Enhancing Innovation Behaviour of Enterprise Personnel through Neurofeedback Training Based on Electroencephalography

Ye Zheng[1,2*]

ABSTRACT

This paper aims to develop a neurofeedback (NFB) training system to improve the innovation behaviour of enterprise personnel based on the electroencephalography (EEG). To this end, an NFB training system was designed to extract feature parameters from real-time EEG signals and generate feedback information. Based on the information, a structural equation model was constructed with 5 types of personalities as independent variables and the 3 aspects of innovation behaviours as the dependent variables. Then, 22 enterprise personnel were divided into the training group and the control group and invited to participate in an experiment of five training sessions. The comparison shows that the post-training innovative ability of the training group is much better than that of the control group. The conclusion sheds new light on personality theory in brain neurology, and the management research from the perspective of brain neurology.

Key Words: Neurofeedback (NFB) training, Electroencephalography (EEG), Innovation behaviour

DOI Number: 10.14704/nq.2018.16.3.1191 **NeuroQuantology 2018; 16(3):61-67**

Introduction

The innovation behaviour of personnel is fundamental to enterprise innovation. At present, both academic and business circles are looking for ways to motivate the behaviour. The innovation behaviour is affected by various factors, including but not limited to personal temperature, working environment, organizational culture and leadership style (Martins *et al*., 2003). The existing research on innovative behaviour is mainly inspired by social psychology, which holds that the behaviour of an individual depends on his/her inherent features and the surroundings (Yuan *et al*., 2010; LePine *et al*., 2001; Tierney *et al*., 1999). However, there is rarely any report on innovation behaviour of personnel from the angles of personality and neurofeedback (NFB).

Personality refers to the collection of relatively stable psychological features, including the thinking pattern, emotions and behaviours that seldom change with time. There are many ways to categorize the personality, such as 16 personality factors (pf) questionnaire, three-dimensional personality matrix, and big five personality test (Van *et al*., 1996). The difference in personality brings about varied values and thinking patterns, which in turn affect the innovation behaviour of each individual. The existing studies have shown that each kind of personality has its unique effect on innovation behaviour of enterprise personnel (Feist, 1998; Hur *et al*., 2014; Chiang *et al*., 2015). The innovation behaviour of enterprise personnel has been defined in many different ways.

Corresponding author: Ye Zheng
Address: [1]School of Humanities, Economics, and Law, Northwestern Polytechnical University, Xi'an 710072, China; [2]Education Center of MPA, Northwestern Polytechnical University, Xi'an 710072, China
e-mail ✉ lbxjbzy@nwpu.edu.cn

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Received: 26 January 2018; **Accepted:** 23 February 2018

For instance, Scott *et al*., (1994) considered it as a complex process from identifying the problem, seeking creative assistance, building a coalition, implementing new ideas, creating innovative prototypes, all the way to forming the commercial products/services. In light of this, the innovation behaviour of enterprise personnel is defined here as the process for personnel to find and produce innovative and useful ideas or things in enterprise activities, and support and develop new methods.

NFB is one of the most popular new approaches for improving innovation behaviour of personnel. It is a type of biofeedback that measures brain waves to produce a signal that can be used as feedback to teach self-regulation of brain function. In essence, the NFB is an operant conditioning paradigm where users learn to influence the electrical activity of their brain (Vernon *et al*., 2003). The NFB is commonly provided using video or sound, with positive feedback for desired brain activity and negative feedback for brain activity that is undesirable. The most common method to capture the NFB is electroencephalography (EEG), an electrophysiological monitoring strategy to record electrical activity of the brain (Heinrich *et al*., 2007). Research shows that the NFB may be a potentially useful intervention for a range of brain-related conditions. It has been used to alleviate pain (Maeda *et al*., 2005), addiction (Peniston *et al*., 1989; Scott *et al*., 2005; Arani *et al*., 2010), aggression (Arani *et al*., 2010), autism (Coben *et al*., 2010), depression (Linden *et al*., 2012), brain damage from stroke (Mihara *et al*., 2013), and trauma (Thornton *et al*., 2008). Over the years, the application of the NFB has permeated from the medical field to economics, management, and education.

