Development of Cognitive and Psychomotor Task for EEG Application with Matlab-based GUI

MNAH Sha’bani 1,2, N.Fuad1,3, Norezmi Jamal1, M.E.Marwan4, Mohd Helmy Abd Wahab1,3, Syed Zulkarnain Syed Idrus5

1 Faculty of Electrical and Electronic, Universiti Tun Hussein Onn Malaysia 86400 Batu Pahat, Johor, Malaysia
2 Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia 86400 Batu Pahat, Johor, Malaysia
3 Computational Signal, Imaging and Intelligence (CSII) Focus Group, Universiti Tun Hussein Onn Malaysia 86400 Batu Pahat, Johor, Malaysia
4 Kolej Poly-Tech MARA Batu Pahat, Sri Gading 83300 Batu Pahat, Johor Malaysia
5 Faculty of Applied and Human Sciences, Universiti Malaysia Perlis, 01000 Kangar, Perlis, Malaysia

*Corresponding author’s e-mail: norfaiza@uthm.edu.my

Abstract. Conventionally, the evaluation of cognitive and psychomotor ability performance is typically based on self-writing reports. However, such assessment was unable to measure the actual performance during the task execution. Furthermore, the performance results perceived by the instructor is mainly subjective. For an alternative solution, a new approach is proposed to acquire brainwave signals (i.e. electroencephalogram (EEG)) during task performance. The application of EEG offers a promising approach in evaluating skill abilities at physiological level. Hence, a task related to the assessed skill needs to properly design to ensure the induced EEG signal is reliable for performance evaluation. With the aid of Graphical User Interface (GUI), the time frame of each response can be capture and recorded. Therefore, this paper presents the development of task assessment in evaluating the performance of cognitive and psychomotor abilities based on EEG signal.

1. Introduction

Human action, feeling, emotion, unconscious mind and any state of human body are instigated from neural activity of the brain. This neural activity is represented by an electrical signal called electroencephalogram (EEG). EEG is a non-invasive measurement of brainwaves at a variety of frequencies in microvolt range signals [1]. This generated signal is recordable using an array of electrodes, which are placed over the scalp of a human subject by an international standardize 10-20 electrode placement system [2]. Till now, the used number of electrodes can up to 256 electrodes. EEG consists of five major frequency bands, which are known as delta (0.5–4 Hz), theta (4–8 Hz), alpha(8–13 Hz), beta (13–30 Hz) and gamma (30–45 Hz) waves. Each wave has different characteristics and prominent in specific behavioural responses [3].

EEG has been used widely in medical and clinical research [4, 5], brain computer interfaces [6, 7] and physiological studies [8]. Earlier, EEG devices required a lot of time for preparation due to the
amount number of gel type electrodes used. Fortunately, recent development of EEG devices with a smaller number of dry electrodes offer portability and ergonomic for daily use at low cost [9]. This new development accelerates the use of EEG in educational research such as performance evaluation and learning effectiveness. EEG signals allow researchers to track changes in complex learning behaviour by measuring and analysing the fluctuation of brainwave at a specific time instance of the interest signal [10].

Cognitive and psychomotor are two important domains in educational performance evaluation as introduced by Benjamin Bloom [11]. Conventional method of assessing these domains usually through written self-report and verbally. However, the reliability of the performance evaluation can be argued due to several physiological reasons. Therefore, assessing a real-time individual EEG signal can provide genuine information of mental load processing. Due to this, various number of approaches through the literature review in designing task for EEG application.

Menon, V., et. al. [12] constructed an arithmetic task based on addition and subtraction. The author proposed two parameters in increasing the level of difficulty, either by increasing the number of operand and increase the rate of stimulus (i.e. question) over time. Zyma, I., et al. [13] proposed serial subtraction of two numbers. The difficulty level was increased by manipulating the number of operations per minute. A single EEG channel analysis has also been done to evaluate arithmetic performance such as in [14]. In this study, the calculation task involves three level of difficulties, which was determined by the number of operands, mixed arithmetic operation and carry over operation.

