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 some 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 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 beta and gamma bands as compared with the healthy control group in an investigation of the Stroop effect. In terms of electroencephalography (EEG) frequency bands, beta and gamma bands have been found to be associated with 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).

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 (Kalvar, 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...
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 electrical activity of the brain during relaxation (Porjesz and Begleiter, 2003), when the brain consumes 20% of the body's total energy at rest (Raitche 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., 2009). 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, Republic of 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 naive 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 (μV²) and relative (%) power were smoothed using fast Fourier transforms and averaged in
five frequency bands by NeuroGuide’s spectral analysis system: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (30–50 Hz). Source localization and visualization based on the 10/20 system was performed with Matlab software (MathWorks, Natick, Massachusetts, USA). Additionally, the activity at 19 sites was divided into three regions by averaging within each region: frontal (FP1, F3, F7, Fz, FP2, F4 and F8), central (T3, C3, Cz, T4, and C4), and posterior (T5, P3, O1, Pz, T6, P4, and O2). Of the five frequency bands, we focused on beta and gamma activities in the frontal region to test the hypotheses addressed in this study (Fig. 1).

2.4. Statistical analysis

Prior to the formal analysis, we conducted an exploratory data analysis to identify and remove outliers to avoid the possibility of spurious results. As repeated or multiple outcomes from the same subject are correlated, the statistical methods that are affected by those correlations among outcomes should be considered. In this study, a generalized estimating equation (GEE; Liang and Zeger, 1986; Zeger and Liang, 1986), which is an extension of the generalized linear model for multivariate responses, was used to assess the group effect on the absolute or relative power in each band. The GEE has been used to characterize the EEGs (Classen et al., 2004; Gur et al., 2006; Lesser et al., 2008; Mason et al., 2009; McLaughlin et al., 2010; Miller et al., 2007; Wang et al., 2007). In this study, group (Internet addiction vs. healthy control), region (or site), and their interaction effects were tested using GEE. The group-by-region (or site) interaction term was used to detect differential group effects in the absolute or relative power in each band by region (or site). In the absence of evidence of an interaction effect, the effect of group was tested.

Comparisons of demographic and clinical variables between patients with Internet addiction and healthy controls were conducted using independent-sample t-test or χ²-test. We used Pearson’s correlations to explore correlations between frontal beta or gamma activity and demographic/clinical variables in patients with Internet addiction and healthy controls. Statistical analyses were performed using IBM SPSS Statistics version 20 (IBM Inc., New York, USA) and R version 2.15.2 (http://www.r-project.org) and p-values less than 0.05 were considered statistically significant. However, correlational analyses were treated as exploratory, and p-values were not adjusted for multiple tests.

3. Results

3.1. Demographic and clinical data

No significant differences in age, sex, education, or IQ were observed between groups (Table 1). However, patients with Internet addiction had higher scores on the BDI, BAI, and BIS-11 than did control subjects. Additionally, the Internet-addiction group showed impaired inhibitory control on the stop-signal task compared with the control group.

3.2. EEG activity

3.2.1. Absolute power

Fig. 2 shows the scalp topography of the two groups in terms of the absolute power in each band. The GEE results showed a significant group-by-region interaction effect for the absolute power in the beta band. In all areas, the Internet-addiction group showed lower absolute power in the beta band than did the control group (frontal region: estimate = −3.610, χ² = 7.662, p = 0.006; central region: estimate = −3.250, χ² = 6.920, p = 0.009; posterior region: estimate = −4.514, χ² = 12.474, p < 0.001). On the other hand, we found no group-by-region interaction effect for the absolute power in the gamma band. However, the main group effect was statistically significant in all three regions (p < 0.01). The Internet-addiction group showed higher absolute power in the gamma band than did the control group (estimate = 0.396, χ² = 8.823, p < 0.01).

In the frontal region, the interaction effect between group and site was statistically significant for the absolute power in the gamma band (p < 0.01). As shown in Fig. 3, the absolute power in the gamma band of the Internet-addiction group was higher than that of the control group at all seven sites (FP1: estimate = 0.434, χ² = 8.551, p < 0.01; FP2: estimate = 0.455, χ² = 10.698, p < 0.01; F3: estimate = 0.340, χ² = 5.390, p = 0.02; F4: estimate = 0.431, χ² = 8.350, p < 0.01; F7: estimate = 0.419, χ² = 7.524, p < 0.01; F8: estimate = 0.423, χ² = 7.959, p < 0.01; Fz: estimate = 0.464, χ² = 9.253, p < 0.01).

The group effect size at F3 differed from that at Fz (p < 0.01). Although no group-by-site interaction was observed for the absolute power in the beta band, the Internet-addiction group showed lower absolute power than did the control group (estimate = −3.370, χ² = 7.591, p < 0.01; Fig. 3).

