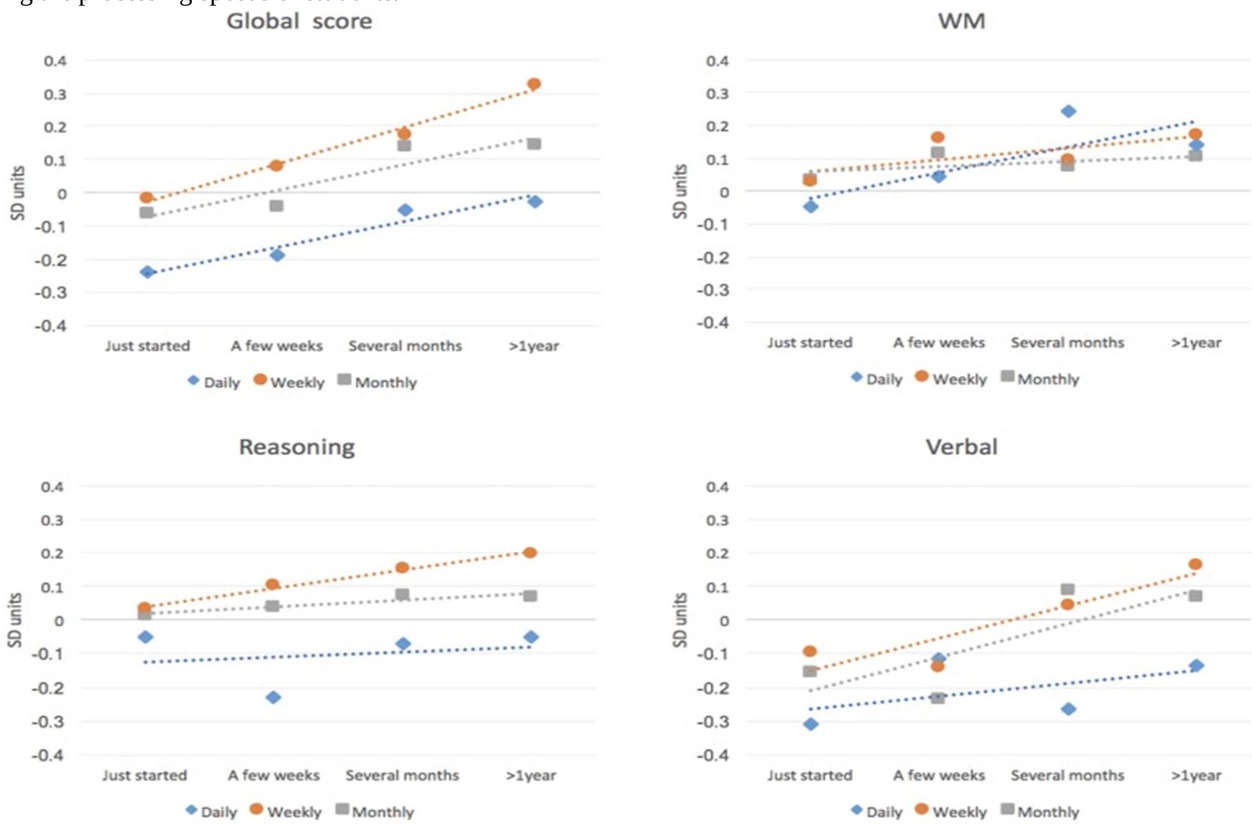
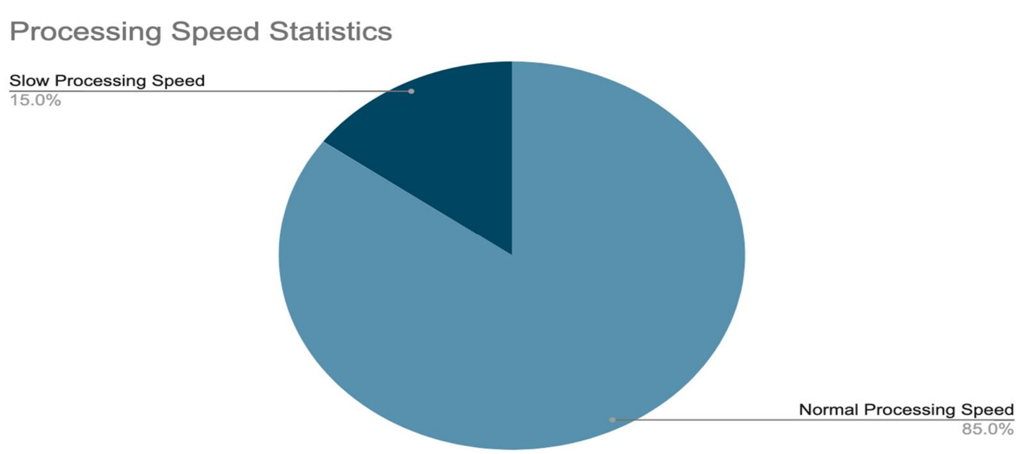
A. Improvement in Cognitive scores using secondary data

