Brain activation for response inhibition under gaming cue distraction in internet gaming disorder

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KEYWORDS
Craving; Dorsolateral prefrontal cortex; Go/NoGo task; Superior parietal lobe

Abstract We evaluated neural substrates related to the loss of control in college students with internet gaming disorder (IGD). We hypothesized that deficit in response inhibition under gaming cue distraction was the possible mechanism for the loss of control internet use. Eleven cases of IGD and 11 controls performed Go/NoGo tasks with/without gaming distraction in the functional magnetic resonance imaging scanner. When the gaming picture was shown as background while individuals were performing Go/NoGo tasks, the IGD group committed more commission errors. The control group increased their brain activations more over the right dorsolateral prefrontal cortex (DLPFC) and superior parietal lobe under gaming cue distraction in comparison with the IGD group. Furthermore, brain activation of the right DLPFC and superior parietal lobe were negatively associated with performance of response inhibition among the IGD group. The results suggest that the function of response inhibition was impaired under gaming distraction among the IGD group, and individuals with IGD could not activate right

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DLPFC and superior parietal lobe to keep cognitive control and attention allocation for response inhibition under gaming cue distraction. This mechanism should be addressed in any intervention for IGD.

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Introduction

The internet has become one of the most important tools in daily life. However, loss of control of internet use has been labeled as internet addiction and its diagnostic criteria have been developed [1]. Internet addiction is now prevalent worldwide [2–4]. Among internet addicts, internet gaming disorder (IGD) is most common [2,5]. IGD has been regarded as a behavior addiction [6]. However, until now, whether it is an addiction related to a deficit in impulse control has not been definitively established.

Internet addiction has been reported to be associated with substance use among adolescents and adults [4,7–9]. In a recent study with functional magnetic resonance imaging (fMRI), the brain activations of gaming craving for internet addiction are observed to be similar to those of substance craving [10]. Thus, IGD may share some common mechanisms with substance use disorders. Impairment of response inhibition is the core concept to explain the loss of control in substance use [11]. The deficit has been investigated with Go/NoGo tasks in fMRI [12–14]. An increased error rate in Go/NoGo tasks has been found in adolescents with internet addiction [15]. By contrast, better performance in Go/NoGo tasks has also been found among individuals with excessive internet use [16]. Only one previous study has demonstrated that adults with IGD have higher brain activation of anterior cingulate for interference inhibition in the Stroop task [17]. However, the neurobiological mechanism for proponent response inhibition in Go/NoGo tasks among adults or adolescents with IGD has not been studied. The proactive-control mechanism is underdeveloped in adolescents and matures progressively in adults [18]. Evaluation of adults with IGD could reveal the function of response inhibition in their mature stage.

Attention bias induced by substance cues has been shown to interfere with the Stroop task [19]. The neural mechanism of attention bias has been studied in substance users; its result suggests that attention bias caused by cocaine cue impairs the executive function and cognition control [20]. However, whether the gaming cue impairs the response inhibition has not been evaluated along with the neural substrates of this effect among individuals with IGD.

Thus, the aim of this fMRI study was to evaluate brain activation when performing a Go/NoGo task for college students with IGD, and compare it with a control group. Furthermore, we investigated the change in brain activations when the target of Go/NoGo tasks was distracted by gaming pictures.

Methods

Participants

Eleven men with IGD and 11 control male participants were recruited via an advertisement posted on the Bulletin Board System on the college campus. The inclusion criteria for the case group were: (1) diagnosis of internet addiction based on diagnostic criteria for Internet addiction for college students (DCIA-C)1; (2) addiction to the same popular online game in Taiwan; and (3) right-handedness. Those diagnosed with no internet addiction were classified as the control group.

Exclusion criteria included: life-time substance use disorder, other than nicotine dependence; current major depressive episode; current psychotropic medication use; history of bipolar I disorder; psychotic disorder; neurological illness and injury; and mental retardation or intolerability to MRI. Sample sizes of 11 cases and 11 control participants were comparable to those of previous fMRI studies in behavior addiction [21]. The study was approved by the Institutional Review Board (IRB) of Kaohsiung Medical University.

