Altered Regional Cerebral Glucose Metabolism in Internet Game Overusers: *A ^{18}F-fluorodeoxyglucose Positron Emission Tomography Study*

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ABSTRACT

Introduction: Internet game overuse is an emerging disorder and features diminished impulse control and poor reward-processing. In an attempt to understand the neurobiological bases of Internet game overuse, we investigated the differences in regional cerebral glucose metabolism at resting state between young individuals with Internet game overuse and those with normal use using ^{18}F-fluorodeoxyglucose positron emission tomography study.

Methods: Twenty right-handed male participants (9 normal users: 24.7±2.4 years of age, 11 overusers: 23.5±2.9 years of age) participated. A trait measure of impulsivity was also completed after scanning.

Results: Internet game overusers showed greater impulsiveness than the normal users and there was a positive correlation between the severity of Internet game overuse and impulsiveness. Imaging data showed that the overusers had increased glucose metabolism

FOCUS POINTS

- Internet and Internet game overuse are similar to pathological gambling, which is a type of impulse control disorder involving the inability to resist the impulse to perform an action that is harmful to oneself or others.
- Internet game overusers showed greater impulsiveness than normal users. Imaging data showed that overusers had increased glucose metabolism in the orbitofrontal cortex, striatum, and sensory regions, which are implicated in impulse control, reward processing, and somatic representation of previous experiences.
- Internet game overuse shares psychological and neural mechanisms with other types of impulse control disorders and substance/non-substance-related addiction.

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in the right middle orbitofrontal gyrus, left caudate nucleus, and right insula, and decreased metabolism in the bilateral postcentral gyrus, left precentral gyrus, and bilateral occipital regions compared to normal users.

Conclusion: Internet game overuse may be associated with abnormal neurobiological mechanisms in the orbitofrontal cortex, striatum, and sensory regions, which are implicated in impulse control, reward processing, and somatic representation of previous experiences. Our results support the idea that Internet game overuse shares psychological and neural mechanisms with other types of impulse control disorders and substance/non-substance-related addiction.

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INTRODUCTION

Internet game overuse is a new and rapidly growing addictive phenomenon worldwide.[1] More than one out of eight adults in the United States shows signs of being addicted to the Internet.[2] A similar or higher rate has been reported in several countries in Asia[3] and Europe.[4] Among these, South Korea may be one of the nations that suffers most from this phenomenon. In 2007, the Korea Agency for Digital Opportunity and Promotion reported that 1.7% of Korean adults were classified as definitive Internet overusers. These were defined as those who used the Internet for an average of 3.4 hours/weekday and 4.9 hours/weekend day, and 90.8% of the time that overusers stayed online was spent playing Internet games.[5] Internet game overuse and pathological computer game use have been considered a type of behavioral addiction that is accompanied by withdrawal symptoms and tolerance.[1,2,5] Although an increasing number of individuals, especially young people, suffer from Internet game overuse, no study has examined the neurobiological factors underlying Internet game overuse.

Recent research has suggested that Internet and Internet game overuse may be based on psychological and cognitive mechanisms that are similar to those underlying pathological gambling.[2,6,7-9] According to the *Diagnostic and Statistical Manual of Mental Disorders*, Fourth Edition, pathological gambling is a type of impulse control disorder involving the inability to resist the impulse to perform an action that is harmful to oneself or others. Internet game overuse is similar to pathological gambling in that it does not directly involve intoxicant substances, but entails dysfunctions in impulse control[3,10] and reward.[11,12] Yen and colleagues[3] conducted an Attention-Deficit/Hyperactivity Disorder Self-Rated Scale study in a large high school student population and found that adolescents with Internet addiction had higher uncontrolled impulse levels than non-addicts. Using the Yale-Brown Obsessive-Compulsive Scale modified for Internet use, Shapira and colleagues[10] found that adults with Internet addiction or pathological Internet use met the *DSM-IV* criteria for an impulse control disorder. Moreover, Internet game overusers have also shown impaired performance on a reward-based decision-making task.[12] Based on these lines of evidence, Internet game overuse may result from abnormalities in neural circuits that are involved in impulse control and reward processing. However, little is known about the neural mechanisms underlying Internet game overuse.

