Prefrontal cortical activation in Internet Gaming Disorder Scale high scorers during actual real-time internet gaming: A preliminary study using fNIRS

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ABSTRACT

Background: Observation of real-time neural characteristics during gameplay would provide distinct evidence for discriminating the currently controversial diagnosis of internet gaming disorder (IGD), and elucidate neural mechanisms that may be involved in addiction. We aimed to provide preliminary findings on possible neural features of IGD during real-time internet gaming using functional near-infrared spectroscopy (fNIRS). *Methods:* Prefrontal cortical activations accompanying positive and negative in-game events were investigated. Positive events: (1) participant's champion slays or assists in slaying an opponent without being slain. (2) the opposing team's nexus is destroyed. Negative events: (1) participant's champion is slain without slaying or assisting in slaying any opponent. (2) the team's nexus is destroyed. Collected data were compared between the IGD group and control group, each with 15 participants. *Results:* The IGD group scored significantly higher than the CTRL group on the craving scale. Following positive events, the IGD group displayed significantly stronger activation in the DLPFC. Following negative events, the IGD group displayed significantly weaker activation in the lateral OFC. *Discussion and Conclusions:* Individuals scoring high on the IGD scale may crave for more internet gaming after encountering desired events during the game. Such observations are supported by the correlation between the craving scale and DLPFC activation. The IGD group may also show diminished punishment sensitivity to negative in-game experiences rendering them to continue playing the game. The present study provides preliminary evidence that IGD may demonstrate neural characteristics observed in other addictive disorders and suggests the use of fNIRS in behavioral addiction studies.

INTRODUCTION

Along with the worldwide rapid growth in the gaming industry, interest in video gaming has increased substantially across many countries. Recent statistics indicate that there are approximately 3.24 billion gamers around the world (Statistica, 2021), meaning that about 40% of the global population play video games. While playing video games has its virtues (Granic, Lobel, & Engels, 2014), some gamers experience negative consequences related to impairments in mental health and everyday functioning (Ko, 2014; Kuss, 2013; van den Eijnden, Koning, Doornwaard, van Gurp, & ter Bogt, 2018). Acknowledging such an impact, the Diagnostic and Statistical Manual of Mental Disorders fifth Edition (DSM-5) introduced Internet Gaming Disorder (IGD) as a condition for further study with suggested diagnostic criteria. Following such a movement, the International Classification of Diseases also

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included criteria for gaming disorder in its eleventh edition (ICD-11). However, debate on whether IGD should become an official diagnosis is yet controversial (Aarseth et al., 2017; Király & Demetrovics, 2017; Petry & O'Brien, 2013) and demands additional research to distinguish pathological gaming from healthy use.

One widespread approach in examining the fundamental characteristics of IGD is through observing its neural mechanisms, particularly mechanisms that may be associated with dysfunction or problematic use. Such neuroscientific observations are especially important considering the aforementioned controversy surrounding the diagnosis of IGD. For instance, some argue that there is little evidence internet games can be addictive, and that excessive gaming is only a symptom (e.g., Wood, 2008). Others argue that there exists insufficient evidence indicating that IGD fits the traditional definition of addictive disorders, a definition which primarily focuses on biological, physiological, and neural factors, and that IGD only demonstrates impairment in control (e.g., Downing, 2014). Thus, including IGD in the DSM may suggest that any rewarding human activity may be potentially viewed as subject of addiction (Shaffer, Hall, & Bilt, 2000). Regarding such disputes, neuroimaging research may provide the evidence needed to support IGD as a distinct behavioral addiction and observing neural activations during actual gaming would help elucidate the effects of internet gaming on addictive behavior.

Previous research has used magnetic resonance imaging (MRI) to investigate such mechanisms and suggested its similarity to already established psychopathologies such as substance use disorder and gambling disorder. In particular, association with regions involving impulsivity and executive control functions, such as the orbitofrontal cortex (OFC) and dorsolateral prefrontal cortex (DLPFC), have been extensively reviewed (Dom, Sabbe, Hulstijn, & van den Brink, 2005; Ge et al., 2017; Han, Hwang, & Renshaw, 2011; Han et al., 2018; Jin et al., 2016; Kim et al., 2019; Tanabe, Regner, Sakai, Martinez, & Gowin, 2019). For example, a study by Lee, Park, Namkoong, Kim, and Jung (2018) showed that individuals with IGD exhibited smaller gray matter volume in the anterior cingulate cortex (ACC) and OFC, known to be related to evaluation of reward, error processing and behavioral adjustment. Another study by Jin et al. (2016) discovered resting-state functional connectivity abnormalities in the prefrontal-striatal network using seed regions such as the ACC, OFC and DLPFC in individuals with IGD, suggesting similar neural features with substance dependence.

However, there exist clear limitations in the extant MRI research in that they did not observe neural activations when participants with potential internet gaming problems are actually playing the game. The apparent reason for such a limitation is that playing long immersive internet games (lasting 20–40 min) inside a MRI scanner would not only be costly due to its mechanical design, but may also cause excessive head motion which would be difficult to address despite pre-processing. Thus, MRI studies have relied heavily on resting-state functional connectivity analysis, or

experimental manipulations involving game 'cues.' Nevertheless, as one can imagine, neural responses to game cues may differ substantially from responses to active real-time internet game playing. For instance, Kätsyri, Hari, Ravaja, and Nummenmaa (2013) demonstrated that active game playing has a different effect in the striatum compared to vicarious game playing through an experimental design where participants played a 2–10 min shooting game (which was selected due to its accessibility in the scanner, unlike most internet games) inside an MRI scanner. Considering such a difference, observing neural activations during real-time gaming would provide a more direct examination on the mechanism through which internet games increase problematic internet game use.

The present study aimed to address such limitations using functional near-infrared spectroscopy (fNIRS), which is a neuroimaging method that measures fluctuations in concentrations of oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (HbR) based on the absorption of near-infrared light in cortical areas (Tak & Ye, 2014). While fNIRS is similar to functional MRI (fMRI) in that it measures blood oxygenation level-dependent (BOLD) signals, it holds many advantages such as its superior temporal resolution compared to fMRI, tolerance to motion artifacts, unnecessariness of constraint, low cost, and portability (Pinti et al., 2020), rendering it an adequate method for observing neural activations during gameplay. Previous research indicates fNIRS to be useful in monitoring time-resolved hemodynamic/oxygenation fluctuations in the prefrontal cortex (PFC) and temporal gyrus when playing video games (Li, Zhang, Long, Gong, & Lei, 2018; Matsuda & Hiraki, 2006; Moro et al., 2016; Ono et al., 2014).

