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Improvement of Working Memory Performance by Parietal Upper Alpha Neurofeedback Training

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Abstract

Working memory (WM) is a part of human memory, which is the ability to maintain and manipulate information. WM performance is impaired in some neurological and psychiatric disorders such as schizophrenia and ADHD. Neurofeedback training is a self-regulation method which can be used to improve WM performance by changing related EEG parameters. In this paper, we used Neurofeedback training to improve WM performance in eight healthy individuals. The protocol consisted of individual upper alpha up-training in parietal brain lobe of participants, which is a part of the fronto-parietal network and related to the central executive functions of WM. Power of individual upper alpha band in channels P3 and P4 was used for Neurofeedback training in five sessions. 2-back working memory test was used to measure WM performance before and after the course. Results indicated the success of subjects in Neurofeedback training and the enhancement of individual upper alpha power in both channels (P3 and P4). Results of the 2-back test indicated that improvements in response accuracy and response time of test were significant. Also, the correlation between the change in power of individual upper alpha band in channel P3 and change in response time of 2-back test was significant approximately (r= -0.571 and P=0.076). In conclusion, it seems that individual upper alpha Neurofeedback up-training in parietal lobe is an appropriate method to improve WM performance.

Keywords: Individual upper alpha band; N-back test; Neurofeedback; Parietal lobe; Working memory performance.
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1. Introduction

Working memory (WM) refers to the ability to maintain and manipulate information over short periods of time in the context of concurrent processing and can be subdivided into the initial encoding of information, maintenance and retrieval of WM items [1]. Short-term memory is only consisted of maintaining information and some studies defined it as a part of WM [2]. WM performance is impaired in some neurological and psychiatric disorders such as Alzheimer, schizophrenia and ADHD.

There are some ways to improve WM performance and this matter is an interest for researchers. EEG biofeedback or Neurofeedback is one of these ways. In this method person tries to regulate his EEG parameters by receiving multimedia feedback from values of these parameters. This procedure takes some minutes in a session and psychiatrist identifies the number of its sessions. Researches indicate that WM performance was improved in healthy or patient people by enhancing or attenuating some EEG parameters through Neurofeedback training [3].

One of the problems in the topic of Neurofeedback training to improve WM performance is the selection of Neurofeedback protocol or in other means, selection of EEG parameter and location of signal recording. Another problem is the selection of WM test which should indicates accuracy and speed of responding, before and after the Neurofeedback course. In this paper we tried to use the best Neurofeedback protocol to improve WM performance. In addition, we tried to select the most appropriate WM test for evaluating WM performance. Then signal processing and statistical analysis were done to identify trainability of the protocol and quantify WM improvement.

2. Materials and Methods

A) Protocol Design

The researches of Klimesch indicate that alpha band activity and especially upper alpha band activity is related to WM performance [4]. Also the relation between memory and alpha activity in parietal and occipital brain lobes has been demonstrated in many researches [5]. Escolano et al used channels P3, P4, Pz, O1 and O2 in these two areas for upper alpha Neurofeedback up-training (enhancing upper alpha band activity) in order to improve WM performance [6]. On the other hand, according to the importance of fronto-parietal network in central executive functions of WM [7], it seems the parietal lobe is a better region than occipital lobe for selecting channel. In a Neurofeedback research, parietal channels were used for enhancing upper alpha band activity [8]. So we employed a protocol consisted of enhancing upper alpha power in P3 and P4.

An important problem in upper alpha up-training is selecting this band individually. On the basis of Klimesch research [4], everyone has his own alpha band, which can be identified according to the individual alpha peak frequency (IAF). IAF is the frequency at which signal spectrum reaches its maximum value within 7.5-12.5 Hz range in eyes-closed condition. Typically, the alpha wave dominates in eyes-closed condition, and as shown in Figure 1, a salient rise and fall is seen in the alpha range of spectrum. At a certain frequency, the spectrum reaches its maximum value in this range. This frequency, which is dependent on the subject, is IAF. Individual alpha band is defined as a frequency interval of [IAF-4 IAF+2]. The range of [IAF-4 IAF-2] is defined as individual lower alpha band 1, [IAF-2 IAF] is defined as individual lower alpha band 2 and [IAF IAF + 2] is known as individual upper alpha band.

