Cognitive Assessment through MIDI Drum Technology for the Uneducated

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Abstract: *In today's world, where education is often seen as a cornerstone for cognitive development, there exists a substantial disparity in the assessment of cognitive abilities across different populations. Globally, approximately 800 million individuals are either illiterate or have had minimal education, and this demographic often goes overlooked in neuropsychological research due to the inherent bias of existing cognitive assessment tools towards literate and educated individuals. This gap presents a significant challenge in the accurate evaluation and understanding of their cognitive abilities, which are shaped by a lifetime of unique experiences and learning processes. To address this challenge, we propose a novel solution: a MIDI drum system designed to evaluate cognitive performance through the medium of music, a universal language that transcends the barriers of literacy and formal education. This system is engineered to be intuitive, leveraging pre-programmed rhythms to interact with users in a way that does not require reading or writing skills. The objective of this system is multifaceted: to provide a reliable measure of various cognitive domains, such as processing speed, working memory, and reasoning, through the rhythmic responses elicited from the participants. The proposed MIDI drum system incorporates a tactile interface with embedded sensors that detect and record the nuances of each interaction. By analyzing the timing, consistency, and pattern recognition in the drumming performances, the system offers a robust assessment of cognitive functions. The objective is to harness the rhythmic data to draw correlations with cognitive performance metrics, using advanced algorithms to interpret the results.*

Keywords: **Psychometric Test, MIDI, KNN, Cognitive, reasoning**

1. Introduction

A significant segment of the global population, approximately 800 million, consists of illiterate and low-educated individuals. The lifetime learning experiences of these individuals profoundly shape their cognitive skills. However, the current neuropsychological tools available are predominantly designed for higher-educated demographics, presenting a challenge in accurately gauging the cognitive performance of this substantial population.

The proposed solution introduces a MIDI drum system with embedded pre-programmed rhythms, designed to address the cognitive assessment challenges of the illiterate and low-educated segment. This system integrates a drum pad with sensors and a microcontroller unit for MIDI signal generation in response to user interactions and records the data

The MIDI drum system adeptly assesses various cognitive abilities. It records Processing Speed by measuring participants' response times to rhythmic cues. Fluid Reasoning is tested through changing rhythm patterns, while Logical Reasoning evaluates the discernment of these patterns. Quantitative Reasoning is gauged by predicting numerical rhythm sequences. The device's memory game assesses

Working Memory, challenging users to reproduce rhythm sequences and offering insights into their short-term recall. Perceptual reasoning is determined by the interpretation of sensory information from rhythms. Together, the system's recording capability and memory game provide comprehensive insights into these cognitive domains.

Upon data collection, the K-Nearest Neighbours (KNN) algorithm is utilised to predict cognitive performance. The drumming performances, paired with their respective cognitive responses, form a comprehensive dataset. This dataset is then divided into training and testing sets. The KNN algorithm processes the training set, determining classifications based on the 'k' nearest neighbours' feature distances. Notably, the model boasts an impressive 96% accuracy rate, demonstrating its capability to predict cognitive responses for new instances based on their feature values

2. Literature Review

In the paper titled "The power of music: Its impact on the intellectual, social and personal development of children and young people" by Susan Hallam[1] states empirical evidence relating to the effects of active engagement with music on the intellectual, social and personal development of children and young people. It draws on research using the most advanced technologies to study the brain, in addition to quantitative and qualitative psychological and educational studies. It explains how musical skills may transfer to other activities if the processes involved are similar. It explores the evidence relating to the impact of musical skills on language development, literacy, numeracy, measures of intelligence, general attainment, creativity, fine motor coordination, concentration, self-confidence, emotional sensitivity, social skills, team work, self-discipline, and relaxation. It suggests that the positive effects of engagement with music on personal and social development only occur if it is an enjoyable and rewarding experience. This has implications for the quality of the teaching. In the paper titled "Please don't stop the music: A meta-analysis of the cognitive and academic benefits of instrumental musical training in childhood and adolescence" by Rafael Román-Caballero , Miguel A. Vadillo , Laurel J. Trainor Juan Lupiáñez[2] states that "An extensive literature has investigated the impact of musical training on cognitive skills and academic achievement in children and adolescents. However, most of the studies have relied on cross-sectional designs, which makes it impossible to elucidate whether the observed differences are a consequence of the engagement in musical activities. Previous meta-analyses with longitudinal studies have also found inconsistent results, possibly due to their reliance on vague definitions of musical training. In addition, more evidence has appeared in recent years. The current meta-analysis investigates the impact of early programs that involve learning to play musical instruments on cognitive skills and academic achievement, as previous meta-analyses have not focused on this form of musical training. Following a systematic search, 34 independent samples of children and adolescents were included, with a total of 176 effect sizes and 5998 participants. All the studies had pre-post designs and, at least, one control group. Overall, we found a small but significant benefit ($g\Delta = 0.26$) with short-term programs, regardless of whether they were randomized or not. In addition, a small advantage at baseline was observed in studies with self-selection (g pre = 0.28), indicating that participants who had the opportunity to select the activity consistently showed a slightly superior performance prior to the beginning of the intervention. Our findings support a *nature and nurture* approach to the relationship between instrumental training and cognitive skills. Nevertheless, evidence from well-conducted studies is still scarce and more