Image acquisition

The fMRI scanning was performed in a 3 Tesla General Electric MR scanner (Sigma VH/I, software: version 4.0). Liquid crystal display goggles were placed over the eyes. The MR sequence for functional imaging was a gradient-recalled echo planar imaging (EPI) sequence [64 × 64 matrix; 24-cm field of view, echo time (TE) = 40 milliseconds; repetition time (TR) = 3 seconds; 3-mm thick slices with 0-mm gap]. Forty-one image planes were collected in an axial orientation with the aid of sagittal localizer images to encompass the whole head. Head motion < 2 mm was corrected by post-processing using Statistical Parametric Mapping (SPM, Wellcome Department of Cognitive Neurology, London, UK) [2].

Procedure

All invited participants were interviewed by a psychiatrist for a diagnosis of online gaming addiction according to DCIA-C1 and screening for exclusive criteria based on the Mini-International Neuropsychiatric Interview [22]. Then, they were arranged to complete the Chen Internet Addiction Scale (CIAS) [23], Fagerstrom Test for Nicotine Dependence (FTND) [24], and the level of gaming urge prior to entering block-design fMRI. All participants scored lower than the cut-off point of FTND (≥ 5) for screening medium nicotine dependence.

Behavior task

The task included two sections of Go/NoGo performance: original and game-distracting sections (Fig. 1) that were separated by 30 seconds of rest. There were two conditions in each section: Block A — the Go condition, had 20 trials showing white polygons (except pentagons) on a black background; Block B — the NoGo condition, had 10 presentations of no-target (pentagons) and 10 presentations of...
target (polygons other than pentagons). The participants were informed to press the button as quick as possible for the polygons, except for the pentagon. Every block of 30 seconds contained 20 polygons for those shown for 0.5 seconds with 1 second of inter-trial interval in pseudo-randomized sequence. A section of 160 trials contained eight blocks, presented in the order ABABABAB. In the original Go/NoGo section the background was black. In the game-distracting section, the different gaming pictures were shown 0.5 seconds prior to the presentation of the polygons and ended along with polygons as the background (Fig. 1). The sequences of blocks and polygons were identical in the two sections. Prior to fMRI, all participants had practiced the original Go/NoGo tasks to be familiar with the rules of the tasks.

Data analysis

All time series exported from the GE system were converted into SPM5 format using MRicro [25]. The subsequent image preprocessing and statistical analysis were performed using SPM5 package (Wellcome Department of Cognitive Neurology, London, UK).

At the first level, mean images for each individual were created, depicting the subtraction of BOLD response during Block A (Go block) from that during Block B (NoGo block; Block B–Block A) in original and game-distracting sections on a voxel-by-voxel basis with SPM5. In the original section, the subtraction demonstrated the brain activation associated with response inhibition. In the game-distracting section, the subtraction represented brain activation for response inhibition under distraction of gaming pictures. These mean images were then combined into case and control groups (Fig. 2).

The full factorial analysis of SPM5 was utilized to process the secondary analysis. The repeated measure factor for "Original versus game-distracting response inhibition" and the group factor (case vs. control group) were utilized to analyze the brain activation for response inhibition (Block B–Block A). We first determined group differences in response inhibition of the original section with threshold $p < 0.001$ and cluster size $> 20$ voxels (case group – control group and control group – case group). Then, we further evaluated the difference in the effect of gaming distraction on response inhibition between the IGD and control groups by using interaction analysis of group and repeated measure factors with threshold $p < 0.001$ and cluster size $> 20$ voxels (IGD group – control group; defined as between-group difference; Fig. 3). Conversion of the Montreal Neurological Institute (MNI) to the Talairach coordinates [26] was conducted with a linear algorithm, and Brodmann areas were identified with the Talairach Daemon [27]. The first several seconds of every block (10 scans; 30 seconds) was within the transitional period between the blocks, therefore, we only processed the BOLD data collected from

![Figure 1. Design of behavior task in functional magnetic resonance imaging.](image-url)
the last eight scans (24 seconds) of every block in the design matrix to minimize the carry-over effect [28].

For region-of-interest (ROI) analysis, we defined ROIs based on the brain regions that were significant in interaction analysis. The brain activation corresponding to response inhibition in the original section and game-distracting sections was calculated by MarsBaR (http://marsbar.sourceforge.net/) based on a sphere with 5-mm radius [29]. The correlation between the ROIs and commission error, and gaming urge were examined by Spearman correlation among the cases and all participants with SPSS version 14 (SPSS, Chicago, IL, USA). A p value < 0.05 was considered significant.