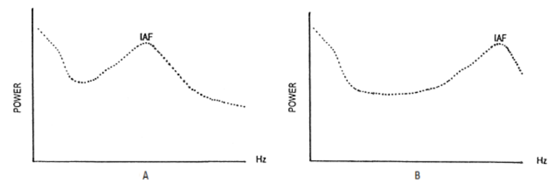


Fig. 1. EEG power spectral density in eyes-closed condition for two persons with different IAF. (A) One with low IAF (8 Hz). (B)Another with high IAF (11.5 Hz).

Eight healthy participants (five men and three women) contributed in this project. They participated in 5 Neurofeedback sessions consisted of 15 minutes (three 5minutes parts) individual upper alpha up-training. The Neurofeedback course duration ranged between 10 and 15 days (2 to 4 days between continuous sessions). Two minutes rest signal was recorded in eyes-closed condition, before and after each session, and we named them as rest1 and rest2 respectively. These rest signals were recorded in the same Neurofeedback channels (P3 and P4). Rest1 was used to find IAF. According to the possibility of having more than one peak in the alpha range, IAF has been introduced as weighted frequency average in this range (Equation 1) [4].

$$IAF = \frac{\sum_{f=f1}^{f2} p(f) \times f}{\sum_{f=f1}^{f2} p(f)} \quad (1)$$

In Equation 1, f1 and f2 are 7.5 Hz and 12.5 Hz respectively and P(f) is the power spectral density of rest1. So the value of IAF in rest1 has been used to find individual upper alpha band for Neurofeedback training.

An important point is that every channel has its own IAF. So individual upper alpha band has been selected for each channel individually (P3 and P4). Also IAF may change during Neurofeedback course, because of the possibility of mental changes in the participant or Neurofeedback effect [6]. Therefore, the IAF of rest 1 was calculated in every session and Neurofeedback training of each session was done based on session's IAF.

B) Data Recording

PROCOMP2 amplifier and BIOGRAPH INFINITI 5 software (Thought Technology Ltd., Montreal, Quebec, Canada) were employed for signal recording and Neurofeedback training. Electrode impedances were maintained below 10 kΩ. Power line noise was eliminated by 50 Hz band-stop filter in the device and sample rate of signals is 256 Hz.

Experiments were administered in a small isolated room in Atieh Clinical Neuroscience Center (Tehran, Iran). Figure 2 shows the setting of the experiments.

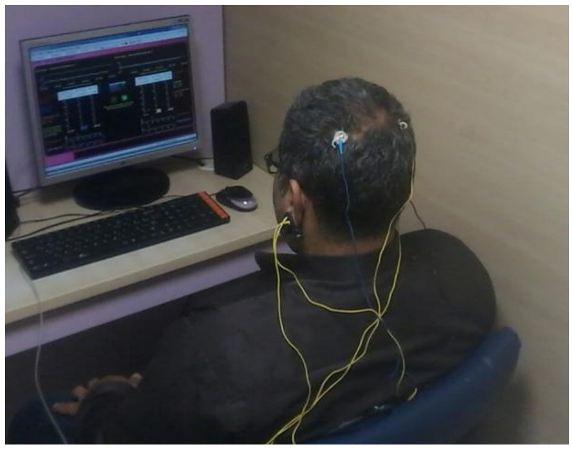


Fig. 2. One of the subjects in the Neurofeedback training condition.

C) Neurofeedback Training

Figure 3 shows a window used for Neurofeedback training in BIOGRAPH INFINITI 5 software.

