Neurofeedback Training Intervention for Enhancing Working Memory Function in Attention Deficit and Hyperactivity Disorder (ADHD) Chinese Students

Zhiyi Wang*

ABSTRACT

Our study aimed to develop a neurofeedback training programme for enhancing the EEG-based alpha band and executive working memory. The study design is pre-test/post-test Control Group (CG), and analyses were limited to those randomized to the neurofeedback intervention. The sample were ADHD students below 15 years of age (7-14 years), of whom 10 completed the 5-week training assessment in the experimental group (EG), whereas 9 completed the assessment in the CG, students from elementary and secondary schools referred to a Chinese psychiatry clinic. The average age of the sample was 13.48 years in the EG. The findings showed the beneficial effects of neurofeedback training, which improved in ADHD students. These findings revealed that most of the working memory function measurements exhibited significant differences between the EG and CG. A neurofeedback training programme enhances the working memory function in ADHD students.

Key Words: Neurofeedback training, ADHD, working memory, brain waves activity

DOI Number: 10.14704/nq.2017.15.2.1073

Introduction

Attention Deficit and Hyperactivity Disorder (ADHD) is one of the most common neurodevelopmental disorders in childhood (Linden et al., 1996; Walshaw et al., 2010; Coogan et al., 2016). The prevalence rate of this disorder among school-aged children and adolescents has been reported between 4.2 and 6.3 percent (Polanczyk et al., 2010). Many studies have proposed theories of deficit in executive functions in individuals with ADHD, about self-control (Barkley, 1997), Self-regulation (Linden et al., 1996), inhibition (Lijffijt et al., 2005; Alderson et al., 2007; Huber et al., 2012; Alderson et al., 2008), and working memory (Kane et al., 2007). Working memory has been introduced as a cognitive system that aims at keeping the focus on practical situations (Kane et al. 2005).

In many studies, working memory have been shown as a complex system with at least three major components, such as working memory capacity as executive attention (Engle, 2002; Lo and Chen, 2017), executive working memory as controller for attention and responsible for the supervision and coordination of sub-function system (Baddeley, 2007; Li et al., 2017; Rapport et al., 2008), and working memory outcomes, such as learning or academic performance (De Jong, 1998; Rapport et al., 1999; Gathercole et al., 2004). Some studies have shown that the working memory capacity is related to executive working memory (McCabe et al., 2010; Baddeley, 2007) as well as working memory outcomes among students (Rapport et al., 2008; Gathercole & Alloway, 2008; Zhou et al., 2017; Alloway et al., 2005).

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Furthermore, deficits in working memory seem to be a serious issue for many students as working memory deficits is related to negative working memory outcomes (De Jong, 1998; Rapport et al., 2008; Perciavalle et al., 2016; Rapport et al., 1999). Gathercole et al. (2004), for example, reported a relationship between increases of working memory skills and performance in a longitudinal study with a student sample aged 7 and 14 years. Rapport et al. (2008) investigated working memory deficits in ADHD. He reported that working memory deficits in ADHD are apparent across the cognitive systems even after controlling for reading speed.

ADHD students have to face different challenges, such as math and reading learning (Loe & Feldman, 2007) and attention control (Martinussen & Tannock, 2006), which can be associated with working memory deficit (Kofler et al. 2010). Another source of ADHD students' working memory deficit is brain-related controls, such as failure in information activation (Rapport et al., 2001; Alderson et al., 2007; Alderson et al., 2008; Peng et al., 2017).

Studies over the past two decades have reported the relationship between memory function and electroencephalogram (EEG) alpha activity (Klimesch, 1996, 1999; Klimesch et al. 2006). So, neurofeedback strategies might be helpful to improve external working memory deficits in children. We can result that external working memory deficits should not result in lower levels of executive working memory, preventing ADHD students from negative long-term and short-term effects concerning performance and well-being. In a recent study Bink et al. (2015) described neurofeedback as a serious issue for many adolescents with ADHD. They described neurofeedback as therapies that aim at altering brain activity by giving feedback of EEG activity to patients.