In an attempt to understand the neurobiological bases of Internet game overuse, we investigated the differences in regional cerebral glucose metabolism at resting state between young individuals with Internet game overuse and those with normal use, using ^{18}F-fluorodeoxyglucose positron emission tomography (FDG PET). We hypothesized that Internet game overusers would show altered metabolism in the prefrontal and striatal regions, which are implicated in impulse control and reward processing.

METHODS

Participants

This study was performed in accordance with the Declaration of Helsinki and approved by the institutional review board of Seoul National University Bundang Hospital. All participants gave written informed consent before participating in this study. Participants were recruited from a large survey study investigating behavioral and cognitive profiles of individuals addicted to Internet, which are being prepared

as a separate report. Among the participants for the survey study, those who met the criteria for Internet game overuse or normal use and who gave written informed consent to participate in the follow-up imaging study were invited to the current study. Internet game overuse was defined based on the Korean Internet Game Addiction Scale (IGS),[13] a standardized questionnaire developed to assess the severity of Internet game use that is described below in detail. The exclusion criteria for both Internet game overuse and normal use groups were a history of substance abuse or dependence; a history of major psychiatric disorders, such as schizophrenia, psychotic episodes, or hospitalization for psychiatric disorders; and current treatment for mental disorders other than those being investigated in this study.

Eleven men with Internet game overuse and nine men with normal Internet use participated in the study. All subjects were right-handed. Table 1 provides demographic information for participants in each group. There was no significant difference in either age (mean age±SD=23.5±2.9 years vs 24.7±2.4 years, P=.29) or duration of education (mean duration±SD=13.3±1.8 years vs 14.1±1.8 years, P=.21) between the groups. The IGS score of the overuse group was naturally higher than that of the normal user group (mean score±SD=55.4±7.0 vs 25.3±4.4, P<.0001). Table 2 provides a summary of Internet game playing activities of Internet game overusers. Participants in the overuser group reportedly spent an average of 22.6 hours per week on Internet games last month and 63.6% of them had been playing Internet games >4 years. The longest continuous span the overusers played the game without a break was 11.5 hours on average. The most common type of games was multi-player, online strategy simulation game (eg, Starcraft, Blizzard Entertainment, 1998).

TABLE 1.
Group Characteristics

	*Internet game overusers (n=11)**	*Normal users (n=9)**	P-value
Age (years)	23.5±2.9	24.7±2.4	.29 (NS)
Duration of education (years)	13.3±1.8	14.1±1.8	.21 (NS)
IGS score	55.4±7.0 (range 47–67)	25.3±4.4 (range 20–31)	<.0001

* Values are mean ± SD.

NS=not significant; IGS=Internet Game Addiction Scale.

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Self-Report Measures of Internet Game Addiction and Impulsivity

The IGS was developed by the Korean Game Industry Agency to identify individuals who addictively use Internet games.[13] The IGS is a 20 item questionnaire consisting of five subscales: game-dependence behavior, declined self-control, hypersensitiveness, functional deficit, and absorption. Items are measured on a 4 point Likert scale ranging from 1 (not at all) to 4 (very much). The severity of Internet game overuse

TABLE 2.
Internet Game Playing Activities of the Internet Game Overusers

Question	*Answer*	*Percentage*
How long have you played the game?	<1 year	9.1
	1–2 years	18.2
	3–4 years	9.1
	>4 years	63.6
What is your favorite game?	Single player, PC/ Console	9.1
	Multi-player, online strategy simulation game (eg, Starcraft)	63.6
	Multi-player, card gambling	–
	Competitive board game (eg, Chess)	–
	Massive multi-player online role play game	27.3
Are there images of game scenes in your mind even when you are not playing?	Not at all	27.3
	Rarely	18.2
	Commonly	27.3
	Often	9.1
	Always	18.2
How many hours per week did you play last month?	22.6±15.0 hours (mean±SD)	
How many continuous hours have you ever played?	11.5±6.3 hours (mean±SD)	