We focused our observations on the prefrontal cortical area including the medial and lateral OFC, and DLPFC, which have been suggested to be associated with substance use, IGD, and addiction (Crockford, Goodyear, Edwards, Quickfall, & el-Guebaly, 2005; Feil et al., 2010; Kober et al., 2010; London, Ernst, Grant, Bonson, & Weinstein, 2000; Schoenbaum, Roesch, & Stalnaker, 2006; Tanabe et al., 2007; Tanabe et al., 2009; Volkow, Wang, Tomasi, & Baler, 2013). Since we attempted to investigate brain responses evoked by positive and negative game events, our particular areas of interest were the medial and lateral OFC. Albeit the OFC is well-known for its association to reward value, decision making and emotion (Kringelbach, 2005; Rolls, 2004; Rolls & Grabenhorst, 2008), studies also emphasize the functional distinction between the medial and lateral OFC. To be specific, the medial OFC is suggested to be related to pleasant stimuli and rewards, while the lateral OFC is suggested to be related to unpleasant stimuli, not receiving expected rewards, and punishment (Kringelbach, 2005; Kringelbach & Rolls, 2004; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Rolls, Cheng, & Feng, 2020). As research indicates that preference to win (high reward sensitivity) and insensitivity to loss (low punishment sensitivity) are characteristics defining substance use and internet addiction (Dong, Huang, & Du, 2011; Dong, Hu, & Lin, 2013; He et al., 2017; Jonker, Ostafin, Glashouwer, van

Hemel-Ruiter, & de Jong, 2014; Potts, Bloom, Evans, & Drobes, 2014), we hypothesized that individuals who score high on the IGD scale would show stronger medial OFC activation in response to positive game events, and weaker lateral OFC activation in response to negative game events, meaning that they would be sensitive to rewards but less responsive to punishment.

Much of extant research on the function of the DLPFC in substance use disorder and gambling disorder have focused on its association with craving, which is generally defined as "a subjective experience of wanting to use a drug" (Tiffany & Wray, 2012) although the definition now expands to other substances and behavior as well. For example, Grant et al. (1996) hypothesized that activation in the DLPFC reflects triggering of memories, which in turn leads to craving. The hypothesis was based on his observation on the correlations between metabolic increases in the DLPFC and other regions related to memory, including the amygdala and cerebellum when individuals who abused cocaine were exposed to drug-related stimuli. More recently, George and Koob (2013) suggested that DLPFC activation increases craving by potentiating the response to drug-related stimuli. To test such hypotheses and draw causal relations between the DLPFC and craving, Hayashi, Ko, Strafella, and Dagher (2013) inactivated the DLPFC using transcranial magnetic stimulation while exposing smokers to smoking cues and discovered that it prevented increase in craving. The role of the DLPFC in craving has also been evident in studies on behavioral addictions such as pathological gambling (Converasano et al., 2012; Crockford et al., 2005) and IGD (Ko et al., 2013; Sun et al., 2012). Considering such evidence, we were eager to examine DLPFC activation while individuals scoring high on the IGD scale engaged in the games they craved.

However, due to the intricate and anomalous nature of internet games such as gaming length or frequency of event occurrence, analyzing whole game sessions may be inadequate. To solve this complication, we referred to prior research which suggested that craving may result from reinforcement (Paulus, 2007; Wise, 1988; Weiss, 2005). Indeed, the effect of in-game reinforcement on game persistence and desire to play has been reviewed (Billieux, Deleuze, Griffiths, & Kuss, 2015; Chumbley & Griffiths, 2006; Kuss & Griffiths, 2012), and such findings are in line with research on gambling (Griffiths, 1999; Jacobsen, Knudsen, Krogh, Pallesen, & Molde, 2007; Skinner, 1953). Hence, we hypothesized that individuals who score high on the IGD scale would demonstrate higher craving for gaming and that such high craving would be reflected in the DLPFC following positive events in the game.

Through this study, we aimed to elucidate the neural characteristics of IGD during gameplay. We used an event-related approach to determine (1) whether individuals who score high on the IGD scale showed distinct patterns of activation following positive and negative events during internet gaming and, (2) if so, which regions showed such discriminative patterns.

MATERIALS AND METHODS

Participants

Participants were recruited through online advertisements and were screened for past diagnosis of psychological disorders, substance use, and neurological diseases. Participants who took medication within the past month with possible neurological effects were excluded. To limit potential confounding effects, participants were also asked to put away their smartphones on arrival. We only recruited males in their 20s to exclude sex and age as confounding factors. All participants completed the Korean version of the Internet Gaming Disorder Scale (K-IGDS; Cho & Kwon, 2017; Lemmens, Valkenburg, & Gentile, 2015), which measures the degree of dysfunction based on the DSM-5 IGD diagnostic criteria. The scale was used as the criteria for assigning participants into the high internet gaming disorder score group (IGD group) or the control group (CTRL group). More specifically, participants who scored 25 or less were assigned to the CTRL group, and participants who scored 48 (which is suggested to be the ideal cutoff score for the diagnosis of internet gaming disorder) or more were assigned to the IGD group. The final mean K-IGDS score was 67.93 ($SD = 21.17$) in the IGD group and 12.20 ($SD = 6.64$) in the CTRL group. A minimum playtime of 85 min per day was additionally required for participants in the IGD group.

