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Multisensory Teaching and Beta and SMR Oscillatory Activities in Foreign Language Vocabulary Retention: A Neurolinguistic Study

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Abstract

Retention and learning are neurolinguistic and psycholinguistic processes. The brain electrical response to the cognitive processes that happen in the cortices is inescapable. During neuronal activities, created waves can be recorded and displayed by quantitative electroencephalogram (QEEG) in a non-invasive form. Beta waves are created by thinking, learning, computations, reasoning, attention, and problem-solving activities. This study's primary goal is to objectively investigate the variables impacts of multisensory and non-multisensory methods of instruction on vocabulary retention concerning beta and beta1 waves frequency changes. To meet the purpose, some pre-school novice male and female foreign language learners (age: 5-6 years) participated in this study voluntarily and were assigned into two experimental groups: The Multisensory (three girls and four boys) and Non-multisensory (one girl and six boys) teaching groups. The analyses of the collected data on pre- and post-brain QEEG records of beta and beta1/SMR waves' variations indicated no significant difference between the two groups in the brain oscillatory changes. However, the case study analyses specified the supremacy of beta1 frequency ranges in the Multisensory post-records. The comparative findings of pre- and post-Expressive One Word-Picture-Matching Test (EWPMT) showed that the Multisensory group outperformed the Non-multisensory one; besides, a significant positive relationship was found between beta wave frequency changes on Fp1 and mean score of EWPM post-test in the Multisensory group. The study concluded that the multisensory approach could be a promising method to improve retention at the pre-school level.

Keywords: Beta wave, Beta1 wave, foreign language vocabulary retention, multisensory teaching, QEEG

Introduction

Vocabulary is the critical skill that students need for success in their language learning. Language teachers always make great efforts to teach new language words; correspondingly, linguists and researchers have endeavored to find the most adequate vocabulary learning strategies to ease the recall process. Despite that, there may be many words that have never been learned or retained. Retention is "Keeping vocabulary in long-term memory and retrieving it for meaningful use in appropriate contexts" (Daloglu, Baturay, & Yildirim, 2009, p. 203). Retention is contributed to the memory systems, and it mostly relies on episodic memory (Dickerson & Eichenbaum, 2010).

The episodic memory (EM) develops during middle childhood and is attributed to neural development of the hippocampus and prefrontal cortex (Chiu, Schmithorst, Brown, Holland, & Dunn, 2006; Ghetti & Bulge, 2012). The improvement in the use of encoding strategies, such as rehearsal techniques and organization vastly, occurs in the middle childhood (Chiu et al., 2006; Hulme,

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Thomson, Muir, & Lawrence, 1984). The children's ability to semantically organize information and their capability to successfully regulate memory traces lead to the strategy and, as a result, memory improvements (Ghetti & Alexander, 2004; Ornstein et al., 2006).

The implementation of the strategies to advance the memory capacity and the development of frontal areas during childhood make this period of life, critical and suitable for examining EM (Blankenship & Bell, 2015). Based on the Situational Word Co-occurrence theory, children naturally learn new words in an associative manner of co-occurrence probabilities. That is, for example, the word "duck" is learned and encoded by its co-occurrence probabilities as "water," "feather," "pond," etc. (Lancia, 2007). According to this theory, in natural context of learning a child gathers the statistical information about the new words relating to the co-occurred situation (Lancia, 2007, p. 1235). Similarly, the Spreading Activation Theory explains the activation of the stored words to be recalled based on the semantic network and Word Co-occurrence theories (Traxler & Gernsbacher, 2006).

Retention is the only way to measure memory performance and learning (Karlsgodt, Shirinyan, Van Erp, Cohen, & Cannon, 2005). Empirical studies indicate that cognition disorders of memory and language can be assessed at the level of the cerebral cortex (Daube & Rubin, 2009). Most studies in the field examined retention and maintenance load on the prefrontal lobe (Karlsgodt et al., 2005).

The prefrontal cortex, along with the frontal lobe, provides extensive cognitive networks that represent more straightforward besides more concrete knowledge and memory, short- and long-term (Fuster, 2008). Studies indicated that patients with frontal lesions have difficulties in free recall and recognition as well as language (e.g., Fuster, 2008; Janowsky, Shimamura, Kritchevsky, & Squire 1989; Shimamura, Janowsky, & Squire, 1991; Squire, 1986; Tulving, 1987).

The findings of an empirical study by Rouault and Koechlin (2018) asserted that the prefrontal cortex comprised inferential and hierarchical control processes and subserves sentence generation. Applying fMRI during artificial language acquisition, Opitz and Friederici (2003) showed the interaction between the hippocampus and the prefrontal regions and highlighted the importance of the prefrontal cortex in learning, memory, and language processing.

One of the most fundamental principles of human neurological functions is sensory processing (Williamson, 2011). While processing a stimulus, every sensory stimulus sends afferent signals to specialized brain regions, and then the nerve cell receptors on the particular region receive and decode the signal (Williamson, 2011). This idea indicated that the neocortex is a multisensory organ. A multisensory approach to teaching can be described as one that engages the maximum number of senses – seeing, speaking, hearing, and doing – to reinforce memory and recall, thus harnessing the full range of cognitive abilities of the learners.

Over decades, implementations of the integrative sensory approaches to learning and teaching indicated their effectiveness (Falzona, Callejab, & Muscatc, 2011; Fernald, 1943; Gillingham & Stillman, 1997). *Multisensory* teaching is an inclusive strategy that improves each learner's path through learning (Falzona et al., 2011). Sensory cues are the pathways to memory encoding and provide prior knowledge for long-term retention (Falzona et al., 2011). The sensory representation facilitates auditory, visual, and tactile association besides metacognition in language learning and paves the way for memory maintenance and retention (Falzona et al., 2011).

Young children can only sense and understand and, as a result, learn the materials that exist in their presence, so they prefer concrete objects with which they can explore. Lessons incorporating manipulatives produce greater achievements for students than those which do not use manipulatives (Falzona et al., 2011). The manipulatives provide the teachers with the situation of integrating multisensory learning into their elementary classrooms. Concurring to Reys (1971), manipulative materials are objects that can be felt, touched, and dealt with by learners (cited in Downpours et al, 2008). These are materials that concentrate on multiple senses and are characterized by the learners' physical associations. Chester et al. (1991) characterized manipulative materials as anything that a learner can move either physically or mentally to discover the solution to a problem (cited in Downpours et al., 2008). Sowell (1989) delineates two kinds of manipulatives: Concrete manipulatives and pictorial representations. The concrete/real ones are things that learners can work with without a mediator, whereas pictorial manipulatives can be any audiovisual presentations, e.g., pictures of objects in printed shapes (cited in Spicer, 2000).

Besides the manipulatives, the role of the teacher as a guide to mediate the process of teaching and learning is crucial to multisensory teaching (Rains, Kelly, & Durham, 2008). Most of the literature on elementary education concerning multisensory teaching incorporates manipulative materials to involve as many senses as possible (Rains et al., 2008).

In an experimental study, Beaucage, Skolney, Hewes, and Vongpaisal (2019) demonstrated that multisensory input in encoding of the stimulus properties caused greater cognitive control in 3-yearolds. Griva and Chostelidou (2013) fostered multisensory teaching (use of movement activities in a story-based context) in a bilingual context to improve foreign language components and skills. The intervention motivated the learners, attracted their interests, and captured their attention to learn FL in a relaxed and happy context. The project's formative and summative estimate revealed that the multisensory project was an exciting experience that influenced the bilingual vocabulary development and intercultural awareness of the children. Applying multisensory techniques to the two experimental groups of the third-grade learners with dictation problems, HassanNia, Najafi, and Rezaei (2017) tried to check their development in word dictation, and the results indicated improvements in the multisensory group. In an action research, D'Alesio, Scalia, and Zabel (2007) applied direct instructional approach of multisensory teaching, using graphic organizers, classical music, and Brain Gym exercises, at elementary level and concluded that this intervention improved the number of vocabulary that the students recognized, understood, and used over five times as many words.

Applying multisensory techniques in teaching vocabulary, language components, and skills in both native and non-native contexts indicated positive effects in favour of multisensory group than the other control or experimental groups (Beaucage et al., 2019; Biron et al., 2013; Newman, 2019; Werchan, Baumgartner, Lewkowicz, & Amso, 2018).

The trans membranes between neurons during neural improvement induce currents within and around the neurons, which can be recorded by electroencephalography (Blankenship & Bell, 2015). *Quantitative Electroencephalography* (QEEG) measures the spatial distribution of voltage fields and variation over time and is the most reliable and precise non-invasive laboratory technique for scrutinizing cortical functions. The best-known frequency bands are alpha (8–12 Hz), delta (0–4 Hz), theta (4-7 Hz), beta (12–30 Hz), and gamma (30–70 Hz) frequency bands (Hsu, Cheng, & Chiu 2017; Marcuse, Fields, & Yoo, 2016). Based on the best-known characteristics of the brain waves concerning the behaviors, beta, and beta 1 (sensory motor rhythm/SMR) wave frequencies might be changed as a result of learning and memory processes (Demos, 2005). SMR/beta1 waves are related to relaxed yet focused attention in learning, stillness, calm mental state, and intentional processing, beta waves are associated with thinking, focused and sustained attention and problem-solving activities (Demos, 2005; Guntekin et al., 2013; Wróbel, 2000).

