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Research Article

Computer-Aided Cognitive Training Based on Electroencephalography-Neurofeedback for English Learning*

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Abstract

This paper aims to disclose the effect of cognitive training on English learning. For this purpose, the author reviews the existing computer-aided cognitive-training programs, and developed a targeted cognitive-training approach based on electroencephalography (EEG)-neurofeedback (NFB). Then the approach was applied to a randomized controlled test on the cognition and perception of English learners. The experimental results show that the participants in the test group witnessed significant progress in English learning skills and communicative competence, and post-NFB alpha magnitude could increase independent of NFB conditions. The research findings provide new insights into the application of cognitive training based on NFB-EEG.

Keywords

Neurofeedback (NFB) • Cognitive Training • Electroencephalography (EEG) • English learning

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As is known to all, people differ greatly in how much information they can maintain, manipulate, and transform in their brains all at once. These differences directly exert influence on such outcomes as abstract reasoning, academic performance, and the acquisition of new skills. Most English learners pursue their communicative competence in English learning: the ability to communicate with other English speakers in various fields, including but not limited to, business, tourism, politics and academics. However, there are many difficulties in learning English. In cognitive theory, English learning is viewed as a conscious and reasoned thinking process, involving the deliberate use of learning strategies, i.e. special ways of processing information that enhance information comprehension, learning or retention. This thinking process can be trained through brain activities under special strategies. The most consistent finding in the existing research is that working memory training programs can reliably improve the short-term memory skills (Ball, Berch & Helmers, 2002; Willis, Tennstedt & Marsiske., 2006; Ngandu, Lehtisalo & Solomon, 2015).

Cognitive training aims to maintain and even improve the cognitive abilities by training the brain, similar to the way body fitness is improved by physical exercises (Simons *et al*., 2016). The training reflects the hypothesis that regular performance of certain activities helps maintain or improve cognitive reserve, that is, the ability to meet the various cognitive demands of life. The cognitive reserve is evident in an ability to assimilate information, comprehend relationships, and develop reasonable conclusions and plans (Scarmeas & Stern, 2003). Despite the strong evidence on the plasticity of the brain throughout life and the association between high levels of mental activity and reduced risks of agerelated dementia, scientific support for the concept of brain fitness is still limited (Soveri, Antfolk & Karlsson, 2017). So far, there has been some evidence that some cognitive training programs can improve performance on tasks in which task executors were trained, less evidence that improvements in performance generalize to other related tasks, and almost no evidence that brain training generalizes to every day cognitive performance (Rizos *et al*., 2010).

One of the most popular cognitive training technologies is neurofeedback (NFB) (Zoefel, Huster & Herrmann, 2011). The NFB is a type of biofeedback that promotes the self-regulation of brain, using electroencephalography (EEG) to display real-time brain activities (Vernon *et al*., 2003). It enables the brain to function more efficiently and the participants to control their electroencephalography (EEG) activity. The NFB is generally applied based on EEG activity. It is widely agreed that the NFB is suitable for training those involved in some cognitive task. As a part of mental process, such a task blesses the participant with the behaviour and ability to perceive and acquire knowledge.

Cognitive linguistics, an interdisciplinary branch of cognitive science, is closely related to cognitive psychology and linguistics (Tomasello, 2000). It treats language as a kind of cognitive action, and cognition as departure of language learning and acquisition (Louwerse, 2001). In short, cognitive linguistics is a discipline based on our experience of the world and the way we perceive and conceptualize it (Verdonk *et al*., 2005). In spite of the long research history of cognitive linguistics, the relationship between cognition and language acquisition is still unclear. To make up for the gap, this paper explores English learning process from the perspective of NFB-based cognitive training.

Methodology

Computer-Aided Cognitive Training

Recent years have seen the integration of advanced technologies in cognitive linguistics. Computer assistance is now commonplace in cognitive training. Table 1 lists some of the typical computer-aided cognitive training programs.

