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EEG and personality dimensions: A consideration based on the brain oscillatory systems

Sang Eun Chi [1], Chang Bum Park [1], Seung Lark Lim, Eun Hye Park, Young Hyurk Lee, Kang Hee Lee, Eun Joo Kim, Hyun Taek Kim *

Department of Psychology, Korea University, Seoul 136-701, Republic of Korea

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Abstract

Relationships between EEG and personality dimensions were investigated in the Korean population. Subjects were 68 healthy undergraduate students (32 males, 36 females). The Korean version of the Eysenck Personality Scales (EPS-Adult), Behavioral Inhibition System/Behavioral Approach System (BIS/BAS) scale, and Positive Affect and Negative Affect scale (PANAS) were used. EEG recordings of two different conditions (eyes open and eyes closed) were performed twice with the interval of 6 weeks. Analytical methods used in the present study rendered two coincident tendencies: Theta band was negatively related to neuroticism in the eyes open condition, alpha and delta band were positively and negatively related to psychoticism in the eyes closed condition respectively. Despite that these results showed complex interactions, they are considered to be consistent with the theory of Robinson (2001) that delta, theta, and alpha waves are associated with activity of the brainstem, limbic system, and the thalamo-cortical arousal system respectively.

Keywords: Personality; EEG; Extraversion; Psychoticism; Neuroticism; Impulsivity

* Corresponding author. Tel.: +82 2 3290 2065; fax: +82 2 3290 2530.
E-mail address: neurolab@korea.ac.kr (H.T. Kim).
[1] S.E. Chi and C.B. Park contributed equally to this work.

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1. Introduction

Eysenck and Eysenck (1975) conceptualized personality as three trait dimensions: psychoticism (*P*), extraversion–introversion (*E*), and neuroticism (*N*), and hypothesized the "conceptual nervous system (c.n.s.)" as the core underlying mechanism of personality structure. Consequently, brain arousal has been accepted as the key component of Eysenck's personality model.

The electroencephalogram (EEG) enabled the relationship between brain arousal and personality dimensions to be tested. Studies of the relationship between EEG measures and *E* have been studied extensively, especially, since Eysenck (1994) referred to the alpha range as the "standard measure of cortical arousal, ever since the discovery of the ARAS (ascending reticular activating system)". The results of previous studies, however, have been inconsistent and contradictory (Gale, 1983; Stelmack, 1990). Gale (1983) argued that the kind of environment mediates the arousal inducing properties; and the predicted relationship between alpha characteristics and *E* occurred only in those experimental settings that assured a moderate level of arousal. Gale assumed resting conditions with eyes closed to be of low arousal, conditions with repeated opening and closing of the eyes to be of moderate arousal, and various kinds of task performance to be of high-arousal (Knyazev, Slobodskaya, & Wilson, 2002).

The human brain's oscillatory phenomenon, which can be observed in scalp EEGs, accompanies important brain functions. According to the brain area, the experimental procedure, and the associated behavior, these rhythms are generally confined within a frequency band (Gray, 1994; Buzsáki & Chrobak, 1995; Baçar, 1998; Farmer, 1998; Traub, Jefferys, & Whittington, 1999). Even though the mechanisms that determine the oscillation frequency are not completely understood, it is generally known that brain rhythms arise through the synchronization of neurons (Maex & De Schutter, 2003). Bland and Oddie (2001) reported that theta band oscillation and synchrony in the hippocampal formation and associated structures took part in sensorimotor integration. It is reasonable to assume that the features of the intrinsic oscillatory phenomena are related to the structures and functions of the corresponding neural generators, and that different features in EEG bands may predict individual differences in brain function and structures. On the contrary, it is possible that features in this frequency domain do not represent individual differences reliably because of the highly complex nature of the brain network. Therefore, it is necessary to test not only the EEG–personality relationship, but also its reliability.

