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An fMRI study of cognitive control in problem gamers

Maartje Luijten [a,b,c,*], Gert-Jan Meerkerk [d,e], Ingmar H.A. Franken [a], Ben J.M. van de Wetering [f], Tim M. Schoenmakers [d,e]

[a] *Institute of Psychology, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands*
[b] *Department of Radiology, Erasmus MC – University Medical Center Rotterdam, P.O. Box 2040, 3000 CA Rotterdam, The Netherlands*
[c] *Behavioral Science Institute, Radboud University Nijmegen, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands*
[d] *IVO Addiction Research Institute, Heemraadssingel 194, 3021 DM Rotterdam, The Netherlands*
[e] *Erasmus MC – University Medical Center Rotterdam, P.O. Box 2040, 3000 CA Rotterdam, The Netherlands*
[f] *Bouman Mental Health Care, P.O. Box 8549, 3009 AM Rotterdam, The Netherlands*

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ABSTRACT

A small proportion of video game players develop uncontrolled gaming behavior. A dysfunctional cognitive control circuit may explain this excessive behavior. Therefore, the current study investigated whether problem gamers are characterized by deficits in various aspects of cognitive control (inhibitory control, error processing, attentional control) by measuring brain activation using functional magnetic resonance imaging during Go–NoGo and Stroop task performance. In addition, both impulsivity and attentional control were measured using self-reports. Participants comprised 18 problem gamers who were compared with 16 matched casual gaming controls. Results indicate significantly increased self-reported impulsivity levels and decreased inhibitory control accompanied by reduced brain activation in the left inferior frontal gyrus (IFG) and right inferior parietal lobe (IPL) in problem gamers relative to controls. Significant hypoactivation in the left IFG in problem gamers was also observed during Stroop task performance, but groups did not differ on behavioral and self-reported measures of attentional control. No evidence was found for reduced error processing in problem gamers. In conclusion, the current study provides evidence for reduced inhibitory control in problem gamers, while attentional control and error processing were mostly intact. These findings implicate that reduced inhibitory control and elevated impulsivity may constitute a neurocognitive weakness in problem gamers.

1. Introduction

Video gaming has become very popular since the enormous increase in the use of computers and the internet. While people can gain various benefits from playing online video games (Granic et al., 2014), an estimated three to eight percent of gamers in Western countries develop uncontrolled gaming behavior (Gentile, 2009; Grant et al., 2010; Van Rooij et al., 2011). Consequently, in the past few years an increasing number of problems associated with uncontrolled online video game playing have been reported by health-care institutions (Wisselink et al., 2013). Similar to substance-dependent individuals, this subset of online game players displays excessive and compulsive online gaming behavior resulting in psychological, social, and occupational or academic problems (Van Rooij et al., 2011; Kuss and Griffiths, 2012). In this group, game-playing behavior is continued despite adverse consequences, a major reason for the inclusion of internet gaming disorder in an annex of the Diagnostic Statistical Manual – Fifth edition (DSM-5) as a potential new disorder, awaiting further evidence. This clearly indicates that more research is needed to resolve the conceptual confusion concerning the definition and core elements of this proposed disorder to stimulate the development of adequate prevention and treatment.

Cognitive control is one of the key processes involved in the regulation of potentially harmful behavior (Ridderinkhof et al., 2004), and it has been described as a multifactorial construct in which cognitive operations are posited to allow individuals to select appropriate behavior, optimize goal-directed behavior, and adapt behavior accordingly (Botvinick et al., 2001; Ridderinkhof et al., 2004). Inhibitory control, error processing and attentional control are three widely investigated aspects of cognitive control measured by Go–NoGo and classic Stroop tasks (Carter et al., 2000; Hester et al., 2004; Chambers et al., 2007; van Noordt and Segalowitz, 2012). Inhibitory control is mostly involved in the inhibition of automatic and inappropriate behavior, while error processing is involved in the monitoring of performance errors and ongoing behavior in order to prevent future mistakes. Additionally, attentional control facilitates the processing of relevant

* Correspondence to: Behavioural Science Institute, Radboud University Nijmegen, P.O. Box 9104, Room: A06.19a, 6500 HE Nijmegen, The Netherlands. Tel.: +31 24 3612567.
E-mail address: m.luijten@bsi.ru.nl (M. Luijten).