In this paper, an NFB training system was designed to extract feature parameters from real-time EEG signals and generate feedback information. Based on the information, a structural equation model was constructed with 5 types of personalities as independent variables and the 3 aspects of innovation behaviours as the dependent variables. Then, the model hypotheses were verified through an experiment of 22 enterprise personnel and a contrast analysis between the training group and the control group. The results show that the innovation behaviour of enterprise personnel could be improved by adjusting some frequency band in the EEG.

Methods

Design

In our study, the enterprise personnel were divided into the NFB group and the control group. All personnel received five training sessions within the same period of time. The progress within each session is illustrated in Figure 1.

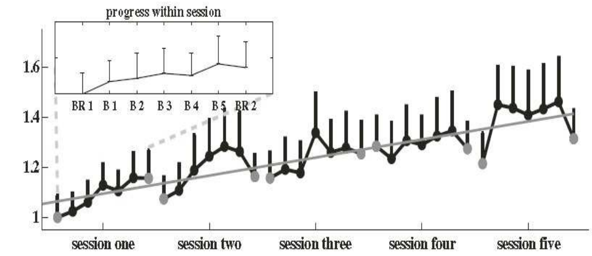

Figure 1. The progress within each session

The NFB training system (Figure 2) records the brain waves with the EEG.

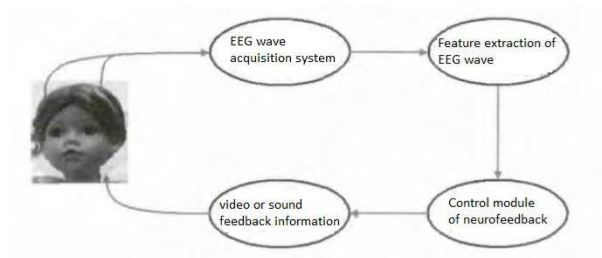

Figure 2. The structure of the NFB training system

First, the calibration measurement of electrooculogram was performed to detect the eye movement, and the base rate of 7 minutes was recorded. Second, the second base rate was recorded after five training sessions. To test the innovation ability, each individual received a mental test based on the first base rate at the start and the end of the experiment. The control group was tested in the same procedure to evaluate the effect of NFB training on innovative ability.

Participants

A total of 22 enterprise personnel were invited, including 12 in the NFB training group and 10 in the control group. The differences in age, gender, and education background were not considered in the experiment. The training group has 5 males and 7 females, all of whom are between 25 and 28; the control group has 5 males and 5 females, all of whom are between 24 and 27.

The members of the training group received 5-day NFB training, aiming to enhance the alpha frequency band and innovation behaviour. The members of the control group did not receive the training from day 2 to day 4. The author prepared an innovation behaviour questionnaire, including 47 questions, and a personality questionnaire. Scores were given to each person against two checklists. The purpose is to evaluate the effect of NFB training on innovation behaviour of enterprise personnel.

EEG-based alpha frequency band recordings

The NFB device consists of Ag/AgCl electrodes, an elastic cap with external feedback sensors, and sensors connectable to PC via optical fibres. The main technical specifications are as follows: sampling rate 1,000Hz, A/D conversion precision 16bit, input impedance>50MΩ, and noise level $\ll 2.5\ \mu Vp-p$.

For the ease of reading, the signals were amplified by a BrainAmp 32-channel system, sampled at the frequency of 1,024 times/second, analogue filtered between 0.1 and 50Hz, and stored at a sampling rate of 1,000Hz. The amplification is beneficial to feature extraction and feedback control of the EEG signals. The signals could be read from the EEG and further processed by a set of software programmed in Borland C++. The amplifier and impedance parameters can be configured in the software system.

In each NFB training, the user information was created and modified before configuring the filter parameters of the amplifier or the sampling rate. Some training parameters, e.g. feedback interface, training time and individual Alpha frequency (IAF) band (8~12Hz) were selected after impedance detection. Then, the NFB training was started, together with the data collection/ storage and computing/display/control threads. The data were collected by the system, and accumulated under control by multi-thread mechanism. After reaching the length of the time window, the feature extraction was conducted, and the extracted results were fed back via the graphical interface.