Table 1
Typical Computer-aided Cognitive Training Programs

Scholars	Design	Computer program	Sample	Outcomes
Plohmann *et al.*,	2-group quasi-experiment	Four 45~60min sessions per week for 4 weeks	N=10	Limited improvement
Mendozzi *et al.*,	3-group quasi-experiment	Fifteen 45min sessions in 8 weeks; 2 sessions per week.	Test group (n=20); Control group (n=20)	Test group has made greater progress in memory than the control group.
Birnboim *et al.*,	1-group pre-experiment	Computer-based strategy games; 1h per week for 6 months	N=10	Significant progress in some measures of attention
Solari *et al.*,	Randomized controlled trial	RehaCom; two 45min sessions per week for 8 weeks in a treatment centre	Test group (n=40); Control group (n=37)	No difference between the two groups
Tesar *et al.*,	Randomized controlled trial	RehaCom; twelve 1h sessions for 4 weeks	Test group (n=10); Control group (n=9)	Test group has significant progress in spatial-constructional abilities.
Hildebrandt *et al.*,	Randomized controlled trial	VILAT-G; 30min home-based computer training per day for 6 weeks; at least 5 days per week.	Test group (n=17); Control group (n=25)	Test group has progress in verbal learning.
Vogt *et al.*,	3-group quasi-experiment	Brain Stim; 45min home-based training sessions per week for 4 weeks	High-intensity group (n=15); Low-intensity group (n=15); Control group (n=15)	Training effects are independent of dosage.
Mattioli *et al.*,	2-group quasi-experiment	RehaCom; three 1h sessions per week for 3 consecutive months	Test group (n=10); Control group (n=10)	Test group has significant progress in attention tests.
Shatil *et al.*,	2-group quasi-experiment	Cogni-Fit Personal Coach; three home-based training sessions per week for 12 weeks	Test group (n=59); Control group (n=48)	Test group has made greater progress than the control group.

Previous studies have proved the advantages of computer-aided training over other cognitive trainings. First, the computer-aided training can be self-regulated and tailored to specific needs; Second, the computer programs can provide immediate feedbacks on the results, which are not necessarily clear to the participants. In light of these, this study examines the feasibility of computer-aided cognitive training, and applies a computer program in a randomized controlled trial on the effect of English learners' cognition and perception.

Experimental Design

For each participant, the experiment contains 35 sessions on the weekdays, one session per day, in seven consecutive weeks. The participants were divided into two groups without difference in age or gender. One group received NFB training (the test group), while the other did not (the control group). During the training, the participants were seated in comfortable chairs in a quiet room. Then, an EEG-NFB-based computer-aided cognitive training system was designed for pre- and post-training EEG measurement. The system consists of a 128-channel electrode cap (as per the Extended International 10/20 System of Electrode Placement), an amplifier and a measurement software platform. The EEG frequency bandpass was set to 0.05~100Hz. There were two tasks during the pre- and post-training EEG measurement, namely the n-back task and oddball task. In each training session, the n-back task contains three 5min independent blocks and 1min practice before each block. During each block, the participants were asked to react to the letter flashing on the monitor.

Participants

Twelve students were recruited from a university in China and randomly divided into the two groups. All of them aged between 20 and 22. Two participants were excluded from subsequent statistical analyses, because the scores of the second cognitive performance assessment fell out of the 95% confidence interval. The final sample encompasses 5 participants in the test group (2 males and 3 females), and 5 in the control group (4 males and 1 female).

EEG Measurement

During the experiment, the EEG was measured with electrodes placed in an elastic cap according to the International 10-20 system. P3, Pz, P4, O1 and O2 were employed to achieve the same conditions as in normative data. The amplifier bandwidth was set to 0.5~30Hz.

An expert electroencephalographer was invited to read out the EEG signals from the measured EEG and further processed them through visual editing for quantitative analysis. In our study, the NFB was administered at electrode Pz with a BioGraph, which recorded the base rates for offline statistical analyses.

NFB Training

There are four frequency bands of EEG: delta (0.5~3.5Hz), theta (3.6~7.5Hz), alpha (7.6~12.5Hz) and beta (12.6~19Hz). The absolute value (AP) was obtained for each of these frequency bands.

In the cognitive training, the theta and alpha bands of EEG were used. Let Z be the theta-alpha ratio:

$$Z = (\log(\text{theta AP}/\text{alpha AP}) - \mu)/\sigma \quad (1)$$

where μ and σ are the mean value and the standard deviation of the normative sample of the participants, respectively.

Two EEG measurements were made by each student to identify the one with the most abnormal Z value. Based on EEG activity, the NFB training was performed on the group of the student. Then, the threshold was selected every 2min, such that the student received the reward between 70% and 80% of the time. The ratio was computed every 10 milliseconds and compared with the threshold through the measurement.

Statistical Analysis

The EEG data were analysed by Fast Fourier Transform (FFT), and computed by bandpass of 5~15Hz. The pre-training analysis results of the two groups are listed in Tables 2 and 3, respectively.

Table 2
The Analysis Result of the Test Group

Serial No.	Age	Pre-training score	Post-training score	Gender
1	21	50	72	F
2	21	57	67	M
3	20	61	69	F
4	20	52	66	F
5	22	47	62	M

Comparing the pre- and post-training scores, it can be seen that the test group had made greater progress than the control group.