Results

Behavior task

The behavior analyses were conducted by the Mann–Whitney U test. There was no difference in age and educational levels between the 11 case and 11 control participants (Table 1). The case group had significantly higher levels of CIAS score and gaming urge prior to scanning. The IGD group had made more commission errors (response to pentagons) in the gaming distracting Go/NoGo task, but not in the original Go/NoGo task, than the control group. However, the commission error significantly increased with gaming distracting in the IGD group (Z = 2.54, p = 0.01), but not in the control group (Z = 1.13, p = 0.26). Two-way analysis of variance demonstrated that the difference in errors between gaming distracting and the original section was higher among the case group than the control group (F(1,20) = 9.23, p = 0.006, ηp² = 16.57). These results suggest that the function of response inhibition was attenuated by the gaming cue among the IGD group.

Activated brain regions for response inhibition observed in original sections among cases and controls

The case group activated bilateral superior parietal lobe, fusiform temporal lobe, and anterior cingulated, right
dorsolateral prefrontal cortex (DLPFC), inferior parietal lobe, middle frontal lobe, insula, and orbital frontal lobe, and left posterior cerebellum for response inhibition. The control group activated the left inferior occipital and right anterior prefrontal lobe for response inhibition (Table 2 & Fig. 2).

Difference in brain activation for response inhibition with/without gaming-distraction between IGD and control groups

Comparison of the activations for the original Go/NoGo task between cases and controls (Table 3 & Fig. 3) revealed that the former had higher activation over the right superior parietal lobe. Table 3 & Fig. 3 shows that the control group had higher increased activation under gaming distraction (response inhibition under gaming distraction – original response) than the case group over the right superior parietal lobe (Area 7), DLPFC (BA 9), and posterior cerebellum.

ROI analysis for brain activation and behavior data

The ROI analysis in Table 4 reveals that the commission errors in the original Go/NoGo task were negatively associated with the ROI of the right superior parietal lobe in the case group. It reveals that activation of the right superior parietal lobe positively contributed to response. The commission errors under gaming distraction were positively associated with the ROI of the right superior parietal lobe (BA7) and DLPFC (BA9) in the case group. This indicated that the more these two areas were activated, the more mistakes were made under gaming distraction. For all participants, the ROI of the superior parietal lobe (BA7) and DLPFC (BA9) were negatively correlated with the gaming urge prior to scanning. This indicates greater craving response prior to scanning, and higher vulnerability to the effect of gaming distraction over the superior parietal lobe and DLPFC. In the IGD group, the ROI of the DLPFC was also negatively associated with the gaming urge prior to scanning.

Discussion

In this study, there was no difference in performance of response inhibition between the IGD and control groups. Previous reports revealed lower brain activation and concluded the impaired response-inhibition of subjects

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>IGD group</th>
<th>Control group</th>
<th>Z*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commission errors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original Go/NoGo</td>
<td>1.09 ± 0.94/40</td>
<td>0.72 ± 1.42/40</td>
<td>1.27</td>
</tr>
<tr>
<td>Game distracting Go/NoGo</td>
<td>3.27 ± 3.04/40</td>
<td>0.45 ± 0.82/40</td>
<td>2.80*</td>
</tr>
<tr>
<td>CIAS score</td>
<td>75.82 ± 9.76</td>
<td>40.63 ± 12.27</td>
<td>3.97**</td>
</tr>
<tr>
<td>Education age</td>
<td>16.09 ± 1.22</td>
<td>16.18 ± 1.40</td>
<td>0.44</td>
</tr>
<tr>
<td>Gaming urge prior to scan</td>
<td>5.64 ± 2.69</td>
<td>0.09 ± 0.30</td>
<td>-3.83**</td>
</tr>
</tbody>
</table>

*p < 0.01.
**p < 0.001.

CIAS = Chen Internet Addiction Scale; IGD = internet gaming disorder.