Average gaming time per day was 4.23 h ($SD = 3.70$) in the IGD group and 1.64 h ($SD = 0.86$) in the CTRL group, and the difference between the two groups was significant ($t = 2.64$, $P = 0.01$) The emotional state of the participants was also measured via the Korean version of Center for Epidemiologic Studies Depression Scale – Revised (K-CESD-R; Lee et al., 2016), consisting of twenty questions. The K-CESD-R was included due to the high comorbidity between IGD and depression (González-Bueso et al., 2018; Ostinelli et al., 2021), and based on previous studies which suggest that such an association is also evident in neuro-imaging findings (Liu et al., 2018). While the IGD group ($M = 9.40$, $SD = 6.00$) scored slightly higher than the CTRL group ($M = 8.13$, $SD = 6.98$), there existed no significant difference in the K-CESD-R score ($t = 0.53$, $P = 0.60$). All participants were within the third lowest rank to the fourth highest rank in the gaming tier system (which consists of nine ranks total), eliminating the three highest and two lowest tiers so as to control for gaming skill. There existed no significant difference in game rank ($t = 1.02$, $P = 0.32$) between the IGD group ($M = 2.33$, $SD = 1.23$) and the CTRL group ($M = 1.93$, $SD = 0.88$). All participants were right-handed and had been playing League of Legends for more than a month. A total of 30 subjects participated in the study (15 CTRL group, 15 IGD group). 22 out of 30 participants gave their consent on collecting personal information regarding age and education level. Consenting participants were either college students or college graduates. The mean age was 23.89 ($SD = 2.42$) in the IGD group, and 22.08 ($SD = 2.10$) in the CTRL group,

and there was no significant age difference between the two groups ($t = 1.87$, $P = 0.08$). All participants provided written consent and were compensated with 20,000 won (about 17 U.S. dollars).

Behavioral measurement

The Korean Gaming Craving Scale for youths (KGCS; Im, Kwon, Heo, & Lee, 2014) was used to measure participants' craving level. While originally developed and validated for youth, the five questions in the questionnaire do not specify or limit measurement.

Game

The game used in this study was a multiplayer online battle arena game called League of Legends (LOL). Launched in 2009, LOL is one of the most popular internet games around the world with approximately 27 million players (Gray, 2021; Mishra, 2021). Currently in Korea, League of Legends has a playtime ratio of 42.54% among all games, ranking it first place for the last 167 weeks (Gametrics, 2021). In the game, 10 players that are divided into 2 teams control their virtual characters (known as champions) to battle with the opponent team. Players strategically attempt to slay the opposing team's champions to accomplish their final goal, which is to destroy the enemy's base (called the 'Nexus'). Slaying opponents reward the player with in-game gold that would provide items to upgrade their characters, while being slain would recall the player's champion back to the team's base after a short term of penalty time. The game does not end until one team's Nexus is destroyed or one team surrenders through a team vote. One round of a game lasts for about 20–50 min.

fNIRS data collection and pre-preprocessing

fNIRS data while participants played one round of LOL were collected using NIRSIT Lite (OBELAB Inc., Seoul, Republic of Korea), which is a fNIRS instrument with 5 dual-wavelength (780 and 850 nm) laser sources and 7 detectors, comprising 15 channels that are 30 mm distanced between each pair. The 15 channels are located on both sides of the DLPFC (channels 2, 3, 12, 14), OFC (channels 1, 4, 7, 10, 13, 15), and frontopolar prefrontal cortex (channels 5, 6, 8, 9, 11). Figure 1 shows the position of the channels. The sampling rate for measuring neural hemodynamic responses was 8.138 Hz.

To remove systematic responses induced by heartbeat and to diminish slow-wave drift, the collected raw NIRS signal was converted into an optical intensity signal using two fourth-order Butterworth filters (low-pass and high-pass) with cutoff frequencies each set at 0.1 and 0.005 Hz. The signal-to-noise ratio criterion for deciding bad quality channels was <30 dB, and the corresponding channels were rejected to avoid misinterpretations. The obtained optical intensity signals were converted into the HbO and HbR concentration change time series through the modified Beer-Lambert law (MBLL).
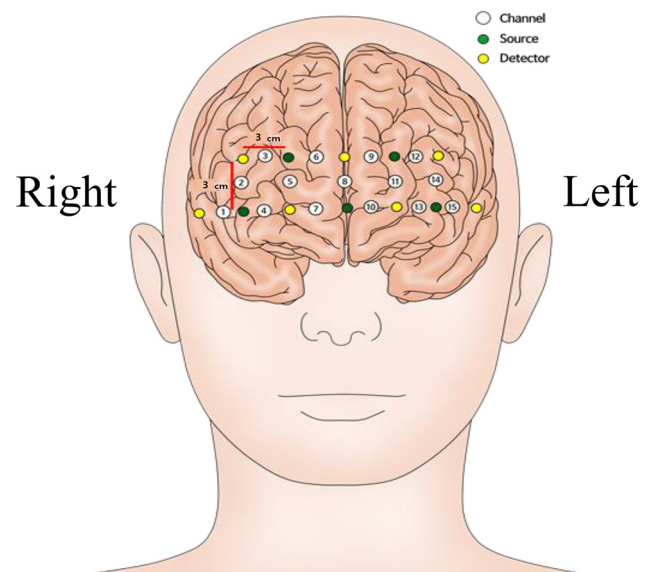

Fig. 1. Schematic position of fNIRS channels
Adapted from "Mutual interaction between genders with stress or non-stress by positive stimulus characteristics using fNIRS," by S. Bak, J. Jeongand J. Shin, 2021, *9th International Winter Conference on Brain-Computer Interface (BCI),* p. 2. Copyright 2021 by IEEE. Adapted with permission.

Data analysis

An event-related approach (Cavanagh & Castellanos, 2016; Li et al., 2018) was used to analyze the HbO and HbR concentrations accompanying specific game events. Video recordings of participants' gameplay was analyzed by an experienced LOL player to mark the time point of the occurrence of positive or negative events. The operational definition of positive and negative events were as follows. Positive events: (1) the participant's champion slays or assists in slaying an opponent champion without being slain. (2) opposing team's nexus is destroyed. Negative events: (1) the participant's champion is slain without slaying or assisting in slaying any opponent champion. (2) the team's nexus is destroyed. After a frame-by-frame review of the gameplay videos, fNIRS data recorded 5 s before and 15 s after the marked time points were clipped. There existed an average of 5.13 positive events ($SD = 3.44$, range 2–15) and 5.40 negative events ($SD = 2.61$, range 0–9) in the IGD group, and 6.00 positive events ($SD = 3.63$, range 0–15) and 3.86 negative events ($SD = 2.53$, range 0–10) in the CTRL group. A previous study using fNIRS while participants played LOL reported similar numbers of events (average of 2.5–4.58 events) and ranges (e.g., 0–8. 1–14) per condition and reported the numbers are sufficient for analysis (Li et al., 2018). It is noteworthy that the wide range in the number of events tagged to each individual in both our study and the aforementioned study is due to the variability of each game session. We checked whether there was a significant difference in the number of events between the compared conditions. The differences in the number of positive ($t = 0.67$, $P = 0.51$) and negative events ($t = 1.63$, $P = 0.11$) between the two groups were both nonsignificant.