Neurofeedback strategies are widely recommended for ADHD students (e.g. Leins et al., 2007; Zang et al., 2016; Drechsler et al., 2007), but research concerning the effectiveness of neurofeedback training programmes is scarce. We found no intervention study examining the effectiveness of a neurofeedback training programme on ADHD students’ executive working memory levels. Neurofeedback training programmes are expected to have positive effects on executive working memory. Sterman and Shouse (1980) proposed that neurofeedback training may facilitate the adjustment of long-term stimulates levels in brain networks and the thalamus of brain. Other studies focused on healthy people, for example Egner and Gruzelier (2003), showed that neurofeedback training can control the EEG waves, and these changes are associated with improvements in attentional processing and their memory in terms of behavioral and brain electro. According to observations, memory function has a positive effect on alpha band (Klimesch, 1999). Some studies have used neurofeedback strategies to overcome the differences between participants using upper alpha band in accordance with the participants (Hanslmayr et al., 2005). Zoefel, Huster & Herrmann (2011) extended the training period of their previous study to 5 consecutive days (a week) and reported positive effects of long-term training and independent bands (upper alpha) on strengthening cognitive functions, using mental rotation test.

According to the studies, neurofeedback therapy has been shown to be a predictor of executive working memory in process models of neurofeedback, with EEG-based alpha band as a mediator between neurofeedback therapy and executive working memory. Neurofeedback therapy is expected to lead to strengthening of EEG-based alpha band; strengthening of EEG-based alpha band should lead to more working memory capacity and better performance. Several studies have supported a positive relationship between EEG-based alpha band and different components of working memory (Escolano, Aguilar & Minguez., 2011; Stipacek et al., 2003; Ge et al., 2017; Wang et al., 2016).

It is the purpose of our experimental intervention study to investigate the application of a neurofeedback training programme designed to enhance executive working memory of ADHD students. To measure executive working memory, we used N-Back Working Memory test (Kane et al., 2007; Engle & Kane, 2004) and Wechsler Memory Scale-III (WMS-III) (Wechsler, 1997b; Axelrod, 2001). Furthermore, we included EEG-based alpha band as an important brain-related outcome variable (Zoefel, Huster & Herrmann, 2011). For our sample of ADHD students, who have to get used to attention control in many respects, we expected growing external controls during storage and use of information.

Methods
In this study, we designed an experimental $2 \times 2$ with an active control group and focused on the differences between the neurofeedback and control group regarding the effectiveness of the
intervention. For the CG, an alternative training program and memory education CD were provided to improve alpha band, but with a different content.

**Participants**

While recent studies have shown that neurofeedback enhances working memory function in children and adolescents, it is unknown whether the same results can be achieved in ADHD students. Our study evaluated whether neurofeedback training can enhance working memory function and improve alpha band in ADHD Chinese students with conditions such as gender or education level. Participation was voluntary, ADHD students at a Chinese psychiatry clinic, and the confidentiality of responses was assured. There were no differences concerning age (EG: M= 10.41, SD = 2.16; CG: M= 10.53, SD = 2.21), sex and grade (education).

For the neurofeedback group, we implemented a 5-week neurofeedback training programme to improve alpha band and working memory function in ADHD students below 15 years of age (7-14 years). We selected groups of 6 ADHD students with different genders and education levels separately to join the two groups. Two of these participants from the training group and three from the CG withdrew from the study. Finally, we assigned participants, the sample invited of 24 ADHD students with different genders or education levels, to a neurofeedback training group (n = 10) and an active CG (n = 9). We emphasized the importance of correct and honest responses and the main aim of the study to learn more about training development among our participants.

**Neurofeedback training programme**

The therapy effects of neurofeedback training programme have been shown for kinds of neurological and psychological disorders, and it has proven capabilities to improve some cognitive abilities (Escolano, Aguilar & Minguez, 2011). Although several studies have reported the positive effects of neurofeedback training in some areas, there is still no a successful neurofeedback training to improve working memory. In neurofeedback training systems, electroencephalogram (EEG) is the most common way of recording the waves. Our study slightly modified and used a neurofeedback training program similar to that proposed by Klimesch in 1999. The intervention group participated in a 5-week neurofeedback program (two 35-min sessions per week) in a school classroom. We informed the ADHD students about the procedure and the treatment of their data. Also, we used a cover story to inform the ADHD students who would attend a training session to learn something about training programmes in previous studies.

