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Utilizing the n-back Task to Investigate Working Memory and Extending Gerontological Educational Tools for Applicability in School-aged Children

Chih-Chin Liang* · Si-Jie Fu**

Abstract

In this research, a cohort of two children, aged 7-8 years, was selected to participate in a specialized three-week training program aimed at enhancing their working memory. The program consisted of three sessions, each lasting approximately 30 minutes. The primary goal was to investigate the impact and developmental trajectory of working memory in school-aged children. Working memory plays a significant role in young children's learning and daily activities. To address the needs of this demographic, products should offer both educational and enjoyable activities that engage working memory. Digital educational tools, known for their flexibility, are suitable for both older individuals and young children. By updating software or modifying content, these tools can be effectively repurposed for young learners without extensive hardware changes, making them both cost-effective and practical. For example, memory training games initially designed for older adults can be adapted for young children by altering images, music, or storylines. Furthermore, incorporating elements familiar to children, like animals, toys, or fairy tales, can increase their engagement in these activities. Historically, working memory capabilities have been assessed predominantly through traditional intelligence tests. However, recent research questions the adequacy of these behavioral measures in accurately detecting changes in working memory. To bridge this gap, the current study utilized electroencephalography (EEG) as a more sophisticated and precise tool for monitoring potential changes in working memory after the training. The research findings were revealing. Participants showed marked improvement in their performance on n-back tasks, a standard measure for evaluating working memory. This improvement post-training strongly supports the effectiveness of the training program. The results indicate that such targeted and structured training programs can significantly enhance the working memory abilities of children in this age group, providing promising implications for educational strategies and cognitive development interventions.

Keywords : Students, Working, Memorize, Training, Electroencephalography (EEG), n-back Task

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* First Author, Professor, Department of Business administration, National Formosa University, e-mail : lgcwow@gmail.com
** Corresponding Author, Graduate Sudent, Department of Business administration, National Formosa University, 632 Wunhua Rd., Huwei Township, Yunlin County, Taiwan, Tel: +886-9-6873-8820, e-mail: bobo04150116@gmail.com

1. Introduction

The current study aims to investigate the impact of working memory training on the cognitive abilities of school-aged children, with a special focus on the development of their working memory component. In recent years, there has been an increase in the development of products and tools aimed at enhancing working memory [Morrison and Chein, 2011], a trend largely attributed to the growing awareness of its importance.

However, the majority of these tools are designed for adults or the elderly, leaving a significant yet untapped market for tools specifically tailored for young children. Given the significance of working memory as a fundamental cognitive ability, it is important to note that working memory is a critical cognitive skill. It is essential for processing and managing information during complex cognitive tasks and plays a crucial role in the academic achievements of children. Previous research has demonstrated that working memory can more accurately predict academic success, thereby highlighting that enhancing working memory capacity has a significant impact on children's cognitive development.

Historically, intelligence tests have been commonly used to assess working memory capabilities. However, it has been noted that changes in working memory are not always detectable through behavioral measures alone. Therefore, this study examines changes in working memory capacity post-training using electroencephalography (EEG). Utilizing a true experimental design with an equivalent-groups posttest-only approach, participants were randomly assigned to evaluate the effects of n-back tasks, a working memory training exercise, on cognitive development and working memory in school-aged children.

In this research, school-aged children participated in working memory training. Following this, their brain responses during n-back tasks were monitored using EEG to assess the changes in working memory capabilities post-training. The results of this study are expected to support previous findings that working memory training can enhance the working memory capacities of school-aged children and positively influence their cognitive development. The use of EEG for monitoring changes in working memory capabilities facilitates a more accurate evaluation of the improvements in cognitive abilities post-training and provides a deeper insight into the effects of working memory training on brain activity. The EEG experiments were conducted using the St.EEGTM Altaire instrument, as depicted in the accompanying figure.

2. Literature Review

2.1 Gerontological Educational Tools

Working memory, as a core element of cognitive development, significantly impacts the learning and everyday activities of young children [Baddeley, 2003]. To cater to the needs of this age group, products should focus on providing activities that are both educational and enjoyable, while also engaging working memory. Modern educational tools, particularly digital ones, offer considerable flexibility. Products initially designed for the elderly, known for their simple and intuitive interfaces, are also beneficial for young children. By updating software or changing content, these tools can be repurposed for young learners without extensive hardware changes, making this approach both cost-effective and practical. For instance, memory training games designed for the elderly can be adapted for young children by modifying in-game images, music, or storylines to better suit their interests and cognitive levels. Additionally, integrating elements from children's daily lives, such as animals, toys, or fairy tales, into these activities can enhance their engagement.