For psychomotor skills, Hatfield, B. D., et al. [15] studied motor skill performance during shooting activity between novice and expert person. The study found that brain activity is reduced in specific brain region of expert relative to that observed in novice. Fuad, N., et al. [16] studied both cognitive and psychomotor performance. The author used various questions for cognitive performance such as arithmetic problem, history, visual, language and general knowledge. For the psychomotor task, a building structure activity using Lego was conducted. However, the task does not utilize GUI in data collection.

Realizing the advantages of EEG signals in providing genuine information of mental processing, this paper developed a set of task assessment with the aid of Matlab-based GUI for cognitive and psychomotor abilities evaluation. This paper is organized as follows: Section 2 presents the designated tasks, where the methodology of designing the tasks is described in detail. Section 3 covers the results of a preliminary study of the designed tasks. Section 4 presents the obtained results and the discussion of the findings. Lastly, the conclusion of the paper is presented in Section 5. Note that, this paper does not present the results of EEG signal analysis.

2. Task Design
Designing an EEG task requires a clear objective of the research outcome. In this paper, the research aims to measure the performance of cognitive and psychomotor abilities using EEG modalities. To ensure the feasibility of the designed task, three criteria has been considered. The first one is the required assessed skill. To induce the correct EEG signals, the task should be properly design relevant to the required skill. For example, problem solving is one of the skills in cognitive domain. Hence, an arithmetic problem is an activity that could be used for that purpose.

Secondly, the background knowledge of the targeted subjects must be identified. The difficulty level of the designated task would be depending on the educational background of the subject. In this paper, the volunteer subjects have come from different educational backgrounds. Thus, a task comprises of mutual knowledge of subjects need to be constructed so that the results are comparable.

Lastly, the strategy on how to execute the task. Brainwaves compose of EEG signals and unwanted signals such as noises and artifact signals. To reduce the unwanted signal, especially artifacts, the subject can be asked not to make excessive eye movement, eye blink and body movement during the data collection. This will benefit on pre-processing stage. Other things need to be considered such as rest state and duration task time. Rest state with a closed eye is needed to acquire the baseline of the EEG signal. Then, the duration time of completing a task relative to the difficulty needs to be determined properly.
In this paper, the task designed for cognitive domain is an arithmetic task. An arithmetic problem involves a wide variety of strategies to solve problems and engage with complex processes [17]. While, for the psychomotor domain, a building structure activity using an interlocking plastic building block toy was designed. Provenzo, E. F. and A. Brett [18] were discussed the role of blocks in the psychomotor domain. After completing each task, the subjects were given a continuous subjective mental load questionnaire (SMEQ) [19] range from 0-150 to indicate their mental effort during the task performance. The details of the designated tasks are briefly explained in the next section.

2.1. Arithmetic Task
In this task, subjects were required to determine an addition or subtraction equation whether correct or wrong. Three difficulty levels involved: easy, medium and hard. The difficulty level was determined based on the size (i.e. range number) of the addition or subtraction and the carry operation involvement [20]. The questions range number was increased from easy to hard level by one-digit to a three-digit number. However, numbers containing zero is not considered because it will affect the task difficulty (i.e. 100 + 200 = 300). Each question holds two different numbers and only one type of operation involved (i.e. 1 + 2 = 3, 12 – 23 = 25, 123 + 456 = 579). The operation was alternately changed between addition and subtraction through the task. Table 1 summarizes the structure of the designed arithmetic questions. To minimize the probability of having subjects that unable to respond within the given time, the questions are designed to not produce a negative result.

| Structure          | Difficulty level |
|--------------------|------------------|
|                    | Easy  | Medium | Hard  |
| Operand range number | 1-9   | 11-99  | 100-500 |
| Digit              | 1     | 2      | 3     |
| Number of operands | 2     | 2      | 2     |
| Operation type     | +/-   | +/-    | +/-   |
| Carrying operation | Yes   | Yes    | Yes   |

Each subject had to answer a total of 15 arithmetic problems, were 5 questions for each level. Figure 1 illustrates the timeline of the task execution. Initially, a trial session of five questions with random difficulties was given for the subjects to become familiar with the task. The purpose is to eliminate learning effect [21]. Next, the subjects were required to rest with closed eyes for 20 seconds. After that, the actual task began for 90 seconds, where each question had up to 6 seconds to be answered. Lastly, the subject needs to rest again but with opened eyes before the session was finished.

