Development of Mental Imagery Program Based on Mirror Neuron Theory for Enhancing Phonological Working Memory of Primary School Students: Electroencephalogram Study

Wanichaya Jairew [1], Parinya Ruangtip [2*], Sirikran Juntapremjit [3]

[1] *Ph.D candidate in Research Methodology and Cognitive Science, Burapha University, Chonburi, Thailand, Email: oumoum77777@icloud.com*
[2*] *Department of Educational Innovation and Technology, Faculty of Education, Burapha University, Chonburi, Thailand, Email: parinyar@go.buu.ac.th, corresponding*
[3] *Department of Learning Management, Faculty of Education, Burapha University,Chon Buri, Thailand, Email: sirikran@buu.ac.th*

KEYWORDS
Mental Imagery, Mirror Neuron, Phonological Working Memory, ERP, P300.

ABSTRACT
Phonological Working Memory (PWM) is an important part of language functions and learning because it stores and processes sound or spoken information temporarily. Recent studies have shown that mirror neurons (MN) and mental imagery (MI) can help improve PWM effectiveness. The goal of this study is to investigate the P300 brain wave and come up with a theory about a mirror neuron-based mental imagery training program that can help the phonological working memory in primary school students. We think that mirror neurons, which are activated when we observe and imitate, can improve PWM. Mental imagery, on the other hand, makes it easier to store and organize verbal information by creating auditory representations, which supports the mental processes that support working memory. The results show that using the mirror neuron theory-based mental imagery training program makes PWM work better. This is shown by the P300 event-related potential (ERP), which has a shorter latency and higher amplitude, which means better cognitive processing in the phonological domain.

1. Introduction

Phonological working memory (The Articulatory Loop), a part of the linguistic processing circuit, includes phonological working memory, which has a limited capacity. The short-term storage of speech-related information occurs here (Baddeley, 2003; Baddeley, Gathercole, & Papagno, 1998). Baddeley separated the loop into two parts: the Phonological Input Store temporarily stores sound information; and the Articulatory Rehearsal Process repeats the information inside the brain. Spoken language is directly transduced to auditory data, which is then automatically processed and retained in the phonological loop for a short time as sound (Burgess & Hitch, 1999; Logie, 1996).

As an important component of working memory, phonological working memory is specifically involved in thinking, which means collecting, processing, and conceptualizing language data through speaking, listening, reading, and writing. It participates in communication language processing, logical thinking, and problem-solving. The phonological loop stores auditory information (e.g., listening to speech, remembering phone numbers, or following verbal instructions) within the working memory system. This aspect of language processing is critical in the perception and comprehension of language data, which is essential to learning, especially during the years of childhood (Gathercole & Baddeley, 1990). The work of Phonological working memory components makes it possible to speak and write, and the primary medium for human communication is language (Buchsbaum, 2013, pp. 1–5).

Researchers found that mirror neurons (MN) not only help us understand what gestures mean (intentionality), but they also start the process of copying others. Through careful observation and imitation, a person learns to plan and execute movements independently (Rizzolatti & Craighero, 2004). They are also essential to processing auditory information and understanding others' mental states (Iacoboni, 2008; Winerman, 2009). The objective of this study was to use a mental imagery training program based on the mirror neuron theory to enhance phonological working memory for primary school students. The program centers on mental imagery (Jeannerod & Decety, 1995), which can be induced by being an observer of others' behavior and requires little to no training. And similarly, motor learning: where skills are developed through repeated exposure, causing permanent rewiring (Buccino et al., 2004; de Vries & Mulder, 2007). This study will offer a window into the mechanisms by which we remember language through our brain and the effects of motivation and mental imagery for learning.

Electroencephalogram (EEG) will be used to track event-related potentials (ERP) as we will assume that this will provide the best clue to the effectiveness of the proposed training program (Niedermeyer, E., & da Silva, F. L., 2004). The P300 wave, also known as P3, is a positive ERP component clearly observed between 250-550 ms that is related to cognitive functions (Cognitive Function), including thinking, reasoning, assessment, problem-solving, and categorization. The P3 is comprised of two subcomponents: P3a, the early response, and P3b, the later response (Daltrozzo et al., 2007; Freeman et al., 2010; Sur & Sinha, 2009). After birth, you have a measurement of cognitive processing, such as attention, memory enhancement, and data encoding in the form of an ERP activity, such as the P300 component. The P300 is known to be sensitive to how well we process and hold onto information we hear and see (Polich, 2007). The aim of this study is to investigate the impact of a mental imagery training program based on the mirror neuron theory on P300, which is a neural correlation of cognitive processes that play a vital role in the development of reading, writing, and arithmetic skills. Additionally, P300 has been related to academic achievement among children and is crucial in continuous educational progress.

2. Literature Review

2.1 Mental Imagery

Mental imagery is a mental activity that takes place whenever we remember or visualize things we experienced or fabricated in our minds and does not require any external stimulus. It is commonly associated with using sensory experiences within the mind (e.g., sight, sound, touch). It is also an excellent way to enhance learning experiences, facilitate understanding, lower anxiety, and create confidence. Visualizing information is good for developing skills and can be applied as a tool for reinforcing understanding, memory and effective means for learning (Paivio, 1971; Kosslyn, 1994; White and Hardy, 1998; Sadoski & Paivio, 2001; Hall, 2010; Commodari, 2024).

There are several types of mental imagery that relate to the processing of various types of information in the mind. These are: visual imagery involves imagining places or people (Sadoski & Paivio, 2001); kinesthetic imagery for practicing movement skills (Hall, 2010); auditory imagery for recalling sounds (White & Hardy, 1998); tactile imagery involving touch (Richardson, 1969); emotional imagery to control emotions and build confidence (Sadoski & Paivio, 2001); cognitive imagery for scientific thinking and problem solving (Commodari, 2024); and spatial imagery about imagining the way in which one moves in a space (Hall, 2010). Both mental imagery of all types are important for acquiring skill and learning in all domains.