Table 1

Demographic and clinical characteristics of the subjects.a

<table>
<thead>
<tr>
<th>Variables</th>
<th>Internet Addiction (N = 21)</th>
<th>Healthy Control (N = 20)</th>
<th>t, χ²</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>23.33 (3.50)</td>
<td>22.40 (2.33)</td>
<td>1.00</td>
<td>0.32</td>
</tr>
<tr>
<td>M/F (number)</td>
<td>12/9</td>
<td>11/9</td>
<td>0.04</td>
<td>0.84</td>
</tr>
<tr>
<td>Education (years)</td>
<td>14.81 (1.94)</td>
<td>14.95 (1.36)</td>
<td>−0.27</td>
<td>0.79</td>
</tr>
<tr>
<td>IQ score</td>
<td>122.9 (10.31)</td>
<td>123.90 (9.82)</td>
<td>−0.32</td>
<td>0.75</td>
</tr>
<tr>
<td>Clinical data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age of Internet use onset (years)</td>
<td>12.76 (3.03)</td>
<td>12.40 (1.90)</td>
<td>0.46</td>
<td>0.65</td>
</tr>
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<td>IAT</td>
<td>75.43 (6.23)</td>
<td>18.45 (8.58)</td>
<td>24.41</td>
<td>&lt;0.001</td>
</tr>
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<td>BDI</td>
<td>14.81 (6.55)</td>
<td>4.50 (4.29)</td>
<td>5.93</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BAI</td>
<td>14.81 (8.41)</td>
<td>7.75 (6.06)</td>
<td>3.07</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BIS-11</td>
<td>72.33 (10.44)</td>
<td>52.80 (14.35)</td>
<td>5.00</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stop signal task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction errors on go trials</td>
<td>1.48 (1.36)</td>
<td>0.50 (1.00)</td>
<td>2.60</td>
<td>0.01</td>
</tr>
<tr>
<td>Proportion of successful stop on stop trials</td>
<td>0.48 (0.06)</td>
<td>0.55 (0.12)</td>
<td>-2.25</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Data are given as mean (SD).
IQ, Intelligence Quotient; IAT, Internet Addiction Test; BDI, Beck Depression Inventory; BAI, Beck Anxiety Inventory; BIS-11, Barratt Impulsiveness Scale 11.
a Independent sample t-test was used.
b Chi-square test was used.
With respect to delta, theta and alpha bands, we found no group-by-region interaction effect for absolute power, and the main group effect was not significant in any of three regions.

3.2.2. Relative power

Fig. 2 shows the scalp topography of the two groups for the relative power in each band. The GEE results revealed no group-by-region interaction effect for the relative power in each band. The main group effect was not significant for any of the bands in any of the three regions.

In the frontal region, the effect of the group-by-site interaction was not statistically significant for the relative power in any of the bands. However, the main group effect was statistically significant in all seven sites for the relative power in the gamma band ($p < 0.01$). The Internet-addiction group showed higher relative power in the gamma band than did the control group (estimate = 1.503, $\chi^2 = 28.496, p < 0.01$). We found no main group effects for the relative power in the delta, theta, alpha, and beta bands.

3.3. Correlation between behavioral/clinical variables and frontal EEG activity

We found significant correlations between the severity of Internet addiction and absolute beta and gamma power ($r = -0.410, p = 0.008; r = 0.346, p = 0.027$, respectively) in the frontal region. BIS-11 scores were significantly correlated with the absolute power in the beta and with the relative power in the gamma bands in the frontal region ($r = -0.356, p = 0.023; r = 0.363, p = 0.029$, respectively). Additionally, direction errors on the go trials in the stop-signal task were significantly correlated with absolute and relative power in the gamma band in the frontal region ($r = 0.552, p < 0.01; r = 0.465, p = 0.004$, respectively). We found no significant correlations between behavioral/clinical variables and the absolute/relative power in the delta, theta, or alpha bands in the frontal region.

4. Discussion

To our knowledge, this is the first resting-state EEG study to elucidate brain electrical activity in patients with Internet addiction. We found that these patients showed high impulsivity and impaired inhibitory control, and that patients with Internet addiction showed decreased absolute power in the beta band and increased absolute power in the gamma band compared with healthy controls. These EEG activities were significantly related to the severity of Internet addiction as well as to the extent of impulsivity.

