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

Farnaz Farrokh Alaee
Payame-Noor University, Tehran, Iran

The present study aimed to investigate theta/beta ratio (TBR) variations in foreign language (FL) vocabulary retention to analyze the effect of the multisensory language teaching method at the pre-school level. To meet the purpose, the study used quantitative electroencephalography (QEEG) records of 32 volunteered pre-school novice FL learners to investigate the link between TBR and FL vocabulary learning. The participants were assigned into two experimental groups: non-multisensory (seven girls and nine boys) and multisensory (eight girls and eight boys) teaching groups. After 20 sessions of an hour-instruction, the comparative findings of the pre- and post-Expressive One-word Picture Vocabulary Test (EWPT) showed that the multisensory group outperformed the non-multisensory one. The analyses of the collected data on pre- and post-brain QEEG records of TBR variations indicated a significant decrease on Pz in the non-multisensory group and a significant increase on Fz in the multisensory group. The statistical comparison between post-records showed a significant positive correlation was found between TBR oscillatory activities on Fz and scores on the post-test in the multisensory group. The topographic analysis indicated higher TBR frequencies in the non-multisensory group's post-record than the multisensory one, especially a great decrease on Cz in the multisensory group compared to non-multisensory one. The results contributed to the understanding of TBR concerning learning and retention and provided insights into using the multisensory method in the FL context.

Keywords: TBR, multisensory teaching, FL vocabulary retention, QEEG

Introduction

Cognition and learning are often assessed by performance. The brain's empirical performance is brainwaves that can be recorded and analyzed by neuroimaging methods, including quantitative electroencephalography (QEEG). There are five wavebands, measuring in microvolts, in EEG brainwave frequencies: delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-32 Hz), and gamma (upper than 32 Hz) (Hsu, Cheng, & Chiu, 2017). The theta/beta ratio (TBR) is defined as the bands a bit differently than some would, as the theta band goes from 4 Hz up to 8 Hz, with beta represented as from 13-21 Hz (Marcuse, Fields, & Yoo, 2016). The EEG theta/beta power ratio is used to diagnose or help to diagnose attention-deficit/hyperactivity disorder (ADHD) (Gloss, Varma, Pringsheim, & Nuwer, 2016). Previous studies supported TBR and ADHD linkage for many years (Barry et al., 2009). An elevated TBR in EEG reports has long been hypothesized as an inattention index among individuals with ADHD. In contrast, preliminary research has proposed that it might be indicative of cognitive

Farnaz Farrokh Alaee, Ph.D., Department of Linguistics and Foreign Languages, Payame-Noor University, Tehran, Iran.

processing. There is still a need for further research to determine if TBR correlates with cognitive parameters in healthy subjects.

TBR is mostly measured at Fz (in the frontal lobe), Pz (on parietal lobe), and Cz (on central lobe) regions of the brain (Ogrim, Kropotov, & Hestad, 2012). In an Event Related Potential (ERP) study on Fz, Pz, and Cz in 47 participants (university student), Clarke, Barry, Karamacoska, and Johnstone (2019) asserted that TBR is associated positively with the decline in attention in ADHD individuals. Other observations such as Picken et al.'s (2020) experiment, however, contend that TBR is a marker of cognitive processing capacity in both healthy and atypical participants. Correspondingly, Son et al.'s (2019) supported the role of frontal TBR as a deficit in attentional control. In their study the EEG data indicated elevation of TBR during mind wandering compared to focused attention in healthy subjects. They presented TBR as a marker of brain processes involved in executive control processes and in coordination with the hippocampal region and the frontal cortex during the retrieval and consolidation of memories.

Increases in TBR indicate relatively lower theta and higher beta wave oscillations, that is, increasing anxiety and decreasing learning and concentration (Gloss et al., 2016; Marcuse et al., 2016; Ogrim et al., 2012); inexplicably, Bakker et al. (2015) reported higher theta and lower beta wave frequencies in a consolidation period, the offline period the novel words need to be lexically integrated and acquire word-like neural representation. Their EEG study found that novel words elicited lower theta and higher beta power than existing words over left frontotemporal channels; unfamiliar and recently learned words induced less beta desynchronization than existing words. These contradictory results from different experiments demand further research to delineate which aspects of cognitive processes are primarily associated with TBR, especially in healthy subjects.