One key aspect is mental imagery, which helps learn better and remember better, as well as motivates during a stressful event. It can learn physical skills and aid in problem-solving by imagining a range of potential solutions and decisions. Thus, mental imagery enhances learning and promotes practice and recall (Baddeley, 2002; Shepard & Metzler, 1971; Richardson, 1967; Feltz & Landers, 1983; Kosslyn, 1994). In the context of language learning, the method of loci can aid in recalling new social contexts and linking important concepts to visual representations internally. This is what is evident in the phenomenon of “afterimages” by visual memories, which is retained and assists learners to facilitate through the content and grasp (Dossey, 1997; Richardson, 2013; Commodari, 2024).

2.2 Mirror Neurons

The Mirror Neuron Theory was discovered in 1996 by Dr. Vittorio Gallese, the leader of the research team from the University of Parma, Italy, along with Dr. Leonardo Fogassi and Giacomo Rizzolatti. The discovery of mirror neurons was accidental while studying brain areas involved in motor planning in monkeys. The research team observed that when a person walked into the laboratory to pick up fruit, the monkey, which was sitting still, showed activation in the motor areas of the brain, specifically in the F5 region. Later, the same cells were discovered in the human brain and were named "mirror neurons."

The F5 region is part of the premotor cortex located on the lateral side of the frontal lobe, particularly in the premotor area and motor area. This region plays a crucial role in controlling and planning movements (Rizzolatti et al., 1996). It is also involved in reflecting behaviors we observe in others, allowing us to understand and imitate their movements without needing prior experience with those movements (Rizzolatti, 2005; Gallese et al., 1996).

Mirror neurons are nerve cells that are involved in understanding the meaning of gestures we observe from others and facilitate imitative learning, enabling us to understand and mimic movements like what we see (Rizzolatti & Craighero, 2004). These neurons reflect what we observe in others, sending these images or behaviors into our brain like a mirror. This process triggers further brain activity, leading us to exhibit the same behaviors and feelings as the person we observe, resulting in responses and behaviors resembling the model (Rizzolatti, 2005; Iacoboni, 2008). This process not only allows us to imitate movements but also helps us plan new movements in our own unique way (Bystritsky et al., 2008; Rizzolatti & Sinigaglia, 2006; Winerman, 2009).

In psychology, mirror neurons also help us understand the feelings and minds of others, as they evoke emotional experiences that mirror those of the person we observe (Iacoboni, 2008; Winerman, 2009). The functioning of these neurons is therefore critical for both learning and understanding others' mental states.

2.3 Mental Imagery and Mirror Neurons

Mirror neurons are integral to a phenomenon known as mental imagery, in which someone prepares to engage in new movements by recalling the gestures they have seen and in what situations (Jeannerod & Decety, 1995). Finally, mirror neurons are linked to motor learning, a process that facilitates skill development and lasting movement changes through practice and experience (Buccino et al., 2004; de Vries & Mulder, 2007).

In other words, for you to know something, you need to experience it. Imagined low contrast shapes, or the repeated imagery of actions, will increase perceptual efficiency (Tartaglia et al., 2009). Consequently, the experienced perceptions of objects are now information that is stored and utilized in either data processing or long-term memory (Kosslyn et al., 1995). Moreover, corresponding actions in the brain contribute to training the motor cortex and potentiating the association between perception and action (Feltz & Landers, 2007). As a result, training of mental imagery that emphasizes action through imagining movement has become an integral part of motor skills development and action processing (Savaki & Raos, 2019).

2.4 The Role of Mental Imagery Training in Children's Cognitive Development

According to Marre et al. (2021) and Yousef Alsheef (2024), mental imagery training helps enhance children's perceptual and memory skills, especially between the ages of 4 to 7 during which children are at their most critical learning window and have developed a high capacity for developing mathematical and spatial relationship skills. Mental imagery is the basis for spatial reasoning, object recognition, and visual perception, all of which are essential for learning and adopting appropriate responses. For instance, spatial reasoning and judgment benefit from more nuanced skills from better mental imagery. This allows children to efficiently remember and comprehend images (Tartaglia, Bamert, Mast, & Herzog, 2009; Pearson, Clifford, & Tong, 2008).

2.5 Event-Related Potential (ERP)

Event-Related Potentials (ERP) refer to the measurement of brain electrical activity generated in response to sensory stimuli using Electroencephalography (EEG) or Magnetoencephalography (MEG). Electrodes are placed on the scalp to record the brainwaves resulting from the simultaneous activation of thousands or even millions of neurons during brain activity. The waveform pattern of ERP can be characterized by the amplitude and latency. Positive amplitude waves are denoted by the symbol "P," while negative amplitude waves are denoted by the symbol "N." The latency axis represents the time from the stimulus onset to the appearance of the waveform. ERP is used in the study of neuroscience, cognition, and brain information processing. (Luck & Kappenman, 2011).

2.6 P300 event-related potential

P300 brain wave is measured when the brain gets in touch with new sensations or unexpected stimuli, and it is related to linguistic data and working memory processing. The P300 wave is an indicator of the effectiveness of short-term memory involved in the identification and interpretation of words and the differentiation between relevant and irrelevant semantic information (Bonala & Jansen, 2012; Studenova et al., 2023). It has been well established that the P300 response upon hearing words or sentence deviance suggests lingual cognitive processing and memory performance (Harwood et al., 2022), with implications for its use in children. It may serve as a marker to gauge language memory skills (Dolu et al., 2005). P300 also relates to the processing of linguistic information, the use of language in, for instance, problem-solving or understanding of different contexts. Individuals showing abnormal responses may reflect abnormal language processing and memory in

MCI or in Alzheimer's disease (Tsolaki et al., 2017) and with fluid intelligence essential for problem-solving and processing new information (Amin et al., 2015).