Recently, Robinson (1999, 2000, 2001) claimed that delta, theta, and alpha waves are associated with the activity of the brainstem, limbic system, and the thalamo-cortical arousal system, respectively. The main evidence supporting this view is that direct stimulations of the brainstem and thalamic arousal systems produce corresponding characteristic frequencies of around 4 Hz and 10 Hz in scalp EEG recordings, respectively (Guyton, 1976), while stimulation of the limbic system produces hippocampal waves of about 7 Hz (Gray, 1991). Robinson (2001) asserts that EEG activity's spontaneous alpha frequency is the natural frequency of thalamo-cortical free oscillation, and that the thalamo-cortical alpha system exerts an inhibitory effect over the brainstem delta system. This is based on both the fact that the diffuse thalamic projection system exerts an inhibitory effect on the ARAS in a general way (Samuels, 1959), and on the results from averaged evoked potential (AEP) analyses by Robinson himself. Knyazev et al. (2003) supported this inhibition theory with the results of absolute spectral power measurements.

The aim of the present study is to test the EEG–personality relationship among Koreans who have a different cultural background from Westerners. Through two identical EEG recording sessions separated by an interval of 6 weeks, consistent relationships between EEG frequency bands and personality measures were evaluated. As Robinson's theory provides a much clearer theoretical base for brain oscillatory systems, the alpha–delta inhibitory relationship proposed by Robinson was tested with the factor analytic method by Knyazev et al. (2003). In addition, the relationship between *E* and *P* was discussed.

2. Materials and method

2.1. Subjects

Sixty eight students (32 males, 36 females), aged between 19 and 25 years (mean, 20.88; SD, 1.97), participated as subjects (called Ss below) in this study. They gave written informed consent to completing the self-report questionnaires and the psychophysiological protocols.

2.2. Procedure

At the first session, Ss completed the Korean version of the Eysenck Personality Scales (Lee, 2000), the BIS/BAS scale (Carver & White, 1994), and the PANAS (Watson, Clark, & Tellegen 1988). The Korean version of the EPS (Adult) consists of the EPQ-R (81 items), EPQ-R Short (48 items) and the IVE (40 items). While the EPQ-R (81 items) and the IVE (40 items) used in the present study were already standardized and validated in the Korean population, the BIS/BAS scale and the PANAS were translated for the present study by an experienced clinical psychologist. The addiction (A) and the criminality (C) dimensions in the EPQ-R were not analyzed.

After this, the EEG recording procedure followed. EEG was recorded under two different conditions (eyes closed and eyes open) to induce different levels of arousal. Ss were seated in an electrically shielded room approximately 150 cm in front of a monitor, and told to avoid excessive body movement. An experimenter was sitting with the Ss during recording to maintain their full cooperation and participation. Prior to recording, Ss were informed as to the experimental procedure. The whole procedure lasted about 11 min including six separated 1-min recording phases (three eyes open conditions and three eyes closed conditions by turns), five 1-min breaks.

EEGs were recorded using a Grass model 12 system. Gold-coated electrodes were affixed at seven scalp sites (Fz, Cz, Pz, F3, F4, P3, and P4) according to the International 10–20 system (Jasper, 1958) and referred to right ear (A2) electrode with a forehead ground, with impedances at 10 kΩ or less. Additional electrodes were placed at 5 mm above and below the right eye to measure vertical EOG activity. Data were continuously digitalized at 500 Hz, and bandpass filter of 0.1–100 Hz was applied on-line.

The second session was accomplished 6 weeks later. The EEG recording procedure was the same as in the first session.