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was calculated by summing the score for each item, which ranged from 20–80 points. According to previous reports,[5,13] Internet game overuse was defined as the IGS score >42. Among 464 volunteers who participated in the original survey study (mean age=23.2±4.4 years; 260 men, 202 women, and 2 unknown), 7.9% were identified as overusers, who habitually engage in Internet games and are more prone to Internet game addiction.

Because impulsivity has been closely associated with behavioral addiction including Internet game addiction, we also assessed the level of impulsivity with the Barratt Impulsiveness Scale Version 11 (BIS-11).[14]

Image acquisition and analysis

PET scans were acquired using an Allegro PET scanner operating in three-dimensional mode. Participants had fasted for at least 6 hours before scanning. They received intravenous injection of 185 MBq of FDG in a dimly lit, quiet waiting room and were instructed to remain lying comfortably during a 40 minute FDG equilibration period. Participants were then led to the adjacent imaging suite and positioned within the PET camera so that the head was aligned in the scanner relative to the canthomeatal line. Ten minute emission scans and attenuation maps using a Cs-137 transmission source were obtained. Attenuation-corrected images were reconstructed using the 3D Row-Action Maximum-Likelihood algorithm with a 3D image filter of 128×128×90 matrices with a pixel size of 2×2×2 mm.

Preprocessing and statistical analysis were performed using SPM2 software (www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB 6.5 (Mathworks Inc). The PET images were normalized to the standard coordinate system, developed and distributed by the Montreal Neurologic Institute, implemented in SPM2. All images were smoothed using a 12 mm FWHM 3D Gaussian filter. Glucose metabolism at each voxel was proportionally scaled into the global mean. To reveal brain regions where glucose metabolism was significantly different between the two groups, voxel-based independent sample t tests were conducted, creating a map of t statistics. For statistical inference, the height threshold (*P*) was set at *P*=.001 (uncorrected) and the extent threshold (k) was set at 20 voxels.

Statistical analysis

A difference between unpaired data was analyzed by an unpaired Student t test. Correlation between IGS and BIS scores was evaluated by calculating the Pearson linear correlation coefficient. Except for SPM analysis, $P<.05$ was considered significant.

RESULTS

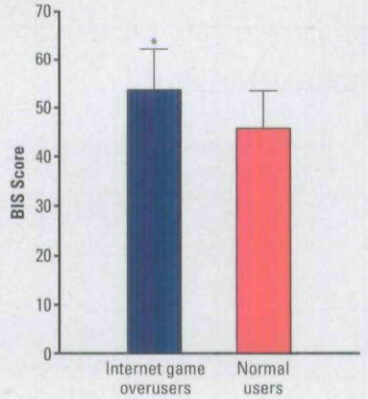
Behavioral results

Statistical analysis on BIS scores was conducted to test the difference in trait levels of impulsivity between the Internet game overusers and normal users (Figure 1). The overusers showed greater impulsiveness than the normal users (mean BIS score±SD=53.5±8.9 vs 45.6±8.0, $P<.05$). To investigate an association between the severity of Internet game overuse and impulsiveness, IGS scores and BIS scores were entered into a Pearson correlation analysis. Internet game addiction scores were positively correlated with scores of impulsiveness (r=.58, $P<.01$) (Figure 2).

Imaging results

Image analyses resulted in brain regions showing significant differences in resting glucose metabolism between the Internet game overusers and normal users (Table 3). The Internet game overusers had significantly increased resting glu-

FIGURE 1.
Comparison of BIS scores between the Internet game overuse and normal use groups



* $P<.05$

BIS=Barratt Impulsiveness Scale.