Stimuli and experimental procedure

In each session, the IAF was deemed as the peak frequency of the alpha band at the first base rate, and the upper alpha (UA) was defined as the frequency band from the IAF to the IAF+2Hz. The feedback was represented by coloured squares.

The feedback to the participants depends on the average UA amplitude. The relationship between the UA amplitude and the base rate was expressed in colours. Specifically, red and green respectively represent the amplitude above and below the base rate. Here, the average UA amplitude was coloured red if it was over 97.5% above the base rate, green if it was below 2.5% under the rate, and grey if it fell outside these two ranges.

Note that the amplitude value was deemed as invalid if the spectrum of eye movements was outside the UA band. Besides, the participants were asked not to close their eyes at the base rates. Otherwise, the participants cannot receive visual feedback and the whole training will become meaningless.

The big five personality test model (Mccrae *et al.*, 1987) was introduced for the feedback training. The five factors of the model include neuroticism, extroversion, openness, agreeableness, and conscientiousness. The innovation behaviour was assessed by the mental rotation test. In each training, a reference ball and five other balls were presented, and at most one of the five balls was convertible into the reference ball. After the alpha feedback training, the participants were given the opportunity to test their experience.

Statistical analysis

For all participants, the average UA amplitude was calculated for the base rates in each training session. The pairwise t-test was employed to analyse the statistics of the experiment, with the NFB training effect as an independent variable.

To evaluate independence, the pre-training and post-training frequencies were contrasted, and the amplitude differences were calculated to identify the frequency scope above and below the UA. The lower alpha was tested for IAF-3~IAF-1Hz, and lower beta for IAF+3 to IAF+5Hz. Due to frequency interference, the scope within 1Hz above and below the UA could not be evaluated. The amplitude differences are displayed in Figure 3, where the dashed line represents the frequency spectra at the first base rate of the first session, while the continuous line represents the frequency spectra at the first base rate of the last session.

To compare the innovation behaviour, the raw scores of the independent samples (x=100, SD=10) were tested by pairwise t-test method. Both the NFB group and the control group exhibited better innovation behaviour after the training. Next, the author attempts to verify if the members of the NFB group underwent greater improvement than those in the control group.

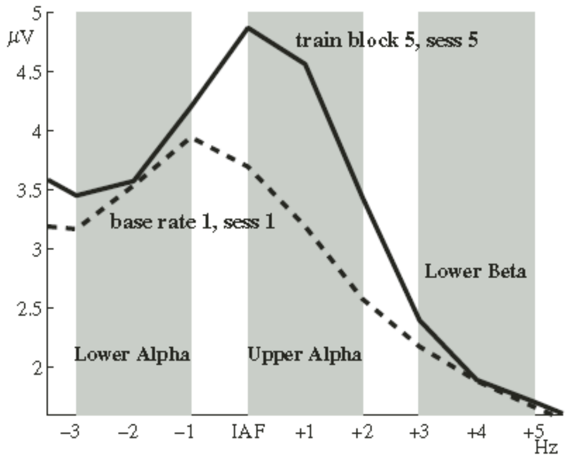

Figure 3. The comparison of amplitude differences

Results

Trainability

The average IAF was 9.1±0.87Hz at the first base rate and 9.06±0.57Hz at the second base rate, indicating no significant change during the training. In Figure 1, the trainability is reflected by the positive slope of UA amplitude over the time, and the gradient of the fitted regression line for each member is clearly above zero($t(10)=3.12$, $p=0.011$).

In the last session, the UA amplitude at the first base rate was obviously higher than that at the first base rate of the first session ($t(10)=3.56$, $p=0.002$), but the same effect was not found in the control group. The raw EEG data (Figure 4) also demonstrate the increase of the UA.

Independence

The initial scale was derived according to the innovation behaviour questionnaire and personality questionnaire. Then, the Bartlett's test and Kaiser-Meyer-Olkin (KMO) were carried out. The test value of the former was 2,287.86, with the significance level below 0.001, and the KMO value was 0.918. This means the scale was suitable for factor analysis.