The mean value and standard deviation of scores before and after training in both groups are shown in Table 4.

The NFB effect on EEG parameters are presented in Table 5.

Table 3
The Analysis Result of the Control Group

Serial No.	Age	Pre-training score	Post-training score	Gender
1	22	46	49	M
2	20	51	52	M
3	22	62	64	F
4	21	57	58	M
5	20	41	45	M

Table 4
Pre- and Post-training Scores

	Test group		Control group	
	Pre-training	Post-training	Pre-training	Post-training
Performance score	71.2±12.98	82.6±13.96	71.4±11.64	73.6±2.77
Verbal score	85.2±13.86	91.6±15.06	86.1±13.96	85.0±11.26

Table 5
NFB Effect on EEG Parameters

		Pre-training > Post-training		Post-training > Pre-training	
EEG parameter	Frequency band	Global Prob.	Leads p<0.05	Global Prob.	Leads p<0.05
Test group					
Absolute Power	Delta	0.03*	Fpl, Fp2, F3, F4, C3, C4, P3, P4, F8, T4, T6, Fz, Cz, Pz	0.96	
	Theta	0.03*	Fp1, Fp2, F3, F4, C3, C4, P3, F7, F8, T4, T5, T6, Fz, Cz, Pz	0.90	
	Alpha	0.03*	P4, T4	0.65	
	Beta	0.01*	Fp1, Fp2, F3, F4, P4, F7, F8, T4, Fz	0.97	
Relative Power	Delta	0.1	C3, O1, T3, T5	0.94	
	Theta	0.17	T6	0.65	
	Alpha	0.91		0.11	T6
	Beta	0.59		0.21	
(AP theta/AP alpha) ratio		0.16			0.92
Control group					
Absolute Power	Delta	0.15	F4, C3, O1, O2	0.96	
	Theta	0.09	O1, T6	0.86	
	Alpha	0.29	T5	0.63	
	Beta	0.012	O1, T5	0.51	
Relative Power	Delta	0.03*	Fp1, Fp2	0.77	
	Theta	0.10	T6	0.29	
	Alpha	0.62		0.31	T6
	Beta	0.95		0.11	
(AP theta/AP alpha) ratio		0.28	Cz	0.77	

Note. * "Leads p<0.05 " means the corresponding places indicating major differences

Results

NFB Performance

According to the trend lines in Figure 1, all test group participants increased their peak alpha frequency through the training.

Figure 1 shows the normalized percent-time above the training threshold. After cognitive training, there was no overall improvement for either group. In most sessions, however, all participants of the test group witnessed an increase in performance, while those in the control group exhibited the exactly opposite trend.

The average change of the test group and control group in different cognitive domains after the NFB training are recorded in Table 6.

According to the general trends of cognitive performance in Table 6, the participants of the test group made greater progress than their control group counterparts in English learning through the NFB-based cognitive training. Comparing the pre- and post- NFB performances, it is safe to say that the cognitive training enhanced the speed and accuracy of English skills.

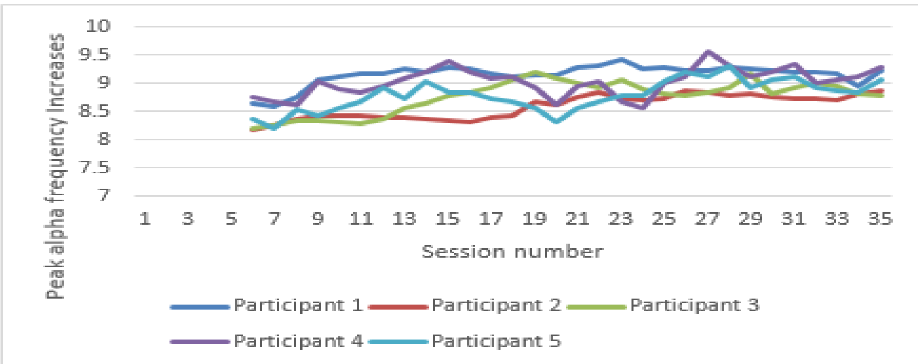

Figure 1. Variation in peak alpha frequency across sessions for all participants

Table 6
Credibility analysis of the scale

Item	Test group	Control group
Reading		
Reading speed	+	-
Reaction time	+	+
Self-reported thinking speed	+	-
Syllable accuracy	+	+
Spelling		
Spelling speed	+	-
Spelling accuracy	+	+
Writing		
Writing ability	+	-
Writing skills	+	-
Writing speed	+	+
Listening		
Listening accuracy	+	-
Listening speed	+	-

EEG Results

After the NFB cognitive training, two participants of the test group and two of the control group saw an increase in their alpha magnitude. Meanwhile, one participant of the test group witnessed no change to her alpha magnitude through the training, and one participant of the control group experienced a decrease in her alpha magnitude

During the experiment, the peak alpha frequency could be obtained from the frontal and posterior areas of the brain. The pattern of peak alpha frequency results is displayed in Figure 2.