The program used for statistical analysis was NIRSIT Lite Analysis Tool v3.1.0, which is based on MATLAB (The MathWorks, Natick, MA). The HbO and HbR level of the first 2 s of each clip was used as baseline to normalize the clip time series. The normalized clip time series were averaged to compose a representative negative and positive event-related time series for each participant. Then, each participant's event-related time series were averaged to a group level, composing a representative time-locked HbO and HbR response for the CTRL group and IGD group. The group level differences of HbO and HbR response accompanying events were compared between the IGD group and CTRL group through two sample t-tests.

Ethics

The study procedures were carried out in accordance with the Declaration of Helsinki. The research was approved by the Institutional Review Board of Yonsei University. All participants were informed in detail about the study and all provided written informed consent.

RESULTS

Regarding behavioral measures, a two sample t-test showed that the IGD group ($M = 15.00$, $SD = 6.34$) scored significantly higher than the CTRL group ($M = 6.73$, $SD = 2.22$) on the KGCS ($t = 4.77$, $P < 0.001$).

Each group's average HbO and HbR response time series across all channels to positive and negative events are shown in Fig. 2. The two groups showed similar averaged HbO and

HbR concentration pattern trends in both conditions. In the case of the occurrence of positive events, the HbO concentration peaked right after the occurrence of the event (5 s) and slowly decreased in both groups, while the HbR concentration decreased until the occurrence of the positive event and slowly increased after. In the occurrence of negative events, the HbO concentration peaked following the occurrence of the event, rapidly decreased, and increased again. Symmetrically, the HbR concentration decreased until the occurrence of the event, rapidly increased, and began to decrease again. Such HbO and HbR concentration trends reflect overall response to the events in the game.

The group level differences of HbO and HbR response in each channel are shown in Fig. 3 and Fig. 4. Considering all regions measured, the IGD group generally showed stronger HbO responses than the CTRL group following positive events. Particularly, such difference was statistically significant in channel 3, located on the right DLPFC ($t = 2.07$, $P = 0.048$). The t-values were 0.94 ($P = 0.35$) and 1.09 ($P = 0.29$) in channels 7 and 10, respectively, which measured activations in the hypothesized medial OFC. Differences in HbR responses were statistically nonsignificant in all channels. Symmetrically reflecting the results in HbO responses, the lowest t-value was -1.58 ($P = 0.13$) in channel 3.

Following negative events, the HbO responses differed significantly between the two groups in that the IGD group showed weaker activation than the CTRL group in channel 1, which is sited on the right lateral OFC ($t = -2.06$, $P = 0.049$). Difference in HbR response was significant in channel 7, located on the medial OFC. The IGD group's HbR concentration was stronger than that of the CTRL group's ($t = 2.37$, $P = 0.03$). However, the HbO response in channel 7 was
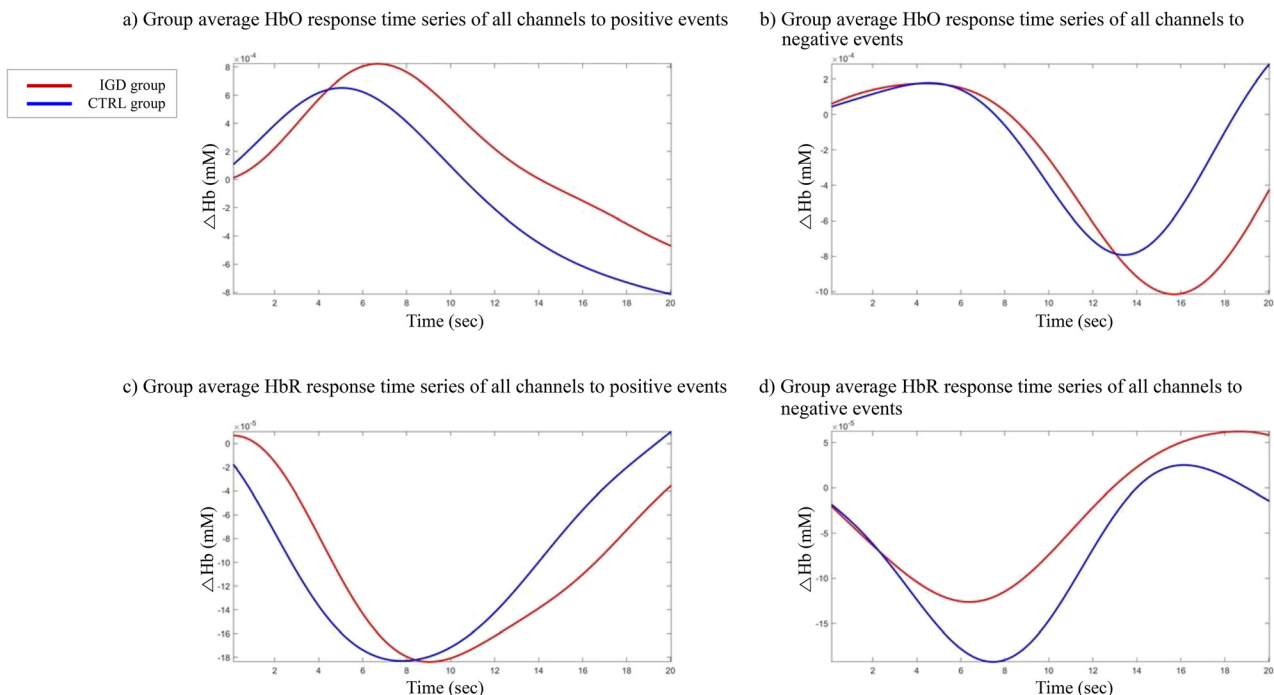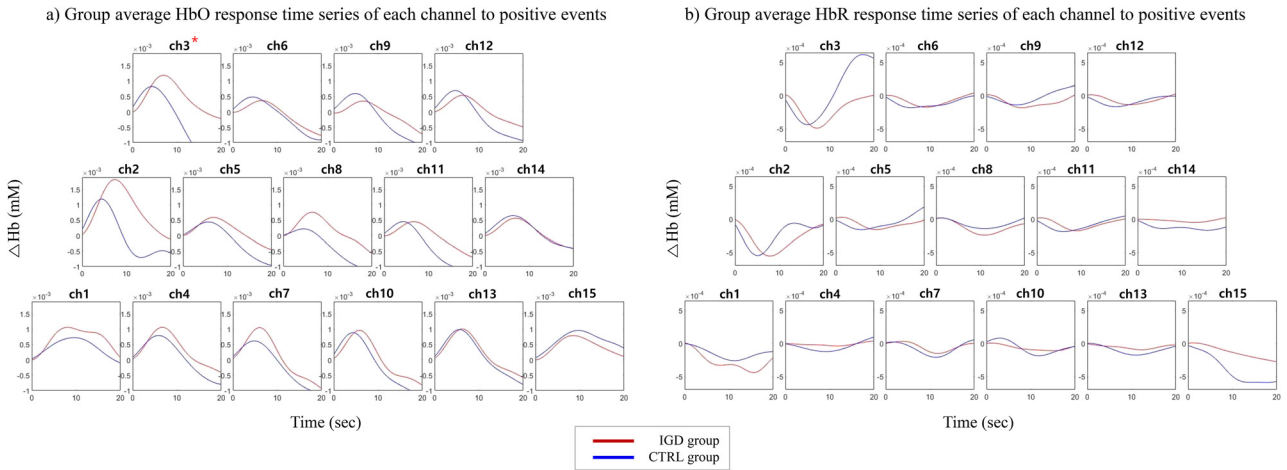