Today, researchers increasingly recognize brain oscillations as useful tools to reveal substrate neuronal mechanisms involving memory formation. The increases or decreases of the brain oscillatory amplitude were accompanied with memory emergence (Daube & Rubin, 2009). According to Hanslmary and Staudigl (2013), brain oscillatory amplitude variations are associated with memory, encoding, and retrieval processes.

Brain regions involved in different functions as language and memory were typically recognized and scrutinized by Brodmann's cytoarchitecture of the brain. Brodmann's (1909) anatomical model of the brain was correlated to the points presented in the 10-20 system, an inclusive method of standardization of the brain cortices on the scalp. In this system, F stands for frontal, T for temporal, P for parietal, and O for occipital lobes. The odd numbers (F1, F3, …) indicate the left side and the even numbers (F2, F4, …), the right side of the brain (Marcuse et al., 2016).

The advent of neuroimaging using positron emission tomography (PET) and magnetic resonance imaging (MRI) indicated the localization of brain activation as asserted by Brodmann's brain map (Zilles & Amunts, 2010). The map presents the segregation of the cerebral cortex into 52 regions. Brodmann area number 10 (Anterior prefrontal cortex /most rostral part of superior and middle frontal gyri) is the closest match to the Fp1 and Fp2 brain areas, and Brodmann area number 09 (Dorsolateral prefrontal cortex) is closely matched with F3 and F4 regions of the brain (Garey, 1994). These areas were evaluated in different neuroimaging investigations to search for attention, perception, working memory, and language (Fuster, 2008; Zilles & Amunts, 2010). Brain activities from these areas are brain waves that are named based on their ranges and frequencies. Each type of brain wave represents some activities related to brain functions.

Lim, Yeo, and Yoon (2019) investigated the possibility of diagnosing two mental states of concentration and immersion using the electroencephalography to analyze the brain waves during cognitive tasks, representing these states. The comparing results from the thirty-two college students indicated a decrease in alpha waves but an increase in beta and beta1/SMR waves during concentration and immersion in the frontal and occipital lobes, with a higher increase in immersion.

Frontal beta rhythms, which came from F1, F3, F4 and Fps, were induced by a problem-solving task in an experiment by Kropotov (2009). The acquired data from EEG illustrated dependency of the frontal beta rhythms' increase to the difficulty of the task, indicating the correlation between beta wave frequencies and problem-solving activities.

The input goes through processes unseen to the researcher; the matter of what happens in the brain during learning is a secret. The ceaseless electrical activity in the brain is demonstrated by electrical recordings from the head (Guyton & Hall, 2006). The current study scrutinized the brain learning and retention processes at the collection of derivations for multiple channels recorded simultaneously from the surface of the brain cortex using QEEG. Using non-invasive neuroimaging techniques (EEG waves and brain maps) and seeking an interdisciplinary approach, the present study intended to compare the beta and beta1 QEEG data between the Multisensory and Non-multisensory teaching groups, we tried to objectively and empirically examine how these different methods had affected vocabulary retention.

As far as we searched, no study has been done to investigate the effect of multisensory teaching on foreign language vocabulary in the Iranian context, considering the brain wave changes. Regarding the gap in the literature, even though so many studies on retention (Calkins, 2007; Rothbart & Posner, 2005; Rueda, Posner, & Rothbart, 2004, cited in McClelland, Acock, Piccinin, Rhea, & Stallings, 2013; Hilton, Twomey, & Westermann, 2019) have been published in other fields of study, the literature search failed to yield any published research on this topic in the field concerning multisensory approach. Research in the field of language teaching/learning is restricted to some quantitative or specific qualitative peripheries to measure performance. Investigating the transient flow and sources of brain activity in healthy/normal human subjects to check the inside changes caused by the applied method is rare. The present study endured financial problems and sometimes, participants' unfamiliarity with the new instruments of measuring neural activities to benefit from neurological and psychological findings in choosing and presenting the materials of teaching.

Another distinguishing factor about the study is that in most of the studies in the field, using neuroimaging method, the process of data gathering happens during task performance (see Ghetti & Bulge, 2012; Hsu, Cheng, & Chiu, 2017; Young et al., 2017) while this study provided two QEEG records (pre- and post-records) to check the probable permanent or contemporary influence of the instruction on the brain waves and activities after the periods of instruction. Mcevoy, Smith, and Gevins (2000) believed that task-related EEG has high reliability for research, and can be used as part of clinical evaluation to measure improvements in cognitive function. In an investigation, they reported high reliability for EEG records after checking them through one-hour-after-task, 7day-after-task, and during the task in the test-retest reliability. Moreover, they concluded that EEG records benefited from high reliability and indicated consistency in results even after intervals in the resting states.

Considering the gap in the literature, the following hypotheses were formulated:

H1: Beta and beta1 (Sensory Motor Rhythm/SMR) wave frequencies on Fp1, Fp2, F3, and F4 increase at the QEEG post-records of the Multisensory and Non-multisensory groups in FL vocabulary retention.

H2: The preschool FL learners in Multisensory teaching group outperform their counterparts in the Non-multisensory instruction group on the EWP-post-test.

H3: There are positive correlations between beta, and SMR frequency changes on Fp1, Fp2, F3, and F4 in post-records and the standard scores on the EWP-post-test in the Multisensory and Non-multisensory groups.

Method

Participants

Sixteen healthy preschool foreign language learners (6 girls, and 10 boys, age range: 5 to 6 yrs, Mean age: 5.6 yrs) in Mashhad (Khorasan Province, Iran) volunteered to participate in this study (in summer 2019), and two girls were excluded from further analysis due to technical failures. Their mother tongue was Persian, and they were of the same English proficiency level (novice to language). The priority of studying children at young age, as compared with adults, is their neural plasticity property (Wong, Morgan-Short, Ettlinger, & Zheng, 2012).

The participants were randomly assigned into two experimental groups of multisensory and non-multisensory teaching methods groups-six boys and a girl (volunteers of a thirteen-person class) in the non-multisensory group and three girls and four boys (volunteers of an eleven-person class). The study was conducted in an unprivileged region in Mashhad, Iran. According to the data collected by means of the questionnaires, the participants had no experience in English- no English class attendance, and no travel to English language countries.

The participants' parents were asked to fill out a researcher-made questionnaire. The questionnaire gathered demographic data on the parents' English proficiency and educational level, the students' previous participation in foreign language classes, and their foreign travel to English language countries. The volunteered parents signed the questionnaire and expressed their agreements with their children's participation in the study.

Instruments

Teaching Materials

The materials for the study were new English words that existed in *Pockets 1* (Herrera & Hojel, 2009) that was the book taught in the institute as well as some selected vocabulary items. The selected situations of the book were "My classroom," "My clothes," "Our pets," "Party food," and "Nature around us." The vocabulary selection criteria were based on Cross Situational Word Co-occurrence (Lancia, 2007; Suanda, Mugwanya, & Namy, 2014; Vouloumanos & Werker, 2009; Yu & Smith, 2012), and Spreading Activation theories of words (Traxler & Gernsbacher, 2006).

Eighty new English words were taught (52 words existed in the textbook in the pictorial format and 28 items were the activated words on the related semantic networks. Since the textbook presented situations such as, "party food," "my classroom," or "our pets" to be taught, the 28 new words were selected based on the semantic networks of the related context. For example, in the "party food" section, the pictures of pizza, orange juice, lemonade, ice-cream, tomato, lettuce, sausage, French fries, apple, banana, grape, peach, plate, glass, birthday cake, balloon, and snack were presented in the textbook, and the context-related words such as dance, sweet, sour, salty, chocolate cake, cream, candle, gift, cucumber, coca, and tea which were not materialized were presented as the concrete manipulatives of the similar semantic network. Besides the book pictures, concrete manipulatives were used in the classroom. As defined in the previous sections, concrete manipulatives are real materials that learners can work with them without an intermediary, while pictorial manipulatives can be any audiovisual presentations, e.g., pictures of objects in printed forms (Sowell, 1989, cited in Spicer, 2000).

Expressive One-word Picture Matching Test (EWPMT)

The study assigned pre-test and post-test design to investigate the effect of the treatments/instructions empirically and to compare the results of QEEG records with the students' English language scores on the pre- and post-tests. A language test including a 40-item multiple-choice expressive word picture matching test was constructed and administered based on the selected vocabulary items to be taught to meet the retention goal of the study.

The Expressive One-word Picture Matching Test (EWPT) was formulated in accordance with the Expressive One-word Picture Vocabulary Test (Martin & Brownell, 2011). The test assesses the child's English-speaking vocabulary and is suitable for children 2 to 18 years old, and depending on the age the level will be changed. It needs 20 minutes to be administered, and it provides the researcher with the standardized score, percentile rank, and age equivalent score.