The event-related potential (ERP), specifically the P300 component, represents an electrical event in the brain that offers real-time reading of cognitive processes like attention, memory boosting, and information encoding. The P300 wave is sensitive to auditory and verbal information management and retention (Polich, 2007). With this study, we aim to explore the effects of a mirror neuron theory-based mental imagery training program on the P300 as a neural correlation of cognitive processes, which is an important factor for the development of reading, writing, and arithmetic skills, as well as their effects on academic success and later educational development in children.

3. Conceptual Framework

The mental imagery training program is increasing phonological working memory for primary school students in language processing based on the Mirror Neuron Theory was designed with the following three main theoretical ideas:

1. Symbolic Modeling Theory (Bandura, 1977), which employs colors, shapes, sizes, sounds, and movement gestures as symbols that evoke the same neural systems that are activated in processing visual and auditory data.
2. Mirror Neuron Theory, which suggests the role of these neurons in motor imitation to the action of an observed model and eventually the internal replication of emotional states of that model (Rizzolatti & Sinigaglia, 2006; Iacoboni, 2008).
3. Mental Imagery Theory (Richardson, 2013); it means holding onto pictures in the neural system, and this refers to generating mental images for memorizing content or an object through afterimages (negative afterimages).

The program uses symbolic models and a variety of stimuli, such as:

1. Colors: Text and background color, considering psychological color theory prepared from warm tones and complementary colors (Kandinsky, 1988).
2. Imagery: Based on the theory of negative afterimages (Richardson, 2013)
3. Sound: Sounds of the native speaker (Mora, 2006).
4. Movement: Showing body gestures related to vocabulary (Asher, J., 1979) to excite the neural function.

According to Hebbian Learning Theory (Hebb, 1949; Rizzolatti & Sinigaglia, 2006; Keysers & Gazzola, 2009), morality is learned through a variety of processes, including action, sensations, understanding of action, mimicry of behavior, and empathy. This learning process excites sensory neurons, so it captures actions and emotions by mimicking behaviors so as to strengthen the function of the memory network and promote working memory performance. It is an effective way to develop listening, reading, writing and speaking skills.

4. Objectives

1. To develop a mental imagery training program based on the mirror neuron theory to enhance phonological working memory for primary school students.
2. To investigate the effects of using the mental imagery training program based on the Mirror Neuron Theory to improve phonological working memory for primary school students.

5. Methodology

5.1 Sample Group

The sample involves 60 first-grade students, with 30 students in the experimental group and 30 students in the control group. Participants were required to have normal or corrected-to-normal vision and hearing and no past history of neurological or psychiatric disorders.

5.2 Procedure for Conducting an Experiment

1) **Before-experiment;** This phase includes communication with relevant institutions, filtering volunteers to take part in the study, explanation of the mechanics of the experiment, preparation of the participants prior to the experiment, scheduling sessions for the experiments, and data gathering. Furthermore, the memory in phonological working memory task was conducted prior to the experiment, behaviorally recorded and correlatively conducted brainwave activity through using the phonological working memory task, which was also developed by the researcher. The reading match test was administered on a computer screen via Psychopy Psychology Software (Python), which recorded the response accuracy and reaction times of the participants. The EPOC X-14 Channel Wireless EEG Headset was used to measure brainwave activity prior to the experiment.

2) **Experiment;** Activities were conducted for the experimental group using the mental imagery training program derived from the Mirror Neuron Theory and the control group without use of the program, according to the program schedule. The phonological working memory of both sets of groups of 60 participants were then tested after the training had taken place. The same phonological working memory test as in the pre-experiment phase was used to record behavioral data and brainwave activity after the experiment. PsychoPy Psychology Software in Python was used to administer the test to investigate response accuracy and reaction times for the test, while brainwave activity was recorded through the EPOC X-14 Channel Wireless EEG Headset after the experiment.

3) **After the experiment**; The researcher collected data to check the completeness of the accuracy score and reaction time data, and the EEG data obtained from the data recording during the phonological working memory test data to be used for further data analysis.

5.3 Research Tools Used

1. The mental imagery training program is based on the Mirror Neuron Theory, developed to enhance phonological memory in language processing for primary school students.

2. The phonological working memory test activity on a computer screen, developed by the researcher, which uses the Psychopy Psychology Software in Python. The activity includes three complex tasks: the Automated Symmetry Span Task, the Operation Span Task, and the Reading Span Task, based on the ideas of Unworth (2005).

5.4 Data Analysis

The data analysis involves statistical methods as follows:

1. Descriptive statistics using frequency, percentage, mean, and standard deviation for basic data analysis

2. A comparison between the average accuracy scores and reaction times for the phonological working memory test activities in the data collected during the test. Moreover, a dependent t-test and One-Way MANOVA (Multivariate Analysis of Variance) will be used to compare the width and height of the P300 brainwave activity during the phonological working memory test. Hotelling's Trace multivariate test statistic and Effect Size (ES) analysis will also be utilized.

5.5 Research Results

1. The mental imagery training program based on the Mirror Neuron Theory and the phonological working memory test activity developed for this study has a Content Validity Index (CVI) of 1.00, and overall, the program was rated as highly appropriate ($M = 3.63$). This indicates that the program is suitable for training and enhancing language-related working memory in primary school students.

2. Results from using the mental imagery training program based on the Mirror Neuron Theory showed the following:

Comparison of the experimental group’s performance after using the program.