For decades one of the main concerns in the field of learning has been retention processes. Retention is essential to learning, and the materials that are not retained are called "unlearned"; therefore, retention is a fundamental part of learning (Ritter, Baxter, Kim, & Srinivasmuthy, 2013). The chemical changes at the neuron level create a memory (Guyton & Hall, 2006). Understanding these neurobiological changes helps the investigators scrutinize the external stimuli's effect on memory formation to select the best method for memory enhancement.

Memory requires conscious attention (Atkinson & Shiffrin, 1971), the essential point considered by the teachers in the classroom. They always complain about their student's lack of attention. However, attention is "selective", and though the brain always pays attention, the relevant and essential items differ to individuals (Wolfe, 2014, p. 168). Teachers always try to find attention-getter ways to enhance students' learning and retention. Many researchers investigated the ways the brain encodes information, and they found the techniques appeal to multiple senses to enhance memory encoding and learning (Sprenger, 1999).

The specialized architectures of the brain and processing mechanisms enable the combination and integration of multisensory information. When different sensory organs receive the multitude of multisensory inputs, the cognitive, perceptual, and the motor system encode, integrate, decode, and segregate the information so that the input is perceived as a coherent perceptual representation (Murray, Lewkowicz, Amedi, & Wallace, 2016). This multisensory processing is fundamental to live and learn (Williamson, 2011).

The multisensory approach emphasizes presenting all information via sensory modalities: visual, auditory, and tactile. Multisensory teaching is not just limited to only two skills of reading and listening. Instead, it engages the learners with the material in more than one way. In almost every time of multisensory teaching, all senses (taste, smell, touch, sight, hearing, and movement) of the learner will be used. The multisensory teaching method is helpful for all students and is a way to enhance memory in learning new materials (Fernald, 1943; Gillingham & Stillman, 1997).

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 foreign language (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 children's bilingual vocabulary development and intercultural awareness. Applying multisensory techniques to the two experimental groups of the third-grade learners with dictation problems, 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 the 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 favor of the multisensory group than the other control or experimental groups. Nevertheless, as far as it has been searched, no study has been done to investigate the effect of multisensory teaching on foreign language vocabulary in the FL context, considering the brain wave changes.

Neurofeedback training is an effective method to improve brain waves (Demos, 2005; Gruzelie, 2014; Sherlin, 2009). Multisensory teaching can be a suitable replacement for cumbersome training sessions of neurofeedback. During an experiment, Khanjani et al. (2012) investigated the effect of neurofeedback training compared to Fernald's multisensory instruction on six dyslexia children. The learners were applied to three experimental groups: one receiving neurofeedback training and one Fernald instruction, and the last group receiving both types of training. The results indicated that the third group learners (receiving both neurofeedback and multisensory training) showed higher performance than the two other groups. However, there was no difference in the students' scores in the first two experimental groups, indicating that the multisensory approach could positively train the brain like the electrical training by neurofeedback device.

The advent of functional neuroimaging methods provides a new opportunity to gain insight into human memory formation's neuronal basis. Memory information is stored across interconnected brain regions (Norris, 2017). Brain areas involved in different functions as language and memory can be more distinctively recognized and scrutinized by Brodmann's brain map. Brodmann's (1909) anatomical model of the brain was correlated to the points presented in the 10-20 system, which is a globally perceived method of standardization of the brain cortices on the scalp.