From Table 1, it is clear that the Cronbach's alphas were all greater than 0.75, indicating high reliability of the scale. Table 2 shows the fitness indices: $\chi^2/df(<2)$, RMSEA (<0.08), CFI (>0.90), IFI (>0.90), and TFI (>0.90) of the scale.

As shown in Table 2, all fitting indices reached the ideal level, revealing that all the scales had desirable structural validity. The correlations between the dependent variables (neuroticism, extroversion, openness, agreeableness and conscientiousness) were presented in Table 3.

Table 1. Credibility analysis of the scale

Item	α value
Personality characteristics	0.827
neuroticism	0.794
extroversion	0.776
openness	0.862
agreeableness	0.832
conscientiousness	0.815

According to the above statistical analysis, the author constructed the structural equation model with 5 types of personalities as independent variables and the 3 aspects of innovation behaviours as dependent variables. The relationship between independent and dependent variables was shown in Figure 5.

According to Figure 5, the path coefficients from neuroticism to the three aspects of innovation were -0.282, -0.289 and -0.189, respectively, all of which reached the significant level. This means the neuroticism has a negatively impact on innovation behaviour of enterprise personnel. The path coefficients from extroversion, openness, agreeableness and conscientiousness to the three aspects of innovation were all positive, revealing the positive impacts of these types of personalities on the innovation behaviour of enterprise personnel.

Discussion

The statistical analysis confirms that the EEG-based NFB training can improve the innovation behaviour of enterprise personnel. All participants of the NFB training group exhibited better innovation behaviour after five sessions of NFB training.

During the five days, the UA amplitude underwent a linear increase (Figure 1). For the first base rate, the UA amplitude in session 5 was higher than the pre-training amplitude in session 1, which signifies that each session is based on the training experience of the previous session. Although the frequency scope above and below the UA was not affected by the training, the statistical data demonstrate that the other UA frequency bands may be controlled.

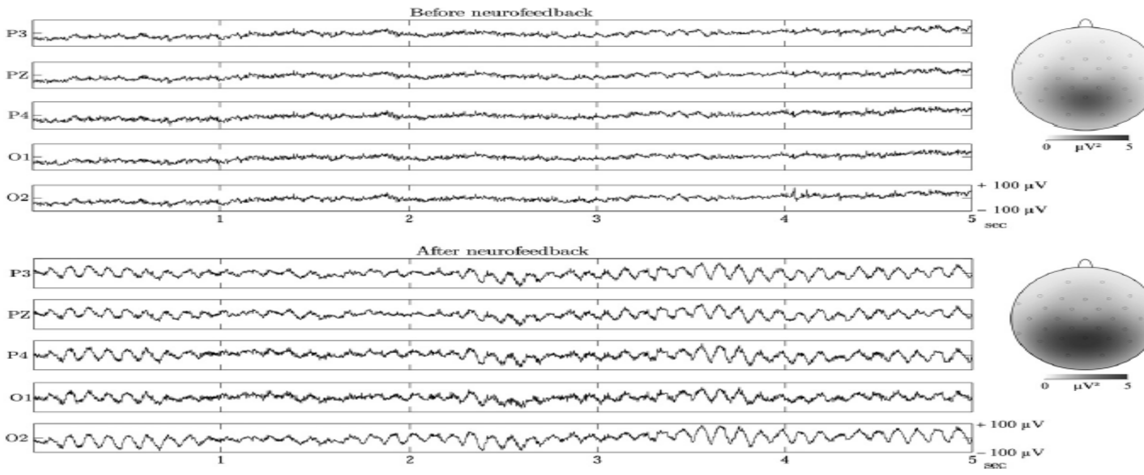

Figure 4. UA increment in the raw EEG data

Table 2. Validation analysis of the scale

Variable	χ^2	*df*	χ^2/df	*RMSEA*	*CFI*	*IFI*	*TFI*
Personality characteristics	977.092	546	1.790	0.046	0.919	0.921	0.908
Neuroticism	365.412	169	2.162	0.058	0.915	0.914	0.916
Extroversion	282.516	130	2.174	0.059	0.931	0.928	0.932
Openness	383.171	139	2.757	0.072	0.902	0.901	0.903
Agreeableness	402.121	171	2.351	0.063	0.904	0.902	0.906
Conscientiousness	310.247	132	2.350	0.063	0.921	0.918	0.922
Innovation behavior of personnel	90.537	56	1.617	0.043	0.977	0.978	0.969