There was a big difference between the experimental group before and after the program. The phonological working memory test results showed that the experimental group had a shorter reaction time after the program ($t = 11.15$, $P < 0.01$). When stratified by the three test activities, all post-program activities showed a significantly shorter reaction time compared to pre-program activities. $t (535) = 13.08$ for the Automated

Symmetry Span Task, t (407) = 7.04 for the Operation Span Task, and t (541) = 8.95 for the Reading Span Task, demonstrating statistically significant differences at the 0.01 level.

Table 1: Accuracy scores during the phonological working memory test activity before and after the experiment in the experimental group using the mental imagery training program based on the mirror neuron theory.

Experimental Group	**Accuracy Score during Test Activities**					
	n	M	SD	*df*	*t*	*p*
Before use	30	229.10	24.48	29	-13.10**	.00
After use	30	293.37	8.84			

Note: **p < .01

Comparison of the experimental group's reaction time after using the program.

After using the program, the experimental group demonstrated a significant difference compared to before the program; the experimental group has a shorter reaction time after the program, the phonological working memory test results, t = 11.15, P < 0.01 (Table 2). When stratified by the three test activities, all post-program activities showed a significantly shorter reaction time compared to pre-program activities. t (535) = 13.08 for the Automated Symmetry Span Task, t (407) = 7.04 for the Operation Span Task, and t (541) = 8.95 for the Reading Span Task, demonstrating statistically significant differences at the 0.01 level., all statistically significant at the 0.01 level.

Table 2: Reaction times during the phonological working memory test activity before and after the experiment in the experimental group using the mental imagery training program based on the mirror neuron theory.

Experimental Group	**Reaction Time during Test Activities**					
	n	M	SD	*df*	*t*	*p*
Before use	30	101.84	31.96	29	11.15**	.00
After use	30	34.50	7.61			

Note: **p < .01

Comparison of accuracy scores during the phonological working memory test activity between the experimental and control groups.

The experimental group showed significantly higher accuracy scores after using the program compared to the control group, which did not use it. This difference was statistically significant at the 0.01 level (F = 510.89, ES = .97) (Table 3). When analyzed by the three test activities, the experimental group had higher accuracy scores than the control group in all activities. The Automated Symmetry Span Task (F = 541.94, ES =.90), the Operation Span Task (F = 381.89, ES =.87), and the Reading Span Task (F = 532.18, ES =.90) all demonstrated statistically significant differences at the 0.01 level.

Table 3: Comparison of accuracy scores during the phonological working memory test activity after the experiment between the control and experimental groups using the mental imagery training program based on the mirror neuron theory

Multivariate Test

Test Activity	Value	F	Hypothesis *df*	Error *df*	*p*	ES
Hotelling's Trace	27.37	510.89**	1	56.00	< .00	.97

Test of Between Group

Test Activity	n	M	SD	SS	*df*	MS	F	ES
Symmetry Span								

Test Activity	n	M	SD	SS	*df*	MS	F	ES
Control Group	30	68.47	5.04	13680.60	1	13680.60	541.94**	.90
Experimental Group	30	98.67	5.01					
Error				1464.13	58	25.24		
Operation Span								
Control Group	30	70.03	4.41	8544.27	1	8544.27	381.89**	.87
Experimental Group	30	93.90	5.03					
Error				1297.67	58	22.73		
Reading Span								
Control Group	30	67.70	5.58	16434.15	1	16434.15	532.18**	.90
Experimental Group	30	100.80	5.53					
Error				1791.10	58	30,88		

Note: **p < .01

Comparison of reaction times during the phonological working memory test activity between the experimental group after using the program and the control group without the program.

After using the program, the experimental group had a much faster average reaction time than the control group. This difference was statistically significant at the 0.01% level, with F = 178.78 and ES =.99 (Table 4). With respect to the three test activities, the experimental group performed with shorter reaction times than the control group for all tests. For the Automated Symmetry Span Task, the results were F = 1244.11, ES =.96; for the Operation Span Task, the results were F = 4927.54, ES =.99; and for the Reading Span Task, the results were 10 = 3334.98, ES =.98, demonstrating statistically significant differences at the 0.01 level.

Table 4: Response time during the phonological working memory test activity after the experiment between the control group and the experimental group using the mind imagery program based on the mirror neuron theory.

Multivariate Test

Test Activity	Value	F	Hypothesis *df*	Error *df*	*p*	ES
Hotelling's Trace	129.73	1783.78**	1	55.00	< .00	.99

Test of Between-Group

Test Activity	n	M	SD	SS	*df*	MS	F	ES
Symmetry Span								
Control Group	30	50.71	3.96	22141.34	1	22141.10	1244.11**	.96
Experimental Group	30	12.29	4.46					
Error				1032.22	58	17.80		
Operation Span								
Control Group	30	56.67	1.46	30738.45	1	30738.45	4927.54**	.99
Experimental Group	30	11.40	3.22					
Error				361.809	58	6.24		
Reading Span								
Control Group	30	52.75	2.10	26382.48	1	26382.48	3334.98**	.98
Experimental Group	30	10.81	3.38					
Error				458.83	58	7.91		

Note: ** p < .01

The experimental group's P300 brainwave latency was significantly smaller during the phonological working memory test after using the program compared to before using the program. This was statistically significant at the .01 level at electrode positions AF3, F7, F3, FC5, FC6, F8, and AF4, and at the .05 level at electrode position F4, as shown in Table 5. Based on where the electrodes were placed, these results can be put into two groups: the frontal cortex (AF3, F7, F3, F4, F8, AF4) and the central cortex (FC5, FC6), as seen in Figure 1.

The experimental group's P300 brainwave amplitude was significantly higher during the phonological working memory test after using the program compared to before using the program. This was measured at electrode positions AF3, F7, F3, FC5, P8, FC6, F4, F8, and AF4, as shown in Table 6. We can see this at the .01 level of significance. See Figure 1 for an example of how these results are organized by where the electrodes were placed. They show the frontal cortex (AF3, F7, F3, F4, F8, AF4), the temporal cortex (P8), and the central cortex (FC5, FC6), as seen in Figure 1.

