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Resting-state beta and gamma activity in Internet addiction

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ABSTRACT

Internet addiction is the inability to control one's use of the Internet and is related to impulsivity. Although a few studies have examined neurophysiological activity as individuals with Internet addiction engage in cognitive processing, no information on spontaneous EEG activity in the eyes-closed resting-state is available. We investigated resting-state EEG activities in beta and gamma bands and examined their relationships with impulsivity among individuals with Internet addiction and healthy controls. Twenty-one drug-naïve patients with Internet addiction (age: 23.33 ± 3.50 years) and 20 age-, sex-, and IQ-matched healthy controls (age: 22.40 ± 2.33 years) were enrolled in this study. Severity of Internet addiction was identified by the total score on Young's Internet Addiction Test. Impulsivity was measured with the Barratt Impulsiveness Scale-11 and a stop-signal task. Resting-state EEG during eyes closed was recorded, and the absolute/relative power of beta and gamma bands was analyzed. The Internet addiction group showed high impulsivity and impaired inhibitory control. The generalized estimating equation showed that the Internet-addiction group showed lower absolute power on the beta band than did the control group (estimate $= -3.370$, $p < 0.01$). On the other hand, the Internet-addiction group showed higher absolute power on the gamma band than did the control group (estimate $= 0.434$, $p < 0.01$). These EEG activities were significantly associated with the severity of Internet addiction as well as with the extent of impulsivity. The present study suggests that resting-state fast-wave brain activity is related to the impulsivity characterizing Internet addiction. These differences may be neurobiological markers for the pathophysiology of Internet addiction.

1. Introduction

Internet addiction is defined as an inability to control Internet use, which may lead to serious impairment in psychological and social functioning (Griffiths, 1997; Young, 1996). Individuals with Internet addiction experience various psychiatric symptoms such as depressed mood or anxiety (Kalwar, 2010). Impulsivity is also related to Internet addiction, and Cao et al. (2007) reported that adolescents with Internet addiction were more impulsive than were controls as measured by both the Barratt Impulsiveness Scale-11 (BIS-11) and the GoStop impulsivity paradigm (Cao et al., 2007). Lee et al. (2012) compared the impulsivity of those suffering from Internet addiction with that of those with pathological gambling and found that the Internet-addiction group showed increased impulsivity at a level comparable to that of patients with pathological gambling (Lee et al., 2012). Although the pathological aspects of Internet addiction have been reported, only limited evidence about the neurobiological changes underpinning the impulsivity or response inhibition associated with Internet addiction has been published. Some researchers have provided electrophysiological evidence obtained from individuals with Internet addiction. For example, Dong et al. (2010) investigated response inhibition in subjects with Internet addiction by recording event-related potentials (ERPs) during a Go/NoGo task. The authors reported that the Internet-addiction group exhibited lower NoGo-N2 amplitude and higher NoGo-P3 amplitude than did the normal group (Dong et al., 2010). The Internet-addiction group showed greater activation in the anterior cingulate cortex compared with the healthy control group in an investigation of the Stroop effect in a color-word Stroop task performed during functional magnetic resonance imaging (Dong et al., 2012).

In terms of electroencephalography (EEG) frequency bands, beta and gamma bands have been found to be associated with response inhibition. A few studies have reported increased beta power in the frontal areas during successful stop trials (Alegre et al., 2008; Aron, 2011). Swann et al. (2009) found increased beta band activity in the right inferior frontal cortex during successful stop trials at 100–250 ms

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after presentation of the stop stimulus. These findings suggest that beta band activity may be related to inhibitory control. Gamma activity, a high-frequency rhythm of EEG activity, is thought to represent the allocation of the attentional resources and cognitive processes that occur in the brain (Karakas et al., 2006; Muller et al., 2000). During a Go/NoGo task, synchronization changes in the gamma band have been observed (Harmony et al., 2009). Additionally, gamma band synchronization of the orbito-frontal cortex may reflect inhibitory control (van Wingerden et al., 2010).

Although the aforementioned studies reported EEG activities during cognitive processing associated with response inhibition, the spontaneous EEG activity obtained under the resting-state eyes-closed condition has been increasingly recognized as the brain-activity correlate of cognition and behavior (Barry et al., 2009). The resting EEG registers the ongoing rhythmical electrical activity of the brain during relaxation (Porjesz and Begleiter, 2003), when the brain consumes 20% of the body's total energy at rest (Raichle and Mintun, 2006; Shulman et al., 2004). A network of brain regions exhibits increased activity during the resting state (default mode network), and this activity appears to reflect ongoing cognitive processes (Andrews-Hanna et al., 2010). To date, the resting-state EEG activities associated with impulsivity or response inhibition have been collected, especially from patients with attention deficit hyperactivity disorder (ADHD). The EEGs of the majority of patients with ADHD are characterized by a decreased fast-wave activity, primarily in the beta band, and increased slow-wave activity, primarily in the theta band (Barry et al., 2003). Barry et al. (2010) also reported decreased gamma activity during resting-state in children with ADHD. Pathological gambling has been categorized as an impulse control disorder. Recently, Thomsen et al. (2013) reported that patients with pathological gambling were more impulsive than were controls in a stop-signal task, and they also showed reduced resting-state synchronization in the high gamma range (55–100 Hz) on magnetoencephalography.