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stimuli and inhibits the processing of less relevant stimuli to increase the likelihood that the most appropriate stimuli will guide behavior (Franken, 2003). A dysfunctional cognitive control circuit may explain the excessive and compulsive gaming behavior of problem gamers such as the inability to control the amount of game playing, particularly when excessive gamers are confronted with gaming-related cues (Brand et al., 2014). In addition, adequate cognitive control is of key importance when habitual and rigid behavioral patterns need to be changed. A substantial literature suggests that both substance dependence and behavioral addictions, such as pathological gambling, are characterized by reduced cognitive control (Lubman et al., 2004; Verdejo-Garcia et al., 2008; Van Holst et al., 2010; Luijten et al., 2014). Regarding problematic gaming, previous studies found elevated self-reported impulsivity levels (Cao et al., 2007; Park et al., 2010; Littel et al., 2012; Ding et al., 2014) and reduced inhibitory control during affectively neutral conditions (Cao et al., 2007; Littel et al., 2012; Zhou et al., 2012) or when confronted with gaming-related cues (Decker and Ga, y2011; van Holst et al., 2012; Liu et al., 2014). Some studies, however, did not find impairments in behavioral inhibitory control in problem gamers (Dong et al., 2010; Ding et al., 2014). Studies investigating attentional control are also inconclusive as yet, with some studies showing an association between reduced attentional control and problematic gaming or internet addiction (Kronenberger et al., 2005; Dong et al., 2013), and other studies failing to find reduced attentional control as indicated by Stroop interference scores in problem gamers (Mathews et al., 2005; Bailey et al., 2010; Dong et al., 2012). With regard to brain activation related to inhibitory and attentional control in problem gamers, most neuroimaging studies suggest less efficient recruitment of prefrontal and parietal brain regions as compared with findings in controls (Mathews et al., 2005; Bailey et al., 2010; Dong et al., 2012; Littel et al., 2012; Brand et al., 2014; Ding et al., 2014; Liu et al., 2014).

Studies investigating error processing in problem gamers are very scarce. To the best of our knowledge, one previous study investigated error processing in problem gamers. That electroencephalographic (EEG) study used event-related potentials (ERPs) to show reduced error processing in problem gamers (Littel et al., 2012).

In line with these summarized findings, a recent review concluded that while some similarities in cognitive control functions were identified between problematic gaming and substance-dependent individuals, research in this field is yet in an early, inconclusive stage (Luijten et al., 2014). Therefore, the aim of the current study was to investigate various aspects of cognitive control and associated brain functions in a group of problem gamers. More specifically, inhibitory control, error processing and attentional control were investigated using a Go–NoGo and a Stroop task while brain activation was measured with functional magnetic resonance imaging (fMRI). Additionally, self-report measures to investigate related personality traits were obtained. The current study further aimed to address the specificity of reduced cognitive control for problematic gaming by including as controls participants that regularly plays games without losing control over their game playing, and by carefully matching these non-problematic gamers with the problematic gamers on other potentially addictive behaviors such as smoking and alcohol use. The inclusion of a well-matched non-problematic gamers as a control group is important for the field as it ensures that potentially observed problems in cognitive control are specifically related to problematic gaming behavior.

Based on previous literature, it was hypothesized that problem gamers would show increased self-reported impulsivity levels and reduced self-reported attentional control compared with non-problematic gamers. Furthermore, impairments in inhibitory control, error processing and attentional control were expected for behavioral measures of the Go–NoGo and the Stroop task. Finally, problematic gamers, as compared with non-problematic gamers, were expected to show reduced brain activation associated with cognitive control in the anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC), and inferior frontal gyrus (IFG) as well as parietal and subcortical regions.