**Working memory function and EEG-based alpha band assessment tools**

**N-Back test**

We used the test N-Back to improve working memory as indicator of executive working memory (Kane et al. 2007; Wang et al. 2014). This exercise, 4 or 5 days (a week) daily for 80 minutes, improves working memory and fluid intelligence. The part Dual of this exercise means that participant reminds two different stimulus, including location object and sound of alphabet pronounced. The part N-Back shows that several previous steps must be remembered for decision-making and responding similarity of location or sound. The reliability and validity of the scale have been supported in previous studies. We obtained a Cronbach's alpha coefficient of 0.82 for the scale.

**Wechsler Memory (Direct Numbers)**

We used the Wechsler Memory Scale (WMS-III) of the working memory questionnaire as other indicator of executive working memory. While the scale N-Back reflected the improvement working memory and fluid intelligence, the WMS measured short-term memory by measuring rote memory, accuracy and movement of thinking patterns. Direct data measure rote memory, and reverse data show the ability to focus, patience and flexibility. The subtest was performed in two stages. In the first step, participants had to remember numbers heard and tell the given numbers at the end of each row in the same order. In the second step, the numbers were presented again in auditory form, but in reverse. The reliability of subscales of WMS was calculated by the Split Half and intra-rater methods for the sub-tests.

**EEG-based alpha band**

Neurofeedback device used in this study was the model FlexiComp Infiniti, 10-channel system of the company TAT Technology in Canada, including 110 MB and 200 gr of weight, sampling frequency 2048 samples per second, external sensors and automatic calibration and sensors compatible with memory card and PC connectivity via optical fiber, ability to install a set of the software Biograph Infiniti, developer tools, EEG, and ability...
to record data. This device is high-quality used for research work. There was an active electrode in area FCz and two electrodes (reference and grand) on ears, and filters were automatically set on the alpha band (8-12 Hz) and threshold. Alpha went up by one's ability to get points.

Results
We invited 24 ADHD students below 15 years of age (7-14 years), of whom 10 (97.33 average IQ, 56.2% parents literacy) completed the 5-week training assessment in the EG, whereas 9 of the 24 participants (97.31 average IQ, 59.4% parents literacy) in the CG. In this study, working memory function parameters and balance indicators was measured for each participant. Table 2 and Table 3 show baseline differences between the CG and the EG in respect of the variables IQ and parents literacy. Further, we can result that male participants attained more positive results than female did.

Table 1 shows the correlations between the dependent variables (N-Back test, Wechsler Memory test and EEG-based alpha band) at time 1 and time 2. With respect to the amount of pre training, the scores levels were the poorest. In the EG, the Wechsler Memory test showed a significant increase from 4.16 ± 1.46 to 10.09 ± 2.02, the N-Back test showed a significant increase from 6.14±2.43 to 13.91±1.24, and the power of alpha from 2.31±1.25 to 3.6±2.02. As can be seen in the EG, the post-training results for all the indicators are significantly different after 5 weeks compared with the pre-training results (P<0.05), but no significant differences in the CG. The Wechsler Memory and N-Back test showed that working memory function increased in the EG. Further, the findings illustrates that neurofeedback training improved the alpha band and executive working memory in elementary and secondary students, ADHD patients between the EG and the CG. Our study in Table 2 compared the differences between time 1 and time 2, in detail, regarding parents literacy and IQ types for the EG and the CG. Our data illustrate that male ADHD students attained more significant differences than did female regarding the CG and the EG (Table 2). Table 3 shows the alpha results, agree with those reported by Escolano, Aguilar and Minguez (2011).

Table 1. The statistical difference and results with participants working memory function characteristics between the EG and the CG

<table>
<thead>
<tr>
<th></th>
<th>EG group (n = 10)</th>
<th>CG group (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before training</td>
<td>After training</td>
</tr>
<tr>
<td>Age</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Male</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N-Back test</td>
<td>6.14±2.43</td>
<td>13.91±1.24**</td>
</tr>
<tr>
<td>Wechsler Memory test</td>
<td>4.16±1.46</td>
<td>10.09±2.02*</td>
</tr>
<tr>
<td>EEG-based alpha band</td>
<td>2.31±1.25</td>
<td>3.36±2.06***</td>
</tr>
</tbody>
</table>

Paired t-test, *P-value<0.05; **P-value<0.01; ***P-value<0.001

Table 2. The N-Back test with different age, gender, parents' literacy and IQ results of the EG and the CG participants