We analyzed secondary data and prior work related to brain training to understand that cognitive processing speed improves after sessions of brain training - this was a key motivation to pursue the study and make the app CogniBuddy that was successful in improving the processing speeds of students.



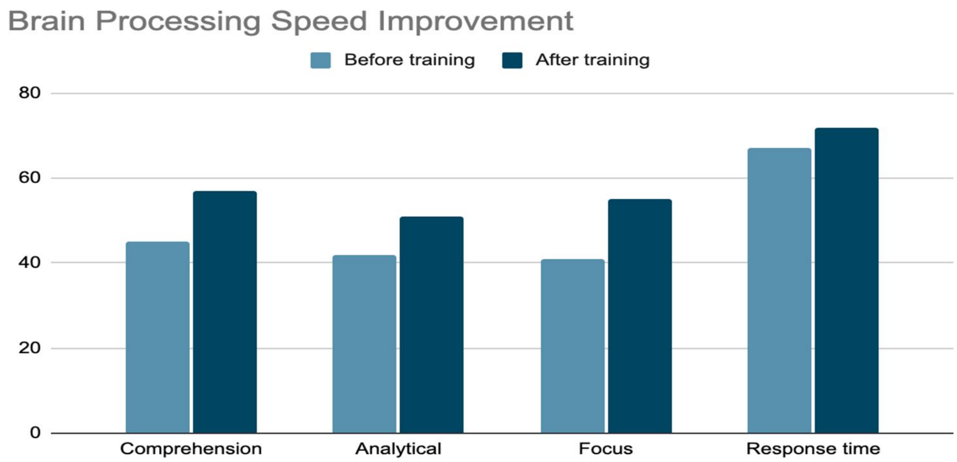
Cognitive scores in Study 2 for people who report brain training at different frequencies and over different durations. Participants who had just started brain training showed significantly scaled disadvantages in Global and Verbal score relative to participants who reported no brain training. These lower scores were most pronounced for participants who reported brain training on a daily basis. There was an increase in cognitive scores with duration of training such that those who trained weekly for at least a year had Global scores 0.32 SDs higher than the non-training population. Smaller scaled trends in the same direction were evident for the Reasoning variables.

PIE chart about what percentage of students are affected by slow processing speed



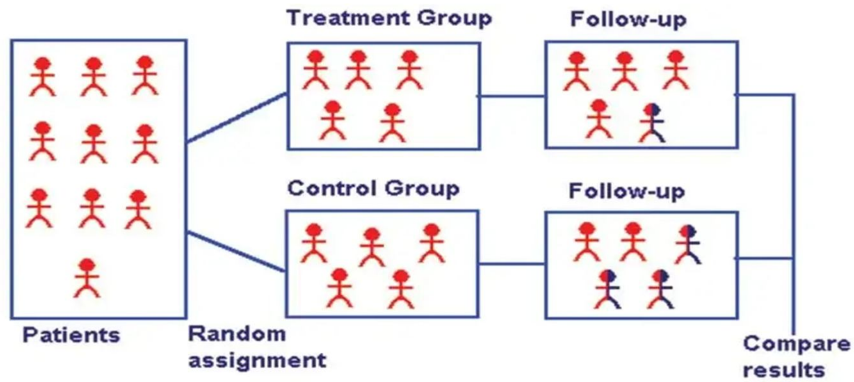
Data about the app

Scores before and after for comprehension, analytical skills, and response time: bar chart