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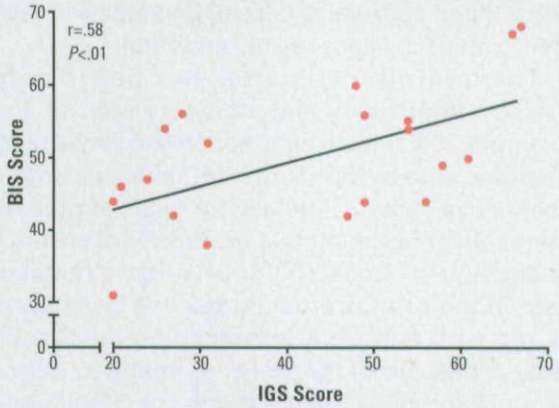
cose metabolism in the right middle orbitofrontal gyrus (BA 11), the left caudate nucleus, and the right insula (BA 13), compared to the normal users (Figure 3). To further investigate whether the levels of metabolism in these clusters were associated with the severity of Internet game overuse, correlation analyses were conducted between the IGS score and average glucose metabolism extracted from each cluster within the overuser group. No statistically significant correlations were found between the IGS score and average metabolic activity in the identified clusters (all $P>.3$).

The Internet game overusers had significantly decreased glucose metabolism in the bilateral postcentral gyrus (BA 2/3), the left precentral gyrus (BA 4), and the right superior parietal lobule (BA 7), as well as in the right superior occipital gyrus (BA 18) and the left inferior occipital gyrus (BA 19) (Figure 4). Correlation analyses were conducted between the IGS score and average glucose metabolism extracted from these clusters, within the overuser group. No statistically significant correlations were found between the IGS score and average metabolic activity in the identified clusters (all $P>.1$).

DISCUSSION

This study, to the best of our knowledge, is the first neuroimaging investigation of resting metabolic changes associated with Internet game overuse. We found that Internet game overusers had

FIGURE 2.
Relationship between the IGS and BIS scores



IGS=internet gaming scale; BIS=Barratt Impulsiveness Scale

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TABLE 3.
Brain Regions Showing Different Levels of Resting Glucose Metabolism Between the Internet Game Overusers and the Normal Users ($P<.001$ uncorrected, k=20)

				Coordinates			
Laterality	*Region*	*BA*	*k*	*x*	*y*	*z*	*Z*
Internet game overusers > Normal users							
Left	Caudate nucleus		60	−20	22	4	3.69
Right	Insula	13	44	24	22	4	3.61
Right	Middle orbitofrontal gyrus	11	20	34	50	−18	3.42
Internet game overusers < Normal users							
Left	Postcentral gyrus	2	353	−56	−22	52	4.52
Left	Postcentral gyrus	3	*	−56	−12	42	3.60
Left	Precentral gyrus	4	*	−36	−24	74	3.46
Right	Postcentral gyrus	3	77	26	−30	52	3.97
Right	Postcentral gyrus	3	27	62	−20	48	3.31
Right	Superior occipital gyrus	18	51	20	−102	16	3.72
Left	Inferior occipital gyrus	19	54	−40	−86	−12	3.47
Right	Superior parietal lobule	7	27	24	−72	46	3.35

* Brain region that belongs to the cluster listed in the row directly above.

BA=Broadmann's area.

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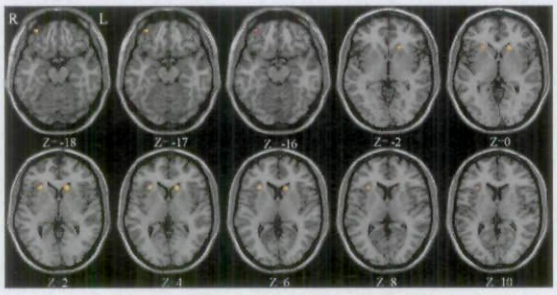
altered resting state glucose metabolism in the orbitofrontal cortex, striatum, and somatosensory regions, which are implicated in impulse control, reward processing, and somatic representation of previous experiences. Internet game overusers reported greater impulsiveness than normal users and the degrees of Internet game overuse and impulsiveness were positively correlated. These results indicate that neurobiological mechanisms underlying Internet game overuse may be similar to those of impulse control disorder and substance/non-substance-related addiction.