studies are necessary to reach firmer conclusions." In the paper titled "Music Interventions and Child Development: A Critical Review and Further Directions" by Elisabeth Dumont, Elena V. Syurina, Frans J. M. Feron and Susan van Hooren[3] states that "Research on the impact of music interventions has indicated positive effects on a variety of skills. These findings suggest musical interventions may have further potential to support educational processes and development of children. This paper reviews the latest evidence on the effect of musical interventions on the development of primary school-aged children. Four electronic databases were searched from January 2010 through June 2016 using music, music instruction, music education, music lesson, music training, development, child, student, and pupil as key words for the search. Two reviewers independently evaluated the studies to determine whether they met the stated inclusion criteria. Studies were compared on study setup, methodological quality, intervention components, outcome variables, and efficacy. A review of these selected studies (n = 46) suggest beneficial effects of music intervention on development of children, although clear conclusions cannot be drawn. Possible influencing factors that might contribute to the outcome of intervention are reviewed and recommendations for further research are made." In the paper titled "How musical training affects cognitive development: rhythm, reward and other modulating variables." by Miendlarzewska EA, Trost WJ[4] states that "Musical training has recently gained additional interest in education as increasing neuroscientific research demonstrates its positive effects on brain development. Neuroimaging revealed plastic changes in the brains of adult musicians but it is still unclear to what extent they are the product of intensive music training rather than of other factors, such as pre existing biological markers of musicality. In this review, we synthesize a large body of studies demonstrating that benefits of musical training extend beyond the skills it directly aims to train and last well into adulthood. For example, children who undergo musical training have better verbal memory, second language pronunciation accuracy, reading ability and executive functions. Learning to play an instrument as a child may even predict academic performance and IQ in young adulthood. The degree of observed structural and functional adaptation in the brain correlates with intensity and duration of practice. Importantly, the effects on cognitive development depend on the timing of musical initiation due to sensitive periods during development, as well as on several other modulating variables. Notably, we point to motivation, reward and social context of musical education, which are important yet neglected factors affecting the long-term benefits of musical training. Further, we introduce the notion of rhythmic entrainment and suggest that it may represent a mechanism supporting learning and development of executive functions. It also hones temporal processing and orienting of attention in time that may underlie enhancements observed in reading and verbal memory. We conclude that musical training uniquely engenders near and far transfer effects, preparing a foundation for a range of skills, and thus fostering cognitive development." In the paper titled "Got Rhythm? Better Inhibitory Control Is Linked with More Consistent Drumming and Enhanced Neural Tracking of the Musical Beat in Adult Percussionists and Non Percussionists" by Jessica Slater, Richard Ashley, Adam Tierney, Nina Kraus[5] states that "Musical rhythm engages motor and reward circuitry that is important for cognitive control, and there is evidence for enhanced inhibitory control in musicians. We recently revealed an inhibitory control advantage in percussionists compared with vocalists, highlighting the potential importance of rhythmic expertise in mediating this advantage. Previous research has shown that better inhibitory control is associated with less variable performance in simple sensorimotor synchronization tasks; however, this relationship has not been examined through the lens of rhythmic expertise. We hypothesize that the development of rhythm skills strengthens inhibitory control in two ways: by fine-tuning motor networks through the precise coordination of movements “in time” and by activating reward-based mechanisms, such as predictive processing and conflict monitoring,