2. Methods

2.1. Participants

Based on classroom/internet screening 22 male problem gamers and 23 male controls were invited to participate in the current study. During the screening procedure, potential participants completed the Videogame Addiction Test (VAT, van Rooij et al., 2012). In line with a previous study investigating cognitive performance in problem gamers (Littel et al., 2012), a VAT score of 2.5 or higher/1.5 or lower was required for problem gamers and controls, respectively. Age between 18 and 30 years old was an inclusion criterion for both groups. Exclusion criteria were a) current or past substance dependence (other than cigarettes), b) current or past serious physical or mental illness, c) current use of psychoactive medication, or medication that may affect blood circulation and/or respiration, and d) fMRI contraindications. To assess these criteria, the following questions were posed to participants: Do you use medication? Do you have mental problems, or did you have any mental problems in the past? Did your parents, caregivers, friends or any health care professional ever express any concerns about your mental well-being? Have you been diagnosed with attention deficit hyperactivity disorder? Do you use any drugs other than alcohol and nicotine? Following this questioning, participants were also excluded in case of any doubts about their mental well-being.

In line with the aim of the current study to compare problem gamers with casual gamers, controls were required to game between 2 and 15 h per week. Immediately after scanning, participants completed the VAT again (average number of days in between screening and scanning was 31 days (range 4–91). To be included in the analyses, participants were required to have again a VAT score of 2.5 or higher/1.5 or lower. Six controls and four problem gamers no longer met this requirement and were therefore excluded from the analyses. By applying this strict inclusion criterion, we ensured that the included participants were stable problematic gamers and that the controls consisted of game players who did not lose control over their gaming behavior. One more control participant was excluded because of a severe brain abnormality. The final group consisted of 18 problem gamers and 16 controls. Detailed participant characteristics are displayed in Table 1, and details on types of games played are presented in Table 2. The study was conducted in accordance with the Declaration of Helsinki, and all participants provided written informed consent after explanation of study procedures. The ethics committee of Erasmus MC-University Medical Centre Rotterdam approved the study.

2.2. Procedures

Smoking participants were instructed to abstain from smoking for 1 h before the experiment to reduce the acute effects of nicotine on cognitive performance without introducing significant withdrawal effects on cognitive performance. Smoking status was objectively confirmed using a calibrated Micro+Smokerlyzer (Bedfont Scientific Ltd., Rochester, UK). After scanning, participants completed a list of several questionnaires and received a financial compensation of €25.

2.3. Questionnaires

For the assessment of problem gaming, the 14-item VAT questionnaire was used (van Rooij et al., 2012). An example of a VAT item is ‘How often did you try to reduce your gaming time without success?’ Optional answers ranged from one to five (i.e., ‘never’ to ‘very often’). All items were averaged across the scale, resulting in single score representing an index of problematic gaming behavior. The Barratt 30-item Impulsiveness Scale 11 (BIS-11) was used to measure self-reported impulsivity (Patton et al., 1995). Furthermore, the 20-item Attentional Control Scale (ACS) was used to measure self-reported attentional control, including attentional shifting, focusing, and controlling thought (Koster et al., 2009; Fajkowska and Derryberry, 2010). Alcohol consumption was measured using the Quantity-Frequency-Variability Index (Lemmens et al., 1992). This three-item questionnaire measures quantity, frequency, and variability (binge drinking) of alcohol use.

2.4. Task paradigms

2.4.1. Go–NoGo task

Participants completed the Go/NoGo task in which letters were presented at 1 Hz (Nestor et al., 2011; Luijten et al., 2013). Letters were presented for 700 ms followed by a 300-ms blank screen. Participants were required to make a button press response as fast as possible to each letter (Go trials) and to withhold this response whenever the letter was the same as the previous one (NoGo trials). NoGo