The orbitofrontal cortex has been implicated in impulsivity and inhibitory control. For example, individuals with borderline personality disorder who suffer from high levels of impulsivity have shown significantly reduced glucose metabolism in the medial orbitofrontal cortex.[15] In substance abusers, higher glucose metabolism in the orbitofrontal cortex has been associated with better performance on the Stroop task, a measure of the ability to inhibit impulses or a prepotent response tendency.[16] Bolla and colleagues[17] found that better performance on a computerized risk-taking task was associated with greater activation in the right orbitofrontal cortex during the task in both cocaine addicts and normal controls. Overall, these previous studies showed that reduced activity in the orbitofrontal cortex during cognitive performance was associated with problems involving impulsive behavior and response control.

Our results seem contradictory because we found that resting state orbitofrontal metabolic activity, which was obtained without engagement in an explicit task, was higher in the Internet game overusers, who also scored higher on the impulsivity scale, than in the normal users. However, London and colleagues[18,19] reported increased glucose metabolism in brain regions including the lateral orbitofrontal area in substance abusers. A volumetric neuroimaging study found that greater orbitofrontal volume was associated with poorer working memory performance in older adults.[20] Moreover, increased glucose metabolism in the orbitofrontal cortex was related with worse performance on the Stroop task in healthy young adults.[16] Greater resting glucose metabolism in the orbitofrontal cortex may be indicative of task-independent mental hyperactivity and greater effort in inhibitory control associated with it. That is, Internet game overusers may be more likely to be engaged in random thoughts and constantly place them in the mode of regulatory control for better everyday performance. Alternatively, it is possible that the association between glucose metabolism in the orbitofrontal cortex and impulsivity is nonlinear, so that the metabolic activity, either too high or too low, results in abnormal impulse control.

The striatum has been strongly implicated in addiction and reward processing.[21-23] In the present study, the Internet game overusers had increased glucose metabolism in the left caudate nucleus. This is consistent with the findings of a study in substance abusers by London and colleagues[19] in which methamphetamine abusers had increased glucose metabolism in brain

FIGURE 3.
Brain regions showing greater glucose metabolism in the Internet game overusers than in the normal users



P<.001 uncorrected, k=20. Number in each transaxial brain image indicates distance (mm) from anterior commisure–posterior commisure plane.

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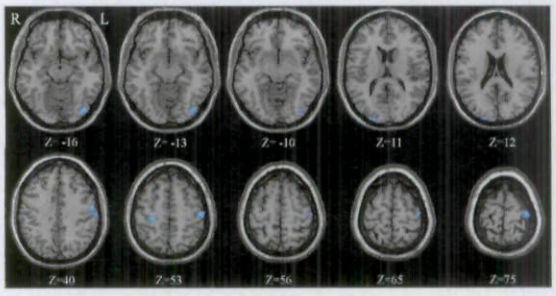
FIGURE 4.
Brain regions showing lower glucose metabolism in the Internet game overusers than in the normal users



P<.001 uncorrected, k=20. Number in each transaxial brain image indicates distance (mm) from anterior commisure–posterior commisure plane.

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regions including the ventral striatum and lateral orbitofrontal cortex. However, a functional magnetic resonance imaging (MRI) study showed a reduction of ventral striatal and ventromedial prefrontal activation during a gambling task in pathological gamblers, which was correlated with gambling severity.[24] The striatal functional activity in substance and non-substance related addiction is unclear. Because the striatum and orbitofrontal cortex receive major dopaminergic innervations,[8,23,25,26] altered metabolic activities in these regions may be associated with an alteration of dopaminergic neurotransmission in Internet game overusers, which has been suggested by a genetic study.[11] A follow-up imaging study of the dopaminergic system is currently ongoing in our laboratory to test this hypothesis.