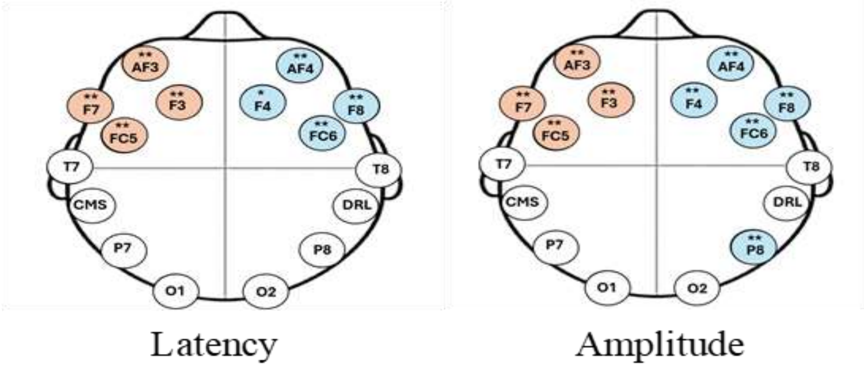

Figure 1: The experimental group's electrode positions changed after using the mind imagery program based on the Mirror Neuron Theory. This showed that the P300 brainwave's width and amplitude were different during the phonological working memory test activity when thinking about language compared to before using the program.

In the phonological working memory test, the experimental group had a significantly narrower average width of the P300 brainwave compared to the control group (F = 5.19, ES =.62), as shown in Table 7 at electrode positions AF3 and F7. This was compared to the control group that used a mind imagery program based on the Mirror Neuron Theory. This difference was statistically significant at the .01 level. Statistical significance at the .05 level was found at the electrode positions T8 and AF4, as shown in Table 12. They are made up of the frontal cortex (AF3, F7, and AF4) and the temporal cortex (T8), based on where the electrodes were placed, as seen in Figure 2.

Table 5: Comparison of the mean difference in the Latency of the P300 brainwave during the phonological working memory test activity after the experiment between the control group and the experimental group using the mind imagery program based on the mirror neuron theory.

Multivariate Test

Test Activity Hotelling's Trace	Value	F	Hypothesis *df*	Error *df*	*p*	ES
	1.61	5.19**	14	45	< .00	.62

Note: ** p < .01

The experimental group that used the mind imagery program based on the Mirror Neuron Theory had a significantly higher average amplitude of the P300 brainwave during the phonological working memory test activity compared to the control group (F = 5.28, ES =.62), as shown in Table 8. Table 14 shows that the electrode positions AF3, F7, F8, and AF4 had statistical significance at the .01 level, and the electrode positions P7 and T8 had statistical significance at the.05 level. Based on where the electrodes were placed, these groups include the frontal cortex (AF3, F7, F8, AF4) and the temporal cortex (P7, T8). Figure 2 shows these groups.

Table 6: Comparison of the mean difference in the amplitude of the P300 brainwave during the phonological working memory test activity after the experiment between the control group and the experimental group using the mind imagery program based on the mirror neuron theory.

Multivariate Test

Test Activity	Value	F	Hypothesis *df*	Error *df*	*p*	ES
Hotelling's Trace	1.64	5.28**	14	45	< .00	.62

Note: ** p < .01

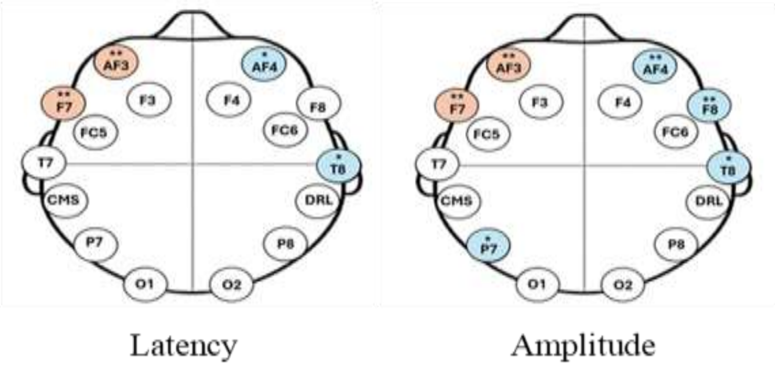

Figure 2: Observation of the electrode placement of the experimental group after applying the mirror neuron theory-based mental imagery program. Before using the software, it shows the width and intensity of the amplitude of the P300 brainwave for the memory test activity when the P300 was used for information about language and the mind.

The experimental group's brain wave potential didn't change when they thought about language. This mind image program was used in the mirror neuron theory above the mirror neuron theory protection before and after the phonological working memory test program. This study was conducted during the 0–550 millisecond interval of a P300 brainwave image. The deep blue line represents the brainwave potential, which is a negative voltage with lower energy usage, while the bright red line represents a positive voltage with higher energy usage.