In his model, Brodmann (1909) introduced 52 regions on the cerebral cortex. Brodmann Area Number 6 (part of the frontal cortex near the center, situated just anterior to the primary motor cortex) is the closest match to the Cz brain areas, Brodmann Area Number 7 (part of the parietal cortex, situated posterior to the primary somatosensory cortex) and Number 8 (part of the frontal cortex, located just anterior to the premotor cortex) which are respectively matched with Pz and Fz regions of the brain (Garey, 1994). These areas were evaluated in different neuroimaging investigations to search for possible TBR measurement on anterior cingulate, internal versus external attention, perception, attentional shifting, perseverance, self-awareness, and sensory functions (Bakker et al., 2015; Fuster, 2008; Marcuse et al., 2016; Ogrim et al., 2012; Picken et al., 2020).

This study examined the effect of multisensory teaching on FL vocabulary retention and tended to scrutinize the changes of TBR as a representative frequency band of inattention. In particular, applying and comparing the QEEG data between the multisensory and non-multisensory teaching groups, it tried to objectively and empirically examine how these different methods affected TBR in vocabulary retention.

Method

Participants

Thirty-two FL learners (aged 5-6 years) volunteered to participate in the study. They were all right-handed, and their native language was Persian. The participants were later assigned into two experimental groups, namely multisensory (eight boys and eight girls, volunteers of a twenty-person class) and non-multisensory (nine boys and seven girls, volunteers of a 19-person class). An advantage of studying children at this relatively young age, as compared with adults, is that investigating learning an FL in adulthood is dramatically more difficult than doing so as a child because of the changes and differences due to neural plasticity (Wong, Morgan-Short, Ettlinger, & Zheng, 2012).

Language Test

The Expressive One-word Picture Vocabulary Test (EWPT) (r = 0.87) was designed according to the Expressive One-Word Picture Vocabulary Test-4 (Martin & Brownell, 2011). The test assessed the child's English-speaking vocabulary and is suitable for children within the age range of 2-18 years old. The test required 20 minutes to be administered, and it provided the researcher with the standardized score, percentile rank, and age equivalent score. The EPMT in this study included 40 items to be circled by the participants after the teacher's articulation (Figure 1).

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Figure 1. EPMT: The participants were to circle the picture related to the word articulated by the teacher.

QEEG Records

Brain oscillatory activities were recorded and measured using Mitsar-QEEG-201 device (FDA 510K K143233), equipped with 21 individually-shielded silver-chloride electrodes placed according to the international 10-20 system located at brain regions. The EEG sampling rate was 500 Hz. Impedances were greater than 200 MOhms. The montage was referential (average), and there were five minutes E-C (eye-closed) and five minutes E-O (eye-opened) records for each participant. The data were artifacted to 1.55 to 2.45 minutes.

Fz, Pz, and Cz electrodes can exhibit EEG activity more typical of frontal, parietal, and frontocentral activities (Clarke et al., 2019; Marcuse et al., 2016; Ogrim et al., 2012). Following some studies in the literature (e.g., 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 present study aimed to analyze TBR power from Fz, Pz, and Cz.

Procedure

Before any teaching session, QEEG brain maps were recorded as pre-records, and the EPMT was administered as pre-tests. Then the students were assigned to two groups of multisensory and non-multisensory one. After 20 sessions of instruction, another QEEG record was taken from participants as post-records and EPMT was administered as the post-test.

In the multisensory group, manipulatives and realia (Rains, Kelly, & Durham, 2008) were used. The teacher was a guide to mediate the process of teaching and learning, and the participants touched, saw, and sometimes smelt and tasted the real objects while they were familiarizing with their meanings. On the contrary, in the non-multisensory group, the vocabulary items were presented (using flashcards and songs), while some of them were translated into Persian. Later, the participants were asked to repeat the words.

Data Analysis

The pre-tests and the post-tests (Expressive One-word Picture Vocabulary Test/EWPT) scores were analyzed using Statistical Packages for Social Sciences (SPSS, Version 25). *T*-test was applied to the data to check the normality of the sample size. To draw more reliable conclusions, the pre-test results were compared to the initial (before instruction) brain map records of QEEG; in the same fashion, the final report of the brain maps and the post-test scores were compared, assigning paired t-test statistics.

