The Neural Mechanism of Working Memory Training Improving Emotion Regulation

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Abstract. Thirty-six patients with high anxiety were recruited. The subjects were divided into working memory training group and control group in a voluntary and random manner, with 18 individuals in each group. The training group was trained for 21 days of working memory, and the control group was not trained for working memory. The subjective emotion ratings and the ERP indicator late positive potential (LPP) of the two groups of participants were recorded, under three experimental conditions (watching negative images, cognitive reappraisal, attentional distraction). It was found that the LPP amplitude reduction was significantly higher for training group than control group specifically in the condition of cognitive reappraisal. This study showed that working memory training can improve the ability cognitive reappraisal and can be a potential intervention for promoting the emotional regulation of individuals with high trait anxiety.

Keywords: Memory training · Emotional regulation · Neural mechanism · Dual N-back · Anxiety

1 Introduction

Working memory is the ability to temporarily maintain and manipulate information as individuals perform cognitive tasks [1]. It plays an important role in human cognition. Emotion regulation affects deeply in our mental health and the emotional regulation strategies (including cognitive reappraisal and distraction [2, 3] have a certain correlation with life satisfaction, positive emotions, depression, anxiety.

Some studies have established that working memory ability and emotion regulation are connected. Working memory capacity could control an individual's attention, which is very important for emotional regulation [4]. Some scholars had found that the emotional regulation framework of selection, optimization and compensation required internal resources, and this required people's ability to control attention and working memory [5]. Other researchers directly reported that in a down-regulation task,

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participants with higher working memory capacity experienced and expressed fewer emotional responses; and the participants with lower working memory capacity were more susceptible to emotional contagion and less successful in applying reappraisal strategies [6].

Previous study had found that working memory training could improve individuals' working memory capacity [7], and could affect other cognitive functions associated with working memory, such as various executive functions and attention control [8–10]. The effect extended even to the emotional realm. Studies had found that extensive working memory training could weaken the anger, exhaustion and depression of the participants [11]. and improved the heart rate variability (HRV), which could reflect the ability of emotional regulation [12].

In recent years, more and more researches focused on the relationship between emotional regulation and anxiety. A meta-analysis found that infrequent use of appropriate emotional regulation strategies leaded to more anxiety [13]. Neurological studies related to emotional regulation found that poor regulation was associated with higher levels of anxiety [14, 15].

A previous study showed that working memory training could reduce the anxiety level of anxiety patients and healthy individuals. Improvement of working memory ability could improve the performance of high-anxiety individuals in various cognitive tasks [16]. Individuals who had working memory training with high-task participation, had a significant decline in their trait anxiety compared to before [17]. But it's not known whether working memory training improves emotional regulation in individuals with high anxiety, although it has been shown in healthy people. Cognitive reappraisal and attentional distraction are commonly used emotional regulation strategies. Compared with distraction, reappraisal is considered to be a more adaptive emotional regulation strategy and was considered to be helpful to relieve anxiety [18, 19].

ERP is a special brain evoked potential with excellent temporal resolution and accurate capture of rapid emotional responses. It is ideal for studying the temporal processing of emotions. Previous ERP studies of emotional regulation had found that late positive potential (LPP) was a good electrophysiological indicator of emotional regulation [20]. The LPP amplitude of the negative emotion pictures is significantly larger than the neutral ones [21]. Besides, LPP amplitude decreases during emotion regulation [22], and thus LPP could be used as an emotion regulation index [23–25].

Based on the existing research, this study would like to explore the effects of working memory training on emotional regulation in high-anxiety individuals, using both behavior and neural indictors The training tasks was a dual n-back working memory task based on smartphone APP. And the regulation included two strategies of reappraisal and distraction. We hypothesized that working memory training could improve the adaptive emotional regulation i.e., cognitive reappraisal ability of individuals with high anxiety, which was shown in the decreased LPP during reappraisal in training group.

2 Method

2.1 Participants

Participants were selected by means of the trait sub-scale of State Trait Anxiety Inventory (STAI-T) A total of 36 individuals with STAI-T score higher than 50 were recruited. All the participants were college students and graduate students.