We found increased glucose metabolism in the right insula in the Internet game overusers. The insula is known to play a crucial part in addiction because of its role in conscious urges to abuse drugs.[27] Functional imaging studies have shown activation of the insula during urges for cigarette smoking,[28-30] cocaine,[31,32] and alcohol,[33,34] and insular activity has frequently been correlated with self-reported urges.[28,29,31] Smokers with brain damage involving the insula were able to quit smoking easily, immediately, without relapse and without a persistence of the urge to smoke.[35] Recently, a functional MRI study revealed a cue-induced activation of the right insula in subjects with Internet game addiction.[36] These results, together with our data, support the notion that the insula is involved in conscious urges for addictive behaviors and decision-making processes that precipitate relapse.

The Internet game overusers in this study showed decreased glucose metabolism in the bilateral somatosensory and occipital regions. According to the somatic marker model of addiction proposed by Verdejo-Garcia and colleagues,[37] addiction is partly explained by dysfunctional neural representations of the somatic states elicited by emotional experiences. This leads to an insensitivity to the negative long-term consequences of addictive behaviors. The somatosensory cortex is a key region in the model, where the somatic states from previous experiences are represented. In this model, the somatosensory cortex acts as a structure that represents and delivers emotional states for addictive stimuli to the striatum when inducers (such as drugs and other addictive stimuli) are presented. Then, the striatum biases decisions based on the received emotional states for addictive stimuli. Reduced metabolism in the somatosensory region may indicate that Internet game overusers have dysfunctional somatic representations of the previous emotional experiences elicited by rewarding or punishing events, which make them unable to make decisions based on the long-term outcome. This view supports the previous finding that Internet game overusers showed impaired performance in a reward-based decision making task.[12] Altered functional activity in the occipital cortex has been frequently observed in neuroimaging studies of addiction[29,38,39]; however, whether it has a specific role in the process of addiction is unclear.

Newly emerging Internet media, such as social networking services (Facebook, MySpace, and Cyworld) may have addictive aspects as strong as Internet games. However, it should be noted that there might be behavioral and neurobiological differences between Internet game overuse and other forms of Internet overuse. On social networking web sites, one can extend one's senses of identity and self in a real space, while Internet game overusers convey one's senses of identity and self to virtual Internet game spaces while playing games.

Little is known about the neurobiological basis of non-Internet based video or console game overuse. Thus, it is hard to look into the similarities and differences between the neurobiology of Internet-based and other non-Internet based virtual game overuses. However, structural characteristics of games are known to be associated with their addictability.[40,41] For example, traditional video games end at some point or become repetitive and boring, while most Internet games are endless because they have the main features of infinite achievement, not meeting a finite goal. Therefore, one can speculate that Internet-based and non-Internet based virtual game overuses may not share similar neurobiological bases.

CONCLUSION

This study demonstrates that Internet game overuse may be associated with abnormal neurobiological mechanisms in the orbitofrontal cortex, striatum, and somatosensory regions, which are implicated in impulse control, reward processing, and somatic representation of previous experiences. Altered resting state glucose metabolism in the ventromedial prefrontal cor-

tex and striatum may be associated with abnormal dopaminergic neurotransmission in Internet game overuse in a similar way to what has been observed in substance abuse and other types of behavioral addiction. Together with previous behavioral and cognitive findings in Internet game overuse, our imaging and behavioral results suggest that Internet game overuse may be considered as a type of impulse control disorder or non-substance-related addiction that shares psychological and neural mechanisms with substance-related addiction. ***CNS***