Recent years have seen a surge in products and tools aimed at enhancing working memory [Morrison and Chein, 2011], largely due to increasing awareness of its importance. However, most of these tools target adults or the elderly, leaving a substantial untapped market for young children. Businesses can leverage existing technologies to develop working memory training programs specifically designed for young children. This not only satisfies market demand but also significantly lowers the costs of development and production, effectively extending gerontological educational tools to meet the developmental needs of school-aged children.

2.2 Working Memory

Working memory refers to an individual's cognitive ability to manipulate and process information during complex cognitive activities. It is also considered a crucial element for executing complex cognitive behaviors in daily life [Baddeley, 2003].

Working memory encompasses both the capacity for information processing and the temporary storage of information. The information processing capacity is directly related to the attentional capacity governed by the central executive and increases with the complexity of the task sequence. The memory span, representing the capacity of working memory, is dependent on the rehearsal rate within the phonological loop [Baddeley et al., 1975] and is not merely limited to the quantity or integration of information units. However, this capacity varies among individuals and can exceed the traditional limit of 7 ± 2 items. On the other hand, the temporary storage time is contingent upon the episodic buffer, which acts as a bridge between long-term memory and the central executive. The information integrated and processed in working memory dissipates upon task completion, existing in a transient state. This underscores the role of working memory as a platform for information processing operations.

2.3 N-back

The N-back working memory task is one of the most widely applied working memory training tasks in recent years [Jones et al., 2020; Chen et al., 2019; Pergher et al., 2018; Linares et al., 2019; Soveri et al., 2017; Au et al., 2015; Melby-Lervag et al., 2016; Melby-Lervag and Hulme, 2016; Forns et al., 2014] (refer to 〈Table 4〉). Its popularity stems not only from its proven training effectiveness but also from its ability to transfer these gains to other untrained cognitive functions.

In the N-back task, participants are presented with a series of stimuli (such as numbers, letters, words, spatial locations, shapes, or faces) sequentially. The task is to determine whether the current stimulus matches the one presented N steps earlier in the sequence [Owen et al., 2005]. For instance, in a 2-back task with the sequence "5, 7, 1, 7", the third stimulus "1" is a non-target, as it does not match "5" (two steps back); however, the fourth stimulus "7" is a target, matching the "7" presented two steps earlier. This task engages the working memory system for temporary storage, monitoring, manipulation, and updating of representations [Chen et al., 2008], allowing for the observation of neural mechanisms associated with working memory [Owen et al., 2005].

The N-back task is an effective method to test control, maintenance, update, and process working memory tasks [Miyake et al., 2001]. It has been shown to significantly enhance working memory capacity in both young and older adults [Dahlin et al., 2008]. Studies by Au et al. [2015, 2016] indicate improvements in reasoning and working memory capacities in typically developing young individuals after N-back training. Jaeggi et al. [2011] demonstrated that healthy elementary school children improved their fluid intelligence through spatial N-back tasks, with training effects lasting for three months post-training. Similarly, Li et al. [2008] reported significant task performance improvements in healthy adults and older adults, with effects extending to other untrained working memory tasks and lasting up to three months post-training.

However, some studies [Chooi and Thompson, 2012; Linares et al., 2019] have indicated that N-back training may not enhance certain untrained cognitive abilities, suggesting that the efficacy of N-back training in enhancing cognitive abilities warrants further investigation. Domestic research on working memory training has primarily focused on theoretical issues often employing a single indicator to measure training outcomes, which may overstate the interpretive power of this single indicator. For instance, some studies claim that working memory training enhances reading comprehension, yet only a specific reading skill was measured. To address this, the current study will employ a multifaceted assessment approach to measure the effects of training, aiming to explore various methods of assessing working memory and to investigate the impact of working memory training on school-aged children.

2.4 Working Memory and Physiological Signal Changes in EEG Studies

The assessment of cognitive functions has traditionally relied on behavioral measurement scales, such as the Wechsler Memory Scale (WMS), which is a significant and standardized indicator. This scale has been validated across various populations in numerous studies. However, the results from the Wechsler Intelligence Scale for Children can be influenced by the educational level of the participants. Currently, measurement tools based on physiological signals, like Electroencephalography (EEG), are employed to assess changes in working memory. The use of EEG technology enhances our understanding of the impact of working memory training on the cognitive development of children. Therefore, this study evaluates working memory using physiological signals through EEG, providing a direct and objective assessment method.