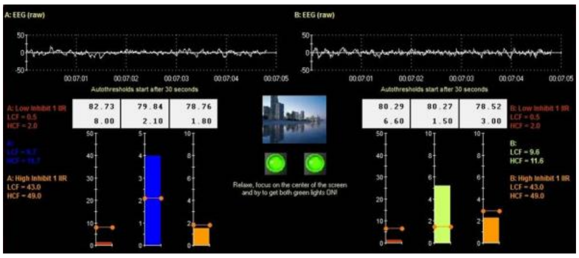


Fig. 3. Neurofeedback training window.

According to the Figure 3, the study subject should run the animation in the center of window by selecting mental strategies. The animation continues until two lights (below it) are turned on. Every light is related to one channel and it becomes turned on when the power of individual upper alpha band becomes more than threshold level. Valuation of the thresholds is based on regulating the time percentage that power is more than threshold. This percentage is adjusted to 80% of time approximately. The subject should limit his mental strategies in the duration of Neurofeedback course to employ the best strategy to success in Neurofeedback [9].

D) Working Memory Test

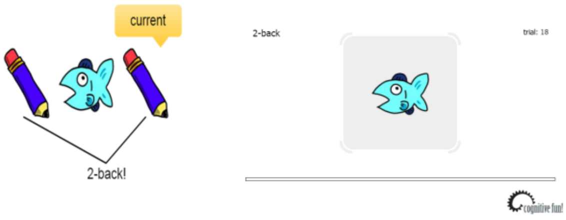
An appropriate WM test should be employed before and after the Neurofeedback training course to identify WM performance and its change during the course. As mentioned in introduction part, we want to measure accuracy and speed of WM performance to evaluate it. In this project, N-back working memory test was used to access the above aims. This test is a good case for evaluating executive WM [10].

In this test, some pictures are presented to the subject swiftly and continuously. When the current picture repeats what he saw N pictures ago, he should respond and click. Response accuracy (in terms of percentage) is defined based on number of hits, commission errors (false alarms) and omission errors (misses). Equation 2 shows calculation of response accuracy.

$$Response\ Accuracy = \frac{hits}{hits + commission\ er. + omission\ er.} * 100 \quad (2)$$

Response time is defined as the mean of time periods that subject clicks (the time between presenting picture and clicking). High response accuracy and low response time indicate good WM performance.

In this project, N-back test with N=2 (2-back test) was used. Fifty continuous pictures with 2 seconds presentation for each picture, was presented to the subject. The test was done in www.cognitivefun.net website. Figure 4 (A) shows how this test works and Figure 4 (B) shows the test setting.



(A) (B)

Fig. 4. (A) How 2-back test works. (B) The space of performing 2-back test.

E) Signal Processing

All of the signals were filtered between 0.4 and 45 Hz with a sixth-order Butterworth band-pass filter [11]. In addition, high amplitude noisy parts of the signals were eliminated by thresholding.

Power spectral densities of signals were obtained by welch method with 4 seconds Hanning window and 50% overlapping.

3. Results

The analyses were done in MATLAB 2012a and IBM SPSS Statistics 22.

In order to find the effect of Neurofeedback session on individual upper alpha power (Neurofeedback parameter), this parameter in 1st and 15th minutes of Neurofeedback signal was obtained in all sessions. A 5-level factor was employed to distinguish sessions. Because of the normal distribution of these measures and equality of variances, 2-way repeated measures ANOVA was used for investigating the effect of session on Neurofeedback parameter. This analysis indicates significant increment of Neurofeedback parameter during session time in both channels (P_{P3}=0.037, P_{P4}=0.016).

In order to find the effect of Neurofeedback course on Neurofeedback parameter, the correlation coefficient between the number of training part, i.e., 1 to 15 (every Neurofeedback session has 3 parts. So there are 15 Neurofeedback parts) and measure of Neurofeedback parameter in relevant part was calculated. Neurofeedback parameter in each part is the averaged value from all subjects. According to the normal distribution of both sides of correlation in both channels, pearson correlation coefficient was used. These coefficients for channel P3 and P4 were 0.507 (P=0.027) and 0.55 (P=0.017), respectively. The P values indicate that the correlation coefficients are greater than 0 significantly (for both channels).