Fig. 2. Group average HbO (top) and HbR (bottom) response time series of all channels to positive (left) and negative events (right)
The concentration trends show the overall response to the events in the game.

Fig. 3. Group average HbO (left) and HbR (right) response time series of each channel to positive events
Note. The red line indicates the response of the IGD group, while the blue line indicates the response of the CTRL group. Significant results are marked with ∗.
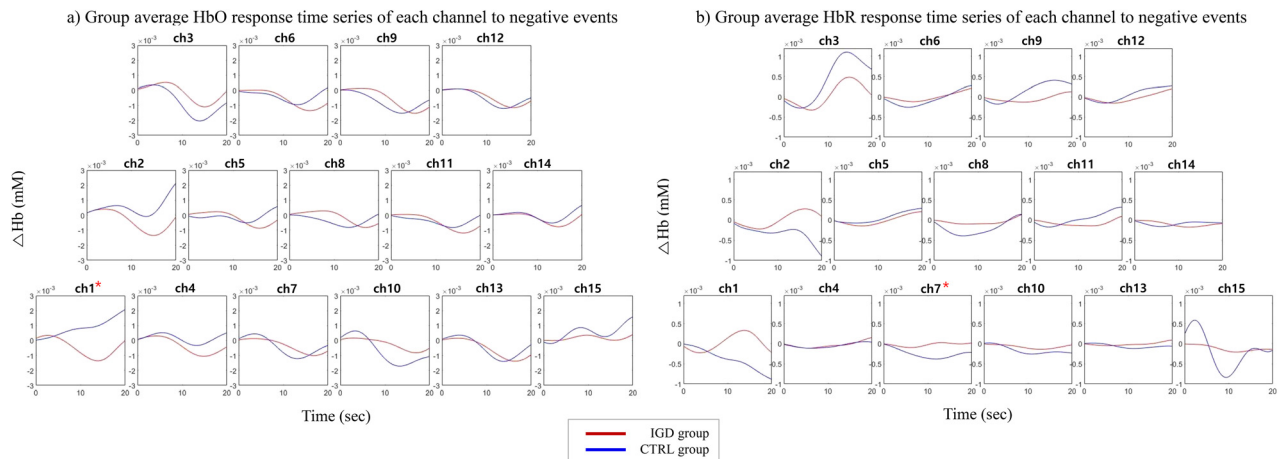
Fig. 4. Group average HbO (left) and HbR (right) response time series of each channel to negative events
Note. The red line indicates the response of the IGD group, while the blue line indicates the response of the CTRL group. Significant results are marked with ∗.

statistically nonsignificant ($t = 0.22$, $P = 0.82$). Though horizontally symmetrical to the HbO response, the HbR concentration difference in channel 1 was not significant statistically ($t = 1.74$, $P = 0.09$). The t-maps of HbO and HbR responses to positive and negative events are shown in Fig. 5, and visuals on significant regions are shown in Fig. 6.

DISCUSSION

In line with our hypothesis, we were successful in discovering distinctive neural features of IGD in the prefrontal cortical area during spontaneous real-time gaming. Moreover, we preliminarily specified particular regions within the area that may be characteristic in IGD: the OFC and the DLPFC.

As hypothesized, significantly weaker activation following negative events in the IGD group's lateral OFC was observed