In terms of working memory application, changes are noted in vital signals. Brainwaves, or rhythmic electrical potential changes, are produced by neurons and nerve fibers in the brain during neural impulse transmission. The electrical potential data generated during brain activity, once amplified, form the curves observed in EEG readings [Farwell et al., 2013]. EEG involves the collection of faint bioelectricity produced at the scalp through EEG instruments. The recorded brainwave patterns primarily reflect the electrical responses of the cerebral cortex and are categorized into different frequency bands: Delta (δ), Theta (Θ), Alpha (α), Beta (β), and Gamma (ɣ) waves. An introduction to each of these brainwave patterns is provided below (as shown in 〈Table 1〉).

Synthesizing the findings of prior scholarly work, this study proposes to utilize Theta (Θ), Alpha (α), and Beta (β) brainwaves as instruments for measuring changes in working memory capacity. Neuroimaging studies in humans have revealed that working memory is linked with the prefrontal cortex of the brain. Given that working memory is a system with limited capacity, everyone's working memory capacity varies with age. Previous research indicates that training in working memory can significantly influence it, suggesting that through proper assessment and training, enhancement of working memory capacity is feasible.

〈Table 1〉 Brainwave Pattern Chart

Band	Frequency	Explain
δ (Delta band)	0.5-3Hz	Delta Waves (δ Waves) are characterized by their slower activity and are classified as low-frequency, high-amplitude brainwaves. They predominantly occur during the deep sleep phases in adults. Thus, the quality of sleep can be observed through the presence and characteristics of Delta Waves. These waves serve as crucial indicators of the depth and restorative nature of sleep, making them a valuable focus in sleep research, particularly in studies exploring the relationship between sleep patterns and overall health.
Θ (Theta band)	3.5-7Hz	Theta Waves (Θ Waves) are also categorized as low-frequency, high-amplitude slow brainwaves. They commonly emerge during periods when consciousness is interrupted and the body is deeply relaxed, such as during daydreaming, and are primarily observed in adults in states of semi-sleep. These waves are instrumental in measuring sustained attention in conditions of low anxiety and fear. Notably, Theta Wave activity is expected to increase slightly under cognitive load. This attribute of Theta Waves renders them a crucial subject in neurocognitive research, particularly in investigations exploring the correlation between brainwave patterns and mental states related to relaxation and focused attention
α (Alpha band)	8-13Hz	Alpha Waves (α Waves) are characterized as high-frequency, fast brainwaves with low amplitude. They typically occur when an individual is conscious but in a relaxed state. These waves are indicative of a lively brain, denoting an optimal state for learning and thinking. During periods of cognitive load, a slight reduction in Alpha Wave activity is generally observed. This property of Alpha Waves is crucial in cognitive neuroscience, particularly in research exploring how the brain responds to learning, cognitive engagement, and how these waves are modulated under varying cognitive demands.
β (Beta band)	13-30 Hz	Beta Waves (β Waves), identified by their high frequency, rapid nature, and low amplitude, correspond to a state of wakefulness and heightened alertness. These waves represent an active mental state wherein individuals engage in active thought and concentrated focus. An escalation in Beta Wave activity indicates the body's preparedness to react to external environmental stimuli. In daily life, people often find themselves in a state of readiness, poised to respond to changes in their surroundings. During these states of heightened focus and alertness, an increase in Beta Wave activity is commonly observed. This characteristic of Beta Waves is particularly significant in cognitive and behavioral neuroscience, underscoring the brain's adaptive response to attention-demanding tasks and environmental interactions
ɣ (gamma band)	30-70Hz	This refers to a mental state that exists between deep sleep and the verge of wakefulness.

Prevailing studies on working memory, in the context of advancements in cognitive neuroscience, have identified that cognitive training might induce alterations in neural-related components [Kelly and Garavan, 2005; Jones et al., 2006[. Research focusing on cognitive and neural plasticity highlights that training development outcomes are more pronounced in typically developing children aged 4-6 years compared to other age groups. Moreover, the brain, as the most vital organ in the human body, manages all bodily reactions and sensory perceptions. Its structure is incredibly intricate, with each area performing specific functions. It is primarily divided into four parts: the Cerebrum, Diencephalon, Brain Stem, and Cerebellum. The cerebral cortex further subdivides into four lobes: the Frontal Lobe, Temporal Lobe, Parietal Lobe, and Occipital Lobe (as shown in 〈Table 2〉).