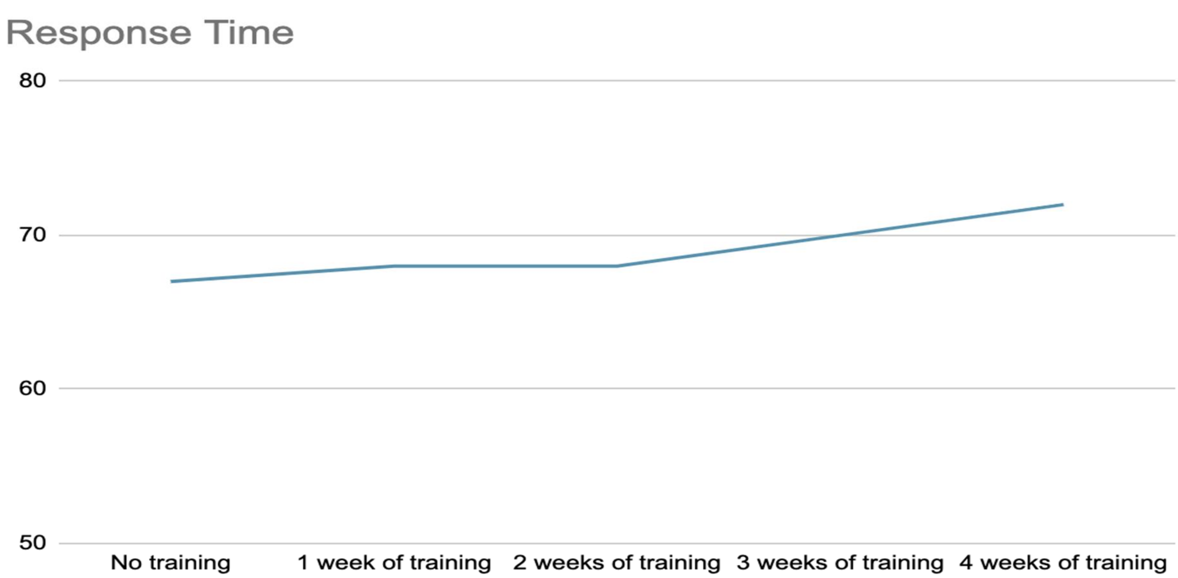


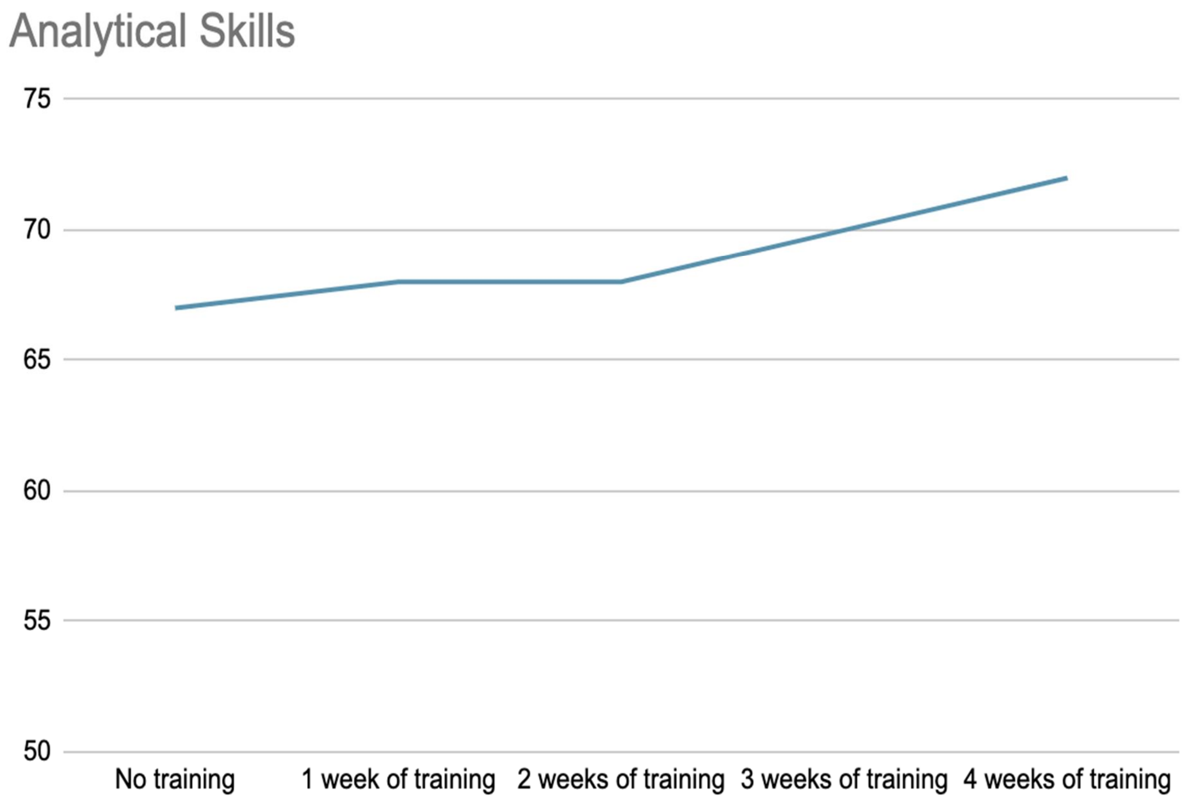
B. RCT Study for the app

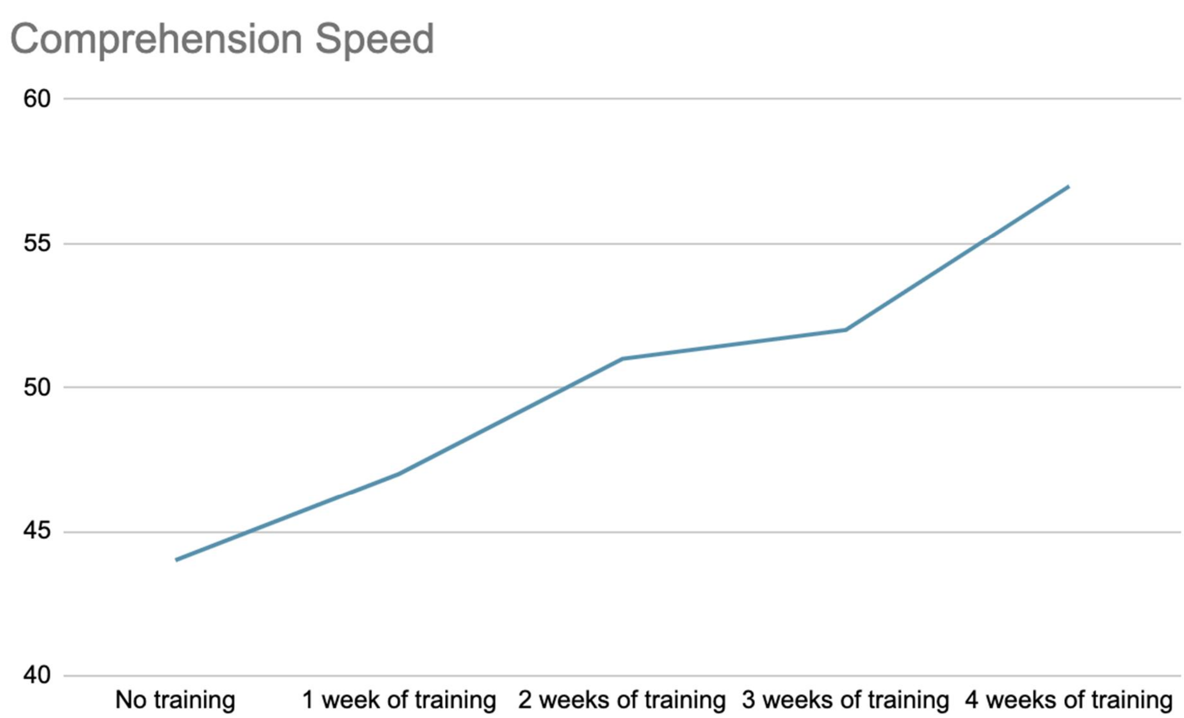
A randomized controlled trial is a form of scientific experiment used to control factors not under direct experimental control. We conducted a randomized controlled trial to generate these statistics and lead to results that are scientifically valid.