which are involved in tracking temporal structure in music. Here, we assess adult percussionists and non percussionists on inhibitory control, selective attention, basic drumming skills (self-paced, paced, and continuation drumming), and cortical evoked responses to an auditory stimulus presented on versus off the beat of music. Consistent with our hypotheses, we find that better inhibitory control is correlated with more consistent drumming and enhanced neural tracking of the musical beat. Drumming variability and the neural index of beat alignment each contribute unique predictive power to a regression model, explaining 57% of variance in inhibitory control. These outcomes present the first evidence that enhanced inhibitory control in musicians may be mediated by rhythmic expertise and provide a foundation for future research investigating the potential for rhythm-based training to strengthen cognitive function." In the paper titled "Motor Learning Induces Plasticity in the Resting Brain—Drumming Up a Connection" by Ali Amad, Jade Seidman, Stephen B. Draper, Muriel M. K. Bruchhage, Ruth G. Lowry, James Wheeler, Andrew Robertson, Steven C. R. Williams, Marcus S. Smith[6] states that "Neuroimaging methods have recently been used to investigate plasticity-induced changes in brain structure. However, little is known about the dynamic interactions between different brain regions after extensive coordinated motor learning such as drumming. In this article, we have compared the resting-state functional connectivity (rs-FC) in 15 novice healthy participants before and after a course of drumming (30-min drumming sessions, 3 days a week for 8 weeks) and 16 age-matched novice comparison participants. To identify brain regions showing significant FC differences before and after drumming, without a priori regions of interest, a multivariate pattern analysis was performed. Drum training was associated with an increased FC between the posterior part of bilateral superior temporal gyri (pSTG) and the rest of the brain (i.e., all other voxels). These regions were then used to perform seed-to-voxel analysis. The pSTG presented an increased FC with the premotor and motor regions, the right parietal lobe and a decreased FC with the cerebellum. Perspectives and the potential for rehabilitation treatments with exercise-based intervention to overcome impairments due to brain diseases are also discussed." In the paper titled "A Case Study of the Use of Taiko Drumming to Improve Attention and Social Interaction Skills for Remote Children with Learning Disabilities" by Yu-Huei Su , Mei-Hua Li , Xin Tong[7] states that "Playing musical instruments helps promote cooperation, enhance attention, increase joint mobility as well as the range of motion, improve rhythm, balance, power, and raise self-esteem. The aim of the study was to explore the effects on remote children’s attention and social interaction skills from taiko drumming. It applied a case study methodology with the subject being a fifth-grade boy with learning disability (LD) and assessed to have unfocused behavior and emotional instability. With experiments conducted in taiko group lessons, the research consisted of a three-month pilot study and further a three-month main study. The pilot study was carried out by giving 12 once-a-week taiko group lessons which lasted 40 minutes each, with the Classroom Attention Observation Form developed by researchers recording the inattentive behavior of the child. The findings showed that the percentage of inattentive behavior in the classroom dropped from 100 to 60 percent. In addition, it was found that the child could obtain much experience of communication and more opportunities to have interaction with others through the process of ensemble taiko drumming. The main study was also carried out by giving 12 once-a-week taiko group lessons which lasted 40 minutes each, with the Chinese Version of SNAP-IV (Gao, 2006) and the Elementary & Junior High School Social Skill Behavior and Characteristic Checklist (Meng, 2004) as the tools. The findings showed that the LD child’s degree of inattention had turned from severe to mild, and his social skill disabilities had a significant reduction as well. In general, the six-month taiko group lessons could effectively improve the attention and social interaction skills of students with learning disabilities, and it is hoped that the findings of this research would provide a wealth of new information and reference for