* Z value for Mann–Whitney U test.
with substance use disorder [12,14,30–32]. The present study demonstrated that the IGD group had higher activation over the right superior parietal lobe for response inhibition than did the control group. Thus, we did not demonstrate the deficit response inhibition among the IGD group.

In line with previous studies using a similar design for cocaine abuse and alcoholism [20,33], when the background of the Go/NoGo task was changed to a gaming picture, more commission errors were found in the IGD group than in the control group. This indicated that performance of response inhibition was impaired under gaming distraction among the

### Table 2

<table>
<thead>
<tr>
<th>Region of activation</th>
<th>L/R</th>
<th>BA</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Voxels</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original response inhibition</td>
<td>IGD group</td>
<td>Superior parietal lobule</td>
<td>R</td>
<td>7</td>
<td>34</td>
<td>−60</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inferior parietal lobule</td>
<td>R</td>
<td>40</td>
<td>48</td>
<td>−50</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inferior parietal lobule</td>
<td>R</td>
<td>40</td>
<td>50</td>
<td>−37</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cerebellum, posterior lobe</td>
<td>L</td>
<td>−16</td>
<td>−86</td>
<td>−16</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anterior cingulated</td>
<td>L</td>
<td>24</td>
<td>−10</td>
<td>8</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anterior cingulated</td>
<td>R</td>
<td>32</td>
<td>14</td>
<td>18</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle frontal gyrus</td>
<td>R</td>
<td>6</td>
<td>46</td>
<td>4</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DLPFC</td>
<td>R</td>
<td>46</td>
<td>55</td>
<td>32</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DLPFC</td>
<td>R</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub-lobar, insula</td>
<td>R</td>
<td>13</td>
<td>32</td>
<td>23</td>
<td>−3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Orbital frontal lobe</td>
<td>R</td>
<td>47</td>
<td>28</td>
<td>15</td>
<td>−13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Orbital frontal lobe</td>
<td>R</td>
<td>47</td>
<td>38</td>
<td>27</td>
<td>−11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior parietal lobule</td>
<td>L</td>
<td>7</td>
<td>−28</td>
<td>−56</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temporal lobe, fusiform gyrus</td>
<td>R</td>
<td>37</td>
<td>48</td>
<td>−49</td>
<td>−16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temporal lobe, fusiform gyrus</td>
<td>L</td>
<td>37</td>
<td>−46</td>
<td>−55</td>
<td>−11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DLPFC</td>
<td>R</td>
<td>46</td>
<td>44</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>Control group</td>
<td></td>
<td>Inferior occipital gyrus</td>
<td>L</td>
<td>17</td>
<td>−22</td>
<td>−92</td>
<td>−9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anterior prefrontal lobe</td>
<td>R</td>
<td>10</td>
<td>40</td>
<td>55</td>
<td>8</td>
</tr>
</tbody>
</table>

p = 0.001.

BA = Brodmann area; DLPFC = dorsolateral prefrontal cortex; IGD = internet gaming disorder; L/R = left/right hemisphere; X,Y,Z = the coordinates of Talairach system for location of human brain.

"\( a \) voxels = 20. Voxel numbers are for contiguous clusters of 3.75 mm × 3.75 mm × 3 mm voxels with threshold cluster size of 20 voxels.

"\( b \) Z scores are given for uncorrected \( p \) values with threshold of 0.001.

### Table 3

<table>
<thead>
<tr>
<th>Region of activation</th>
<th>L/R</th>
<th>BA</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Voxels</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison for original response inhibition</td>
<td>Case group — control group</td>
<td>Superior parietal lobule</td>
<td>R</td>
<td>7</td>
<td>34</td>
<td>−58</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior parietal lobule</td>
<td>R</td>
<td>7</td>
<td>28</td>
<td>−50</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control group — case group</td>
<td>No activation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Case group for (Response inhibition under gaming distracting — original response)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior parietal lobule</td>
<td>R</td>
<td>7</td>
<td>36</td>
<td>−60</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DLPFC</td>
<td>R</td>
<td>9</td>
<td>50</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cerebellum, Posterior Lobe</td>
<td>L</td>
<td>−12</td>
<td>−80</td>
<td>−11</td>
<td>24</td>
</tr>
</tbody>
</table>

BA = Brodmann area; DLPFC = dorsolateral prefrontal cortex; L/R = left/right hemisphere; X,Y,Z = the coordinates of Talairach system for location of human brain.