Participants were randomly assigned to training group18 (5 males and 13 females) and control group 18 (7 males, 11 females). The age distribution of the subjects was 18–26 years old, with an average age of 21.47 ± 2.408. Gender differences between the different groups were not significant, $\chi^2(1) = 0.50$, $p = 0.48$; Age differences were not significant, $F(1,34) = 2.654$, $p = 0.113$.

All participants signed an informed consent form and received a certain amount of compensation. The study was approved by the Ethics Committee of the Institute of Psychology of the Chinese Academy of Sciences.

2.2 The Task of Working Memory Training

The Task of Training Group

The task of the experimental group in this study was working memory training, which used a dual n-back task. The dual n-back task used the feature attributes of color and position. This task was nested in a self-developed Android app for mobile devices with Android 5.0 and above [26].

The training material was a nine-square grid with a color block. The training task was to ask the subjects to remember the color (one of the four colors of red, yellow, green and blue) and the position (3 × 3, 9 positions) of the color block appearing in one of the nine squares. Participants needed to determine whether the color and position of the current patch were the same as the color and position of the nth patch forward. If they were the same, the corresponding button according to the color or position at the bottom of the screen should be pressed; if they were different, the screen button should not be pressed.

In the n-back task, the number of levels was the number of n. Level 1, the participant only needed to compare whether the color and position of the current color block were the same as the previous one. Level 2, the subjects needed to compare whether the current color block color and position were the same as the second one before, and so on. The total number of trials per group was 20 + n. In each trial, the color block was shown for 500 s and the blank screen was 2500 ms. The target test of color and position was random within 4–6 ranges to reduce the use of the guessing strategy of the subjects. Each subject needed 30 training sessions per day, about 30 min. Participants were required to complete 21 days of training within 30 days. These 21 days can be continuous or dispersed.

When the subjects training, the APP's interface would feedback the following information immediately: hit, missed or missed. So that the subjects could quickly become familiar with the rules and improve the training motivation. After the training, the APP interface could feedback the number of hits, missed hits, misses, and total score of the training. Total score = (hit number/target number) × (correct rejection number/non-target number) × 100%. The total score was (0–100). This APP adopted an adaptive paradigm, because adaptive APP was considered to be a necessary condition for improving training level and obtaining far transfer effects [27]. If the scores of the two consecutive groups are >80, the APP would automatically enter the next level; if the test scores were lower than 10 for two consecutive groups, then level would return to the previous level. Daily training would clear the historical scores, that was, the participants would be trained from the first level on each day.

The Task of Control Group
In order to eliminate the possibility that the APP working memory training task might be effective as a placebo, the subjects in the control group were also arranged doing something like a task. As an active control group, they received tweets of psychology and test fee twice a week without any working memory requirements.

2.3 The Task of ERP Emotional Regulation

There were three condition during emotional regulation task: watching negative emotional images, watching negative emotional images with cognitive reappraisal, and watching negative emotional images with attentional dispersion.

The first one was watching negative emotion images, without active emotional regulation strategies, which we called watching negative images condition (WNIC).

The second one was watching negative emotion images meanwhile using cognitive reappraisal, with active emotional regulation strategies, which we called cognitive reappraisal condition (CRC). Reappraisal was a cognitive-verbal strategy that alters the path of emotional responses by reconstructing the meaning of a situation.

The third one was watching negative emotion images meanwhile using attentional dispersion, with active emotional regulation strategies, which we called attentional dispersion condition (ADC).

According to the previous research [28], the guidance for WNIC was "Then you will see some pictures. Please watch each picture carefully and respond naturally." The guidance for CRC was "Then you will see some pictures. Please watch each picture. At the same time, we hope that you can review the picture with an analytical eye, just like watching a movie, or imagine that the picture is artificially synthesized by photoshop." The guidance for ADC was "Then you will see some pictures. When the picture appears, please pay attention to the non-emotional part of the picture, such as the hair, not the features of the face." The order in which the three conditional blocks appear was random for each subject. These tasks had exercises and were guided by main tests.