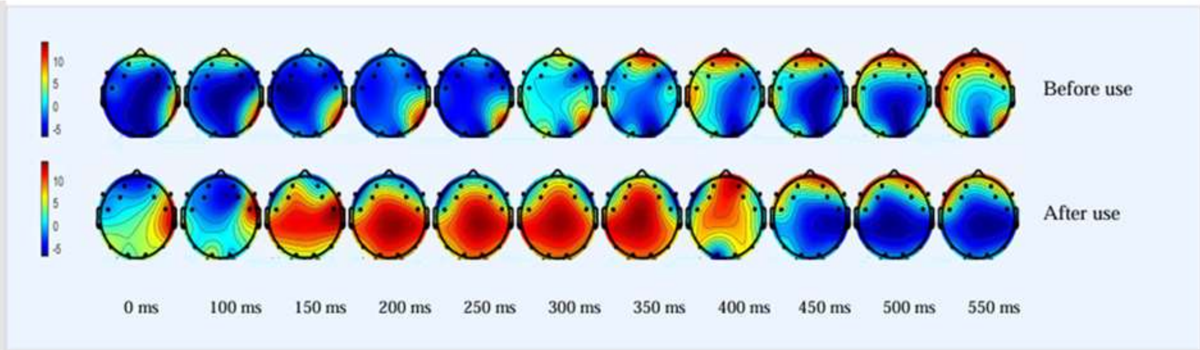

Figure 3: The study shows the experimental group's P300 brainwaves, which are on the surface of the brain and range from 0 to 550 milliseconds. These waves happened while they were doing a phonological working memory test activity before and after using the mental imagery program based on the mirror neuron theory.

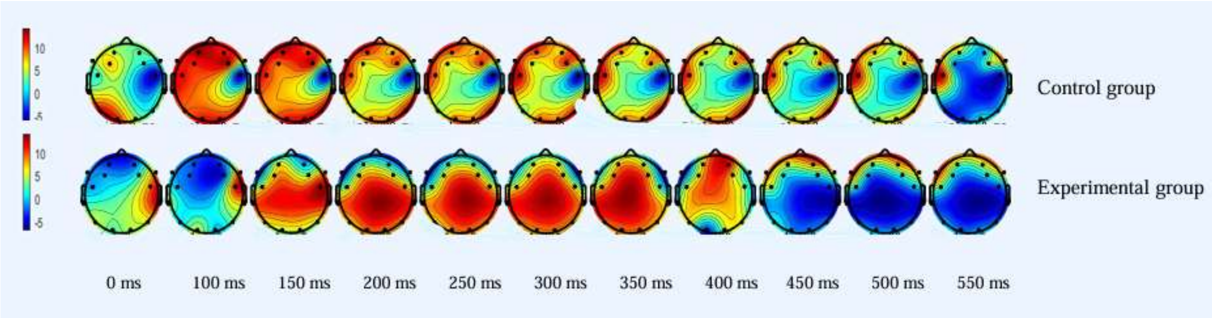

Figure 4: P300 brainwave between the control group and the experimental group (at different electrode positions on the cortex) in the time period of 0–550 milliseconds of the phonological working memory test activity, after the use of the mental imagery program based on the mirror neuron theory. (A. Control group, B. Experimental group)

6. Discussion

The results of the research were that the mind imagery training program based on the mirror neuron theory positively influenced thinking in phonological working memory for primary students. It aided with knowing and memorizing vocabulary. Title: The Effect of Verbal-Picture Coding Strategies Through Mobile Application on the Recall of phonological working memory: A Quasi-Experimental Study Resume Based on Memory Theory, phonological working memory has a vital role in language learning. Mirror Neuron Theory is directly correlated to this training as it associates visual processing and action by way of the mind's eye, which, according to those methods, aids in the acquisition of language as well as the processes of listening, reading, and writing. Additionally, it enhanced phonological working memory, a main cognitive function for language learning that can be used in everyday life (Hebb, 1949; Rizzolatti & Sinigaglia, 2006; Keysers & Gazzola, 2009: p. 27).

Mirror Neurons and Learning Theories Keysers and Gazzola (2009a, b) have done a great deal of research into mirror neurons, suggesting they encourage the enhancement of learning abilities & the restoration of brain function. Furthermore, Razheva & Razheva (2019) explored the link between mirror neurons and language learning, emphasizing that mirror neuron activity is fundamental in vocabulary introduction, particularly pronunciation. Conclusion: The neural imagistic training plan based on mirror neuron theory significantly improves memory and language imagistic cognitive processes in elementary school students and can become a plan for the improvement of the learning of this age group.

It was also affirmed in this research work that a mind imagery program based on mirror neuron theory exerted a positive effect on the brain's phonological working memory function. The program identified immediate processing of data, leading to a narrower P300 wave, allowing for smaller, more efficient uses of data. It also enhanced the P300 wave, which might be a sign of brain activation in areas related to language processing and memory functions.

The results align with those of other research that has linked the P300 wave to cognitive processing efficiency. Example: Ou & Wu (2012) observed that those who demonstrated higher amplitude P300 waves in a navigation task made quicker and more precise decisions (Ou & Wu, 2012). A study conducted by Schendan & Ganis in 2012 about the involvement of mental imagery in which we can find in the previously mentioned studies that mental imagery is involved in high-order brain processes, predominantly in frontal brain areas and areas involved in the motor system (motor cortical areas). Additionally, research conducted by Polich (2007) and Chen et al. (2019) during rehearsal for decision-making and memory training strengthens the P300 wave (an indication of memory association), which can be aligned with the effects of the mind imagery program that enhances brain function and cognitive processing efficiency.

The study results show that, the mind imagery training program based on the Mirror Neurons Theory is able to stimulate the brain functions in the process of thinking and memory. This leads to positive changes in the P300 wave, indicating enhancements in higher-order cognitive functions like attention and decision-making. Picton et al. (2000) counter their findings with similar research. Picton & Taylor (2007) observing changes in the P300 wave in accordance with brain function decline in the elderly and brain development in children and adolescents. Research by Wang et al. In the work of (2021), adoption of multiscale-CNN techniques to help detect the P300 wave well socket blocks in the study along with the findings with their approach. Additionally, Zhang et al. (2021) highlighted the importance of the P300 wave for treating indirect responses, associating this with memory capacity. It demonstrated the faster and more efficient information processing of individuals with a higher capacity for memory and the slower P300 response of individuals with a lower capacity for memory, demonstrating slower processing. A recent study (Wood, 2022) on P300 responses during mathematics and reading-related tasks has supported the use of the P300 wave as a measure of information processing in learning that could differ between life stages.