2.3. EEG post-processing

Experimenters visually selected 48 artifact-free EEG chunks of 4 s duration (24 with eyes closed and 24 with eyes open). Fast Fourier transforms (FFT) was then performed with these data chunks. The EEG power spectra were grouped into five band powers from 0.2 to 49.9 Hz as follows: delta band (0.2–3.9 Hz), theta band (4.0–7.9 Hz), alpha band (8.0–12.9 Hz), beta band (13.0–29.9 Hz), and gamma band (30–49.9 Hz). Total spectral power (from 0.2 to 49.9 Hz) was also obtained. Absolute and relative spectral powers were calculated for every electrode location, EEG band, and each condition (eyes closed and eyes open). For each band, the summation was performed across all electrode sites to obtain aggregated power measures. Before summation, relative powers were z-transformed at each site, and absolute powers were normalized with log-transformation (base 10) and z-transformation. Since aggregated band powers showed the same tendencies with site-specific band powers (data not shown), only aggregated band powers were used for all subsequent analyses.

3. Results

To ascertain reliabilities, the internal consistency of each questionnaire scale was validated with Cronbach's α. P and empathy showed relatively low internal consistencies (Table 1).

Table 2 shows correlation of psychometric measures. Fig. 1 shows scatter plots of EPQ-R and IVE scales. Even though the expected inter-correlations were found, correlation coefficients were generally not high. The considerable and noteworthy correlations were described below.

Positive affect was positively related to E ($r = 0.247$, $p < 0.05$), venturesomeness ($r = 0.319$, $p < 0.01$), and negative affect ($r = 0.260$, $p < 0.05$) while it was negatively related to N

Table 1
Internal consistencies of questionnaire scales ($N = 68$)

		Subject		Normative sample
		Cronbach's alpha	Mean(SD)	Mean(SD)
BIS/BAS[a]	BIS	0.64	21.53(2.71)	19.99(3.79)
	BAS/Reward	0.74	17.22(2.29)	17.59(2.14)
	BAS/Drive	0.81	11.68(2.45)	12.05(2.36)
	BAS/Fun	0.75	11.53(2.33)	12.43(2.26)
PANAS[b]	Positive affect	0.88	25.85(7.93)	29.7(7.9)
	Negative affect	0.88	19.13(7.27)	14.8(5.4)
EPQ-R[c]	Extraversion	0.80	9.29(4.28)	10.39(4.25)
	Psychoticism	0.55	2.81(2.17)	2.65(2.32)
	Neuroticism	0.80	9.46(4.62)	11.27(5.53)
	Lie	0.62	6.85(3.35)	6.74(3.33)
IVE[c]	Venturesomeness	0.83	6.78(3.76)	8.87(3.47)
	Empathy	0.54	8.04(2.15)	8.30(2.29)
	Impulsiveness	0.81	4.07(3.34)	4.98(3.57)

Data of normative samples are adapted from [a]Carver and White (1994), [b]Watson et al. (1988), [c]Lee (2000).

Table 2
Correlations of psychometric measures ($N = 68$)

	BIS	BAS/ reward	BAS/ drive	BAS/ fun	Positive affect	Negative affect	Psycho- ticism	Extra- version	Neuro- ticism	Lie	Impul- siveness	Venture- someness
BAS/reward	0.016											
BAS/drive	−0.072	**0.412****										
BAS/fun	−**0.321****	**0.246***	**0.407****									
Positive affect	−0.236	0.230	0.192	0.200								
Negative affect	0.170	0.191	0.198	−0.072	**0.260***							
Psychoticism	−0.092	−**0.315****	0.129	0.144	−0.127	−0.009						
Extraversion	−0.106	0.042	−0.054	**0.494****	**0.247***	−0.153	−0.066					
Neuroticism	**0.344****	0.237	−0.021	−0.075	−**0.257***	−0.052	**0.290***	−0.180				
Lie	0.066	−0.159	0.080	−0.145	−0.162	−0.024	−0.125	0.004	−**0.256***			
Impulsiveness	0.001	−0.081	−0.123	0.171	0.012	−0.053	**0.330****	0.189	**0.359****	−**0.390****		
Venturesomeness	−**0.317****	0.076	0.136	**0.419****	**0.319****	−0.016	0.083	**0.250***	−0.044	−0.219	0.201	
Empathy	**0.464****	−0.067	−0.219	−**0.319****	−0.216	−0.018	−**0.308***	−0.008	0.181	0.028	0.159	−**0.294***

Bold letters represent significant correlations.
* $p < 0.05$ (2-tailed); ** $p < 0.01$ (2-tailed).