![Figure 1. Timeline of the arithmetic task execution.](image)

2.2. Building structure task
In this task, subjects were told to build a structure using an interlocking building block toy. The structure is a common shape looks like a house as depicted in Figure 4. The task needs to be completed within 120 seconds, otherwise the structure will be counted as incomplete. Note that, during the task execution, although the colour of the bricks is random, this task is only considering the final shape of the structure. Figure 2 illustrates the timeline of the task execution.
2.3. Graphical User Interface (GUI)

The purpose of GUI development for cognitive and psychomotor tasks is to display the questions and instruction of other events (i.e. close eyes, open eyes) automatically during task execution. GUI allows the subject to accomplish both tasks interactively without interruption by the instructor. Additionally, the use of GUI is important to record task start time, events time, response time and accuracy. Since EEG signals are recorded during task execution, the recorded response time is crucial in the EEG segmentation process. This is to ensure that the segmented EEG signal is respective to the subject’s ‘thinking’ period for analysis purposes.

The GUI was designed with brief instruction to guide the subjects in completing both tasks. The instructions are displayed in Malay, the native language of the subjects, in order to reduce the language load [10]. To increase the readability and legibility, the background colour was set to white with blue font colour as recommended in visual performances on visual display unit (VDU) studies [22, 23]. The font size was set to 20 which is adequate for a screen with 1920 x 1080 aspect ratio. These settings are to ensure the comfortability of the subject’s visual during performing the task.

Figure 3 shows an example of an interface during the arithmetic task. The interface was designed with a simple and plain layout to prevent subjects from losing focus during performing the task. Only two buttons are displayed which are the correct and wrong buttons. Each question was displayed up to 6 seconds. If the subjects have not responded until 6 seconds, the interface was cleared for 1 second delay before the next question appears. The delay is purposed to avoid the unintended responses to the next question. Otherwise, if the subjects responded less than 6 seconds, the interface cleared until the remaining time elapse.

The building structure task is a straightforward activity. The interface was designed by displaying the image of the structure and a finish button as depicted in Figure 4. The image of the structure was displayed in an isometric view to represent the three-dimensional view of the structure. Below the finish button, a note to remind the subject to push the finish button when completing the structure was displayed all the time.

3. Preliminary study

Eight healthy subjects age between 19.1±1.1 years were voluntarily involved in data collection. All subjects are social science students at diploma level. Subjects were initially explained with the purpose of the data collection. A screening form was given to ensure their health and mental condition. Then a written consent form was given as an agreement of their data to be used in this research. A short verbal instruction was given to ensure the subjects understand the procedures of the experiment.
The data collection was conducted in a confined room at Kolej Poly-Tech Mara (KPTM), Batu Pahat. Subjects were told to sit comfortably in front of a laptop. To reduce the unnecessary muscle signals, subjects were told to not do body movement throughout the experiment, unless to clicking a mouse. All subjects were taking the arithmetic task first before the building structure task. The EEG signal was collected using an Emotiv Insight mobile headset at 128Hz of sampling frequency.

![Building structure interface](image)

**Figure 4.** Interface in psychomotor task (building structure).

4. Results and discussion

Figure 5 shows the EEG signal acquired from electrode AF3 during arithmetic task performance. By using GUI, the recorded time data can be used to mark the EEG signals respective to the occurring events. For example, during rest with closed eyes event, it can be seen on the signal, the eye blink signals are absent. Furthermore, the EEG signal had been easily segmented into 15 partitions to represents 15 arithmetic questions. This could ease the processing stage in evaluating the performance of the cognitive level at those time instances.