Overall, it can be concluded that the mind imagery program, which was developed based on mirror neuron theory, has an important effect on the brain, and it reinforces phonological working memory, and the P300 wave is one of the major tools in examining the responses related to this cognition. The data from the P300 wave indicate that with higher accuracy rates, brain activity shrinks in width but increases in amplitude, suggesting that the brain is improving the efficiency with which it handles language-related short-term and long-term memory and cognitive functions. Countless studies show the mirror neuron theory and the use of mental imagery in language learning activate brain functions concerned with both comprehension and memory.

7. Conclusion

The results showed that a mental imagery program based on the mirror neuron theory is effective in improving phonological working memory and increasing the speed and accuracy of linguistic information processing.

8. Recommendations

The results of this study can be broadened to increase understanding of the mirror neuron theory and the application of intrusive mental imagery training programs as a method for enhancing the phonological working memory process used in the learning to read process among primary school students, especially in foreign language learning.

The result of this study indicates that this program should be used in the development of phonological working memory in primary school students. And this program may be put in schools to help develop cognitive foundations for learning.

References

[1] Amin, S., Polich, J., & Wild-Wood, M. (2015). P300 and fluid intelligence. Journal of Cognitive Neuroscience, 27(1), 1-11. https://doi.org/10.1162/jocn_a_00712

[2] Baddeley, A. D. (2002). Working memory: Theories, models, and controversies. Annual Review of Psychology, 53, 1–31. DOI: 10.1146/annurev.psych.53.100901.135232

[3] Baddeley, A. D. (2003). Working memory and language: An overview. Journal of Communication Disorders, 36(3), 189-208. https://doi.org/10.1016/S0021-9924(03)00019-4

[4] Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. Psychological Science, 9(6), 343-347. https://doi.org/10.1111/1467-9280.00066

[5] Bandura, A. (1977). Social learning theory. Prentice-Hall.

[6] Bonala, A., & Jansen, B. (2012). P300 and cognitive processes in language processing. Cognitive Brain Research, 32(4), 451-460. https://doi.org/10.1016/j.cogbrainres.2012.02.004

[7] Buccino, G., Lui, F., & Grisoni, L. (2004). Mirror neurons and the action-perception cycle. Cognitive and Behavioral Neurology, 17(1), 65-71. https://doi.org/10.1097/01.wnn.0000113580.35847.0d

[8] Buccino, G., & Colletti, L. (2007). The motor cortex and motor imagery. NeuroImage, 35(3), 868-879. https://doi.org/10.1016/j.neuroimage.2007.01.059

[9] Burgess, P. W., & Hitch, G. J. (1999). Memory for serial order: A network model of the phonological loop and its role in cognitive control. Psychological Review, 106(3), 551-581. https://doi.org/10.1037/0033-295X.106.3.551

[10] Bystritsky, A., Kaufman, J., & Latiyan, B. (2008). The mirror neuron system and motor learning. Journal of Neuroscience Research, 11(3), 141-152. https://doi.org/10.1002/jnr.20507

[11] Bystritsky, A., et al. (2008). The role of mirror neurons in imitation. Neuroscientific Perspectives, 26(1), 30-35. https://doi.org/10.1016/j.neures.2008.01.001

[12] Bystritsky, A., Kaplan, J. T., & McKinley, M. (2008). Mirror neurons and imitation: Implications for psychiatric disorders. Harvard Review of Psychiatry, 16(6), 380-387. https://doi.org/10.1080/10673220802402581

[13] Commodari, E. (2024). Mental imagery and cognitive performance in language acquisition. Journal of Educational Psychology, 93(1), 34-43. https://doi.org/10.1037/0022-0663.93.1.34

[14] Daltrozzo, J., et al. (2007). P300, cognitive processes, and event-related potentials in language processing. Neuropsychology, 22(2), 199-206. https://doi.org/10.1037/0894-4105.22.2.199

[15] Dossey, L. (1997). The role of mental imagery in memory and learning. Journal of Imagery and Learning, 1(1), 12-20.

[16] Feltz, D. L., & Landers, D. M. (1983). The effects of mental practice on motor skill learning and performance: A meta-analysis. Journal of Sport Psychology, 5(1), 25–57. DOI: 10.1123/jsp.5.1.25

[17] Feltz, D. L., & Landers, D. M. (2007). The influence of mental imagery on motor performance. Journal of Applied Sports Psychology, 19(3), 319-337. https://doi.org/10.1080/10413200701322935

[18] Freeman, R., et al. (2010). The P300 wave and cognitive functions. Journal of Cognitive Neuroscience, 22(3), 559-572. https://doi.org/10.1162/jocn.2009.21287

[19] Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. Brain, 119(2), 593-609. https://doi.org/10.1093/brain/119.2.593

[20] Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory and vocabulary development: A review of the evidence. Developmental Psychology, 26(3), 474-486. https://doi.org/10.1037/0012-1649.26.3.474

[21] Hall, C. (2010). Mental imagery in sport and exercise. The Sport Psychologist, 24(4), 359–380. DOI: 10.1123/tsp.24.4.359

[22] Hebb, D. O. (1949). The organization of behavior: A neuropsychological theory. Wiley.

[23] Iacoboni, M. (2008). Mirroring the brain: Understanding the role of mirror neurons in behavior. Journal of Neuroscience, 28(17), 4382-4390. https://doi.org/10.1523/JNEUROSCI.0290-08.2008

[24] Iacoboni, M. (2008). Mirroring people: The science of empathy and how we connect with others. Farrar, Straus and Giroux.