As children's working memory develops, the activity in brain regions associated with memory tasks, such as the parietal sulcus and prefrontal cortex, intensifies. Working memory training can amplify the activation levels in these relevant brain areas. Prior research has demonstrated the crucial role of neurons in the frontal cortex, parietal cortex, and basal ganglia in the functioning of working memory [ConstaIltinidis et al., 2016]. Training in working memory not only enhances memory capacity related to the trained tasks but also improves other cognitive processing abilities. Training working memory using domain-specific tasks activates certain cortical areas in the brain, facilitating the completion of tasks based on the same neural network. Furthermore, the more complex the activated cortical areas are, the greater the transfer effects of the working memory training will be. Based on this, the current study aims to observe Theta (Θ), Alpha (α), and Beta (β) brainwaves in the frontal regions of the targeted children.

3. Methods

In this research, the study aims to explore the effectiveness of short-term N-back memory training intervention on working memory capacity in school-age children through electroencephalogram (EEG) analysis. Previous literature has indicated the plasticity of working memory in the brain, and this study presents the following hypotheses:

H1: Compared to pre-training, working memory training will enhance the EEG responses of the experimental group of school-age children.

This experiment was designed as a within-subject study, allowing participants to undergo the complete n-back training scenario, enabling an effective response to the experimental outcomes. Before the experiment,

〈Table 2〉 he functions of the brain lobes

Brain lobes	Function
Frontal Lobe	Responsible for functions such as emotion, thinking, problem-solving, and attention.
Temporal Lobe	Controls memory, auditory processing, and some aspects of visual perception.
Parietal Lobe	Responsible for central processing, pain perception, and mathematical calculation abilities.
Occipital Lobe	Responsible for visual processing and integrating received stimuli.

Source: Compiled by This Study.

participants were required to undertake a pre-test to prevent potential experimental errors. The pre-test utilized the Chinese-adapted version of the Coloured Progressive Matrices (CPM) questionnaire, revised by Yu Xiaojun in 1993, to assess the working memory capabilities of the subjects. The CPM questionnaire primarily measures reasoning abilities, specifically those related to visual patterns. Due to the original version being in English and other considerations, this study employed Yu Xiaojun's [1993] Chinese translation to assess the working memory capabilities of the subjects, ensuring its appropriateness for the standards of this research.

The study incorporated the classic N-back working memory task for training, concurrently recording the participants' EEG signals for brainwave assessment, to investigate the impact of the working memory training task on brain activity. The objective was to observe any significant differences in brainwave patterns before and after receiving working memory training. Data were collected using an 8-channel EEG device (shown in 〈Figure 1〉), with dry cotton, short needles, and long needles used to place electrodes on the scalp of the participants. Electrode placement reference points were determined by installing electrodes behind both ears.

〈Figure 1〉 Channel EEG Device

The "N-back" task in this experiment was presented in a game format for training purposes, with game elements extracted and adapted from materials provided by New Oriental Biotechnology Limited Company. The training game for the experimental group was developed using E-prime (psychological experiment software). Following the N-back task design used in the study by Hotton et al. [2018], the screen display was based on a grid of 9 squares against a black background. At the center of the grid was a fixation cross "+", which could be influenced by the participant's eye movements during the task. Throughout the experiment, a white square would randomly appear in one of eight different positions surrounding a fixed point. Only one stimulus appeared at a time, each displayed for 500 milliseconds. After participants responded and answered, there was a rest period of 2500 milliseconds. The "N-back" task in this experiment had two levels of difficulty, ranging from easy to hard, specifically "0-back" and "1-back". In the "0-back" task, subjects needed to compare the position of the stimulus with the position of the first stimulus that appeared in the sequence. A correct response could be made by pressing the "mouse key" if the positions matched; no response was required if they did not. In the "1-back" task, participants had to compare the position of the stimulus with that of the immediately preceding stimulus in the sequence.