The Fast Fourier Transform (FFT) power ratio of TBR from Fz, Cz, and Pz areas was compared in two multisensory and non-multisensory separately applying Pearson Correlation to check the probable effect of the treatments (here teaching methods). Each learner's before-treatment brain-record and EMPT were analyzed and compared to his/her after-treatment post-record and post-test.

Results

Statistical Analysis

T-test was applied to the pre-test scores to check the homogeneity of the sample under study (Table 1).

Table 1

Independent Sample T-Test Related to the Participants' Scores on Pre-test

Variable	Groups	N	Mean	Std. deviation	Independent sample *t*-test			Leven's test	
					Sig.	df	t	Sig.	F
Pre-test scores	Multisensory	16	5.25	2.64	0.944	30	0.071	0.36	0.88
	Non-multisensory	16	5.31	2.36					

The result indicated no significant difference between the mean scores in the two groups (multisensory and non-multisensory) ($p > 0.05$). That is, the sample is homogenous.

The results of the dependent sample *t*-test revealed that there are significant differences between the pre-test and post-test scores in the multisensory and non-multisensory groups (Table 2).

Table 2

Dependent Sample T-Test Related to the Comparison of Pre-test and Post-test in Multisensory and Non-multisensory Groups

		N	Mean	Sig.	df	*t*	Std. error mean	Std. deviation
Multisensory	Pre-test	16	5.25	0.0001	15	-24.576	1.19	4.77
	Post-test		34.56					
Non-multisensory	Pre-test	16	5.31	0.0001	15	-17.60	1.35	5.39
	Post-test		29.06					

The results of examining the homogeneity of the regression slopes showed that the assumption was not met and there is a significant difference between the regression slopes ($p < 0.05$). Therefore, one-way analysis of covariance test cannot be used. And the comparison test of the averages of two independent groups was applied.

Table 3

Independent Sample T-Test Related to the Comparison of the Multisensory and Non-multisensory Post-tests

	Groups statistics					Independent sample t-test			Leven's test	
	Groups	N	Mean	Std. deviation	Std. error mean	Sig.	df	*t*	Sig.	F
Pre-test	Multisensory	16	5.25	2.64	0.66	0.994	30	0.071	0.36	0.88
	Non-multisensory	16	5.31	2.36	0.51					
Post-test	Multisensory	16	34.56	5.00	1.25	0.017	30	2.52	0.11	2.69
	Non-multisensory	16	29.06	7.14	1.78					
Score differences	Multisensory	16	-29.31	4.77	1.19	0.004	30	-3.08	0.44	0.55
	Non-multisensory	16	-23.75	5.40	1.35					

As shown in Table 3, there is a significant difference between the mean scores of the multisensory and non-multisensory groups in post-test and the multisensory group outperformed the non-multisensory one.

The independent sample *t*-test analyses indicated that there were not any significant differences between TBR power on Cz, Fz, and Pz in pre- and post-records of multisensory group in comparison to non-multisensory one (Table 4).

Table 4

Independent Sample T-Test Related to the Comparison Between TBR Power in Pre- and Post-records in Multisensory and Non-multisensory One

						Independent sample *t*-test			Leven's test	
	Groups	N	Mean	Std. deviation	Std. error deviation	Sig.	df	*t*	Sig.	F
Theta/beta on Fz	Multisensory	16	-0.74	1.35	0.34	0.152	30	-1.470	0.401	0.73
	Non-multisensory	16	0.031	1.60	0.40					
Theta/beta on Cz	Multisensory	16	0.14	0.78	0.19	0.619	30	0.502	0.625	0.24
	Non-multisensory	16	0.013	0.64	0.16					
Theta/beta on Pz	Multisensory	16	-0.008	1.09	0.27	0.054	30	-2.019	0.117	2.60
	Non-multisensory	16	1.55	2.89	0.72					

As revealed in the table, there are not any significant difference ($p > 0.05$) between TBR power in pre- and post-records in non-multisensory and multisensory groups. That is, there were not any significant difference between participants' TBR in pre- or post-record in the two groups.

Dependent sample *t*-test was applied to the TBR ranges to check the potential changes in pre- and post-records (Table 5).