through the HbO response. In the corresponding HbR results, the horizontally symmetrical concentration pattern showing an increase in the IGD group and decrease in the CTRL group supports the results in the HbO response, indicating evidently weaker activation in the region. Based on previous research, we suggest that activation differences in the lateral OFC may reflect the low punishment sensitivity characteristic to individuals with addictive disorders including substance use disorder, pathological gambling, and IGD (Fauth-Bühler & Mann, 2017; Jonker et al., 2014; Yao et al., 2020). Similar observations were made by Adinoff (2004) in participants with cocaine use disorder, suggesting that such results may imply difficulties in inhibitory control, while Volkow and Morales (2015) suggested that the disruption in addicted individuals' lateral OFC may signify the inability to shift behaviors when no longer reinforced. While conceptually different from IGD, internet addiction, which is also classified as a behavioral addiction, appears to
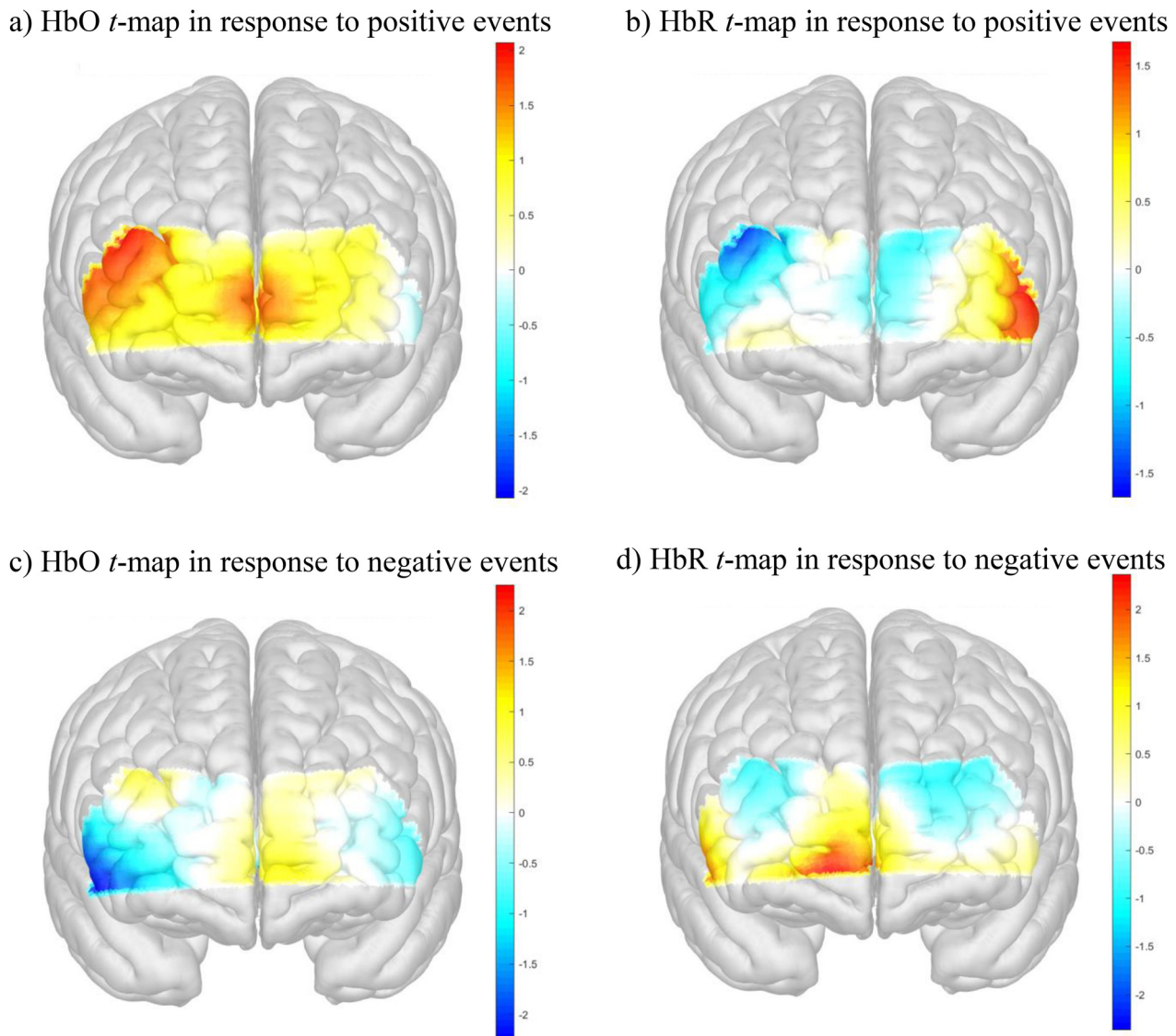
a) HbO *t*-map in response to positive events

b) HbR *t*-map in response to positive events

c) HbO *t*-map in response to negative events

d) HbR *t*-map in response to negative events

Fig. 5. HbO (left) and HbR (right) t-maps (IGD group – CTRL group) in response to positive (top) and negative (bottom) events

show similar characteristics regarding punishment sensitivity. For example, Dong et al. (2011) suggested that individuals addicted to the internet show decreased loss sensitivity based on task-based neural observations, and such suggestions were further supported in a follow-up study (Dong, Hu, & Lin, 2013).

According to the reinforcement sensitivity theory (Gray, 1970, 1982), punishment sensitivity originates from responding to the activation of the fight-flight-freeze system with avoidant behavior when encountering aversive situations. Thus, individuals with low punishment sensitivity engage less in avoiding situations despite the presence of unpleasant stimuli (Jonker et al., 2014). Studies demonstrated that animals with addiction tend to endure unpleasant stimuli to acquire their source of craving (Lesscher & Vanderschuren, 2012; Vanderschuren, Minnaard, Smeets, & Lesscher, 2017), suggesting that their punishment sensitivity is low enough for them to persevere in their pursuit and thus fail to shift behavior. An addicted individual's

persistent pursuit of a particular substance is clearly stated as a criterion for substance-related and addictive disorders in the DSM-5 (American Psychiatric Association, 2013). Applying the theory to IGD and in-game situations, individuals who score high on the IGD scale may experience particular difficulty in quitting the game and continue to play the game in spite of negative in-game events so as to experience potential desired positive events, explaining their tendency to continue excessive game playing.

Statistically significant differences in HbR responses were also observed following negative events in the medial OFC. Specifically, the CTRL group displayed a strong decrease in HbR responses following negative events. However, it should be noted that the HbR response is scarcely used alone in the interpretation of fNIRS data due to its weakness in reliability and is thus usually used in joint with the more pronounced HbO response (Dravida, Noah, Zhang, & Hirsch, 2017; Hoshi, 2007; Plichta et al., 2006; Watanabe, Matsuo, Kato, & Kato, 2003). More specifically, hemodynamic response

a) Region in the right DLPFC shows significantly stronger activation in the IGD group following positive in-game events.

b) Region in the right lateral OFC shows significantly weaker activation in the IGD group following negative in-game events.
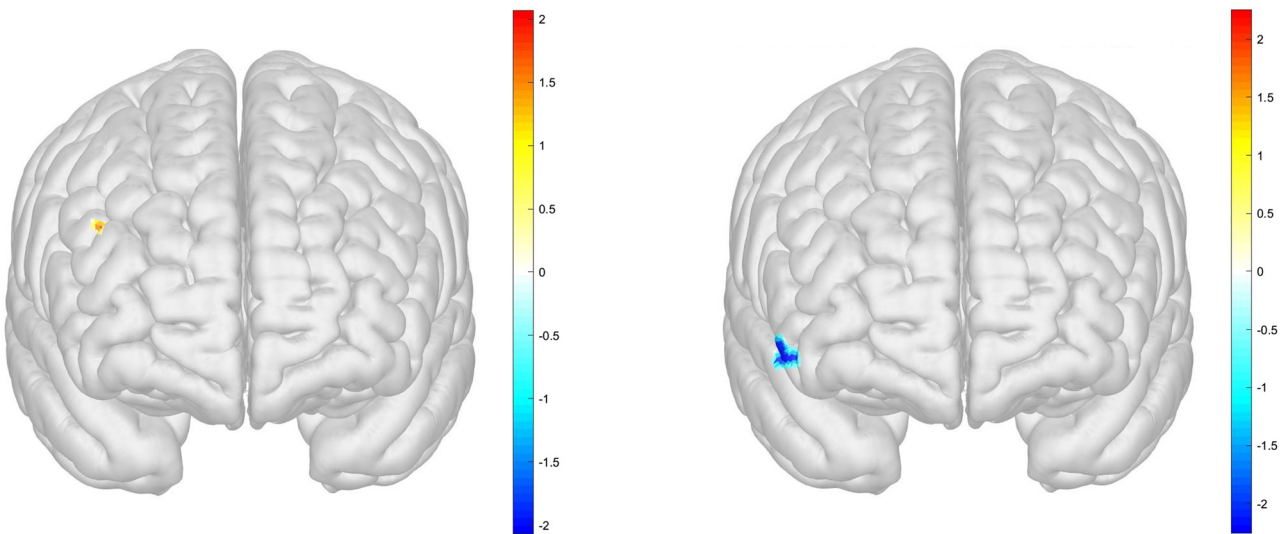