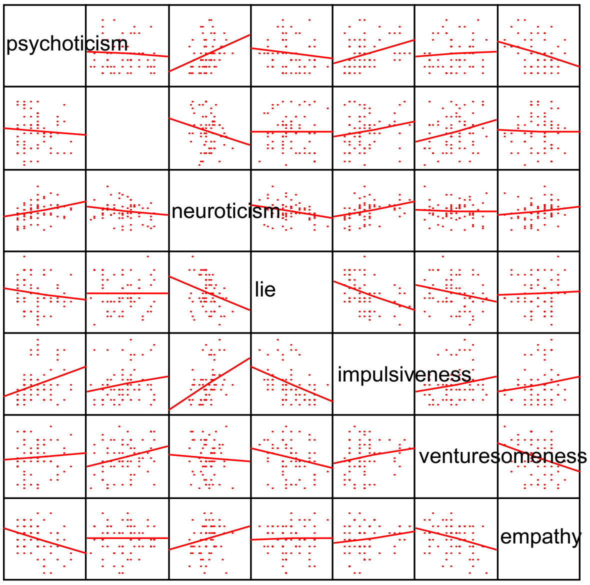

Fig. 1. Scatter plots of EPQ-R and IVE scales are shown.

($r = -0.257$, $p < 0.05$). A positive relationship between P and N was revealed ($r = 0.290$, $p < 0.05$). For the subscales of IVE, impulsiveness showed a positive correlation with P ($r = 0.330$, $p < 0.01$), while venturesomeness showed a positive correlation with E ($r = 0.250$, $p < 0.05$); this coincided with Eysenck's initial view of them as two distinct aspects of impulsiveness, respectively aligning either with P or E (Eysenck, 1997). On the other hand, BIS was positively related to empathy ($r = 0.464$, $p < 0.01$) and was negatively related to venturesomeness ($r = -0.317$, $p < 0.01$).

Table 3 shows the test–retest reliability of the EEG aggregated relative power bands. All of the frequency bands of the EEG from two test-sessions were mutually correlated at the $p < 0.01$ level. It could be concluded that EEG measures and relative power analyses reflected temporally stable conditions of an individual with a 6-week interval. The alpha band showed a remarkably high reliability in the present study.

For each psychological variable, correlations with aggregated relative powers of each band were tested. There were risks of spurious significant results because of increased alpha error rate due to the large number of variables. Bonferroni correction, however, was not applied because it is overly strict for the physiological data which are intrinsically interdependent. Instead, to avoid false positive results, only consistently significant correlations during two sessions were selected (Table 4). There might be hidden factors at work, but it seems unlikely that the consistently significant results arose from random chances in both sessions. This method was expected not only to keep the reliability of measure and analysis, but also to encourage the contrast effect, which could give salience to the consistent data.

First, the data were pooled for co-gender analysis, and later, male and female subjects were analyzed separately to control for a potential gender effect. In the co-gender analysis, for the eyes open condition, N showed a negative correlation with the relative power of the theta band. This result can be interpreted as in conformity with Robinson's suggestion that the limbic system is the

Table 3
Test–retest reliability of EEG aggregated relative power bands ($N = 68$)

Condition	Band	Pearson correlation coefficient
Eyes closed	delta	0.641**
	theta	0.618**
	alpha	0.691**
	beta	0.468**
	gamma	0.456**
Eyes open	delta	0.481**
	theta	0.413**
	alpha	0.697**
	beta	0.371**
	gamma	0.473**

** $p < 0.01$ (2-tailed).

Table 4
Consistently Significant Correlations of psychometric measures with EEG aggregated relative power bands