subsequent research related to the educational counseling of students with learning disabilities." In the paper titled "The Effect of Music Intervention on Attention in Children: Experimental Evidence" by Yuka Kasuya-Ueba, Shuo Zhao and Motomi Toichi[8] states that "Although music has been utilized as a therapeutic tool for children with cognitive impairments, how it improves children's cognitive function remains poorly understood. As a first step toward understanding music's effectiveness and as a means of assessing cognitive function improvement, we focused on attention, which plays an important role in cognitive development, and examined the effect of a music intervention on children's attention. Thirty-five children, aged 6 to 9 years, participated in this study, with data from 29 of the children being included in the analysis. A single 30-minute interactive music intervention was compared with a single 30-minute interactive video game intervention accompanied by computer-generated background music using a within-subjects repeated-measures design. Each intervention was implemented individually. Participants completed a standardized attention assessment, the Test of Everyday Attention for Children, before and after both interventions to assess changes in their attentional skills. The results indicated significant improvement in attention control/switching following the music intervention after controlling for the children's intellectual abilities, while no such changes were observed following the video game intervention. This study provides the first evidence that music interventions may be more effective than video game interventions to improve attention control in children, and furthers our understanding of the importance of music interventions for children with attention control problems."

3. Proposed Methodology

Through an array of sensors and an Arduino Mega microcontroller, the MIDI drum system captures the nuanced interactions of users with pre-programmed rhythms, effectively gauging cognitive domains such as processing speed, fluid reasoning, and working memory. The system consists of eight drum pads, each equipped with precision sensors that detect and relay user inputs to the microcontroller. This setup records processing speed by timing responses to rhythmic cues, providing a direct measure of how quickly individuals can process and respond to sensory information. Fluid reasoning is evaluated through dynamically adapting rhythm patterns, challenging users to adapt and respond to novel and unpredictable sequences. Logical reasoning is assessed by evaluating participants' ability to discern and predict these patterns, while quantitative reasoning is gauged through tasks that involve predicting numerical rhythm sequences.

In practical application, the MIDI drum system adeptly assesses various cognitive abilities. The system's sensors and microcontroller record processing speed by measuring participants' response times to rhythmic cues with high precision, providing a direct metric of cognitive processing speed. Fluid reasoning is tested through the presentation of changing rhythm patterns, which require users to adapt and respond to new and unpredictable sequences, thereby measuring cognitive flexibility and problem-solving skills. Logical reasoning is evaluated by assessing the participants' ability to discern and predict these rhythmic patterns, while quantitative reasoning is gauged through tasks involving the prediction and replication of numerical rhythm sequences.