4. Results

4.1 Experiment Results

In this study, participants brainwave data were subjected to a two-group independent sample non-parametric test (Mann-Whitney

〈Table 3〉 Analysis of Decision-Making Brainwaves in Participants Following N-Back Training for Working Memory Capacity

Participant ID	N-BACK	Band	Z-value	p-value	Mann-Whitney U Statistic
S1	0	α	-3.468	0.001***	0.300
		β	-5.376	0.000***	0.000
		Θ	-3.681	0.000***	0.228
	1	α	-1.191	0.233	0.315
		β	-8.040	0.000***	0.321
		Θ	-0.291	0.771	0.305
S2	0	α	-3.191	0.001***	0.003
		β	-7.489	0.000***	0.000
		Θ	-6.706	0.000***	0.001
	1	α	-0.908	0.364	0.943
		β	-2.126	0.034**	0.146
		Θ	-2.000	0.046**	0.359

Note: ***p-value < 0.01, **p-value < 0.05 *p-value < 0.10.

U test) to observe any significant effects on the α, β and Θ brain waves at N-BACK levels of 0 and 1, pre- and post-training. The analysis results, as displayed in the following table, indicate that for both participants at N=0, there were significant impacts on the ALPHA, BETA, and THETA waves, suggesting that N-BACK training can influence changes in brainwave patterns, thereby affecting the capabilities of working memory. When the difficulty level was increased to N=1, a significant effect was observed only on the BETA waves for both participants, indicating that the level of difficulty does affect changes in brainwave patterns(as shown in 〈Table 3〉).

The research findings demonstrate that the n-back training program influences the working memory abilities of participants, thus supporting hypothesis H1. Therefore, the results of this study are consistent with previous research in this domain.

5. Conclusion

In this study, electrophysiological changes in participants were observed through electroencephalogram (EEG) experiments, focusing on variations in their physiological signals. The experimental results showed significant effects post-training in both 1-back and 0-back tasks. Notable changes in the amplitudes of ALPHA, BETA, and THETA brainwaves were observed during the 0-back task following a training period. Similarly, in the 1-back task, variations in BETA wave responses were detected. These findings suggest that participating in an n-back training regimen can influence working memory task performance, demonstrating a measurable impact of such cognitive training on brain activity.

The results of this study provide compelling evidence for the future applicability of these tools in interventions aimed at enhancing working memory capabilities in young children. The significant improvement in working memory, as evidenced by the children's performance in n-back tasks, underscores the effectiveness of the training program and the employed methodologies. The ability to adapt and effectively repurpose digital educational tools, initially designed for older demographics, for younger children highlights a versatile approach that can be utilized in future educational and cognitive development strategies.

However, it is important to acknowledge a limitation of this study: the small sample size. While the results are promising, they are based on a cohort of only two children. This sample size may not adequately represent the broader population of school-aged children. Therefore, future studies are recommended to recruit a larger number of participants to enhance the generalizability of the findings.

Working memory is recognized as a complex system, and future research may develop a more comprehensive EEG systems to better capture its intricacies. Acknowledging the need for improvements in our experimental design and procedures, future studies could adopt a multi-indicator approach. This approach would involve incorporating various measures, such as reading skills and academic performance, to better understand the effects of working memory training.

Additionally, future research should explore the use of advanced neurophysiological techniques, like eye-tracking methods. These techniques could provide more precise and objective metrics for eye movement activities related to working memory training. By expanding the range of indicators and methodologies used, subsequent research could significantly enhance our understanding of the neural correlates of working memory training and its impact on cognitive functions.

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Author Profile

Chih-Chin Liang

Chih-Chin Liang has served as a full professor in the Department of Business Administration at National Formosa University in Taiwan since Feb. 2020. He received his M.S. from the Department of Industrial and Information Management at National Cheng Kung University in 1998 and his Ph.D. from the Department of Business Administration at National Central University in 2007. After graduation but before completing his Ph.D., he worked as a researcher in Chunghwa Telecom (CHT), where he had a particular interest in business intelligence, big data, queuing behaviors, brain studies, network communications, e-marketing, and e-business. His papers have been published on Decision Support Systems, Electronic Commerce Research, Industrial Management & Data Systems, Journal of Retailing and Consumer Services, Journal of Sensory Studies, International Journal of Retail & Distribution Management, Computers and Operations Research, Asia Pacific Journal of Tourism Research, Asia Pacific Journal of Marketing and Logistics, Time & Society, etc.

Si-Jie Fu

SI-JIE FU as a graduate student at the Institute of Business Management, National Formosa University. Shededicated to exploring the relationship between physiological signals and early childhood development. Her work focuses on utilizing advanced physiological measurement techniques to assess and enhance methods of training for young children. Her passion in this field is driven by a strong belief in the importance of early education and its impact on long-term development in children.