As expected, in the present study, decreased beta band activity was observed in patients with Internet addiction during the resting-state. Decreased beta power has been related to inattention or impulsivity, which is observed in patients with ADHD (Snyder and Hall, 2006). In this study, patients with Internet addiction had significantly higher scores on the BIS-11 than did those in the control group. Our previous research found that patients with Internet addiction showed increased trait impulsivity that reached a level comparable to that in patients with pathological gambling (Lee et al., 2012). Scores on the BIS-11 were also negatively correlated with absolute power in the beta band in the frontal region. Additionally, patients with Internet addiction showed impaired inhibitory control measured by the stop-signal task. Although subjects in the present study did not have comorbid ADHD, trait impulsivity and impaired inhibitory control may be associated with decreased frontal beta power in Internet addiction.

Gamma-frequency oscillations have been speculated to play a role in several important cognitive functions. Widespread gamma activity may be connected to feature “binding” in which separate parts of the brain are involved in attempts to form a coherent image based on data provided by several senses (Tallon-Baudry, 2003; Tallon-Baudry et al., 2005). Abnormalities in the neuronal system including pyramidal neurons and GABAergic inter-neurons may result in deteriorated gamma oscillation (Shin et al., 2011). Furthermore, dysfunctional resting-state gamma activity in the absence of external sensory stimuli may reflect aberrant...
addiction (Ha et al., 2007; Yen et al., 2007). Therefore, the possibility have found relationships between depressive symptoms and Internet state.

the inef (Grin-Yatsenko et al., 2010; Volf and Passynkova, 2002), which was studies have reported increased beta activity in depressive disorder than to Internet addiction per se cannot be ruled out. However, previous hypotheses that this increased gamma activity in Internet addiction may re

data also revealed decreased beta power with increased gamma power in those with Internet addiction compared with healthy controls during the resting state. These findings suggest that resting-state fast-wave brain activity is associated with impulsivity in Internet addiction. These differences may be neuro-biological markers for the pathophysiology of Internet addiction. This research will contribute to a better understanding of brain-based electrophysiological changes in individuals with Internet addiction.

In summary, our results showed high impulsivity and impaired inhibitory control in Internet addiction. The data also revealed decreased beta power with increased gamma power in those with Internet addiction during the resting-state eye-closed condition in subjects. The horizontal bars represent standard errors.

functional connectivity and neural asynchrony while the brain is in “default mode.” Changes in resting-state gamma activity have also been found to be associated with impulsivity or response inhibition (Barry et al., 2010; Thomsen et al., 2013). However, contrary to our hypotheses that patients with Internet addiction would show decreased power in the gamma band in the frontal cortex, increased gamma-band activity during the resting state was observed in these patients. Furthermore, increased gamma power during the resting state was associated with impaired inhibitory control and trait impulsivity. One can speculate that this increased gamma activity in Internet addiction may reflect the inefficient neuronal activity that occurs even during the resting state.

This study has several limitations. Scores on BDI and BAI in the Internet addiction group were higher than those in the healthy control group, which may have had confounding effects. Previous researchers have found relationships between depressive symptoms and Internet addiction (Ha et al., 2007; Yen et al., 2007). Therefore, the possibility that the current findings may be related to depressive symptoms rather than to Internet addiction per se cannot be ruled out. However, previous studies have reported increased beta activity in depressive disorder (Grin-Yatsenko et al., 2010; Volf and Passynkova, 2002), which was associated with anxiety symptoms (Grin-Yatsenko et al., 2010). In contrast, the patients with Internet addiction included in this study showed decreased power on the beta band. Moreover, we found no significant correlation between absolute power in the beta band and depressive symptoms in patients with Internet addiction. An explanatory subgroup analysis revealed no significant differences in absolute power in the beta band between patients with lower BDI (BDI below 15, N = 12) and those with higher BDI (BDI 15 or above, N = 9) scores. Additionally, gamma activity was not significantly related to BDI and BAI scores among those with Internet addiction. Thus, decreased resting-state beta and increased gamma activity may be specific to Internet addiction.

This study also has several strengths. We used study groups that were well matched with respect to age, sex, and IQ, EEG measures have been observed to vary over time with maturation and development (Clarke et al., 2001). As differences in age can affect electrophysiological changes, it is necessary to use age-matched groups. Additionally, only drug-naïve subjects participated in this study. Medications such as anti-depressants (Hunter et al., 2010) and benzodiazepines (Liley et al., 2003) can also affect the EEG activity. By excluding these confounding factors, we were able to analyze the associations between Internet addiction and EEG activities in homogeneous samples.

In summary, our results showed high impulsivity and impaired inhibitory control in Internet addiction. The data also revealed decreased beta power with increased gamma power in those with Internet addiction during the resting-state eye-closed condition in subjects. The horizontal bars represent standard errors.

![Graph A](image1.png)

**Fig. 3.** Absolute power in the beta (A) and gamma (B) bands in the frontal regions of subjects during the resting-state eye-closed condition in subjects. The horizontal bars represent standard errors.

![Graph B](image2.png)

**References**