![EEG segmentation](image)

**Figure 5.** Visualize EEG segmentation by events duration.

A statistical analysis has been done to determine whether the designed tasks are feasible for cognitive and psychomotor evaluation. Figure 6 shows the average accuracy and response time of eight subjects during performing the arithmetic task. The trend of the average accuracy decreases as the level of difficulty increases. The average accuracy from easy to hard level is 87.5%, 45.00% and 35.00% respectively. The response time takes by the subjects was increases as the difficulty level
increases. From 6 seconds of the allocated time, the subjects only took an average of 2.58 seconds for easy level, 4.87 seconds for medium level and 5.00 seconds for hard level. There is slightly different in response time between medium and hard level. In general, the designed arithmetic task can be easily differentiated by the difficulty level.

*SMEQ* using a scale system to indicates the level of mental effort required to complete a task. Theoretically, subjects with higher accuracy have less mental effort. However, since the SMEQ level is determined individually, the scale value is subjective depending on the subject’s judgment. The situation is shown in the individual arithmetic task results in Figure 7. For example, subject S01 and S03 have the same score of accuracy, however, their SMEQ value has a large difference. This shows that the individual perception on self-mental effort is different.

The average completion time in the building structure task is 96.4 seconds. By referring to Figure 8, two out of eight subjects were unable to build the structure completely. For example, subject S02 does not complete the structure within the time given, while subject S04 had built the wrong shape. In
In general, subjects were used less mental effort in the building structure task than in the arithmetic task. Four subjects perceived their mental effort in SMEQ to zero, but practically there could be no zero points in performing a task. Furthermore, SMEQ for subject S06 was put at zero although the completion time was approaching to end time. Once again, this evidence indicates that a self-written report is very subjective in determining mental effort.

![Individual completion time vs SMEQ](image)

**Figure 8.** Individual response time versus SMEQ of building structure task.

5. Conclusion
The task assessment of performance measure for cognitive and psychomotor abilities using EEG signal with the aid of Matlab based GUI has successfully developed. An arithmetic problem and building structure activities were chosen for cognitive and psychomotor tasks. The GUI has been developed by considering the ergonomic and visual comfortability to minimize the acquiring of the unnecessary physiological signal. Preliminary results show that both tasks are reliable to be used in measuring cognitive and psychomotor abilities. In the arithmetic task, the accuracy was decreased as the difficulty level increased. The time response was increased from easy to hard levels. In the building structure task, most subjects were successfully built the structure within the time given. In terms of SMEQ, results show an inconsistency in both tasks since the scale value was chosen based on individual perceptions. For future works, the acquired EEG signals will be analysed by finding the correlation between the obtained statistical results and the power spectrum density of the interest EEG signal. Parameters such as accuracy, response time and SMEQ scale value will be used for comparison between self-report and EEG signal results to get the actual cognitive and psychomotor performances.

Acknowledgments
Authors wishing to acknowledge Kolej Poly-Tech Mara (KPTM), Batu Pahat for allowing their students and using their space for data collection

References
[1] M. Teplan, "Fundamentals of EEG measurement," *Measurement science review*, vol. 2, no. 2, pp. 1-11, 2002.
[2] H. H. Jasper, "The ten twenty electrode system of the international federation," *Electroencephalography and Clinical Neurophysiology*, vol. 10, pp. 371-375, 1958.
[3] S. Sanei and J. A. Chambers, *EEG signal processing*. John Wiley & Sons, 2013.
[4] M. Sharma, R. B. Pachori, and U. Rajendra Acharya, "A new approach to characterize epileptic seizures using analytic time-frequency flexible wavelet transform and fractal dimension," *Pattern Recognition Letters*, vol. 94, pp. 172-179, 2017.

[5] S.-j. Zhang, Z. Ke, L. Li, S.-p. Yip, and K.-y. Tong, "EEG patterns from acute to chronic stroke phases in focal cerebral ischemic rats: correlations with functional recovery," *Physiological measurement*, vol. 34, no. 4, p. 423, 2013.

[6] E. Yin, Z. Zhou, J. Jiang, F. Chen, Y. Liu, and D. Hu, "A novel hybrid BCI speller based on the incorporation of SSVEP into the P300 paradigm," *Journal of Neural Engineering*, vol. 10, no. 2, p. 026012, 2013.