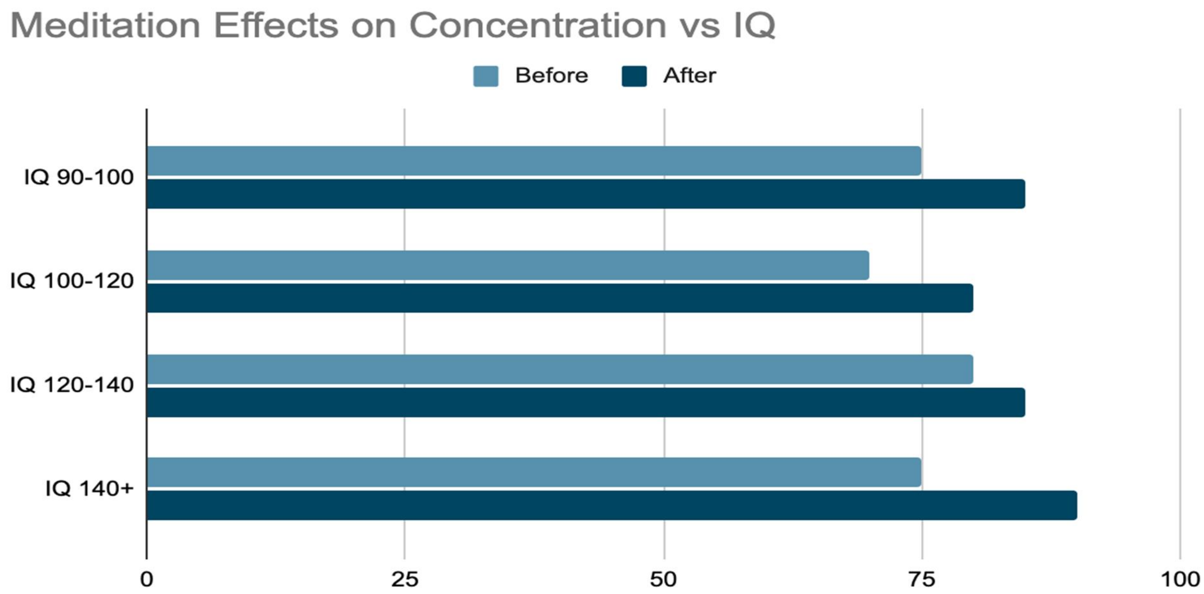
Growth in average response time performance over time - for all 3 factors




Analytical Skills
75
70
65
60
55
50
No training
1 week of training
2 weeks of training
3 weeks of training
4 weeks of training


Comprehension Speed
60
55
50
45
40
No training
1 week of training
2 weeks of training
3 weeks of training
4 weeks of training

Effect of meditation on processing speed: before and after



IX. RESULTS

Our results showed that slow processing speed can be diagnosed early in children and subsequently they could be provided with proper support right from young age to avoid them from living frustrated lives. Brain training for 4 weeks could lead to improved cognitive function in students. Moreover, meditation has a direct impact on concentration, especially in high IQ students suffering from lack of focus due to slow processing speed learning disability. Overall, there was an improvement in all 3 criteria - response, comprehension, and analytical skills through brain training and meditation. The key outcome of this paper was the understanding of brain training, a new scientifically and computationally backed method of measuring information processing speed and capacity, and the development and analysis of an application to increase cognitive performance through meditation and visual techniques.

X. CONCLUSION

Therefore, in conclusion, we analyzed the importance of processing speed and how low processing speed impacts students. Through a study involving primary and secondary data focused on students between the ages 11-17, we worked towards a successful, robust, and novel solution to increase brain processing speed and impact the lives of students across the nation affected with this issue. The app, which is easily usable and accessible and will be published on all major App stores will have the potential to change the lives of countless people and is backed by primary research done in this paper. We conducted a randomized control trial and developed an app based on meditation and improvement in visual processing speed. This is a unique, novel solution and we are the first to do it. Moreover, I also designed a unique way of analyzing the brain's processing speed, which rendered an even more accurate study so we could understand the problem and the solution. I learned about how significant this issue is, even in smart students, and how little has been done to solve it. I also learnt about the urgency of this issue and if I had to do it all over again, I would first start by talking to even more students facing this issue and understanding their demographics. With their demographics on hand, it will be feasible to develop solutions that specifically cater to their needs, leading to less experimentation and faster results. However, I believe that experimentation is what led to a successful solution and a great overall learning experience that will propel my future career and motivations to keep helping students facing a plethora of issues.

XI. PERSONAL REFLECTIONS

Growing up, I would look past my best friend being slower at completing ordinary seeming tasks to which I often remarked her as being lazy. It was only midway through high school that she was diagnosed with the disability of slow processing speed. Ever since then, I've felt terrible remorse for my remarks and have been curious as to how many such people would go undiagnosed if not paid attention to closely. This is what led me to pursue further investigation in this area.

As a high school student, I felt too unequipped to make any real impact on the way slow processing speed is diagnosed and treated. However, I was able to find the right mentor who had a fresh perspective to offer to the solution because of his experience with Machine Learning. We decided to build a brain training app that helps improve cognitive performance.

Through the course of this research, I gained perspective of the various challenges low processing speed poses in teenagers and children and how it affects learning outcomes which academic environments are apathetic to. It was a perpetually exciting task too, since I've come to realize that there's so much more that can be done to create more inclusive learning experiences and solutions based on the cognitive processing speed of individuals. I look forward to conducting further research in the area of child development to come up with solutions to solve learning challenges faced by people of all ages.