In Figures 5 and 6, the values of Neurofeedback parameter in the training parts in terms of the part number is drawn up for channels P3 and P4, respectively. Linear regression and its equation can be seen in the Figures. Statistical analysis indicates that the relation between Neurofeedback parameter and part number can be approximated by linear regression for both channels significantly (P_{p3}= 0.054 and P_{p4}= 0.034).

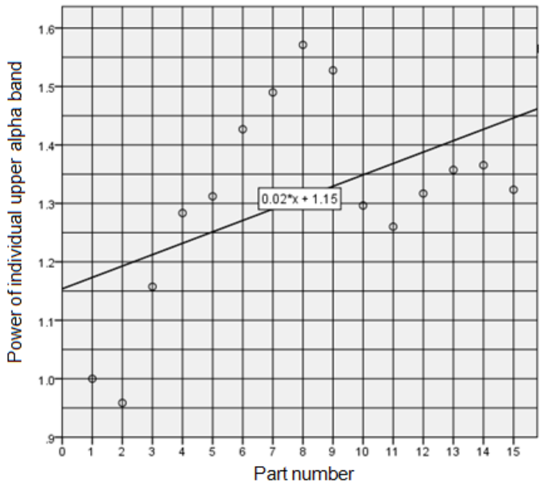


Fig. 5. Values of Neurofeedback parameter in training parts in terms of part number, and linear regression with its equation (channel P3).

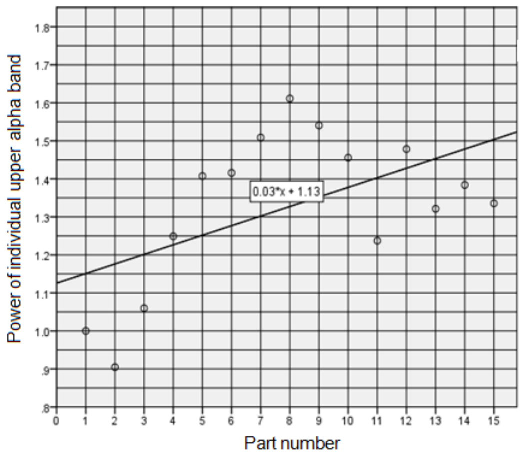


Fig. 6. Values of Neurofeedback parameter in training parts in terms of part number, and linear regression with its equation (channel P4).

The results of 2-back test were analyzed statistically. According to the normal distribution of response accuracy, one-tailed paired t-test was used to investigate the change of this parameter after Neurofeedback course. The result of test indicates a significant increment in response accuracy after Neurofeedback sessions (P=0.005) (Significance level : 0.05). Response time did not have normal distribution. So the non-parametrical one-tailed paired wilcoxon test was used to investigate the change of this parameter after Neurofeedback course. The result of test indicates an approximate significant decrement in response time after Neurofeedback sessions (P=0.055).

Finally, the spearman correlation coefficient between the change of Neurofeedback parameter in channel P3 and the change of response time of 2-back test was less than zero, approximate significantly (r = -0.571 and P = 0.076). In this case, the change of Neurofeedback parameter means the difference of it between 1st minute of Neurofeedback signal in session 1 and 15th minute of Neurofeedback signal in session 5.

4. Conclusion

In this research we tried to use the best Neurofeedback protocol for improving WM performance. We used individual upper alpha up-training in parietal lobe. Evaluation of WM performance was done by n-back WM test, before and after the Neurofeedback course.

The results indicate that the trainability of the protocol was good and subjects enhanced their individual upper alpha power during session and course. Response accuracy and response time of 2-back test was improved significantly after the Neurofeedback course. Therefore, WM performance is improved. In addition, there is an approximate significant correlation between the change of Neurofeedback parameter in channel P3 and the change of response time. It confirms that WM improvement was occurred by Neurofeedback training. This correlation can be due to the stronger relation between neural activity in channel P3 and WM.

Using other parameters of EEG for Neurofeedback training and performing more Neurofeedback sessions can be done in future.

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