Table 5

Dependent Sample T-Test Related to the Comparison Between Pre- and Post-records

				Dependent sample *t*-test		
Groups	N	Areas	Sessions	Sig.	df	*t*
Multisensory	16	Fz	Pre-record Post-record	0.045	15	-2.191
		Cz	Pre-record Post-record	0.485	15	0.716
		Pz	Pre-record Post-record	0.976	15	-0.031

Table 5 to be continued

Non-multisensory	16	Fz	Pre-record Post-record	0.940	15	0.077
		Cz	Pre-record Post-record	0.935	15	0.082
		Pz	Pre-record Post-record	0.048	15	2.15

As indicated, significant differences were reported in Fz TBR ($p = 0.045$) in the multisensory group and Pz TBR ($p = 0.048$) in the non-multisensory group.

Application of Test Scores to the Brain Wave Frequency Changes

The descriptive statistics related to the mean differences of pre- and post-test scores besides the TBR changes mean differences in pre- and post-records were estimated for further analyses.

Table 6.

Descriptive Statistics

Variables	Areas	N	Mean differences	Std. deviation
Post-test scores		32	-26.531	753.5
	Fz		-0.353	507.1
Post-record scores	Cz	32	0.076	0.703
	Pz		0.771	291.2

To check the alleged relationship between the mean differences of pre- and post-test scores and the mean differences of pre- and post-records of TBR changes in the multisensory group, that is, checking the effectiveness of multisensory teaching method on attention and, as a result, retention, Pearson Correlation test was assigned to the data.

Table 7

Pearson Correlation Analyses

Variables		Mean differences scores	TBR on FZ	TBR on Cz	TBR on Pz
Mean differences scores	R Sig.	1.000			
TBR on Fz	R	0.416	1.000		
	Sig.	0.018			
TBR on Cz	R	-0.066	-0.126	1.000	
	Sig.	0.718	0.491		
TBR on Pz	R	0.287	0.380	-0.182	1.000
	Sig.	0.111	0.032	0.320	

The data indicated no significant relationship between the mean differences of the scores on pre- and post-test and TBR changes except for Fz ($p < 0.05$). The more the scores, the more TBR ranges were seen.

Topographic Analysis

As mentioned before, QEEG provides researchers with the color-coded brain maps of the participants under record. The brain maps of the sample (32 participants) in pre- and post-records were compared (Figure 2).

	Pre-record theta localization (theta vs. beta waves localization)	Post-record theta localization (theta vs. beta waves localization)	Pre-record beta wave localization (theta vs. beta waves localization)	Post-record beta localization (theta vs. beta waves localization)
Sample 1				
Sample 2				
Sample 3				
Sample 4				
Sample 5				