As shown in Figure 2, the peak alpha frequency of the test group occurred in the frontal areas. Although the increase is not unexpected, it was expected to appear in the posterior areas instead. The results suggest that the training increased the peak alpha frequency in the frontal areas.

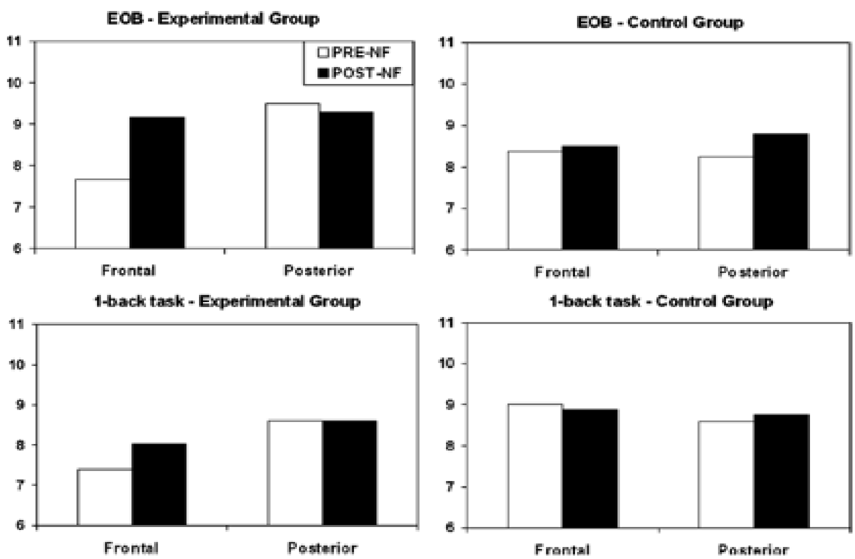

Figure 2. Pre- and post-training peak alpha frequencies Experimental group

Discussion

NFB Effectiveness

This study examines the effects of a new NFB training system on the cognitive performance of English learners. Unlike the existing training plans, our cognitive training focuses on changing the peak frequency by computer-aided system, rather than altering the EEG amplitude.

Both the test group and the control group made progress in English learning through the NFB training. Thus, the NFB training system, which focuses on peak alpha frequency, applies to cognitive enhancement, especially for English learning. Although previous studies have repeatedly shown changes specific to the employed NFB training (Costa, Gadea & Hidalgo 2017; Habibollahi, Souri &Arbabi, 2016; Egner, Strawson & Gruzelier, 2002), our research managed to control all possible non-specific factors of NFB training, leaving only frequency-specific EEG effects on cognition.

Moreover, the experimenter's bias was controlled in our research, because the pre- and post- training cognitive performance can be assessed by experimenters. In recent years, Mikicin, (2015) similarly proved the specificity of EEG-NFB frequency on behavioural changes; Kober *et al*., (2015) disclosed different cognitive influences for participants trained to increase the amplitude of frequencies.

The Relationship between Cognitive Behavioural Changes and EEG Changes

The experimental analysis shows that the post-NFB alpha magnitude could increase independent of NFB conditions. During the post-training assessment, two test group participants and three control group participants witnessed alpha magnitude increase. It is likely that these participants were anxious during the initial cognitive training, as they were unfamiliar with the training process. In future, a special pre-training session should be introduced to familiarize the participants with the NFB procedure and minimize their anxiety. The cognition improvement in our study agree well with some of the previous studies. For instance, many scholars also discovered the correlation between frontal peak alpha frequency topography and cognition (Angelakis, Lubar & Stathopoulou, 2004; Grandy, Markus & Christian, 2013; Mulik, Nazarv & Shatyr, 2017).

Conclusion

The EEG-based NFB training is a promising method for promotion of English learning competence. Many English teachers may be aware of the importance of cognitive training. However, few of them have carried out systematic cognitive training on their students. To solve the problem, this paper sets up a computer-aided NFB cognitive training system based on EEG and applies it to randomized controlled cognitive training of English learners. Through the experiment, the test group showed significant progress in English learning skills. The data analysis shows that the EEG-NFB-based cognitive training may produce varied effects depending on the frequency and modality of training. However, the variation was not observed in our study due to the small sample size. In the future research, the EEG-NFB-based training system will be further verified with a larger sample.

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