The EWPT in the study (Cronbach's alpha =0.74) included 40 items to be circled by the participants after the teacher's articulation (Figure 1)

EWPMT

Draw an X on the right picture

36.Sheep

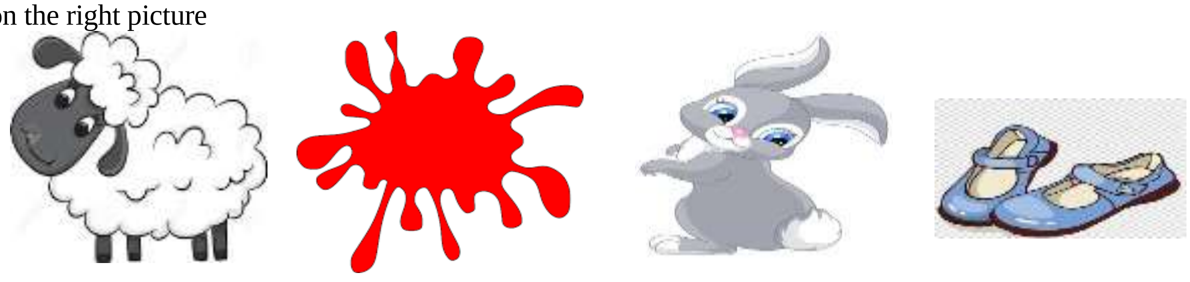


Figure 1.

One item of EWPT, the Teacher/Researcher Reads the Word in the Left Column and the Students Draw an X on the Picture of the Presented Word

Instruments (QEEG Records)

The evaluation instrument was Quantitative Electroencephalography (QEEG). The QEEG device used in this study was Russian Mitsar-EEG- 201 device (FDA 510K K143233) equipped with 21 Channels. The EEG sampling rate was 500Hz. Impedances were greater than 200 MOhms, and the level of electromagnetic contamination was kept below one-third of the total signal energy. It enabled us to measure the brain activity over time using an elastic cap with 21 electrodes placed on the scalp. The electrodes are connected to the recording device and can reflect thousands of simultaneously ongoing brain processes according to the international 10–20 system located at brain regions (Lubar, 2004).

The electrodes placed on Fp1, Fp2, F3, and F4 brain regions can report EEG data more typical of prefrontal and some frontal areas (Marcuse et al., 2016). In this study in accordance with almost all recent research (Angelidis, Hagenaars, Son, Does, & Putman, 2018; Carvalho et al., 2015; Gongora et al., 2016; Guyton & Hall, 2006; Her et al., 2019; Llamas-Alonso et al., 2019; Son et al., 2019), the beta and SMR/beta1 absolute power frequencies from Fp1, Fp2, F3 and F4 areas were investigated. Pre-school children were also talked with to know the device and not to get stressed, since it might influence their brain waves.

Procedure

The study included 20 sessions and each session took one hour. The attention span, the amount of real-time on a task, is around 20 minutes for adults and between 10 to 15 minutes for preschool children (Mc Clelland et al., 2013). Based on the ideas asserted by the scholars and the experiences of the preschool teachers about the attention span at the preschool ages, three to four new vocabulary items were presented each session.

Before starting the instruction session, the participants took EWPMT as the pre-test and their brain waves and maps were recorded as a pre-record. Each QEEG brain record took 10 minutes (5 minutes eyes opened/EO and 5 minutes eyes closed/EC), and the data were artifacted to approximately 2.22 to 2.30 minutes artifact-free data.

Using flashcards and colorful pictures of the *Pockets 1* book, we presented the selected vocabulary to the learners of the Non-multisensory group. The teacher (one of the researchers) pronounced every new word and presented its picture using the flashcard, then she applied a look-and-say approach to learning; that is, she asked the students to look at the pictures in the book and say their names. Sometimes they were asked to come to the board and draw the picture of the word pronounced by the teacher. The students sang, repeated, imitated, and pointed out the new vocabulary items. They did their assignments in their workbook as well. Every five sessions, a quiz in the matching format was taken. At the beginning of each session, the teacher asked about the previously taught vocabulary items, and the students repeated them.

However, teaching in the multisensory group was a demanding job. In addition to the pictures of the book and the related flashcards, the concrete manipulatives were used as essential materials in the Multisensory class. Multisensory teaching involves all senses as auditory, visual, tactile, kinesthetic, and vestibular (sense of balance). The researcher/teacher had to bring realia (such as food, chocolates, wool, silk, leather) as concrete manipulatives to the classroom, and to play with the learners all the time to meet the balance and kinesthetic goals. For some abstract words, they were asked to repeat each syllable of the word by singing, tapping on the desk, and stomping their feet. They were requested to play the role of the word presented feelings or to make manually-some hands-on-activities- the vocabulary items related to the places (such as “farm”), using the realia like wood, grass and leaves.

After the 20-session treatment, a post-test and a post-brain record were taken from both multisensory and non-multisensory groups to check the effectiveness (if any) of each method separately and to compare the results.

Data Analysis

To check the homogeneity of the sample, the scores of the 14 participants in the pre-test (EWPT) were compared applying One-way ANOVA. The scores on the pre-tests and the post-tests (EWPT) were then put into Statistical packages for social sciences (SPSS version 25) to be analyzed. Applying Paired sample t-test, the absolute power of beta, and beta1 from frontal areas (Fp1, Fp2, F3, and F4) were compared in two groups of Multisensory and Non-multisensory separately to check the probable effect of the treatments (here teaching methods). Kolmogorov Smirnov's non-parametric test was assigned to the mean scores of the two experimental groups' post-test to measure the effectiveness of the applying methods.

The color-coded brain maps were then analyzed and compared. The case study of the results on the topographic interpretation of each learner’s before-treatment brain map and first brain wave record in comparison to his/her after-treatment and final brain map and wave results provided scrutinized data.

Findings

The results of One-way ANOVA (p-value=0.8) on EWP-pre-test showed that there was not any significant difference between the experimental groups in their English proficiency level. The descriptive statistical indices of the absolute power frequency ranges of beta and SMR in the fourteen FL participants’ brain records were analyzed (Table 1).

Table 1.
Descriptive Statistical Indices of Beta and SMR Wave Frequency Rates in Multisensory and Non-Multisensory Groups

Variable		Multisensory				Non-multisensory			
		Pre-record		Post-record		Pre-record		Post-record	
		mean	SD	mean	SD	mean	SD	mean	SD
Beta	FP1	10.33	3.32	10.30	1.35	10.88	2.39	12.10	3.57
	FP2	9.19	2.55	9.72	1.95	11.22	2.44	11.29	3.26
	F3	12.85	2.23	12.87	1.84	13.28	1.92	14.69	6.29
	F4	12.99	2.62	14.01	2.45	13.39	2.38	14.59	5.39
SMR	FP1	4.61	1.70	4.10	0.74	4.28	0.86	4.44	1.07
	FP2	4.29	1.44	4.12	1.05	4.35	0.89	4.29	1.12
	F3	6.13	1.73	5.53	1.05	5.52	0.90	5.77	1.55
	F4	6.05	1.66	5.88	1.23	5.47	1.02	5.71	1.27

Hypothesis 1

The application of Kolmogorov/Smirnov non-parametric test on the mean absolute power of beta and beta1 (SMR) frequency ranges on Fp1, Fp2, F3, and F4 indicated the normality of the data in the experimental groups (Table 2).

Table 2.
Statistical Indices of Kolmogorov/Smirnov Test to Investigate the Normality of the Distribution of Beta and Beta1/SMR Waves Frequency Rates in both Multisensory and Non-Multisensory Groups

Variable		Multisensory				Non-multisensory			
		Pre-record		Post-record		Pre-record		Post-record	
		Z	Sig	Z	Sig	Z	Sig	Z	Sig
Beta	FP1	0.92	0.55	0.79	0.64	0.85	0.60	0.97	0.45
	FP2	0.97	0.47	0.73	0.68	0.94	0.52	0.98	0.40
	F3	0.99	0.40	1.00	0.33	0.46	0.84	0.99	0.54
	F4	0.99	0.36	0.93	0.54	0.55	0.79	0.93	0.60
SMR	FP1	0.70	0.70	0.49	0.83	0.95	0.51	0.49	0.83
	FP2	0.75	0.67	0.55	0.79	0.98	0.44	0.96	0.49
	F3	0.89	0.57	0.66	0.72	0.86	0.60	0.44	0.86
	F4	0.99	0.38	0.92	0.54	0.90	0.57	0.84	0.61

Paired sample t-test was run to the mean absolute power of beta and beta1 (SMR) frequency ranges on Fp1, Fp2, F3, and F4 brain areas of the seven participants in each Multisensory and Non-multisensory groups and the outcomes indicated no significant difference (Table 3).