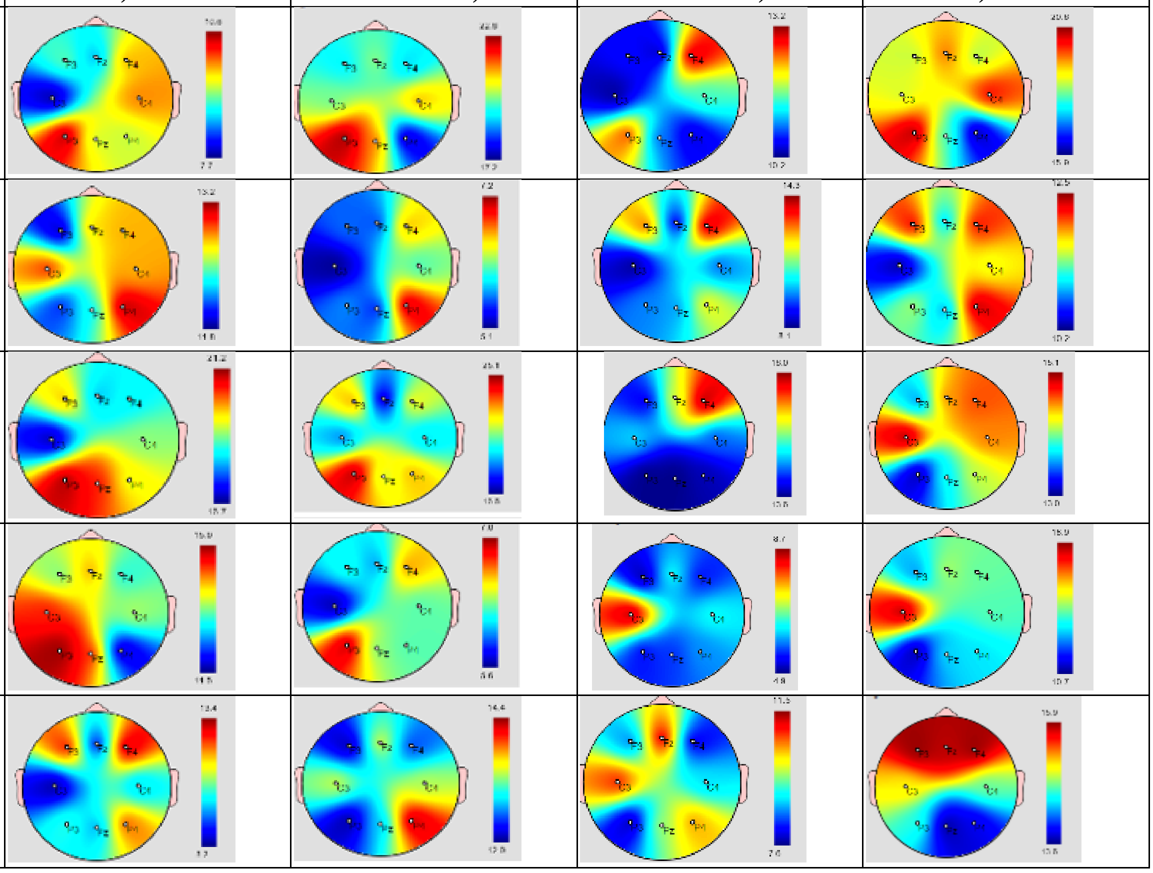

Figure 2. The topographic comparison of brain maps in pre- and post-record sessions (a sample of five participants brain records).

The topographic comparison of brain maps indicated changes in TBR power specially in frontal and parietal areas of the brain. About 11 out of 16 participants in multisensory group showed lower activity of theta versus higher activity of beta in central (C3, C4, and Cz) and parietal (P3, P4, and Pz) regions of the brain indicating the diminution of TBR in post-record. This result was not statistically approved to be significant.

Discussion

The present study tried to empirically investigate the TBR power changes after multisensory teaching (as an effective method to be replaced by neurofeedback training) and compare the results with the non-multisensory group (as a control one) in 32 pre-schoolers.

The analyses of the collected data on pre-and post-brain QEEG records of TBR variations indicated a significant decrease on Pz in the non-multisensory group and a significant increase on Fz in the multisensory group. The statistical comparison between post-records showed a significant positive correlation was found between TBR oscillatory activities on Fz and scores on the post-test in the multisensory group. The topographic analysis indicated higher TBR frequencies in the non-multisensory group's post-record than the multisensory one, especially a great decrease on Cz in the multisensory group compared to non-multisensory one.

TBR frequencies decreased significantly on Pz in the non-multisensory group. The best match of Pz is Brodmann's Area Number 7, which is part of the human brain's parietal cortex. It is believed to play a role in Visio-motor coordination and is linked to a wide variety of high-level processing tasks and activation in association with language use (Simic & Hof, 2015). Lower TBR on Pz showed relatively lower theta and higher beta wave oscillations, that is, decreasing anxiety and increasing learning and concentration on Brodmann's Area Number 7 for Visio-motor coordination. In the non-multisensory group, the flashcards were the central part of teaching, and the most portion of the classroom time was devoted to repetition activities (look and say activities) by flashcards. Looking at the book's pictures and flashcards (visual activity), repeating the new words, the book's manual works engaged audio-visual and Visio-motor processing.