In the each viewing or regulation trial, a fixed point appeared first for 500 ms, followed by the instruction text of a certain condition for 1000 ms. Each negative picture was presented for 5000 ms. Participants needed to apply an emotional regulation strategy consistent with the instructions while watching the picture. Than the subjects needed to complete the 9-level score of emotional valence and arousal, valence 1 (very negative) to 9 (very positive); arousal 1 (very weak)) to 9 (very strong) for this picture. There were 180 negative pictures (560 × 420 pixels) from the International Affective Picture System [29]. 90 for the pretest, 90 for the posttest. The images had no significant difference in valence and arousal between the images the pretest and the posttest. Every 90 pictures were randomly assigned to the 3 conditions, 30 for WNIC, 30 for CRC, 30 for ADC. There was no significant difference in valence and arousal among the 3 conditions.

The subjects sat in the soundproofing laboratory to watch the pictures. Images were presented in the center of the screen using E-Prime 2.0 presentation software. The line of sight was 60 cm and the viewing angle was $9.46 \times 7.13°$.

2.4 Procedures

After the successful recruitment of the training group and the control group, the participants entered the laboratory to receive the emotion regulation ERP task. Then the training group was trained for 21 days of working memory, and the control group did not perform working memory training. After 30 days, all subjects re-entered the laboratory and received the emotion regulation task again. Experimental flow chart was as follows (see Fig. 1).

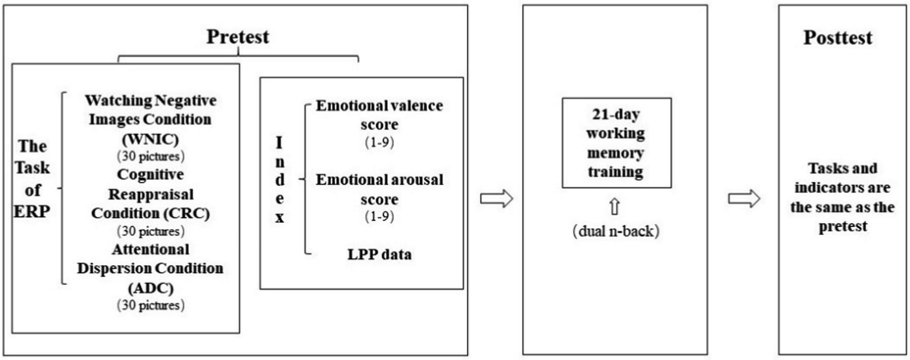

Fig. 1. Experimental flow chart

2.5 EEG Recordings

ERP can be used as a sensitive indicator of emotion. We chose late positive potential (LPP) and a time window of 350–800 ms to assess the impact of work memory training tasks on emotional regulation. 64 electrodes placed on an elastic scalp (Neuro Scan 4.5) were used to record the electrical activity. According to the distribution of the topographic map, we selected the electrodes of P5, P3, P1, PZ, P2, P4, P6, P8, PO5, PO3, POZ, PO4, PO6. In order to reduce the type 1 error, we averaged the data of these electrode points. All electrode impedances were maintained below 5 KΩ. EEG was sampled at the rate of 1000 Hz, by a 0.05- to 100-Hz band-pass amplifying. A low-pass filter at 30 Hz (12 dB/oct) were used to filter the EEG data. There was a baseline correction of 500 ms pre stimulus. According to the images' onset in the emotion regulation task, ERP data were segmented for each condition from −500 ms to 2,000 ms. Trials containing activity over ±80 μV were excluded from averaging. Each block had at least 25 effective trials.

2.6 Data Analysis

All these statistical analyses were conducted with SPSS Version 20.0 software. Firstly, the study analyzed the variance analysis with repeated measures for group (2) × condition (3) × time (2), and analyzed the main effect and interaction effect Then we conducted independent sample t-test for the difference between the pre-test and post-test of the 3 conditions, to determine whether there was significant difference between groups or conditions.