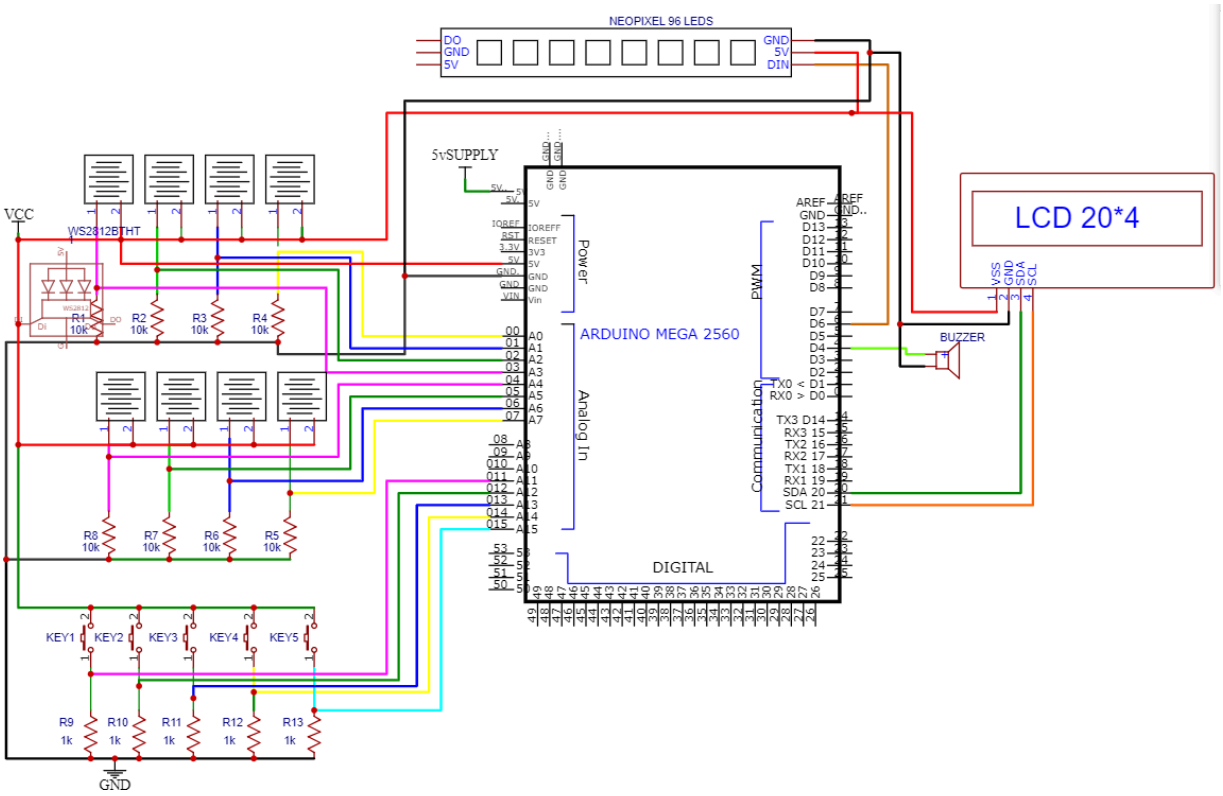

Figure 1: Schematic representation of the Circuit

The device's integrated memory game further challenges users by requiring them to reproduce rhythm sequences, offering valuable insights into their short-term recall and working memory capabilities. Perceptual reasoning is determined by the users' ability to interpret and respond to sensory information from rhythms, providing a comprehensive overview of how individuals process and make sense of auditory stimuli. The Arduino Mega microcontroller processes this data in real-time, ensuring accurate and reliable assessment of cognitive functions across multiple domains.

The system's sophisticated use of the KNN algorithm enhances its predictive capabilities. By first tabulating scores using the MIDI drum with known IQ scores, the system can predict the final IQ score for individuals. It classifies users based on the range in which their IQ scores fall, providing a nuanced and accurate assessment of cognitive abilities.

This is how the algorithm operates:

1. **Extraction of Features**: - The multidimensional feature space is created by the system once it has translated the rhythmic drumming data. Important characteristics are measured, including response time, consistency of patterns, and memory for sequences.

2. **Normalization of Data**: We normalise the feature vectors, bringing all the values into a comparable range, to make sure that no one feature dominates the result owing to size discrepancies.

3. **Calculating Distance**: - To determine the degree of similarity between various data points, the algorithm calculates the distance between feature vectors using an appropriate metric, usually Euclidean.

4. **The Best 'k' Choice**: To make sure the model performs well when applied to new data, we use cross-validation to identify the best 'k' value, or the number of nearest neighbours to take into account.

5. **Categorization**: The method determines the 'k' closest data points and their corresponding cognitive performance ratings for a particular test instance.

6. **Voting by Majority**: - A majority vote determines the final prediction, and the test instance is assigned to the neighbour with the most popular classification.

7. **Model Assessmen**t: - The test dataset is used to evaluate the correctness of the model

4. Results & Discussion

A. Results

The MIDI drum system exemplifies the capacity of technology to improve cognitive testing methods. Our findings suggest that this method can effectively and consistently assess cognitive abilities in population groups that have historically been excluded from such evaluations due to literacy prerequisites. The KNN model's excellent accuracy validates that utilizing rhythmic and musical engagement is a reliable method for evaluating cognitive abilities. This is a notable step in promoting inclusivity in cognitive healthcare and research.

In the future, the capacity of this technology to scale allows for its extensive use in educational and healthcare environments. Subsequent studies can build upon this groundwork by investigating the long-term implications and the possibility of detecting cognitive impairment at an early stage. Furthermore, the favorable response of the participants to the system indicates that these tools have the potential to increase involvement in cognitive assessment, hence decreasing anxiety and enhancing the precision of data gathering.

B. Discussion

The results of this study indicate that the MIDI drum system can effectively assess cognitive abilities in individuals with minimal formal education by using rhythmic and musical interactions. The findings align with existing literature that emphasizes the relationship between musical training and cognitive development. For instance, Hallam (2010) highlighted how engagement with rhythm and music positively influences various cognitive domains, such as processing speed, reasoning, and working

memoryly, research by Miendlarzewska and Trost (2014) demonstrated that rhythmic activities enhance cognitive functions by improving attention, memory, and pattern recognition skills .