Table 3.
Paired Sample t-test Related to Comparison of the Pre- and Post- QEEG Records in Multisensory and Non-Multisensory Groups

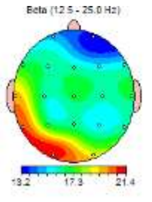
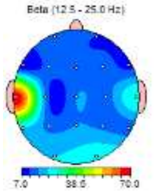
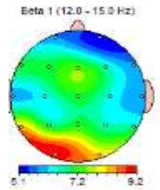
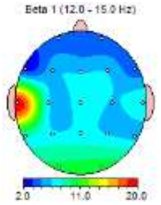
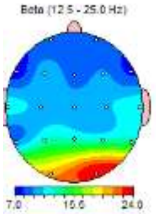
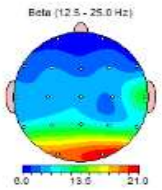
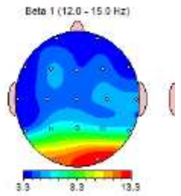
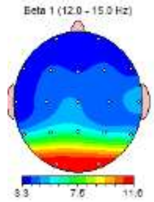
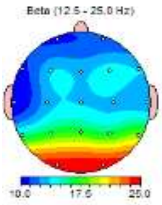
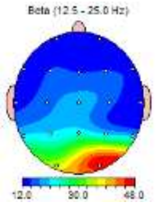
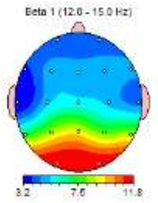
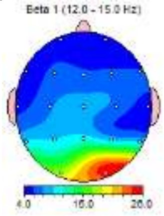
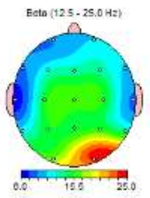
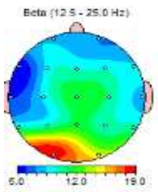
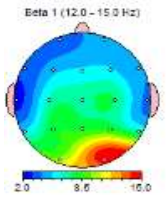
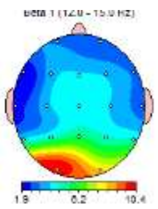
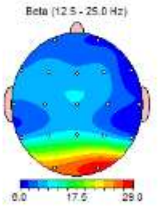
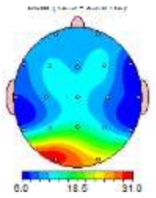
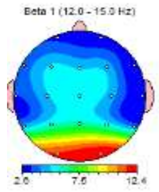
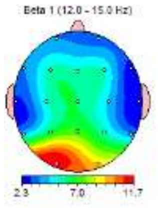
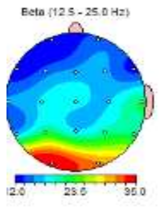
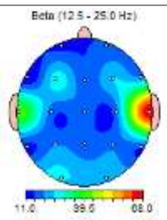
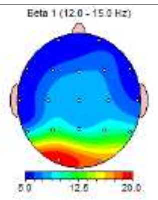
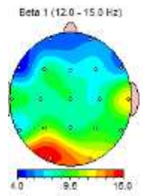
Variable		Multisensory			Non-multisensory		
		t	**df**	**Sig**	**t**	**df**	**Sig**
Beta	FP1	0.02	6	0.98	-1.66	6	0.14
	FP2	-0.46	6	0.66	-0.75	6	0.94
	F3	-0.04	6	0.96	-0.69	6	0.51
	F4	-1.41	6	0.20	-0.81	6	0.44

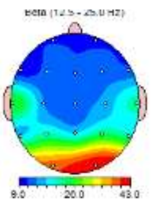
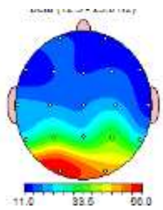
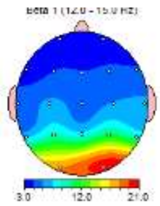
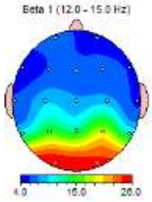
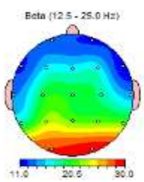
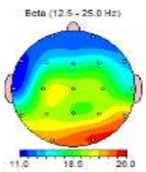
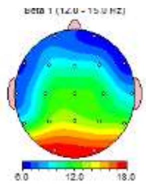
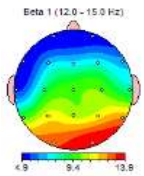
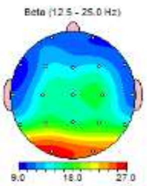
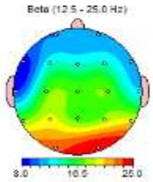
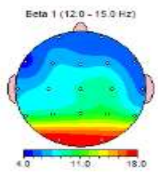
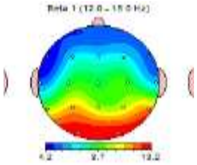
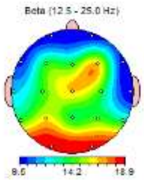
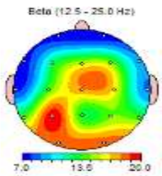
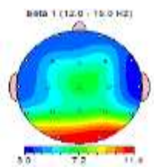
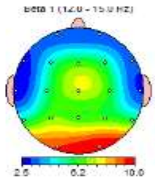
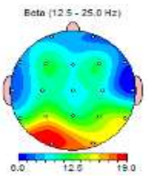
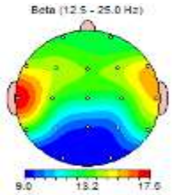
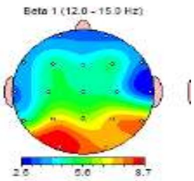
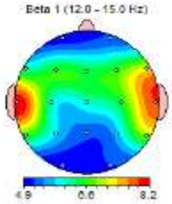
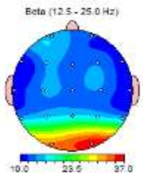
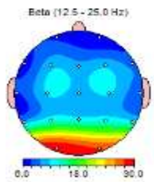
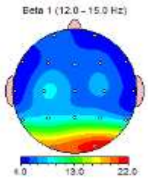
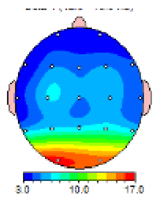
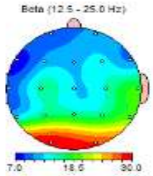
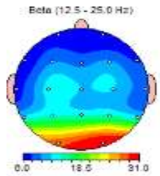
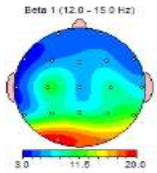
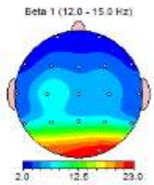
Variable		Multisensory			Non-multisensory		
		t	df	Sig	t	df	Sig
Beta1	FP1	0.85	6	0.42	-0.31	6	0.76
	FP2	0.30	6	0.77	0.16	6	0.87
	F3	1.46	6	0.19	-0.49	6	0.63
	F4	0.44	6	0.67	-0.58	6	0.57

Though the increases in the wave frequencies of beta (in both Multisensory and Non-multisensory groups) and decreases in beta1 (SMR) frequencies were observed at individual post-records in comparison to the pre-records, the differences were not statistically significant (Figure 2).

Figure 2.
Frequency Band Ranges of Beta and Beta1 Mean Absolute Powers on Fp1, Fp2, F3,and F4 at QEEG Pre- and Post-Records of the Multisensory and Non-Multisensory Groups

Based on the statistical analyses, the first hypothesis was disconfirmed. That is, the interventions (Multisensory and Non-multisensory teaching) did not increase beta and beta1 (SMR) wave frequencies on frontal and prefrontal areas of the brain in FL vocabulary retention. The analyses on brain maps indicated changes in brain activity before and after instruction, which were not statistically significant (Figure 3).

	Non-multisensory Beta Pre-record	Post-record	Beta1 Pre-record	Post-record
Participant 1				
Participant 2				
Participant 3				
Participant 4				
Participant 5				
Participant 6				

	Non-multisensory Beta Pre-record	Post-record	Beta1 Pre-record	Post-record
Participant 7				
	Multisensory **Beta** **Pre-record**	**Post-record**	**Beta1** **Pre-record**	**Post-record**
Participant 1				
Participant 2				
Participant 3				
Participant 4				
Participant 5				
Participant 6				

	Non-multisensory Beta Pre-record	Post-record	Beta1 Pre-record	Post-record
Participant 7				

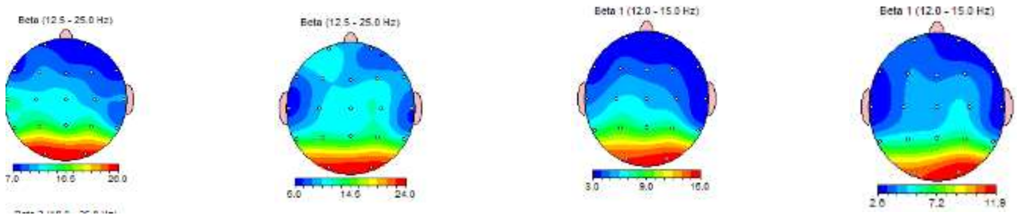


Figure 3.
QEEG Brain Maps Related to Beta and Beta1 Waves Record before and after 20 Sessions of Instruction (Multisensory and Non-Multisensory Teaching) -(Green - Normal Red = Excessive Blue = Diminished Activity)

Hypothesis 2

The results of Kolmogorov Smirnov's non-parametric test on the mean scores of the post-test indicated the normality of the data and the homogeneity of the variances (Table 4).