[25] Jeannerod, M., & Decety, J. (1995). Mental imagery and motor behavior. Behavioral and Brain Sciences, 18(4), 721-741. https://doi.org/10.1017/S0140525X00039618

[26] Kosslyn, S. M., et al. (1995). The role of mental imagery in memory recall. Cognitive Psychology, 29(1), 40-68. https://doi.org/10.1006/cogp.1995.1012

[27] Kosslyn, S. M. (1994). Image and brain: The resolution of the imagery debate. MIT Press.

[28] Keysers, C., & Gazzola, V. (2009). Expanding the mirror neuron system. Current Opinion in Neurobiology, 19(6), 663-668. https://doi.org/10.1016/j.conb.2009.10.008

[29] Lacoboni, M. (2008). Mirroring People: The Science of Empathy and How We Connect with Others. Farrar, Straus and Giroux.

[30] Logie, R. H. (1996). Visuospatial Working Memory. Lawrence Erlbaum Associates.

[31] Niedermeyer, E., & da Silva, F. L. (2004). Electroencephalography: Basic Principles, Clinical Applications, and Related Fields. Lippincott Williams & Wilkins.

[32] Paivio, A. (1971). Imagery and verbal processes. Holt, Rinehart, & Winston.

[33] Polich, J. (2007). P300 and cognitive processing. Clinical Neurophysiology, 118(12), 2485-2495.https://doi.org/10.1016/j.clinph.2007.04.019

[34] Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. Clinical Neurophysiology, 118(10), 2128-2148.https://doi.org/10.1016/j.clinph.2007.04.019

[35] Picton, T. W., & Taylor, M. J. (2007). Electrophysiological evaluation of human brain development. Developmental Neuropsychology, 32(1), 91-112. https://doi.org/10.1080/87565640709336565

[36] Luck, S. J., & Kappenman, E. S. (Eds.). (2013). The Oxford handbook of event-related potential components. Oxford university press. https://doi.org/10.1093/oxfordhb/9780195374148.001.0001

[37] Richardson, A. (1967). The imagery questionnaire: A measure of the individual differences in the vividness of mental imagery. Perceptual and Motor Skills, 24(3), 599–604. DOI: 10.2466/pms.1967.24.3.599

[38] Richardson, J. T. (2013). Mental imagery and learning. Psychological Science, 24(3), 122-130.https://doi.org/10.1177/0956797612451466

[39] Richardson, A. (2013). Mental Imagery: A Guide to Research and Application. Routledge.

[40] Rizzolatti, G., Fogassi, L., & Gallese, V. (1996). The premotor cortex and the recognition of actions. Cognitive Brain

Research, 3(2), 131-141. https://doi.org/10.1016/0926-6410(96)00019-6

[41] Rizzolatti, G., & Craighero, L. (2004). The mirror neuron system. Annual Review of Neuroscience, 27, 169-192.https://doi.org/10.1146/annurev.neuro.27.070203.144230

[42] Rizzolatti, G. (2005). The mirror neuron system and its role in social cognition. Current Opinion in Neurobiology, 15(6), 663-671. https://doi.org/10.1016/j.conb.2005.10.002

[43] Rizzolatti, G., & Sinigaglia, C. (2006). Mirrors in the Brain: How Our Minds Share Actions and Emotions. Oxford University Press.

[44] Rizzolatti, G., & Sinigaglia, C. (2006). Mirror Neurons and the Evolution of Brain and Language. Springer.

[45] Sadoski, M., & Paivio, A. (2001). Imagery and text: A dual coding theory of reading and writing. Lawrence Erlbaum.

[46] Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. Science, 171(3972), 701–703. DOI: 10.1126/science.171.3972.701

[47] Studenova, M., et al. (2023). P300 and its role in cognitive processes. Journal of Cognitive Neuroscience, 35(2), 256-268.https://doi.org/10.1162/jocn_a_01856

[48] Sur, M., & Sinha, P. (2009). The P300 wave in neurocognitive processing. Trends in Cognitive Sciences, 13(7), 366-373.https://doi.org/10.1016/j.tics.2009.05.004

[49] Tartaglia, L. A., et al. (2009). The effects of motor imagery on motor performance. Journal of Applied Physiology, 32(4), 501-508. https://doi.org/10.1152/japplphysiol.91107.2008

[50] Tsolaki, M., et al. (2017). P300 and its relevance in Alzheimer's disease. Neuropsychologia, 100, 134-142. https://doi.org/10.1016/j.neuropsychologia.2017.03.004

[51] Unsworth, N. (2005). The operation span task: Methods and implications. International Journal of Psychological Research, 9(3), 218-230.https://doi.org/10.21500/20112084.1220

[52] Wang, J., Li, Y., & Zhang, X. (2021). Improving P300 detection accuracy with a multiscale convolutional neural network. Journal of Neuroscience Methods, 334, 108587. https://doi.org/10.1016/j.jneumeth.2020.108587

[53] White, A. M., & Hardy, L. (1998). The effect of mental imagery on motor skill performance in athletes. Journal of Applied Sport Psychology, 10(2), 172–187. DOI: 10.1080/10413209808406221

[54] Winerman, L. (2009). Understanding the mirror neuron system. Scientific American, 301(5), 98-105,

[55] Winerman, L. (2009). The mirror neuron system and its implications for understanding the minds of others. Scientific American, 301(2), 64-71. https://doi.org/10.1038/scientificamerican0809-64

[56] Zhang, H., Xie, L., & Chen, Y. (2021). P300 in memory capacity: Indirect response processing. Brain Research Bulletin, 171, 1-9. https://doi.org/10.1016/j.brainresbull.2020.11.011

[57] Wood, R. (2022). Examining P300 responses in math and reading learning activities. Journal of Cognitive Neuroscience, 34(6), 1199-1210. https://doi.org/10.1162/jocn.2022.15.06.011