Table 3. The statistical difference between the NFB training group and the control group

	Neurofeedback training group (n=12)			Control group (n=10)		
Variable	Before training	After training	Overall	Before training	After training	Overall
N	6.12±2.17	3.72±1.16**	-	6.13±2.12	6.01±1.11	-
E	8.52±1.64	15.70±1.23*	-	8.56±1.58	9.65±1.23	-
O	5.56±1.34	10.79±1.51***	-	5.54±1.32	7.71±1.26	-
A	4.36±1.22	9.75±1.39**	-	4.34±1.25	5.59±1.25	-
C	2.32±1.41	5.55±1.31**	-	2.33±1.39	3.38±1.37	-
Age	-	-	26.2±1.7			25.8±1.8
Male	-	-	41.7%	-	-	50%

Paired *t*-test, * P-value<0.05; ** P-value<0.01; *** P-value<0.001
N: Neuroticism; E: Extroversion; O: Openness; A: Agreeableness; C: Conscientiousness

As shown in Table 3, the NFB training reduced the neuroticism and improved extroversion, openness, agreeableness and conscientiousness from the levels of the control group. The result agrees well with the findings of Kleysen *et al.,* (2001). Hence, the enhancement of innovation behaviour was confirmed by the structural equation model with the 5 types of personalities as independent variables.

In addition, the UA of the NFB training group was obviously higher before the second test than before the first test, but the same trend was not observed in the control group. This finding is in line with previous studies (Doppelmayr *et al.*, 2005; Fink, 2005; Klimesch, 1999).

Conclusions

This paper innovatively applies the EEG-based NFB training to enhance the innovation behaviour of enterprise personnel. Some good effects were obtained by treating the UA as an NFB training frequency parameter. Through the research, the author disclosed the exact relationship between 5 different types of personalities and the innovation behaviour of enterprise personnel: the extroversion, openness, agreeableness and conscientiousness have positive effects on innovation behaviour, while neuroticism has a negative impact on innovation behaviour. The conclusion sheds new light on personality theory in brain neurology, and the management research from the perspective of brain neurology.

Of course, there are some inevitable limitations of this research. For instance, since the members of the control group only showed up in two days, it is impossible to evaluate all the effects of the training.

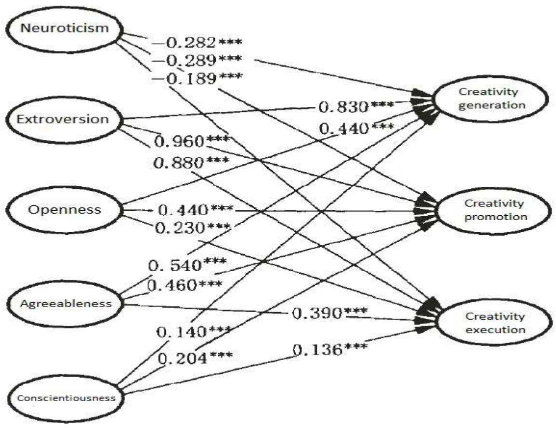

Figure 5. The relationship between independent and dependent variables

However, this research successfully resolved the lack of control group in NFB training studies, through the multi-factor comparison between the NFB training group and the control group. Furthermore, the influence mechanism of the NFB training on innovation behaviour of enterprise personnel remains unclear. In future research, the author will further explore the UA, a promising NFB training parameter, through the modelling of independent parameters like personality features, the alpha frequency distribution and the individual impact of innovation behaviour on the EEG frequency spectrum.

Acknowledgment

This paper was supported by "The Fundamental Research Funds for the Central Universities" (No. 31020170QD107).

References

Arani FD, Rostami R, Nostratabadi M. Effectiveness of neurofeedback training as a treatment for opioid-dependent patients. Clinical EEG and Neuroscience 2010; 41(3): 170-77.

Chiang YH, Hsu CC, Shih HA. Experienced high performance work system, extroversion personality, and creativity performance. Asia Pacific Journal of Management 2015;32(2):531-49.