Table 4.
Statistical Indices of Kolmogorov Smirnov's Test to Investigate the Normality of the Distribution of Mean Scores in Post-Tests Multisensory and Non-Multisensory Groups

groups	Kalmograph / Smirnov test		Levene᾽s Test for Equality of Variance	
	Z	sig	F	sig
Multisensory	0.54	0.93	2.92	**0.11**
Non-multisensory	1.12	0.15		

Independent sample t-test was assigned to the mean scores of the post-tests (EWPT) of the seven preschool FL learners in both experimental groups (Multisensory and Non-multisensory groups), and the results indicated that there was a significant difference ($p<0.05$) between the mean scores, that is, Multisensory group outperformed Non-multisensory group in post-test (Table 5).

Table 5.
Independent Samples t-test Related to the Post-Tests of the Multisensory and Non-Multisensory Groups

Groups		N	M	Mean differences	SD	t	df	Sig
Multisensory	Pre_test	7	5.28	31.85	3.97	4.68	12	0.00
	Post_test		37.14					
Non-multisensory	Pre_test	7	5.28	19.71	5.58			
	Post_test		25.00					

The comparison between pre- and post-tests in both Multisensory and Non-multisensory groups are presented in Figure 4.

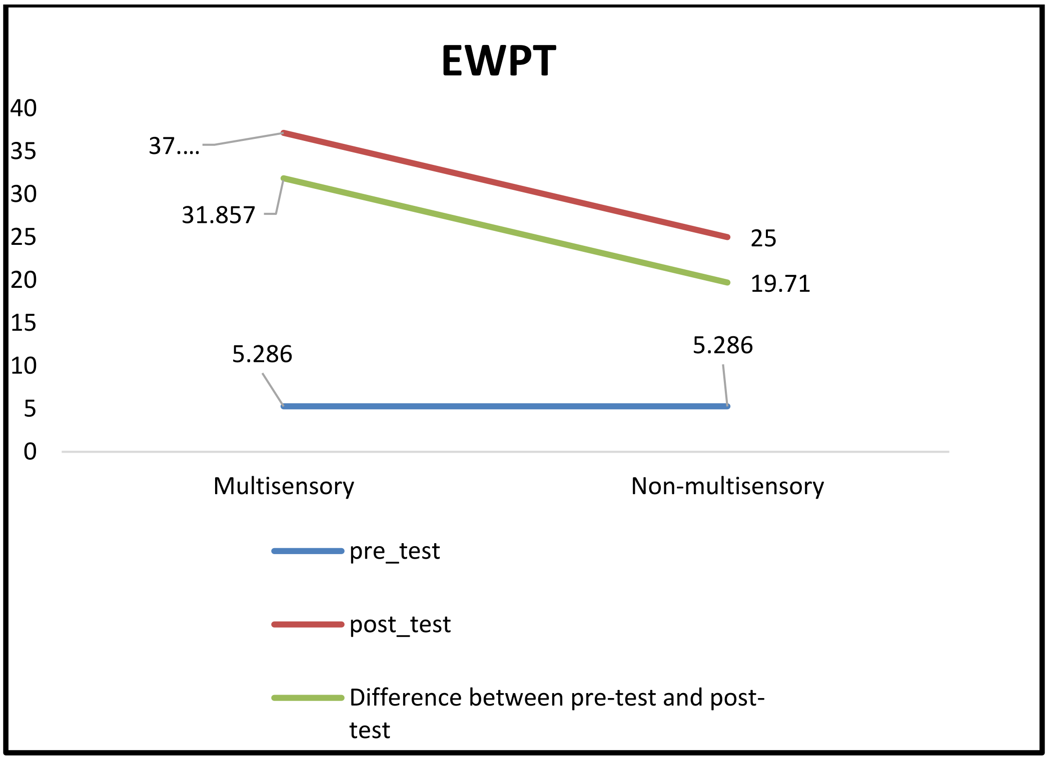


Figure 4.
Comparison of the Mean Scores on Pre-Tests and Post-Tests in the Multisensory and Non-Multisensory Groups

Hypothesis 3

Pearson Correlation Coefficient test showed that there was a significant positive relationship ($p<0.05$) between beta wave frequency changes on Fp1 and mean score of EWP post-test in the Multisensory group (Table 6.). In other words, the more the beta wave frequency increased in the Fp1 region of the brain, the more the scores on the EWPT were.

However, there were no significant correlations between beta wave frequency changes on Fp2, F3, and F4 regions and beta1 (SMR) frequency changes on Fp1, Fp2, F3, and F4 regions and EWP post-test mean scores in both Multisensory and Non-multisensory groups (Table 6).

Table 6.
Statistical Indices of Pearson Correlation Coefficient Test to Investigate the Relationship between Beta and Beta 1 Frequencies and EWPT Mean Scores

Variable		**Multisensorty**		**Non-multisensory**	
		r	**sig**	**r**	**sig**
Beta	Fp1	0.76	0.04	0.63	0.12
	Fp2	0.54	0.09	0.30	0.51
	F3	0.54	0.20	0.40	0.37
	F4	0.35	0.43	0.48	0.27
Beta1	Fp1	0.37	0.40	0.03	0.93
	Fp2	0.46	0.29	0.23	0.61
	F3	0.20	0.65	0.40	0.36
	F4	0.33	0.46	0.42	0.34

The Q-Q plot related to the Multisensory group's beta wave frequencies in the post-records indicated the normality of the distributed data (Figure 5).

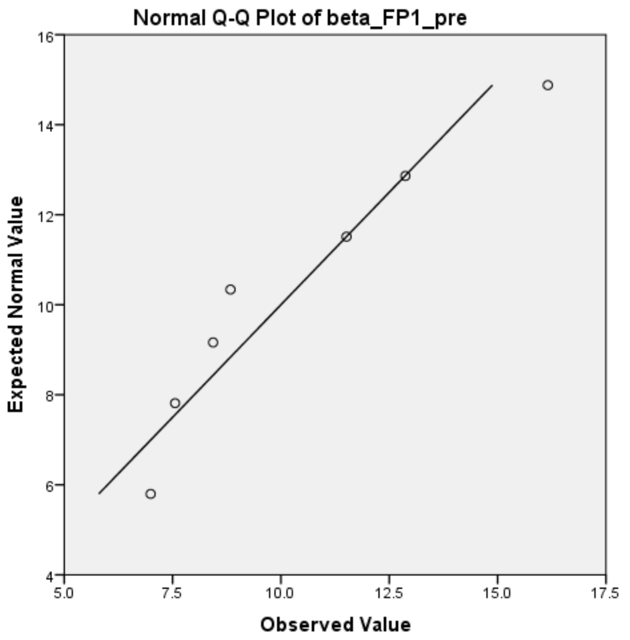


Figure 5.

The Normality of the Distributed Data of Beta Wave Frequencies Related to the Multisensory Group

Low-Resolution Brain Electromagnetic Tomography (LORETA) Interpretation

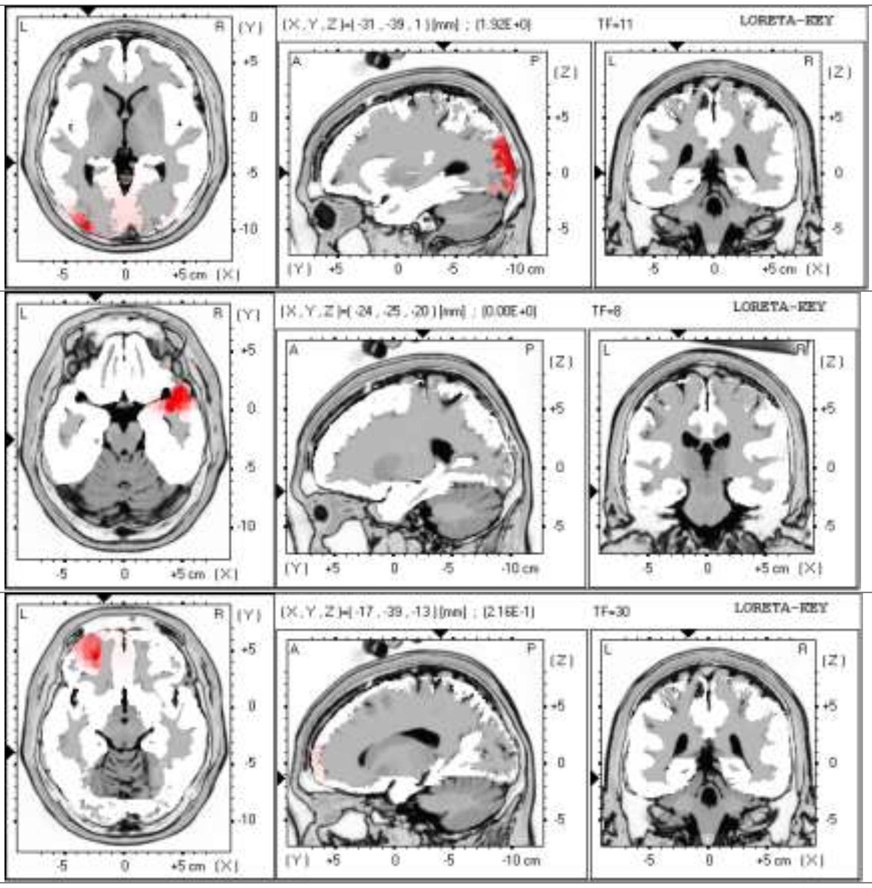
LORETA allows viewing of 3-dimensional electrical current sources in the brain. Time series of cortical electric neuronal activity and cortical connectivity are estimated by LORETA. It illustrates the localization and density images of brain wave activities. The EEG activities of the two groups of the participants and their 3-dimensional source distribution were computed voxel-by-voxel.