"\( a \) Voxel numbers are for contiguous clusters of 3.75 mm × 3.75 mm × 3 mm voxels with threshold cluster size of 20 voxels.

"\( b \) Z scores are given for uncorrected \( p \) values with threshold of 0.001.
IGD group. This supports the hypothesis that gaming cues impair the function of response inhibition in IGD.

Two-way analysis of variance demonstrated that the control group increased activation more on the right DLPFC and superior parietal lobe. This suggested that the control group needed to activate brain areas involved in response inhibition to keep adequate performance under gaming distraction. However, the case group failed to increase brain activation, especially over the right DLPFC and superior parietal lobe, and had worse performance under gaming distraction.

The DLPFC has been found to be activated for the Go/NoGo tasks [24,34,35] and is suggested to be an indicator of capacity for response inhibition [36]. It has a crucial role in cognitive control of motor behavior [37] and contributes to response inhibition. The hypoactivity of DLPFC has also been reported to explain the response-inhibition deficit for substance use disorder and Williams syndrome [38,39]. Based on the brain activation of the control group, DLPFC needs to be further activated to control the motor behavior to follow up the rules of the Go/NoGo tasks. In order to prevent being distracted, the DLPFC should be further activated to keep cognitive control on motor response in the Go/NoGo tasks under gaming distraction. This is in line with previous reports suggesting that the DLPFC is involved in mediating the effects of distraction [40,41]. However, the IGD group did not activate the DLPFC, as in the control group, under gaming cue distraction.

There are two possibilities to explain the deficit. First, the IGD group was more vulnerable to the effect of distraction. They had a deficit to activate DLPFC under general distraction, which resulted in the deficit of response inhibition. Attention deficit hyperactivity disorder (ADHD) is a disorder representing distractibility. Individuals with ADHD have been found to decrease their activation of the DLPFC, resulting in a deficit of attention control [42]. IGD has been reported to be associated with ADHD [43] and showed a similar deficit in brain activation under distraction in the present study. Thus, the mechanism of deficit in cognitive control among ADHD patients might contribute to the deficit in response inhibition under distraction among individuals with IGD. However, this should be demonstrated in further studies.

Another explanation is that the IGD group had a deficit in the activation of the DLPFC under the specific influence of gaming cues. Cocaine users have difficulty modulating the neural mechanisms underlying cognitive control under the distraction of a cocaine cue [18]. In the present study, brain activation of the DLPFC was negatively associated with the gaming urge in the IGD group. This result supports the hypothesis that decreased activity of the DLPFC is associated with the craving response. Furthermore, in our previous study, gaming cues were found to activate the right DLPFC [10]. The function of the DLPFC was occupied by response to gaming use, thus, it was unable to undergo activation to control the motor behavior under gaming cue distraction. This mechanism was supported by the ROI analysis. It demonstrated that the activation of the DLPFC deteriorated, but did not contribute to the performance of response inhibition under gaming distraction in the IGD group. Thus, decreased and impaired function of the DLPFC was one of the most important mechanisms to explain the deficit in response inhibition under gaming cue distraction among college students with IGD.

The superior parietal lobe has been reported to be involved in the function of cognitive control [44,45]. It is implicated in the voluntary orientation of attention to relevant aspects of the environment and allocates top-down attention to memory retrieval [46]. In the present study, it was activated to allocate attention to the Go and NoGo stimuli for the function of response inhibition among the IGD group. Furthermore, activation of the superior parietal lobe was greater among the IGD than the control group in the original Go/NoGo tasks. The ROI analysis demonstrated that its activation was positively correlated with the performance of response inhibition among the IGD group. This suggests that the IGD group had a better activation of the superior parietal lobe to allocate attention. Allocation of attention to the target is important for online gaming. Under good training in the online game, the IGD group could effectively activate the superior parietal lobe to give their attention to the important target.