Beyond the research aspect of the project, I enjoyed designing and developing the mobile application. I used Figma to design the UI/UX and Kotlin for the application. I now have an understanding of the tech stacks used by software developers for various applications alongside the research methods employed by cognitive scientists studying child development. My next aim is to address the several gray areas left in my research and make the application accessible to ios users for which I am working on migrating the codebase to flutter which is a full-stack app development tool. The feeling of having a fully-functional android application on your phone is surreal and it's a skill which I'm certain is going to be handy for future endeavors .

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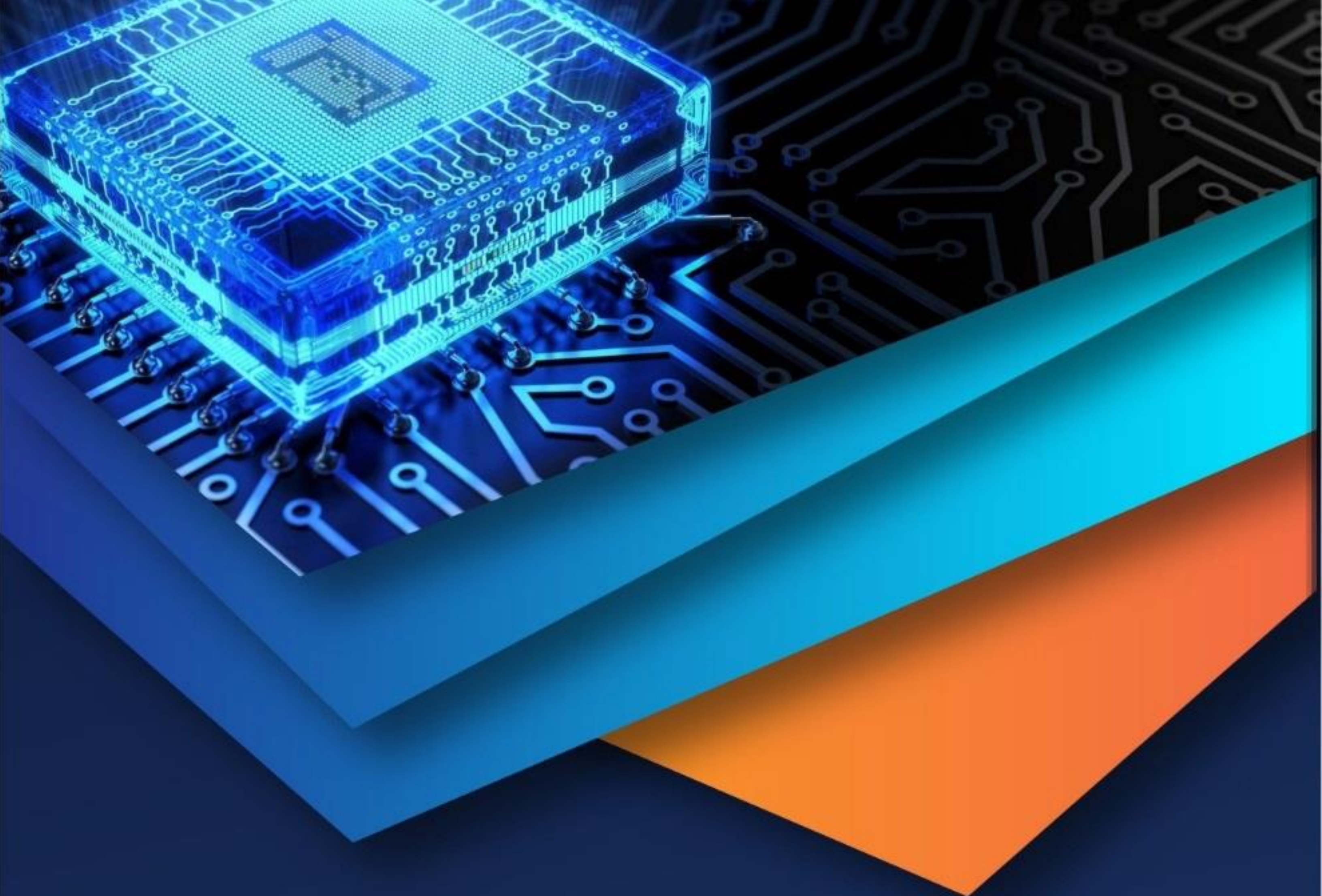

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