Condition	Psychometric measure	Band	Co-gender ($N = 68$)		Male ($n = 32$)		Female ($n = 36$)	
			Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
Eyes closed	Psychoticism	delta	**−0.294***	**−0.299***	−0.356*	−0.204	−0.241	−0.379*
		alpha	**0.301***	**0.309***	0.336	0.263	0.271	0.356*
	Positive affect	delta	**0.251***	**0.243***	0.339	0.259	0.181	0.273
		theta	**−0.285***	**−0.240***	−0.331	−0.068	−0.319	−0.404*
	Lie	beta	**0.258***	**0.288***	−0.015	0.050	**0.433****	**0.507****
	BIS	beta	−0.151	−0.326**	−0.160	−0.421*	**−0.346***	**−0.399***
Eyes open	Extraversion	alpha	−0.245*	−0.082	**−0.365***	**−0.380***	0.030	0.195
	Neuroticism	theta	**−0.350****	**−0.374****	**−0.616****	**−0.493****	−0.014	−0.214

Bold letters represent consistently significant correlations during two sessions.
* $p < 0.05$ (2-tailed); ** $p < 0.01$ (2-tailed).

neural generator of the theta component of EEG (7 Hz) as well as the underlying mechanism of N (Robinson, 2001). Further analyses revealed that this negative correlation was only attributable to male subjects because it was not significant in female subjects. For the eyes closed condition, the relative power of the theta band was negatively related to positive affect in co-gender; a stronger correlation being revealed in female subjects. This result seemed to be contrary to the previous assumption that N, anxiety, and the theta component of the EEG shared the same underlying mechanism; however, it is difficult to make any firm conclusion because of several reasons. First, positive affect showed not only a negative correlation with N but also a positive correlation with negative affect. It might be a problem of the Korean version PANAS which is not standardized in the Korean population. Second, anxiety was not directly measured in the present study. Third, consistent correlations showed different patterns according to conditions (eyes open and eyes closed) and gender. This might imply complex interactions.

Although the neural mechanism of *P* has not been clarified either in previous studies or even in Eysenck's model, the result of the present study showed that *P* was related to the relative power of the alpha and delta bands of the EEG; positively with alpha, negatively with delta band. These results are contradictory to previous reports that there was a small but significant negative correlation between *P* and power in the alpha band (Matthews & Amelang, 1993); however, the results of the present study can be regarded as more reliable because two sessions rendered the same results. According to Robinson (1999), the putative underlying mechanism of the *E* dimension by Eysenck, is under influences of alpha and delta generators. In spite of the fact that the result from the present study was not directly linked to *E*, in a broad sense, it could be considered to be consistent with Robinson's view of the relationship between the alpha system and the delta system.

For the eyes open condition, the aggregated EEG alpha band power of male subjects was negatively related to *E*. If the increase of alpha power indicates low arousal, this result might be interpreted as contrary to Eysenck's theory; however, according to Robinson's hypothesis, alpha wave is the natural frequency of the thalamo-cortical system, and alpha power can be interpreted as the indicator of arousal. Consequently, this result might imply that introverts showed higher arousal levels than extraverts.

To test the alpha–delta inhibition theory by Robinson (2001), absolute power factor analysis (Knyazev et al., 2003) was applied. Normalized delta, theta, alpha bands with combinations of log-transformation (base 10) and *z*-transformation at all sites and two sessions were aggregated and used in this analysis. Three factors (unrotated) were extracted for each condition (eyes closed and eyes open) using the principal component method (Table 5). The tendencies shown in both conditions (eyes closed and eyes open) were similar. The first component accumulates positive loadings of all spectral bands. In the second component, negative relations between alpha and delta frequency bands were raised. The third component showed negative loading to theta power even though the explained variance was not high.