Fig. 6. Regions showing significantly stronger/weaker activation in the IGD group following in-game events

following an event would demonstrate an increase in HbO signal and decrease in HbR signal. However, as can be noticed in Table 1 and Fig. 4, the CTRL group's HbO concentration pattern in channel 7 hardly reflects such a HbR concentration pattern in that it did not increase following the event. Thus, it is difficult to infer that the CTRL group's medial OFC showed significant activation.

Participants in the IGD group showed significantly stronger activation in the DLPFC than participants in the CTRL group following positive events. Previous studies have found cue-induced activation and glucose metabolism increase in the DLPFC in pathological gambling and cocaine use, which were in turn suggested to be related to participants' craving (Crockford et al., 2005; Grant et al., 1996). BOLD signals in the DLPFC increased in smokers who were expecting to smoke in response to smoking videos, indicating the region's association with anticipation and craving (McBride, Barrett, Kelly, Aw, & Dagher, 2006). Similarly, the strong DLPFC activation in the IGD group may be related to the anticipation or craving for more positive events after such has been experienced. The significantly high KGCS score in the IGD group supports such a possibility. However,

Table 1. Differences in HbO and HbR concentration following positive and negative events

| | Positive | | | | Negative | | | |
| | HbO | | HbR | | HbO | | HbR | |
Channel	t-value	P	t-value	P	t-value	P	t-value	P
1	0.5459	0.5896	−0.6381	0.5288	−2.0612	0.0494[***]	1.7449	0.0928
2	1.6712	0.1062	−0.7677	0.4493	−1.3016	0.2045	0.9949	0.3290
3	2.0699	0.0481[***]	−1.5778	0.1263	0.8759	0.3891	−0.9367	0.3575
4	0.7979	0.4319	0.3459	0.7321	−1.6709	0.1067	0.1572	0.8763
5	1.0879	0.2863	−0.2002	0.8429	−0.2804	0.7814	−0.3821	0.7055
6	0.1177	0.9072	0.3734	0.7118	−0.4501	0.6564	0.3646	0.7183
7	0.9416	0.3548	0.0774	0.9388	0.2245	0.8241	2.3684	0.0256[***]
8	1.6920	0.1022	−0.5489	0.5876	0.5181	0.6088	0.9559	0.3479
9	0.4451	0.6598	−0.8096	0.4253	0.4556	0.6525	−1.0056	0.3239
10	1.0869	0.2867	−0.2716	0.7880	1.2630	0.2178	0.6017	0.5526
11	1.0643	0.2966	0.1225	0.9034	−0.1847	0.8549	−0.7604	0.4539
12	0.7790	0.4428	0.3144	0.7556	0.2527	0.8025	−0.7912	0.4360
13	0.2561	0.7998	0.6687	0.5094	−0.2277	0.8217	0.4493	0.6569
14	−0.1457	0.8852	1.4415	0.1609	−0.7412	0.4652	−0.0988	0.9221
15	−0.4328	0.6686	1.2889	0.2084	−0.8657	0.3946	0.4772	0.6372

Note. Corresponding region for each channel: 1) right lateral OFC. 4, 7) right medial OFC. 2, 3) right DLPFC. 15) left lateral OFC. 10, 13) left medial OFC. 12, 14) left DLPFC. 5, 6, 8, 9, 11) frontopolar prefrontal cortex.
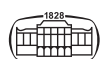
it must be acknowledged that the craving measurement was not collected immediately following positive events. Thus, whether the stronger activation in the DLPFC reflects the acquired craving data remains speculative. Such a limitation was due to the structure of the game and ethical issues in consistently interrupting participants while playing a ranked game. To mitigate the limitation, we performed linear regression to test if the HbO activation of channel 3 predicted the KGCS score. The results indicated that the HbO activation of channel 3 explains a significant amount of the variance in the KGCS score, $F(1, 26) = 6.38$, $P = 0.02$, $R^2 = 0.20$, $R^2_{adjusted} = 0.17$. The regression coefficient was $B = 3325.17$ (Fig. 7).

While using gaming cues instead of actual gaming, Ko et al. (2013) obtained similar results in that individuals who were addicted to internet gaming displayed stronger DLPFC activation in response to gaming cues, and concluded that the activation may possibly be a marker for addiction to internet gaming. In a recent study, Zhang et al. (2021) suggested that the high activation in the DLPFC reflects difficulty in downregulation of craving in individuals with IGD. The present study supports and expands the aforementioned findings to active gaming situations, where craving for internet games may be related to the occurrence of positive events in the game.

Contrary to our hypothesis, the IGD group did not exhibit significantly stronger activation in the medial OFC following positive events. One possible explanation may be the lack of statistical power due to the small sample size. Another explanation may be that rewarding in-game events may have comparable effects on the activation of the medial OFC in both the IGD group and CTRL group. The stimulating effect of the in-game positive events is well shown through the hemodynamic response function (HRF). Regarding such an effect, powerful stimulation itself may have obscured the manifestation of differences made by reward sensitivity. This may be the case considering that

individuals who do not score high on a measure of IGD may also be as responsive to sensational in-game events as reported in prior neuroscientific studies on gambling in nonclinical samples (Camara, Rodriguez-Fornells, & Münte, 2009; Hartstra, Oldenburg, Van Leijenhorst, Rombouts, & Crone, 2010). Moreover, since the medial OFC is also recognized for its role in goal-directed behavior (Gourley, Zimmermann, Allen, & Taylor, 2016; Szatkowska, Szymańska, Marchewka, Soluch, & Rymarczyk, 2011), and since the positive events in the game were in essence related to achieving certain goals, such cognitive components may have outweighed what we hypothesized to observe.