3 Result

3.1 Emotional Valence and Arousal

Valence

Repeated measures analysis of variance for the valence score showed that the conditional main effect was significant, $F(2,68) = 151.5$, $p = 0.00$, $\eta p2 = 0.817$. Post hoc comparisons showed the scores of WNIC ($M = 3.338$, $SE = 0.100$) were significantly lower than the scores of CRC ($M = 4.335$, $SE = 0.089$), and the scores of ADC ($M = 4.716$, $SE = 0.079$). $p < 0.05$. Different conditions and different groups, the average value of the test before and after was shown in the Fig. 2.

The main effects of the groups were not significant $F(1,34) = 0.748$, $p = 0.393$, $\eta p2 = 0.022$, and the interaction between the groups and conditions was not significant $F(1,34) = 2.887$, $p = 0.098$, $\eta p2 = 0.078$.

Arousal

Repeated measures analysis of variance for the arousal score showed that the conditional main effect was significant, $F(2,68) = 55.398$, $p < 0.001$. Post hoc

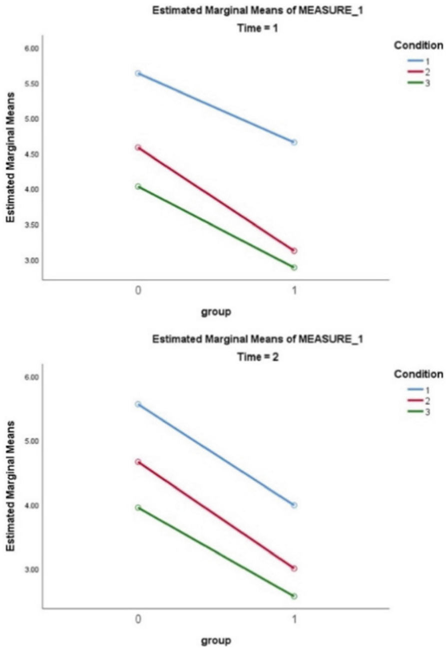

Fig. 2. The means of emotional valance

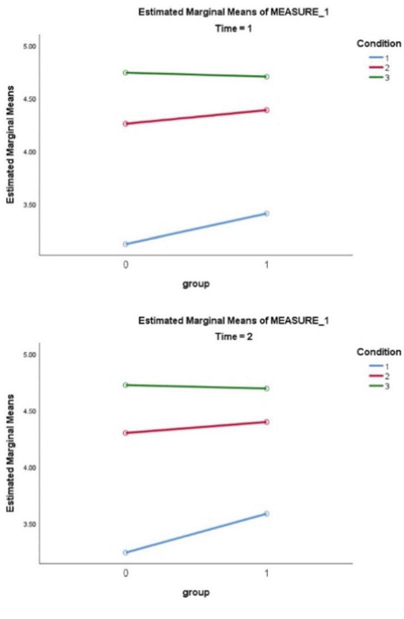

Fig. 3. The means of emotional valance

comparisons showed the scores of WNIC(M = 4.959,SE = 0.215) were significantly higher than the scores of CRC (M = 3.842, SE = 0.212), and the scores of ADC (M = 3.357, SE = 0.209), $p < 0.05$. Different conditions and different groups, the average value of the test before and after was shown in the Fig. 3.

The control group (M = 4.737, SE = 0.271) was significantly higher than the training group (M = 3.369, SE = 0.271). The interaction between the group and the condition was not significant, $F(2,68) = 0.576$, $p = 0.565$. The interaction between the group and time was not significant, $F(2,68) = 0.823$, $p = 0.371$.

3.2 LPP Indicator

For the group (2) × condition (3) × time (2), the variance analysis with repeated measures was performed. The main effect of condition was significant, F = 3.922, p = 0.03, ηp2 = 0.192.

Post hoc comparisons showed that the LPP scores were as follows: WNIC (M = 2.441, SE = 0.197), CRC (M = 2.472, SE = 0.210), ADC (M = 2.065, SE = 0.184). The negative images were significantly higher than the attentional dispersion (p = 0.017), and the cognitive reappraisal was significantly higher than the attentional dispersion (p = 0.013).