[7] U. Orhan, D. Erdogmus, B. Roark, B. Oken, and M. Fried-Oken, "Offline analysis of context contribution to ERP-based typing BCI performance," *Journal of Neural Engineering*, vol. 10, no. 6, p. 066003, 2013.

[8] C. Hagerhall, T. Laike, M. Kuller, E. Marcheschi, C. Boydston, and R. Taylor, "Human physiological benefits of viewing nature: EEG responses to exact and statistical fractal patterns," *Nonlinear Dynamics, Psychology, and Life Sciences*, vol. 19, pp. 1-12, 2015.

[9] J. Xu and B. Zhong, "Review on portable EEG technology in educational research," *Computers in Human Behavior*, vol. 81, pp. 340-349, 2018.

[10] P. Antonenko, F. Paas, R. Grabner, and T. Van Gog, "Using electroencephalography to measure cognitive load," *Educational Psychology Review*, vol. 22, no. 4, pp. 425-438, 2010.

[11] B. Bloom, "Taxonomy of educational objectives. Vol. 1: Cognitive domain," *New York: McKay*, pp. 20-24, 1956.

[12] V. Menon, S. Rivera, C. White, G. Glover, and A. Reiss, "Dissociating prefrontal and parietal cortex activation during arithmetic processing," *Neuroimage*, vol. 12, no. 4, pp. 357-365, 2000.

[13] I. Zyma et al., "Electroencephalograms during Mental Arithmetic Task Performance," *Data*, vol. 4, no. 1, p. 14, 2019.

[14] W. K. So, S. W. Wong, J. N. Mak, and R. H. Chan, "An evaluation of mental workload with frontal EEG," *PloS one*, vol. 12, no. 4, p. e0174949, 2017.

[15] B. D. Hatfield, A. J. Hauffer, T.-M. Hung, and T. W. Spalding, "Electroencephalographic studies of skilled psychomotor performance," *Journal of Clinical Neurophysiology*, vol. 21, no. 3, pp. 144-156, 2004.

[16] N. Fuad, J. Bakar, M. N. Danial, E. Nasir, and M. Marwan, "A Comparative Study Of Learning Methodology Between Cognitive And Psychomotor For Non-Dyslexia Person Via Electroencephalogram (EEG)," *International Journal of Scientific and Technology Research*, vol. 8, no. 7, 2019.

[17] T. Hinault and P. Lemaire, "What does EEG tell us about arithmetic strategies? A review," *International Journal of Psychophysiology*, vol. 106, pp. 115-126, 2016/08/01/ 2016.

[18] E. F. Provenzo and A. Brett, *The complete block book*. Syracuse University Press, 1983.

[19] J. Sauro and J. S. Dumas, "Comparison of three one-question, post-task usability questionnaires," in *Proceedings of the SIGCHI conference on human factors in computing systems*, Boston, 2009, pp. 1599-1608: Association for Computing Machinery.

[20] M. Spüler, T. Krumpe, C. Walter, C. Scharinger, W. Rosenstiel, and P. Gerjets, "Brain-computer interfaces for educational applications," in *Informational Environments: Springer*, 2017, pp. 177-201.

[21] Y. Liu, W. L. Lim, X. Hou, O. Sourina, and L. Wang, "Prediction of human cognitive abilities based on EEG measurements," in *International Conference on Cyberworlds (CW)*, Visby, Sweden, 2015, pp. 161-164: IEEE.

[22] M. Grozdanovic, D. Marjanovic, G. L. Janackovic, and M. Djordjevic, "The impact of character/background colour combinations and exposition on character legibility and readability on video display units," *Transactions of the Institute of Measurement and Control*, vol. 39, no. 10, pp. 1454-1465, 2017.

[23] D. Bhattacharyya, B. Chowdhury, T. Chatterjee, M. Pal, and D. Majumdar, "Selection of character/background colour combinations for onscreen searching tasks: An eye movement,
subjective and performance approach," Displays, vol. 35, no. 3, pp. 101-109, 2014/07/01/ 2014.