<table>
<thead>
<tr>
<th></th>
<th>EG: n=10, age = 1041±2.16</th>
<th>CG: n=9, age = 10.53±2.21</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%  n</td>
<td>Before training</td>
</tr>
<tr>
<td>Relatively good parent literacy</td>
<td>56.2</td>
<td>8</td>
</tr>
<tr>
<td>Medium IQ</td>
<td>97.33</td>
<td>9</td>
</tr>
<tr>
<td>Age 7-11 years (elementary students)</td>
<td>60</td>
<td>6</td>
</tr>
<tr>
<td>Age 12-14 (secondary students)</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>Male</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>Female</td>
<td>50</td>
<td>5</td>
</tr>
</tbody>
</table>

* P<0.05, ** P<0.01
Table 3. The EEG-based alpha band with different age and gender results of the EG and the CG participants

<table>
<thead>
<tr>
<th></th>
<th>EG: n=10, age = 1041±2.16</th>
<th>CG: n=9, age = 10.53±2.21</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before training</td>
<td>After training</td>
</tr>
<tr>
<td><strong>Total alpha results (mean ± SD)%</strong></td>
<td>100</td>
<td>2.31±1.25</td>
</tr>
<tr>
<td><strong>Age 7-11 years (elementary students)%</strong></td>
<td>60</td>
<td>2.24±1.42</td>
</tr>
<tr>
<td><strong>Age 12-14 (secondary students)%</strong></td>
<td>40</td>
<td>3.15±1.06</td>
</tr>
<tr>
<td><strong>Male %</strong></td>
<td>50</td>
<td>3.11±1.18</td>
</tr>
<tr>
<td><strong>Female %</strong></td>
<td>50</td>
<td>3.24±1.12</td>
</tr>
</tbody>
</table>

Paired t-test, *P-value<0.05; **P-value<0.01; ***P-value<0.001

**Discussion**

As the educational level of the population increases, ever more ADHD students should be actively engaged in regular neurofeedback training to enhance working memory function and alpha band. Bink et al. (2015) confirmed that a 25-week neurofeedback training programme, with two to three training sessions every week, decreased behavior problems in adolescents with ADHD symptoms. Neurofeedback therapy may be on means of attention control. However, in line with numerous trial studies, our study revealed that Neurofeedback therapy is effective for elementary and secondary ADHD students.

According to our data results, neurofeedback training programme can improve alpha band in elementary and secondary ADHD students. In our study, 5-week neurofeedback training was conducted, aiming to improve the working memory function and alpha band of Chinese ADHD students. The results of our study proved that neurofeedback therapy is beneficial for ADHD children, thus, psychiatry clinics should promote neurofeedback for ADHD students to boost their attention control quality.

In literature review of our study, similar researches were found with low-age and adolescence students in the community that reported results similar to findings of our study. The researchers also focused on low-age and adolescence students and used different methods of intervention; furthermore, we applied all ADHD students with characteristics such as IQ and parent literacy.

In this study, we proved the different indicators with other clinical researches to evaluate the body working memory function and alpha band. We had limitations to use all the indicators to evaluate EEG-based alpha band, however, the indicators of our study were sufficient to show the differences between the CG and the EG. Additionally, readers can interpret our results with considering following two limitations: a) Our study has not considered differences between the CG and the EG, including differences in family history, Asia and Europe ADHD students; b) other limitation in our study was sample size. To invite a number of participants to join the EG and the CG for our study, time and budget constraints lead to limit the sample size.

According to our data, neurofeedback training programme can enhance working memory function and alpha band in elementary and secondary Chinese ADHD students. Thus, we can conclude that: 1) Regular neurofeedback therapy, such as neurofeedback training programme, enhances the alpha band in low-age and adolescence ADHD students; 2) Training outcomes significantly are affected by gender and age in elementary and secondary Chinese ADHD students. Lower age students (elementary students) attained more positive results than higher age students (secondary students), and male students attained more positive results than female.

Regular neurofeedback therapy should be one way of improving attention control and memory. Our study demonstrated that after 5 weeks of neurofeedback training, ADHD students who were lower age or male attained greater improvements in working memory function than did higher age or female ADHD students. We suggest that future researches can use large sample size and participants consistent in IQ and parents literacy types to obtain more accurate information. Also, they can consider differences among the CG and the EG regarding family history, Asia and Europe ADHD students. Finally, we propose that enhancing the working memory...
function and alpha band of elementary and secondary ADHD students is essential to improving attention control and improving ADHD students’ quality of education.

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