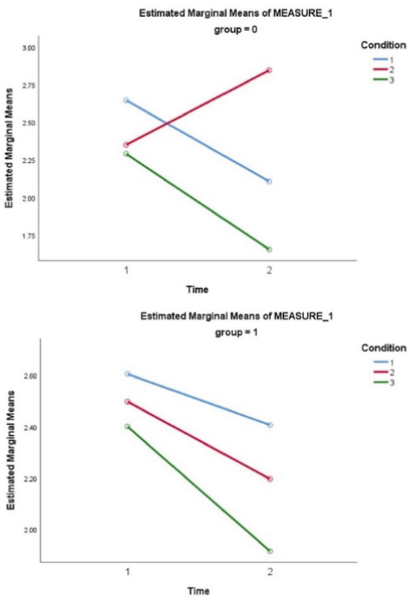

Fig. 4. The means of LPP

The main effect of time was marginal significant, F = 3.944, p = 0.055, ηp2 = 0.104. Pairwise comparisons showed that the pretest (M = 2.465, SE = 0.209) was greater than the posttest (M = 2.187, SE = 0.173).

The interaction of time and condition was significant, F = 5.199, p = 0.11, ηp2 = 0.240. The triple interaction of group, condition and time was significant, F = 4.440, p = 0.020, ηp2 = 0.212.

The LPP differences between pretest and posttest of WNIC, CRC and ADC were calculated. The difference = Pretest-Posttest. This study compared the difference of the 3 conditions. The results showed that only in the condition of cognitive reappraisal, the difference of LPP of the training group reached a significant level, $t(34) = -2.082$, $p = 0.045$. But, this was not observed significantly in the other two conditions (watching negative images and attentional dispersion).

The estimated marginal average of the control and training groups was shown in Fig. 4. The figure showed, for the working memory training group, the LPP value of the post-test was decreased regardless of the pre-test situation. The low LPP value reflected the low response to negative images. This showed that after working memory training, the ability to adjust emotions had become better.

4 Discussion

The current study examined the effect of working memory training on emotional regulation in anxious individuals. For the different emotional regulation strategies of high anxiety individuals, both cognitive reappraisal and attention dispersion are effective.

But, statistical analysis of LPP data showed that working memory training specifically enhanced the ability of individual cognitive reappraisal. Perhaps because cognitive reappraisal requires more participation of working memory, the working memory training can have more impact on this strategy of emotional regulation.

Analysis the neural mechanism of working memory improving the emotional regulation, we believe that working memory requires the participation of the prefrontal lobe. Through the training of working memory, the prefrontal lobe control ability is enhanced, thus changing the cognitive reappraisal of anxious individuals. The results of this study are consistent with the conclusions of an existing study that suggested that the refresh function of working memory may migrate to the trainee's cognitive reappraisal ability, thereby improving the trainee's emotional regulation ability [30].

Further analysis found that the theoretical structure of working memory and emotional regulation have certain similarities. The core function of working memory is to store and process information. In addition to the short-term preservation of information, it also involves processing, such as updating, suppressing, and shifting. The process of emotional regulation is similarities. Emotional regulation requires suppression of bad emotional information, while constantly updating and transforming emotional value information. Therefore, the working memory process can be seen as the cognitive basis of emotional regulation.

How people use emotional regulation strategies to regulate emotions is important for understanding the causes, maintenance, and treatment of anxiety. We found that working memory training can improve the emotional regulation of anxious individuals and promote the use of adaptive cognitive reappraisal, so it is a potential intervention.

However, the number of participants is small, and only subclinical individuals with high anxiety were examined. Future research needs to further investigate the application of training in clinical groups to prove the authenticity of emotional benefits of working memory training.

5 Conclusion

Working memory training can significantly reduce the LPP of cognitive reappraisal in high anxiety individuals, and specifically improve the effectiveness of individual's cognitive reappraisal ability, indicating a promising intervention for anxious people.

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