Taken together, the beta and gamma band activities in the frontal cortex were associated with inhibitory control (Alegre et al., 2008; Aron, 2011; Swann et al., 2009; van Wingerden et al., 2010). Additionally, impulsivity-related disorders such as ADHD and pathological gambling showed decreased beta and gamma activities during resting state (Barry et al., 2003, 2010; Thomsen et al., 2013). To our knowledge, no study has investigated resting-state EEG activities, especially in the beta and gamma bands, in patients with Internet addiction, who would be expected to show high levels of impulsivity. Given that individuals with Internet addiction would likely show high levels of impulsivity, which, as mentioned, may be associated with beta and gamma activities in the frontal cortex, we hypothesized that patients with this condition would demonstrate impaired performance in a stop-signal task compared with healthy controls. Furthermore, we hypothesized that these patients would show decreased beta and gamma power in the frontal cortex compared with healthy controls. To explore resting-state EEG patterns in Internet addiction, we also analyzed the usual delta, theta, and alpha bands.

2. Material and methods

2.1. Participants

Twenty-one patients diagnosed with Internet addiction (age: 23.33 ± 3.50 years) and 20 age-, sex-, and IQ-matched healthy controls (age: 22.40 ± 2.33 years) were enrolled in this study. All patients were seeking treatment at our clinics due to their excessive Internet use. Patients were recruited from the outpatient clinics of SMG-SNU Boramae Medical Center in Seoul, South Korea.

We assessed participants using Young's Internet Addiction Test (IAT; Young, 1996). The severity of Internet addiction was assessed based on total scores on the IAT. Participants also completed Beck's Depression Inventory (BDI; Beck et al., 1961), Beck's Anxiety Inventory (BAI; Beck et al., 1988), and the BIS-11 (Barratt, 1985).

Previous studies have defined excessive Internet users as those with scores of at least 50 on the IAT (Hardie and Tee, 2007; Young, 1996). However, we included only those subjects with scores of at least 70 on the IAT who also spent more than 4 h per day and 30 h per week using the Internet so that we could study only those with a severe Internet addiction rather than those who were merely at high risk due to excessive Internet use. The mean IAT score of patients in the Internet-addiction group was 75.43 ± 6.23, and the mean time spent using the Internet per day and per week was 5.95 ± 2.27 and 45.95 ± 15.87 h, respectively, in this group. Additionally, the Structured Clinical Interview for DSM-IV (SCID; First et al., 1996) was used to identify past and current psychiatric illnesses. Of the 21 patients diagnosed with Internet addiction, four fulfilled DSM-IV criteria for depressive disorder. The primary reason for Internet use in all patients with Internet addiction was online gaming. Healthy controls were recruited from the local community and had no history of any psychiatric disorder. Healthy controls used the Internet less than 2 h per day. The BDI (Beck et al., 1961) and the BAI (Beck et al., 1988) were administered to all subjects to measure depressed and anxious symptoms, respectively. The BIS-11 (Barratt, 1985) was used to measure trait impulsivity. All scales were validated in Korea. The Institutional Review Board of the SMG-SNU Boramae Medical Center approved the study protocol, and all subjects provided written informed consent prior to participation.

Exclusion criteria for all subjects were a history of significant head injury, alcohol or substance abuse, seizure disorder, and psychotic disorder.

All participants were medication naïve at the time of assessment. The Korean version of the Wechsler Adult Intelligence Scale was administered to all subjects to estimate IQ.

2.2. Stop-signal task

The stop-signal task was administered to the participants as part of the Cambridge Neuropsychological Test Automated Battery (CANTAB). This task is used to assess the ability to inhibit a prepotent response (see http://www.camcog.com for details). The number of direction errors on go trials and the proportion of successful stops were calculated based on the behavioral performance of participants.

2.3. EEG recording

The participants were seated and engaged in a resting-state in an isolated sound-shielded room connected to a recording room via a one-way glass window. EEG recordings lasted for 10 min and included the following conditions: 4 min with eyes closed, 2 min with eyes open, and 4 min with eyes closed.

EEG recordings and acquisitions were made using SynAmps2 with a 64-channel Quik-cap and a NeuroScan system (Scan 4.3; Compumedics Ltd., Abbotsford, Australia). A reference, single channel with bipolar electrodes, was attached to the mastoids. A location of the ground channel was between FPz and Fz. The signals were sampled at a frequency of 500 Hz. The electrode impedance was below 5 kΩ, and the EEG signal was band-pass filtered at 0.1–60 Hz using Scan 4.3. Recordings from the NeuroScan system were transferred to the NeuroGuide software (NG 2.5.5; Applied Neuroscience, Inc., St. Petersburg, USA) for spectral analysis in 32-bit cnt form, and 19 sites of 64 channels were driven by a montage set of NeuroGuide as following: FP1, F3, F7, Fz, FP2, F4, F8, T3, C3, Cz, T4, C4, T5, P3, O1, Pz, T6, P4, and O2 (Fig. 1). Artifact removal was performed off-line using the artifact rejection toolbox of the NeuroGuide software. EEG recordings were also visually inspected to eliminate eye muscle movements and other artifacts, and artifact-free epochs of 20–60 s under eyes-closed conditions were selected for spectral analysis. Accepted epochs of EEG data for both absolute (uV^2) and relative (%) power were smoothed using fast Fourier transforms and averaged in

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