However, under gaming distraction, the control group activated the superior parietal lobe more and maintained adequate performance. The superior parietal lobe has been reported to be involved in effects of distraction [47–49]. Under distraction, the superior parietal lobe needs to activate top-down control of attention to the relevant task cue. However, the IGD group decreased activation of the superior parietal lobe under gaming cue distraction. Furthermore, their activation of the superior parietal lobe was negatively associated with the performance of response inhibition under gaming cue distraction. This indicates that the parietal lobe, which normally functions in the original task, was impaired under gaming distraction among the IGD group. Previous behavior analysis has demonstrated that addiction cues can provoke the craving response and distract attention [50]. In the present study, the gaming craving was associated with cue-induced impairment of response inhibition, and decreased brain commission in the original Go/NoGo task.

### Table 4 Association between behavior responses and the ROIs for right dorsolateral prefrontal cortex and precuneus in the IGD group.

<table>
<thead>
<tr>
<th>ROI of significant activate areas</th>
<th>Commission errors&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Pre-scan urge&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Pre-scan urge&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>(L/R; BA; X, Y, Z)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior parietal lobe (R; 7; 28; – 50, 41)</td>
<td>–0.63*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gaming distraction Go/NoGo task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior parietal lobe (R; 7; 36, –60, 42)</td>
<td>0.60*</td>
<td>–0.68***</td>
<td></td>
</tr>
<tr>
<td>DLPFC (R; 9; 51, 9, 31)</td>
<td>0.79**</td>
<td>–0.64*</td>
<td>–0.74***</td>
</tr>
</tbody>
</table>

<sup>a</sup> Commission errors in original Go/NoGo task.

<sup>b</sup> Gaming urge prior to scanning.

* p < 0.05; ** p < 0.01; *** p < 0.001.

BA = Brodmann area; DLPFC = dorsolateral prefrontal cortex; IGD = internet gaming disorder; L/R = left/right hemisphere; ROI = region of interest; X, Y, Z = the coordinates of Talairach system for location of human brain.

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**Internet gaming addiction**

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49
activity of the right superior parietal lobe. This suggests that the IGD group could not activate the superior parietal lobe to maintain top-down control of their attention allocation under gaming cue distraction.

Goldstein has proposed that substance addiction involves loss of self-directed/willed behavioral control, thus yielding control to the automatic sensory-driven formulas elicited by the primary salience of the cues related to the substance of abuse, and this process has been labeled “a syndrome of impaired response inhibition and salience attribution (I-RISA)” syndrome [11]. I-RISA syndrome argues that integration of craving response and impairment of response inhibition leads to a loss of control of substance use behavior. Our previous study showed that gaming-cue-induced craving response in the nucleus accumbens, anterior cingulate, orbital frontal lobe (OFC), DLPFC, and caudate nucleus [10]. From the results of the present study, we suggest that the cue-induced craving impairs the function of response inhibition by deactivating the DLPFC and superior parietal lobe. The attention and cognitive resources have been biased by gaming pictures, therefore, the activation of the DLPFC and superior parietal lobe was also impaired under gaming distraction. This mechanism represents the clinical picture of individuals with IGD, in which their self-control ability becomes inadequate when viewing gaming-related cues. Thus, deactivation of the superior parietal lobe and DLPFC is the possible mechanism for cue-induced loss of control during internet use.

There were several limitations to this study. First, only male college students were included. Second, individuals with comorbid substance abuse and other major psychiatric disorders were excluded, thus, there is a limitation to generalization of the results to those with IGD and other substance use disorders or major psychiatric disorders. Third, the number of participants was limited because they needed to be addicted to the same game at the same time to show a consistent response to gaming cues. Fourth, we did not assess the diagnosis of ADHD in this study, thus, we did not exclude individuals with ADHD. Fifth, the frequency of internet use was not controlled as a covariate. Lastly, the difference between the original and gaming-distraction sections might have been associated with the content of the gaming pictures as well as the color and lightness of the pictures.

In conclusion, despite the above limitations, this is believed to be the first study to test for response inhibition mechanism in IGD. First, this study demonstrates that the gaming-cue-induced reactivity appears to be the underlying mechanism for the deficit of response inhibition among college students with IGD. Second, impaired activation of the right DLPFC and superior parietal lobe was the possible neural mechanism for the loss of control. Thus, impaired response inhibition under gaming cue distraction should be one of the targets of psychological or psychopharmacological intervention for college students with IGD, as in substance use disorder.

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References

Internet gaming addiction