The LORETA on the groups' post-records was used to describe where the cortical representation on reflection of voltage was in the cortex. The analyses revealed the localizations on the parahippocampal, hippocampus, and cingulate gyrus for five participants in the Multisensory group, besides lingual gyrus and parietal lobe for two other participants (Figure 6).

Participant 1

Participant 2

Participant 3



Participant 4

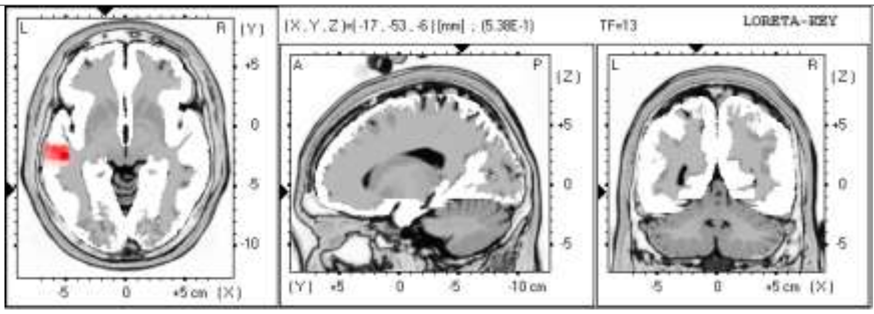


Figure 6.
LORETA Tomogram Showing Increased Activity Signals Localized to the Parahippocampal and Hippocampus Regions in the Multisensory Group

The LORETA results indicated the localization of signals in the areas number 35, 36, 19, 40, 18, 23, and hippocampus for the first best match in the Multisensory group's post-records (Table 7).

Table 7.
LORETA Representations of the Multisensory Group

	The first best match LORETA	Brodmann's area name	Brain Lobe	Z score
Participant 1	----------	Hippocampus	Limbic	1
Participant 2	Area no.35	Parahippocampal	Limbic-Temporal	-20
Participant 3	Area no.36	Parahippocampal	Limbic-Temporal	-13
Participant 4	Area no. 19	Parahippocampal	Limbic-Temporal	-6
Participant 5	Area no.40	Inferior parietal	Parietal	43
Participant 6	Area no.18	Lingual gyrus	Occipital&Temporal	-13
Participant 7	Area no.23	Cingulate gyrus	Limbic-Temporal	29

Discussion and Conclusion

The statistical analyses related to the EWPMT indicated the promising impact of multisensory teaching on FL vocabulary retention at preschool level. On the contrary, the empirical findings of QEEG records showed different results.

The first hypothesis of the study examined the effect of teaching on beta and beta1 waves frequencies on Fp1, Fp2, F3, and F4 in both multisensory and non-multisensory teaching groups. Contrary to earlier findings (such as Budzynski, Budzynski, Evans, & Abarbanel, 2009; Guyton & Hall, 2006; Marcuse et al., 2016), no significant differences were revealed between beta and beta1 frequency changes on pre- and post-records in both experimental groups. This apparent lack of correlation can be attributed to the small number of participants in the study since the data on case study revealed that individuals' beta wave frequencies increased on post-records in comparison to pre-records.

The most surprising result to emerge from the data was presented in Figure 1 and is related to beta1/SMR wave frequency changes in post-records of the Multisensory group's participants. The SMR wave absolute power frequencies decreased at QEEG post-records. Though beta waves frequencies are associated with focused attention, there are many hypothetical functions as prevention of motor planning and movement suggested for the beta1 rhythm (Kropotov, 2016). Inhibition of motor movement and calmness is associated with an increase in beta1 rhythm while as revealed by Gruzelie (2014) it can be due to tiredness as a result of beta1 elevation in neurofeedback training sessions.

This inexplicable result, decrease in beta1/SMR rhythms in the Multisensory groups' post-records, might be due to the positive excitement received after the full-of-activities multisensory sessions, which demanded active participation of the subjects. Another conclusion which can be made based on this decrease in the beta 1 rhythm is the time of the post-records. In almost all of the studies using neuroimaging method, the process of data gathering has been during task performance (Such as Ghetti & Bulge, 2012; Hsu, Cheng, & Chiu, 2017; Young et al., 2017) while in the present study there was a post-record after treatment.

The second hypothesis of the study examined the effectiveness of multisensory instruction in comparison to non-multisensory teaching on FL vocabulary retention. The significant results indicated that the preschool FL learners in Multisensory teaching group outperformed their counterparts in the Non-multisensory instruction group on the EWP-post-test.

Our findings appear to be well supported by Falzon, Calleja and Muscat (2011) who believed in the young children's multisensory learning preference and the promising role of manipulatives in learning new materials; besides, Griva and Chostelidou (2013) asserted the motivational effect of multisensory teaching in bilingual classes.

Our experiment is consistent with previous results (Newman, 2019; Rains et al., 2008; Spicer, 2000) which concluded that multisensory techniques should be incorporated into teaching mainstream especially in the elementary and kindergarten through third grade to enhance learning

The participants in the Non-multisensory group during the EWP-post-test exclusively circled the answer (the pictures in the test after teacher's articulation) either correct or wrong, but the Multisensory group's participants could name more related words during the post-test. For example, for the articulated word "dress" they remembered the other related vocabulary items (as, "shoes", "skirt", "trousers", "hat", …). Unexpectedly, some were able to remember even the co-occurrence probabilities (such as, "party food", "cloth store", "red skirt", "dark blue", …). This quantitative result concurs well with previous findings by Lancia (2007) and Traxler and Gernsbacher (2006) on Spreading Activation and Word Co-occurrence theories indicating the retention of the co-occurred words in the natural context.

The third hypothesis examined the probable positive correlations between beta, and SMR frequency changes on Fp1, Fp2, F3, and F4 in post-records and the standard scores on the EWP-post-test in the Multisensory and Non-multisensory groups. Regarding this hypothesis, the results indicated a significant positive relationship between beta wave frequency changes on Fp1 and mean score of EWP post-test in the Multisensory group.

Coordination among multiple representations in the cortex is another function attributed to beta waves besides focused attention (Kropotov, 2016). The multisensory approach presented multiple information through sensory organs for a new word (Fernald, 1943; Gillingham & Stillman, 1997) which might be coordinated by the beta wave in the frontal areas of the brain in this study.

The prefrontal cortex, including Fp1, Fp2, and Fz is associated with executive functioning, planning and making decisions, and working memory (Gage & Baars, 2010). Brodmann area number 10 (Anterior prefrontal cortex /most rostral part of superior and middle frontal gyri) in the left hemisphere is the closest match to the Fp1 brain area.

There are bidirectional connections between the prefrontal cortex and many subcortical regions (as posterior association cortex, Hippocampus, Amygdala, Thalamus, etc.). Fp1 region is associated with verbal retrieval, visual working memory, as well as verbal analytical and approach behaviors (Gage & Baars, 2010). Attention (which is a representative of the existence of beta rhythm) is an executive function which defines as the ability to focus neural sources on the processing of one piece of information and the exclusion of all others (Fuster, 2008). Executive functions temporally organize purposive behavior, language, and reasoning (Fuster, 2008). The prefrontal damage will cause distractibility in working memory that is sustained attention to internal representation (Fuster, 2008). As its lesion causes indicate, the prefrontal cortex is responsible for the executive memory network.

In line with Lundqvist et al. (2016), our study found that the beta rhythm controls the information held in memory and allows it to influence behavior such as language. The result of our study is consistent with Schmidt et al. (2019) who observed beta oscillations in a plethora of brain recording studies and reported the role of beta rhythm in prefrontal regions (when it increases) as the delay period of working memory tasks that can serve to maintain the current contents and/or to prevent interference from distraction. Therefore, the positive relationship between Fp1 beta wave and the Multisensory participants' scores on the post-test might reveal the effectiveness of the Multisensory method in retrieval.