Our study is not without its limitations. First, we acknowledge that the sample size of the study is small. As we aimed to recruit participants who were genuinely using the online game to a certain degree, our strict participation requirements (K-IGDS score, game play time, and in-game rank) rendered it difficult to recruit a large sample size. Moreover, the expansion of the COVID-19 pandemic in Korea made it difficult to continue recruiting more participants and proceed face-to-face experimentation. Yet, previous studies using neuroimaging methods on behavioral addictions with similar or smaller sample sizes have reported that statistical power may be acceptable (Dong et al., 2011; Dong, DeVito, Du, & Cui, 2012; Dong, Hu, Lin, et al., 2013; Kim, Han, Lee, Kim, & Renshaw, 2012; Ko et al., 2009; Ko et al., 2013; Potenza et al., 2003). The current study may also serve as a preliminary study to calculate the adequate sample size for future studies. Second, while we screened participants for drug use or substance use disorders, we did not ask participants whether they were entirely free of any substances that could be used ordinarily including caffeine or alcohol. Such substance use in the near past may have influenced neural activations. In addition to a more strict control of substances, future fNIRS studies on IGD may also measure cognitive functioning of participants in the case of
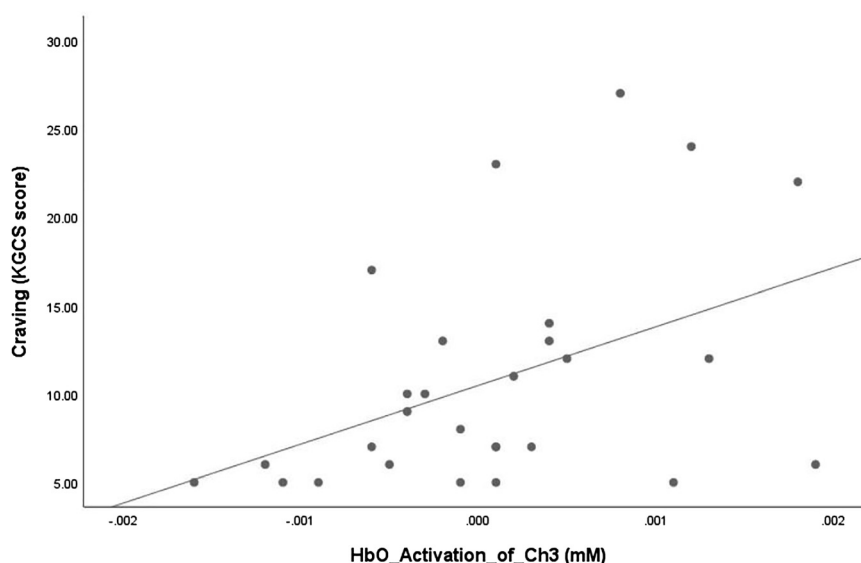

Fig. 7. Linear regression between the HbO activation of Ch3(DLPFC) and craving

assessing neural activity in the PFC. Third, we acknowledge that multiple correction procedures were not included in the analysis. Yet, the fact that NIRSIT Lite is composed of only 15 channels specifically targeting the prefrontal cortex renders such procedures to be too strict in drawing significant results. Acknowledging such disadvantages, previous fNIRS studies with 15–16 channels focusing on the prefrontal cortex have not applied multiple correction methods and reported uncorrected statistical thresholds to be sufficient (e.g., Bak, Jeong, & Shin, 2021; Gateau, Durantin, Lancelot, Scannella, & Dehais, 2015; Holtzer et al., 2011; Suzuki, Miyai, Ono, & Kubota, 2008). Referring to the present preliminary study, future studies may use fNIRS tools with more channels not only to apply strict correction procedures, but to investigate activations of a wider range of cortical areas as well. Fourth, while we used LOL to examine neural activations following in-game events, the results may not be generalized to other genres of games such as online role-playing games, first-person shooting games, and racing games. Moreover, despite the fact that a previous study using a similar design reported comparable numbers of events per condition and reported the numbers are sufficient for analysis (Li et al., 2018), the characteristics of LOL, including long game time per round and variability of occurring events, limited our study to a rather small number of events per condition. Thus, future studies may consider using games that are convenient in acquiring a larger number of events to maximize the quality of observations. It would also be meaningful for future studies to use more simple internet games to render it available to compare neural activations of the IGD group with a more distinct control group that does not play internet games, since the complexity of LOL makes it difficult for individuals who have no experience in the game to participate in such an experiment. Finally, although the participants in the IGD group displayed high scores above the suggested clinical cutoff score on the K-IGDS, results may differ in actual clinically diagnosed groups.

Notwithstanding its limitations, the study holds important implications for IGD and research methodology on behavioral addictions. To our knowledge, this is the first neuroimaging study to examine the neural characteristics of IGD during actual gameplay. Previous neuroimaging studies on IGD have used fMRI and gaming cues, making it hard to observe natural in-game activations in individuals with higher problematic game use potential. Taking advantage of the merits of the fNIRS, we observed distinguishing activation patterns in the lateral OFC and DLPFC following specific events in the game. The results of the study provide preliminary evidence that IGD is similar in neural features to other addiction related disorder, and that response to in-game events may reflect psychological constructs characteristic to addiction. Perhaps most importantly, the present study paves way for future studies to use the fNIRS on diverse behavioral addiction conditions. Taking advantage of its portability, accessibility and tolerance to motion, the fNIRS can be used as a tool for examining neural activation during real-time gambling, smartphone use (e.g., social network service), or other scenarios that are difficult to simulate in a fMRI scanner.

CONCLUSION

In conclusion, distinctive activation patterns in the prefrontal cortical area following positive and negative in-game events were identified in individuals with higher IGD scores. Specifically, stronger activation in the DLPFC was observed following positive events, and weaker activation in the lateral OFC was observed following negative events. Our results suggest that individuals who score high on the IGD scale may crave for more internet gaming after encountering desired events in the game and show diminished punishment sensitivity rendering them to continue playing the game despite unwanted in-game experiences. Such neurobiological and psychological features may be essential in understanding the basis for IGD. While the present study serves as a preliminary study for further elucidating the neural mechanism of IGD, implications of the disorder need to be studied further.

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