REFERENCES

1. Block JJ. Issues for DSM-V: Internet Addiction. *Am J Psychiatry.* 2008;165:306-307.
2. Aboujaoude E, Koran LM, Gamel N, Large MD, Serpe RT. Potential markers for problematic internet use: a telephone survey of 2,513 adults. *CNS Spectr.* 2006;11:750-755.
3. Yen JY, Ko CH, Yen CF, Wu HY, Yang MJ. The Comorbid Psychiatric Symptoms of Internet Addiction: Attention Deficit and Hyperactivity Disorder (ADHD), Depression, Social Phobia, and Hostility. *J Adolesc Health.* 2007;41:93-98.
4. Ferraro G, Caci B, D'Amico A, Di Blasi M. Internet addiction disorder: an Italian study. *Cyberpsychol Behav.* 2007;10:170-175.
5. Ko YS, Kim SJ, Kim BG. *National Research of Internet Addiction.* Seoul, Korea: Korea Agency Digital Oppotunity and Promotion; 2007.
6. Block JJ. Pathological Computer Game Use. Psychiatric Times. 2007;24. Retrieved March 1, 2007, from http://www.psychiatrictimes.com/display/article/10168/55406
7. Goudriaan AE, Oosterlaan J, de Beurs E, van den Brink W. Decision making in pathological gambling: a comparison between pathological gamblers, alcohol dependents, persons with Tourette syndrome, and normal controls. *Brain Res Cogn Brain Res.* 2005; 23:137-151.
8. Hollander E, Pallanti S, Baldini Rossi N, Sood E, Baker BR, Buchsbaum MS. Imaging monetary reward in pathological gamblers. *World J Biol Psychiatry.* 2005;6:113-120.
9. Johansson A, Gotestam KG. Problems with computer games without monetary reward: similarity to pathological gambling. *Psychol Rep.* 2004;95:641-650.
10. Shapira NA, Goldsmith TD, Keck PE Jr, Khosla UM, McElroy SL. Psychiatric features of individuals with problematic internet use. *J Affect Disord.* 2000;57:267-272.
11. Han DH, Lee YS, Yang KC, Kim EY, Lyoo IK, Renshaw PF. Dopamine Genes and Reward Dependence in Adolescents with Excessive Internet Video Game Play. *J Addict Med.* 2007;1:133-138.
12. Kim SH, Ahn CI. Personality trait and Decision-Making of Addicted Internet Game Users. Korean *J Health Psych.* 2005;10:415-430.
13. Oh K, Kim Y, Jang K, et al. *Operation of the Internet Game Addiction Center and the eEementary Study for Development of the Internet Game Addiction Scale.* Seoul, Korea: Korea Agency Digital Opportunity and Promotion; 2005.
14. Patton J H, Stanford MS, Barratt ES. Factor structure of the Barratt impulsiveness scale. *J Clin Psychol.* 1995;51:768-774.
15. Soloff PH, Meltzer CC, Becker C, Greer PJ, Kelly TM, Constantine D. Impulsivity and prefrontal hypometabolism in borderline personality disorder. *Psychiatry Res.* 2003;123:153-163.
16. Goldstein RZ, Volkow ND, Wang GJ, Fowler JS, Rajaram S. Addiction changes orbitofrontal gyrus function: involvement in response inhibition. *NeuroReport.* 2001;12:2595-2629.
17. Bolla KI, Eldreth DA, London ED, et al. Orbitofrontal cortex dysfunction in abstinent cocaine abusers performing a decision-making task. *Neuroimage.* 2003;19:1085-1094.
18. London ED, Ernst M, Grant S, Bonson K, Weinstein A. Orbitofrontal cortex and human drug abuse: functional imaging. *Cereb Cortex.* 2000;10:334-342.
19. London ED, Simon SL, Berman SM, et al. Mood disturbances and regional cerebral metabolic abnormalities in recently abstinent methamphetamine abusers. *Arch Gen Psychiatry.* 2004;61:73-84.
