UNIVERSITI TEKNOLOGI MARA

CLASSIFICATION OF WORKING MEMORY PERFORMANCE IN PRIMARY SCHOOL CHILDREN USING EEG TIME-FREQUENCY IMAGE FEATURES AND CONVOLUTIONAL NEURAL NETWORKS

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Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy
(Electrical Engineering)

Faculty of Electrical Engineering

February 2026

ABSTRACT

The capacity to keep and use information for short amounts of time is referred to as Working Memory. It is presumed that capacity of working memory is crucial for a variety of cognitive and noncognitive abilities. Because these capabilities have a substantial effect on children's learning outcome, working memory assessment during early stage can benefit them. The purpose of the study is to propose an EEG-based working memory assessment system which can overcome the limitation of the current method that is carried out using scores which are subject to response bias during each testing, failing to directly quantify underlying brain activity. Artificial intelligence-based solutions can assist decrease downtime and enhance system performance by detecting tiny changes in memory performance that individuals might overlook. This study focuses on classifying the working memory performance of typically developing children by using visual stimuli assessments adapted from the Automated Working Memory Assessment and correlating the results with electroencephalogram data. The study consists of two stages. The first stage involves recording resting electroencephalogram data. The second stage includes two assessments: the Dot Game, which evaluates visual-spatial short-term memory, and Match the Shape Game, which assesses visual-spatial working memory. Children's resting EEG recordings and performance scores from these working memory activities have been collected and categorised into Low, Medium, and High working memory group, defined based on the standardized score distribution. Spectral analysis revealed that the Low working memory group exhibited significantly higher theta power (4-8 Hz) while the high working memory demonstrated higher alpha power (8-12 Hz), supporting neural efficiency hypothesis. The Fz channel in the prefrontal cortex exhibiting the highest Power Spectral Density and Energy Spectral Density across participants. This channel was subsequently used to extract four time-frequency representations: spectrogram via Short Time Fourier Transform, scalogram via Continuous Wavelet Transform, Hilbert spectrum via Hilbert-Huang Transform, and fused image via Image Fusion as an input to Convolutional Neural Networks, specifically AlexNet and VGG16, trained with mini-batch sizes of 128, 256 and 512. All four feature representations demonstrated consistent trends aligned with the Neural Efficiency Hypothesis, with spectrogram and scalogram showing the most visually distinct pattern between WM groups. The classification models were developed to categorise working memory into three levels: Low, Medium and High. AlexNet achieved optimal performance with spectrogram features at mini-batch size 512 (90% accuracy for Dot Game) and with scalogram features at mini-batch size 128 (80% accuracy for Shape Game), while VGG16 excelled with scalogram features at mini-batch size 256 (82.33% for Dot Game, 80.67% for Shape Game). The recommended optimal configuration comprises AlexNet with spectrogram features and mini-batch size 512 for achieving highest overall performance among other tasks. To ensure the robustness of this result, a secondary evaluation was performed, which confirmed the 90% that the configuration captures fundamental neural oscillation in an entirely unbiased manner. These findings highlight the potential of EEG-based Artificial intelligence models for working memory assessment and provide insight for identifying children with early assessment and aid school administrators in making diagnoses and strategizing teaching methods to enhance academic achievement and mitigate learning challenge.

ACKNOWLEDGEMENT

First and foremost, I wish to express my deepest gratitude to Allah SWT for granting me the opportunity to embark on this PhD journey and for blessing me with the strength to complete this long and challenging endeavour successfully.

My sincere appreciation goes to my main supervisor, Assoc. Prof. Ir. Dr. Ahmad Ihsan bin Mohd Yassin, and my co supervisors, Prof. Ir. Ts. Datin Dr. Wahidah binti Mansor and Dr. Aisyah Hartini binti Jahidin, for their invaluable guidance, unwavering support, and expertise throughout this research. I also extend my gratitude to Assoc. Prof. Dr. Megat Syahirul Amin bin Megat Ali, for his specialized insights and direction.

I would like to acknowledge the School of Electrical Engineering, College of Engineering, UiTM Shah Alam, as well as Sekolah Kebangsaan (SK) Pulau Tuba, SK Selat Bagan Nyior, SK Parit 6, and SK Taman Sri Andalas for providing the necessary facilities and assistance during my data collection phase. Their cooperation was instrumental to the success of this research.

Special thanks are extended to my colleagues and friends, Mirsa, Sherlina, Dihan, Nazrin and many others, who provided their help and support throughout this research. Their assistance made this journey more meaningful and manageable.

This thesis is dedicated to my father, mother and families who have always been source of strength and motivation. To my beloved husband and my sweet daughter, thank you for your patience, love, and understanding. To my darling daughter, who waited for mommy to finish her work every single day with such grace and sweetness, your innocent smiles and hugs were the fuel that kept me going. To my husband, my pillar of strength, the love of my life, thank you for your unwavering support and for standing by me through every challenge. Together, your love and belief in me made all the difference. Alhamdulillah.

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CHAPTER 1
INTRODUCTION

1.1 Background of the study

Recent years have highlighted an increasing academic and educational interest in learning how children acquire, retain and utilize information within learning contexts [1]. Working memory (WM) is a fundamental cognitive mechanism integral to this process, serving as a key element of executive function that allows individuals to temporarily retain and alter information essential for complicated activities, including comprehension, problem solving, and learning [2], [3]. WM, as a system with limited capacity, can only process a certain amount of information at a time and this capacity limits cognitive function [4]. Its performance is regarded to be crucial for a variety of cognitive and noncognitive abilities, including fluid intelligence, numeracy, reading, and attention regulation [5] as well as noncognitive capacities such inhibitory control and boarder self-regulatory behaviours [6].

WM is essential for human cognitive development as it directly affects memory storage capacity and the efficiency of information processing throughout lifespan. The integrity of WM influences an individual's capacity to retain and manipulate information during cognitive tasks. In children, WM is particularly significant as the developing brain is rapidly establishing essential neural networks that underpin cognitive and behavioural abilities [7], [8], [9]. Children's learning abilities are influenced by their capacity to store information in their memories [10]. Their capacity for storing information in their memories determines how well they learn. Those with robust WM skills typically exhibit superior learning outcomes, while children with WM impairments may struggle to remember or solve tasks for an extended period of time [11]. These deficiencies profoundly influence their development trajectory, and may be measured using brain signals, allowing for the development of practical methods that can quantify the severity of WM impairment in children [12].

Research suggests that WM capacity correlates with school achievement, and have an indirect impact on fluid intelligence, which refers to the ability to solve new problems independently of prior knowledge [13], [14]. For instance, pre-school children