The LORETA in post-records revealed the localizations of signals (oscillatory activities) on the parahippocampal, hippocampus, and cingulate gyrus for five participants in the Multisensory group, besides lingual gyrus and parietal lobe for two other participants.

Temporal lobe in the left hemisphere of the brain is recognized to include Wernick's area and responsible for verbal and reading comprehension, visual perception of what an object is, consolidation and realization of auditory input, comprehension of auditory and visual perception (reading and word recognition), linguistic perception and comprehension as well as long term memory (Gage & Baars, 2010). Our findings fit well with the previous evidence pointed to the involvement of the temporal region in long-term memory retrieval. That is the multisensory method of teaching enhanced performance (retention) in the participants' post-test and activated their temporal lobe, which is associated with long-term memory.

Cingulate gyrus, along with parahippocampal are parts of the limbic system which together creates Broca's area (Guyton & Hall, 2006). Broca's area is located in the left inferior frontal lobe and continues to join Wernick's area in the left hemisphere in the temporal lobe by a fibre bundle.

The results on LORETA are strongly supported by Barense's, Henson's, and Graham's (2011) findings. They indicated that lesions in medial temporal lobe would cause impairment in perception as well as long-term memory. Evaluating memory and language in patients with interictal problem (a kind of epilepsy disorder), Mayeux, Brandt, Rosen, and Benson (1980) found that impairment in temporal lobe might be an anomia which can contribute to impairment in verbal learning and memory. These findings indicated the effectiveness of temporal lobe activities in learning and retention. The localization of activities in the parahippocampal and lingual gyrus in this study indicated the involvement of Broca's area and reflected the probable permanent promising effect of multisensory teaching in learning and production of new language vocabulary items.

The first best match for the LORETA key in the Non-multisensory group’s post-records indicated increased activity signals localized to different areas of the cortex: supramarginal gyrus (parietal lobe), lingual gyrus (occipital lobe), fusiform gyrus (occipital lobe), middle frontal gyrus (frontal lobe), and two records of parahippocampal gyrus (limbic lobe).

To sum up, our work applied the noninvasive neuroimaging technique of QEEG to reveal the probable changes in beta and beta1/SMR wave frequencies of pre-school children as a result of multisensory teaching in FL new vocabulary items retention. In this study, two volunteered groups of pre-school participants were assigned into two teaching groups: Multisensory and Non-multisensory groups. Applying pre- and post-test design, the participants' performance on EWPT was analyzed, and the results were compared to the QEEG data pre- and post-records. The scrutinized results showed the effectiveness of multisensory teaching in FL vocabulary retention in these specific groups of participants. They indicated the significant relationship between beta wave activity (increase) in the Fp1 brain region and the students' scores on EWP-post-test. The case study analyses of tomography interpretation illustrated localization of brain activity in temporal lobe for 5 participants in the Multisensory group's post-records indicating the promising effect of multisensory techniques in memory and retention in this specific group of participants.

These findings have several implications. First they can be applied to enhance the FL educators' and researchers' understanding of underlying brain activities and provide insights to examine scientifically new interdisciplinary approaches (such as multisensory approach) to language teaching and learning. Second, the results might have implications for psycholinguists and neuro-linguists to propose an interdisciplinary approach and to evaluate the areas involved in the FL learning process, exposing to teaching methodological variations. Besides, they might be helpful for language teachers to become familiar with the scientific techniques of the methodological evaluation and with more effective methods of FL teaching.

Our work, though an innovative method in investigating the performance in FL retention, has some limitations such as the small number of participants. Therefore, it might not meet the external validity and generalization purposes. The small sample size was due to the participants' unfamiliarity with the brain recording sessions and the heavy cost of QEEG records.

Although studies on animals and patients have illustrated that brain oscillations play a part in memory and retention, little has been done to examine the sources of brain activity in healthy/normal human subjects. Further empirical investigations are needed to estimate the effect of different FL teaching methods on brain oscillatory changes during or after doing tasks of memory enhancement. More experimental studies with a larger number or further case studies using neuroimaging techniques should be done in the field of language teaching to enhance FL teaching and learning.

Conflict of interest

The authors declare that there are no conflicts of interest.

References

Angelidis, A., Hagenaars, M., Son, D. V., Does, W., & Putman, P. (2018). Do not look away! Spontaneous frontal EEG theta/beta ratio as a marker for cognitive control over attention to mild and high threat. *Biological Psychology, 135*, 8-17.

Barense, M. D., Henson, R. N. A., & Graham, K. S. (2011). Perception and conception: Temporal lobe activity during complex discriminations of familiar and novel faces and objects. *Journal of Cognitive Neuroscience, 23* (10), 3052-3067.

Beaucage, N., Skolney, S., Hewes, J., & Vongpaisal, T. (2019). Multisensory stimuli enhance 3-year-old children’s executive function: A three-dimensional object version of the standard Dimensional Change Card Sort. *Journal of Experimental Child Psychology, 189*, 1-13.

Biron, V. L., Harris, M., Kurien, G., Campbell, Ch., Lemelin, P., Livy, D., Côté, D. W. J., Ansari, Kh. (2013). Teaching cricothyrotomy: A multisensory surgical education approach for final-year medical students. *Journal of Surgical Education, 70* (2), 248-253.

Blankenship, T. L., & Bell, T. A. (2015). Frontotemporal coherence and executive functions contribute to episodic memory during middle childhood. *Dev Neuropsychol, 40* (7-8), 430–444.

Budzynski, Th. H., Budzynski, H. K., Evans, J. R., & Abarbanel, A. (2009). *Introduction to quantitative EEG and neurofeedback: Advanced theory and application*. USA: Elsevier Inc.

Carvalho, M. R., Velasques, B. B., Freire, R. C., Cagy, M., Marques, J. B., Teixeira, S., … & Ribeiro, P. (2015). Frontal cortex absolute beta power measurement in Panic Disorder with Agoraphobia patients. *Journal of Affective Disorders, 184*, 176-181.

Chiu C. P., Schmithorst V. J., Brown R. D., Holland S. K., & Dunn S. (2006). Making memories: A cross-sectional investigation of episodic memory encoding in childhood using FMRI. *Developmental Neuropsycholgy, 29*, 321–340.

D'Alesio, R., Scalia, M., & Zabel, R. (2007). *Improving vocabulary acquisition with multisensory instruction*. Master Thesis, Saint Xavier University, Chicago, USA.

Daloglu, A., Baturay, M., & Yildirim, S. (2009). Designing a constructivist vocabulary learning material. In R. de Cássia Veiga Marriott and P.Lupion Torres (Eds.), *Handbook of research on E-learning methodologies for language acquisition* (pp. 186-203). Hershey, PA: Information Science.

Daube, J. R., & Rubin, D. I. (Eds.). (2009). *Clinical neurophysiology* (3rd ed.). Oxford, England: Oxford University Press.

Demos, J. N. (2005). *Getting started with neurofeedback*. London: Norton & Company, Inc.

Dickerson, B. C., & Eichenbaum, H. (2010). The episodic memory system: Neurocircuitry and disorders. *Neuropsychopharmacology, 35*, 86–104.

Falzona, H., Callejab, C., & Muscatc, C. (2011). Structured multisensory techniques in reading and learning patterns: Some considerations. *UT. Revista de Ciències de l'Educació*, 51-71.

Fernald, G. (1943). *Remedial techniques in basic school subjects*. New York: McGraw-Hill Book Co., Inc.

Fuster, J. M. (Ed.). (2008). *The prefrontal cortex* (4th ed.). London: Academic Press, Elsevier.

Gage, N. M., & Baars, B. J. (2010). *Cognition, brain and consciousness: Introduction to cognitive neuroscience*. London: Academic Press, Elsevier.

Garey, L. J. (Ed.). (1994). *Brodmann's localization in the cerebral cortex* (3rd ed.). UK, London: Smith-Gordon Company Limited.

Ghetti S., & Alexander K. W. (2004). "If it happened, I would remember it": Strategic use od event memorability in the rejection of false autobiographical events. *Child Development,75*, 542–561.

Ghetti S., & Bulge S. A. (2012). Neural changes underlying the development of episodic memory during middle childhood. *Developmental Cognitive Neuroscience, 2*, 381–395.

Gillingham, A., & Stillman, B.W. (1997). *The Gillingham manual: Remedial training for students with specific disability in reading, spelling and penmanship*. (8th Ed.). Cambridge: MA Educators Publishing Service.

Gongora, M., Bittencourt, J., Teixeira, S., Basile, L. F., Pompeu, F., Droguette, E. L., …& Ribeiro, P. (2016). Low-frequency rTMS over the Parieto–frontal network during a sensorimotor task: The role of absolute beta power in the sensorimotor integration. Neuroscience *Letters, 116*, 1-5.

Griva, E., & Chostelidou, D. (2013). Estimating the feasibility of a multisensory bilingual project in primary education. *Social and Behavioral Sciences, 116*, 1333-1337.

Gruzelie, J. H. (2014). Differential effects on mood of 12–15 (SMR) and 15–18 (beta1) Hz neurofeedback. *International Journal of Psychophysiology, 93* (1), 112-115.