Table 6 shows correlations of Eysenck's *P*, *E*, and *N* with extracted factors for each condition. In accordance with the correlation analysis, the alpha–delta relationship factor (factor 2) in the eyes closed condition showed a negative correlation with *P* ($r = -0.380$, $p < 0.01$), the theta related factor (factor 3) in the eyes open condition showed a positive correlation with *N* ($r = 0.505$, $p < 0.01$).

Similarly, after controlling for common variance that had positive loadings of all spectral bands (factor 1 for each condition), correlations of *P*, *E*, *N* and absolute power bands revealed a similar trend with the former relative power correlation analysis (Table 7). The negative correlation be-

Table 5
Loadings of aggregated EEG absolute spectral powers ($N = 68$)

	Eyes closed			Eyes open		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
delta	0.691	0.715	0.108	0.744	0.649	0.158
theta	0.921	−0.143	−0.364	0.892	−0.116	−0.437
alpha	0.853	−0.425	0.305	0.823	−0.462	0.331
% of variance	68.393	23.729	7.878	67.588	21.578	10.834

Extraction method: principal components (unrotated).

Table 6
Significant correlations between Eysenck's PEN and factors of aggregated EEG absolute spectral powers for each condition ($N = 68$)

Condition		Psychoticism	Extraversion	Neuroticism
Eyes closed	Factor 1			
	Factor 2	−0.380**		
	Factor 3			
Eyes open	Factor 1			
	Factor 2			
	Factor 3			0.505**

** $p < 0.01$ (2-tailed).

Table 7
Significant partial correlations between Eysenck's PEN and EEG bands for aggregated EEG absolute spectral powers after controlling for common variance (factor 1, respectively) for each condition ($N = 68$)

Condition		Psychoticism	Extraversion	Neuroticism
Eyes closed	delta	−0.366**		
	theta			
	alpha	0.347**		
Eyes open	delta			
	theta			−0.475**
	alpha			0.345**

** $p < 0.01$ (2-tailed).

Table 8
Significant partial correlations between EEG bands for aggregated EEG absolute spectral powers after controlling for the common variance (factor 1, respectively) for each condition ($N = 68$)

Condition		Delta	Theta
Eyes closed	theta	−0.502**	
	alpha	−0.716**	−0.244*
Eyes open	theta	−0.477**	
	alpha	−0.652**	−0.355**

* $p < 0.05$ (2-tailed); ** $p < 0.01$ (2-tailed).

tween alpha and delta bands supports the alpha system's inhibitory effect over the brain-stem delta system (Table 8).

4. Discussion

The EPQ-R showed some distinct correlations with EEG measures in general. This result, however, cannot be generalized because the Korean version of the BIS/BAS scale used in the present study was not validated. The Korean version of the IVE scale did not show any clear correlational pattern with EEG measures.

Analytical methods used in the present study rendered two coincident tendencies: Theta band was negatively related to *N* in the eyes open condition, alpha and delta band were positively and negatively related to *P* in the eyes closed condition respectively.

The fact that relative theta power showed a strong significant negative correlation with *N* during the eyes open condition in male subjects is somewhat contradictory to Eysenck's theory. Since no emotional stress modification was applied in this study, the positive correlation between theta power and *N* was expected to embed Eysenck's theory. Knyazev et al. (2003) pointed out that human anxiety may be seen as a trait predisposing to suppression of 'spontaneous' reaction associated with the brain-stem region (delta oscillations) in favor of cortical mechanism (alpha oscillations) underlying vigilance and rumination. Also, there might be other ways in which theta band and *N* interact in humans without emotional stress.