Coben R, Linden M, Myers TE. Neurofeedback for autistic spectrum disorder: a review of the literature. Applied Psychophysiology & Biofeedback 2010; 35(1): 83-105.

Doppelmayr M, Klimesch W, Sauseng P. Intelligence related differences in EEG-bandpower. Neuroscience Letters 2005; 381(3): 309-13.

Feist GJ. A meta-analysis of personality in scientific and artistic creativity. Personality and Social Psychology Review 1998; 2(4): 290-309.

Fink A. Event-related desynchronization in the EEG during emotional and cognitive information processing: differential effects of extraversion. Biological Psychology 2005; 70(3): 152-60.

Heinrich H, Gevensleben H, Strehl U. Annotation: neurofeedback - train your brain to train behaviour. Journal of Child Psychology & Psychiatry 2007; 48(1): 3–16.

Hur YM, Jeong HU, Piffer D. Shared genetic and environmental influences on self-reported creative achievement in art and science. Personality & Individual Differences 2014; 68: 18-22.

Kleysen RF, Street CT. Toward a multi-dimensional measure of individual innovative behavior. Journal of Intellectual Capital 2001; 2(3): 284-96.

Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Research Reviews 1999; 29(2): 169-195.

LePine JA, Van Dyne L. Voice and cooperative behavior as contrasting forms of contextual performance: evidence of differential relationships with big five personality characteristics and cognitive ability. Journal of Applied Psychology 2001; 86(2): 326-336.

Linden DE, Habes I, Johnston SJ, Linden S, Tatineni R, Subramanian L, Sorger B, Healy D, Goebel R. Real-time self-regulation of emotion networks in patients with depression. PloS one 2012; 7(6): e38115.

Maeda F, Glover GH, Raichle ME. Control over Brain Activation and Pain Learned by Using Real-Time Functional MRI. Proceedings of the National Academy of Sciences of the United States of America 2005; 102(51): 18626-31.

Martins EC, Terblanche F. Building organisational culture that stimulates creativity and innovation. European Journal of Innovation Management 2003; 6(1):64-74.

Mccrae RR, Jr CP. Validation of the five-factor model of personality across instruments and observers. Journal of Personality & Social Psychology 1987; 52(1): 81-90.

Mihara M, Hattori N, Hatakenaka M. Near-infrared spectroscopy-mediated neurofeedback enhances efficacy of motor imagery-based training in poststroke victims: a pilot study. Stroke 2013; 4(4): 1091-98.

Peniston EG, Kulkosky PJ. Alpha-theta brainwave training and beta-endorphin levels in alcoholics. Alcoholism-clinical & Experimental Research 1989; 13(2):271-79.

Rostami R, Dehghani-Arani F. Neurofeedback Training as a New Method in Treatment of Crystal Methamphetamine Dependent Patients: A Preliminary Study. Applied Psychophysiology & Biofeedback 2015; 40(3):151-61.

Scott WC, Kaiser D, Othmer S. Effects of an EEG biofeedback protocol on a mixed substance abusing population. American Journal of Drug & Alcohol Abuse 2005; 31(3): 455-69.

Thornton KE, Carmody DP. Efficacy of Traumatic Brain Injury Rehabilitation: Interventions of QEEG-guided Biofeedback, Computers, Strategies, and Medications. Applied Psychophysiology & Biofeedback 2008;33(2): 101-24.

Tierney P, Farmer SM, Graen GB. An examination of leadership and employee creativity: The relevance of traits and relationships. Personnel Psychology 1999; 52(3): 591-620.

Van Scotter JR, Motowidlo SJ. Interpersonal facilitation and job dedication as separate facets of contextual performance. Journal of Applied Psychology 1996; 81(5): 525-31.

Vernon D, Egner T, Cooper N, Compton T, Neilands C, Sheri A, Gruzelier J. The effect of training distinct neurofeedback protocols on aspects of cognitive performance. International Journal of Psychophysiology 2003;47(1):75-85.

Yuan F, Woodman RW. Innovative behavior in the workplace: The role of performance and image outcome expectations. Academy of Management Journal 2010;53(2):323-42.