The acy rate of the KNN algorithm (96%) in predicting cognitive performance based on drumming interactions further validates the hypothesis that rhythmic engagement can serve as a reliable measure of cognitive abilities. This finding supports Slater et al.'s (2018) work, which shows a correlation between rhythmic consistency and enhanced inhibitory control, suggesting that rhythm-based tasks can be effective indicators of cognitive performance .

However, there are differences between this study and others in the literature. While prior studies, such as Román-Caballero et al. (2020), focused on formal musical training as a determinant of cognitive

improvement, this research used a simplified, intuitive rhythmic interaction that required no prior musical knowledge . This difference might exbroader applicability of the results to populations with minimal education. Additionally, previous studies often rely on longitudinal interventions, while this project demonstrates that even brief, targeted rhythmic tasks can yield measurable cognitive insights. The disparity in methodologies suggests that while both approaches can assess cognitive abilities, rhythm-based assessments may offer a faster, more inclusive alternative for populations that are typically underserved.

The overall findings also resonate with Kasuya-Ueba et al. (2020), who found that music interventions significantly enhance attention control in children, implying that musical engagement can activate cognitive processes effectively across various demographics .

5. Limitations and errors

Several limitations and potential sources of error were identified during the study. One key limitation was the reliance on a single type of rhythmic interaction (drumming) to assess multiple cognitive domains. While effective, this approach might have overlooked certain cognitive functions that could be more accurately measured through different sensory modalities. Additionally, although the sample included a diverse range of participants, the relatively small sample size could have introduced bias and limited the generalizability of the findings. The use of the KNN algorithm, while effective, may also be sensitive to the choice of ‘k’ and distance metrics, which could introduce variability in the predictions.

Another source of error could stem from individual differences in familiarity with rhythm-based tasks. Even though participants did not require formal musical training, some individuals might naturally have better rhythmic abilities, which could skew results. Moreover, technical limitations, such as sensor sensitivity and timing precision, may have affected data collection accuracy. These errors, while accounted for during analysis, highlight the need for further refinement of the system.

6. Recommendations for Future Research

Future research could extend this project by exploring the use of other forms of rhythmic or musical engagement, such as singing or movement-based tasks, to provide a more comprehensive cognitive assessment. Additionally, integrating neuroimaging tools, as suggested by Amad et al. (2017), could offer deeper insights into the brain’s response to rhythm-based cognitive tasks, helping to refine the methodology further .

Expanding the sample size and including more diverse populations from different cultural and linguistic backgrounds could enhance the generalizability of the findings. Another area for exploration is the potential of the MIDI drum system for early detection of cognitive impairments, such as dementia or learning disabilities, through longitudinal studies. Further studies could also test the scalability of this technology in real-world applications, such as in educational settings or community health programs,

where accessible cognitive assessment tools are critically needed.
Finally, improving the algorithm by incorporating other machine learning techniques, such as neural networks or ensemble methods, could increase the precision of cognitive performance predictions, making the tool more robust and adaptable for different populations and contexts.

10. Acknowledgments

My deepest gratitude goes out to the mentors of On My Own Technology Pvt. Ltd. for providing help with this project.

Ms. Reetu Jain

Invaluable guidance from my mentor played a pivotal role. Her insightful feedback and constructive criticism enabled me to pinpoint and address areas requiring refinement, fostering iterative improvement. Additionally, her introduction of novel concepts and methodologies expanded my understanding, equipping me with a more nuanced perspective on the subject matter. Through her mentorship, I not only navigated challenges effectively but also cultivated a deeper expertise, ultimately contributing to the project's success.

Mr.Vinay Vishwakarma

His mentorship provided invaluable guidance, significantly influencing the project's success. My mentor's insightful feedback and constructive criticism were crucial in identifying areas that needed refinement, leading to continuous improvement. By introducing novel concepts and methodologies, the mentor expanded my understanding, offering a more nuanced perspective on the subject matter. This mentorship not only enabled me to navigate challenges effectively but also fostered the development of deeper expertise, which was instrumental in driving the project's success.

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