To understand the nature of *E* and *P*, the relationship between *E* and impulsivity is worthy of note. The EPI-*E* scale was criticized by Guilford (1975) as representing a "shotgun marriage" of sociability and impulsivity, a position that Eysenck and Eysenck (1977) strongly rejected. In the process of developing the EPQ scale, seven of the nine impulsivity items in the EPI-*E* scale vanished, one (no. 39) stayed in the revised *E* scale, and one (no. 5) appeared on the new Psychoticism scale (Campbell & Reynolds, 1984). The situation did not change with the subsequent revision to the *P* scale and the release of the EPQ-R (Eysenck, Eysenck, & Barrett, 1985; Roger & Morris, 1991). Because Eysenck tended to emphasize impulsivity in the PEN model as part of the *P* scale, a number of re-analyses of prior relationships of *E* with behavioral, physiological, and cognitive measures started to appear to redefine the measurement of *E* within the EPQ. Frequently what had previously been reported as relationships between extraversion and arousal were found to hold for the EPI-*E* scale but not for the EPQ-*E* scale and in fact to hold for the EPI-Imp but not the EPI-Soc subscales of the EPI (Revelle, 1997). O'Gorman and Lloyd (1987) showed that impulsiveness rather than EPQ-*E* was the major correlate of differences in EEG-defined arousal, whereas Stenberg (1992, 1994) claimed that impulsivity was associated with lowered arousal, and the *E* effect was mainly attributable to the impulsivity subtrait. Corr and Kumari (1997) reported that both sociability (EPQ-*E*) and impulsivity (IVE-impulsiveness) mediated the effects of arousal.

Not only is the distinction between personality dimensions unclear, but also the neural substrates of them are indefinite. For example, *E* has a dual nature of reticulo-cortical and dopaminergic aspects (Matthews & Gilliland, 1999). Gray, Pickering, and Gray (1994) reported a significant correlation between *P* and dopamine D2 binding in the basal ganglia. More recently, Rammsayer (1998) reported that introverts were much more susceptible to pharmacologically induced changes in D2 receptor activity than extraverts. These facts imply that *E*, impulsivity, and *P* cannot be distinguished clearly, and share common biological mechanisms to some extent according to contexts.

The relationship between *P* and the alpha–delta inhibition effect shown in the present study seemed to generally support Robinson's inhibition theory. For the eyes closed condition, there was no significant correlation between EEG relative powers and *E*, but *P* showed significant correlations with alpha and delta relative power bands. *P* showed a positive correlation with alpha band and a negative correlation with delta band respectively. This result raises two questions: Why is there no difference of arousal according to *E*? Why is alpha–delta relationship related to *P*?

The dominant explanation on the first question from previous theories is that extraverts achieve their optimal arousal level through internal sensation seeking during a low arousal condition. It is, however, not possible to explain the second question. According to the present results, an alternative explanation can be suggested. Considering the general egocentric tendency of a population with high *P* scores, it can be assumed that they would allocate more attentional resources to the internal monitoring processes than to perceptional processes of outer stimuli. In other words, while *N* and *E* dimensions are related to processing and responding of exogenous stimuli, *P* is thought to be more related to processing of endogenous information. Without external visual stimuli in the eyes closed condition, a *P* related mechanism may be more dominant than other mechanisms. Under this hypothesis, if *E* and *P* share a common brain arousal system, which is switched by contexts, not only the results of the present study can be explained, but also the issues about the dual nature of *E* and the disputes during the developmental processes of the EPQ scale can be understood.

A similar view that *P* reflects the relative balance between the tendencies to focus on self and on external factors following aversive events, was proposed by Wallace and Newman (1998); although they matched high *P* with focusing on others, and low *P* with focusing on themselves. This focusing, however, did not mean esteem to others but the blame according to negative events. It can be regarded as the opposite aspect of egocentric *P*. That is to say, in this sense, two theories can be thought to be in accordance.

There are limitations to expand this hypothesis because *P* was positively related to *N*, and *P* was relatively low in internal consistency in the present study. Although it was standardized, the possibility that the Korean version of the EPS might be somewhat different from the original EPS could not be excluded. Also, since the subjects of this study were a Korean population, culture related factors might intervene between personality and EEG measures. Considering that *P* is not a well established concept, further investigations are required to evaluate the relationship between *P* and EEG correlates.

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