20. Salat DH, Kaye JA, Janowsky JS. Greater orbital prefrontal volume selectively predicts worse working memory performance in older adults. *Cereb Cortex.* 2002;12:494-505.
21. Hyman SE, Malenka RC. Addiction and the brain: The neurobiology of compulsion and its persistence. *Nat Rev Neurosci.* 2001;2:695-703.
22. Robbins TW, Everitt BJ. Drug addiction: bad habits add up. *Nature.* 1999;398:567-570.
23. Volkow ND, Fowler JS, Wang G-J, Goldstein RZ. Role of Dopamine, the Frontal Cortex and Memory Circuits in Drug Addiction: Insight from Imaging Studies. *Neurobiol Learn Mem.* 2002;78:610-624.
24. Reuter J, Raedler T, Rose M, Hand I, Gläscher J, Büchel C. Pathological gambling is linked to reduced activation of the mesolimbic reward system. *Nat Neurosci.* 2005;8:147-148.
25. Chang L, Haning W. Insights from recent positron emission tomographic studies of drug abuse and dependence. *Curr Opin Psychiatry.* 2006;19:246-252.
26. Volkow ND, Fowler JS. Addiction, a disease of compulsion and drive: involvement of the orbitofrontal cortex. *Cereb Cortex.* 2000;10:318-325.
27. Naqvi NH, Bechara A. The hidden island of addiction: the insula. *Trends Neurosci.* 2009;32:56-67.
28. Brody AL, Mandelkern MA, London ED, et al. Brain metabolic changes during cigarette craving. *Arch Gen Psychiatry.* 2002;59:1162-1172.
29. Brody AL, Mandelkern MA, Olmstead RE, et al. Neural substrates of resisting craving during cigarette cue exposure. *Biol Psychiatry.* 2007;62:642-651.
30. Franklin TR, Wang Z, Wang J, et al. Limbic activation to cigarette smoking cues independent of nicotine withdrawal: a perfusion fMRI study. *Neuropsychopharmacology.* 2007;32:2301-2309.
31. Kilts CD, Schweitzer JB, Quinn CK, et al. Neural activity related to drug craving in cocaine addiction. *Arch Gen Psychiatry.* 2001;58:334-341.
32. Wang GJ, Volkow ND, Fowler JS, et al. Regional brain metabolic activation during craving elicited by recall of previous drug experiences. *Life Sci.* 1999;64:775-784.
33. Myrick H, Anton RF, Li X, et al. Differential brain activity in alcoholics and social drinkers to alcohol cues: relationship to craving. *Neuropsychopharmacology.* 2004;29:393-402.
34. Tapert SF, Brown GG, Baratta MV, Brown SA. fMRI BOLD response to alcohol stimuli in alcohol dependent young women. *Addict Behav.* 2004;29:33-50.
35. Naqvi NH, Rudrauf D, Damasio H, Bechara A. Damage to the insula disrupts addiction to cigarette smoking. *Science.* 2007;315:531-534.
36. Ko CH, Liu GC, Hsiao S, et al. Brain activities associated with gaming urge of online gaming addiction. *J Psychiatr Res.* 2009;43:739-747.
37. Verdejo-Garcia A, Perez-Garcia M, Bechara A. Emotion, Decision-Making and Substance Dependence: A Somatic-Marker Model of Addiction. *Curr Neuropharmacol.* 2006;4:17-31.
38. Crockford DN, Goodyear B, Edwards J, Quickfall J, el-Guebaly N. Cue-induced brain activity in pathological gamblers. *Biol Psychiatry.* 2005;58:787-795.
39. Wang Z, Faith M, Patterson F, et al. Neural substrates of abstinence-induced cigarette cravings in chronic smokers. *J Neurosci.* 2007;27:14035-14040.
40. Ng BD, Wiemer-hastings P. Addiction to the Internet and Online Gaming. *Cyber Psychology & Behavior.* 2005;8:110-113.
41. Griffiths MD, Davies MN, Chappel D. Demographic Factors and Playing Variables in Online Computer Gaming. *Cyber Psychology & Behavior.* 2004;7:479-487.