TBR increases are associated with inattention and lack of learning (Marcuse et al., 2016). Previous research on ADHD reported that elevated TBR was most reliably associated with inattention (Barry, Clarke, & Johnstone, 2003; Chabot, di Michele, & Prichep, 2005; Monastra et al., 1999; Monastra, Lubar, & Linden, 2001; Monastra, 2008; Quintana et al., 2007; Snyder et al., 2008). Halawa et al. (2017) conducted a QEEG study to spot the frontal TBR alterations during Tests of Variance of Attention (TOVA) in ADHD and healthy children. They found a negative correlation between TOVA results and TBR frequencies. In contrast to Halawa et al. (2017), whose findings indicated a decrease in TBR frequencies on the prefrontal cortex for normal/healthy subjects, the results of the present study showed an unexpected increase of TBR on Fz region.

However, some studies such as Son et al.'s (2019) supported the positive effect of frontal TBR. In their study the EEG data indicated elevation of TBR during mind wandering compared to focused attention. They presented TBR as a marker of brain processes involved in executive control processes and in coordination with the hippocampal region and the frontal cortex during the retrieval and consolidation of memories.

Fz is located on cingulate gyrus and deals with mental flexibility and changing attention from one subject to another (Fuster, 2008), that is executive control processes. It is in correspondence with Brodmann's Area Number 8, which is associated with detailed attention (Fuster, 2008). Keeping with Son et al.'s (2019) and Fuster's (2008) findings, the result of this study on the TBR indicated a positive correlation with the post-tests retention scores.

Besides, Brodmann Area Number 8 plays a significant role in attention to seductive details and gaze attention (Guyton & Hall, 2006). In an empirical study, Wang, Sundararajan, Adesope, and Ardasheva (2017) found that the no-seductive-details condition significantly outperformed the seductive-details condition on recall task. Therefore, increase in TBR which is associated with inattention to seductive details can be desirable for learning and retention/recall as asserted by Wang et al. (2017). The present study's findings match Marcuse et al.'s (2016), who reported that the most significant theta/beta ratios are found at Cz or Fz. This finding may justify the positive correlation between the scores on post-test and the TBR increase on post-records in the multisensory group.

Topographic analyses divulged decrease in TBR rhythm specially on post-record Cz in multisensory group in comparison to the non-multisensory one. Cz includes Brodmann Areas 3, 4, and 6 which are responsible for sensory and motor functions and deals with attentional control (Brodmann, 1909). Attentional control affects learning and facilitates encoding, retrieval, and memory (Tyng, Amin, Saad, & Malik, 2017). It can be concluded that the use of manipulatives besides playing, eating, practicing, and exercising in the multisensory class provided emotional changes in the multisensory group and led to retention.

The statistical indices showed that EPMT post-test scores in multisensory group in comparison to non-multisensory one significantly enhanced. The 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) who asserted the motivational effect of multisensory teaching in bilingual classes.

Conclusion

The research was carried out in order to apply QEEG data to language teaching field. Since multisensory approach stimulates the brain in different ways to develop learning (Fernald, 1943; Gillingham & Stillman, 1997), the study tried to investigate these effects empirically in the field of language teaching by applying a noninvasive device. The advent of the noninvasive neuroimaging techniques opened a new era in the investigation of language learning.

The statistical results have shown the significant correlation between the FL learners' mean score on post-test and the increase in TBR wave frequencies on Fz region at post-records in the multisensory group. The topographic analyses illustrated the lower activity localization of TBR on Cz and Pz in multisensory group's post-records. It indicated that multisensory instruction could be a promising approach to teaching new FL vocabulary items.

The results of the current study will be helpful for English instructors in applying teaching methods used in psychology, such as multisensory method. Also, they might be helpful for language teachers to become familiar with the scientific techniques of the methodological evaluation and more effective methods of FL teaching.

Future research is suggested to reveal brain regions and oscillations involved in the process of foreign/second language learning to improve foreign language teaching and examine the likely permanent or temporary changes in brain waves after doing tasks or teaching periods. 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 more empirically.

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