Guyton, A. C., & Hall, J. E. (2006). *Textbook of medical physiology*. China: Elsevier, Suanders.

Hanslmary, S., & Staudigl, T. (2013). How brain oscillations form memories: A processing-based perspective on oscillatory subsequent memory effects. *NeuroImage, xxx*, 84C, 4-16.

HassanNia, A., Najafi, M., & Rezaei, A. (2016). The comparison the effectiveness of Fernald multi-sensory instruction method and application mnemonics devices in improving dictation problems elementary school third grade dictated disorder students. *Learning Disability, 5* (3), 122-144.

Her, S., Cha, K. S., Choi, J. W., Kim, H., Byun, J. I., woo, J-S. S., Kim, T.J., Lim, J.A., Jung, K. Y., & Kim, K. H. (2019). Impaired visuospatial attention revealed by theta- and beta-band cortical activities in idiopathic REM sleep behavior disorder patients. *Clinical Neurophysiology, 130* (10), 1962-1970.

Herrera, M., & Hojel, B. (2009). *Pockets 1*. China: Pearson Education, Inc.

Hilton, M., Twomey, K. E., & Westermann, G. (2019). Taking their eye off the ball: How shyness affects children's attention during word learning. *Journal of Experimental Child Psychology, 183*, 134-145.

Hulme, C., Thomson, N., Muir, C., & Lawrence, A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology, 38*, 241–253.

Hsu, Ch., Cheng, W., & Chiu, Sh. (2017). Analyze the beta waves of electroencephalogram signals from young musicians and non-musicians in major scale working memory task. *Neuroscience Letters, 640*, 42-46.

Janowsky, J. S., Shimamura, A. P., Kritchevsky, M., & Squire, L. R. (1989). Cognitive impairment following frontal lobe damage and its relevance to human amnesia. *Behav. Neurosci, 103*, 548 – 560.

Karlsgodt, K. H., Shirinyan, D., Van Erp, T. G., Cohen, M. S., & Cannon, T. D. (2005). Hippocampal activations during encoding and retrieval in a verbal working memory paradigm. *NeuroImage, 25*, 1224–1231.

Kropotov, J. D. (2009). *Quantitative EEG, event-related potentials and neurotherapy*. Massachusetts: Academic Press.

Kropotov, J. D. (2016). *Functional neuromarkers for psychiatry*. Massachusetts: Academic Press.

Lancia, F. (2007). Word co-occurrence and similarity in meaning. Retrieved March 14, 2019, from http://mytlab.com/wcsmeaning.pdf .

Lim, S., Yeo, M., & Yoon, G. (2019). Comparison between concentration and immersion based on EEG analysis. *Sensors (Basel)*, *19*(7), 1669.

Llamas-Alonso, J., Guevara M. A., Hernández-González, M., Hevia-Orozco, J. C., & Almanza-Sepúlveda, M. L. (2019). Action video game players require greater EEG coupling between prefrontal cortices to adequately perform a dual task. *Entertainment Computing*, *30*, 10-16.

Lubar, J. F. (2004). *Quantitative electroencephalographic analysis (QEEG) databases for neurotherapy description, validation and application*. USA: Taylor & Francis Group.

Lundqvist, M., Rose, J., Herman, P., Brincat, S. L., Buschman, T. J., & Miller, E. K. (2016). Gamma and beta bursts underlie working memory. *Neuron*, *90* (1), 152-164.

Marcuse, L. V., Fields, M. C., & Yoo, J. (2016). *Rowan's primer of EEG*. New York, USA: Elsevier.

Martin, N. A., & Brownell, R. (2011). *Expressive one-word picture vocabulary test-4 (EOWPVT-4).* USA, Novato: Academic Publication Therapy.

Mastine, L. (2010). The human memory. Retrieved September 12, 2019, from http://www.human-memory.net/types_short.html.

Mayeux, R., Brandt, J., Rosen, J., & Benson, D. F. (1980). Interictal memory and language impairment in temporal lobe epilepsy. *Neurology*, *30* (2), 120-130.

McClelland, M. M., Acock, A. C., Piccinin, A., Rhea, S. A., & Stallings, M. C. (2013). Relations between preschool attention span-persistence and age 25 educational outcomes. *Early Childhood Research Quarterly*, *28*, 314-324.

Mcevoy, L., Smith, M., & Gevins, A. (2000). Test–retest reliability of cognitive EEG. *Clinical Neurophysiology*,*111* (3), 457-463.

Newman, I. (2019). When saying 'go read it again' won't work: Multisensory ideas for more inclusive teaching & learning. *Nurse Education in Practice 34*, 12–16.

Opitz, B., & Friederici, A. D. (2003). Interactions of the hippocampal system and the prefrontal cortex in learning language-like rules. *NeuroImage*, *19* (4), 1730-1737.

Ornstein, P. A., Baker-Ward, L., Gordon, B. N., Pelphrey, K. A., Tyler, C. S., & Gramzow, E. (2006). The influence of prior knowledge and repeated questioning on children's long-term retention of the details of a pedi-atric examination. *Developmental Psychology*, *42*, 332–344.

Rains, J. R., Kelly, C. A., & Durham, R, L. (2008). The evolution of the importance of multi-sensory teaching techniques in elementary mathematics: theory and practice. *Journal of Theory and Practice in Education*, *4* (2), 239-252.

Rouault, M., & Koechlin, E. (2018). Prefrontal function and cognitive control: From action to language. *Current Opinion in Behavioral Sciences*, *21*, 106-111.

Schmidt, R., Ruiz, M. H., Kilavik, B. E., Lundqvist, M., Starr, Ph. A., & Aron, A. R. (2019). Beta oscillations in working memory, executive control of movement and thought, and sensorimotor function. *Journal of Neuroscience*, *39* (42), 8231-8238.

Shimamura, A. P., Janowsky, J. S., & Squire, L. R. (1991). What is the role of frontal lobe damage in memory disorders? In H. S. Levin, H. M. Eisenberg, and A. L. Benton (eds), *Frontal lobe function and dysfunction*(174-195). New York, NY: Oxford University Press.

Son, D., De Blasio, M. F., Fogarty, J. S. Angelidis, A., Barry, I. J., & Putman, P. (2019). Frontal EEG theta/beta ratio during mind wandering episodes. *Biological Psychology*, *140*, 19-27.

Spicer, J. (2000). Virtual manipulatives: A new tool for hands-on math. *ENC Focus*, *7*(4), 14-15.

Squire, L. R. (1986). Mechanisms of memory. *Science*, *232*, 1612 – 1619.

Suanda, S. H., Muguwanya, N., & Laura, L. N. (2014). Cross-situational statistical word learning in young children. *Journal of Experimental Child Psychology*, *126*, 395-411.

Traxler, M. J., & Gernsbacher, M. A. (2006). *Handbook of psycholinguistics*. USA: Elsevier Inc.

Tulving, E. (1987). Multiple memory systems and consciousness. *Human NeuroBiol*, *6*, 67 – 80.

Vouloumanos, A., & Werker, J. F. (2009). Infants' learning of novel words in a stochastic environment. *Developmental psychology*, *45*(6), 1611-1617.

Werchan, D. M., Baumgartner, H. A., Lewkowicz, D. J., & Amso, D. (2018). The origins of cortical multisensory dynamics: Evidence from human infants. *Developmental Cognitive Neuroscience*, *34*, 75–81.

Williamson, K. F. (2011). *Multi-sensory processing in adults: An EEG study of latency and amplitude in the N1 and P2 peaks*. PhD Thesis, University of Colorado, Boulder. Retrieved May 21, 2019 from University of Colorado Theses and Dissertations.

Wong, P. C., Morgan-Short, K., Ettlinger, M., & Zheng, J. (2012). Linking neurogenetics and individual differences in language learning: The dopamine hypothesis. *Cortex*, *48*(9), 1091–1102.

Young, J. J., Rudebeck, P. H., Marcuse, L. V., Fields, M. C., Yoo, J. Y., Panov, F., Ghatan, S., Fazl, A., Mandelbaum, S., & Baxter, M. G. (2017). A Theta band network involving prefrontal cortex unique to human episodic memory. *NeuroImage*. doi: 10.1016/j.neuroimage.2018.08.052.

Yu, C., & Smith, L. B. (2012). Modeling cross-situational word–referent learning: Prior questions. *Psychological Review*, *119*, 21-39.

Zilles, K., & Amunts, K. (2010). Centenary of Brodmann's map: Conception and fate. *Nature Reviews Neuroscience*,*11*, 139–145.

How to Site: Farrokh Alaee, F., Soleimani, H., Haghir, H., Aghayusefi, A., & Jafarigohar, M. (2020). Multisensory teaching and Beta and SMR oscillatory activities in foreign language vocabulary retention: A Neurolinguistic sstudy. *Iranian Journal of Learning and Memory*, *3*(11), 7-25. doi: 10.22034/iepa.2021.251487.1214