

## Web addiction in the brain: Cortical oscillations, autonomic activity, and behavioral measures

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(Received: October 6, 2016; revised manuscript received: February 13, 2017; second revised manuscript received: March 21, 2017; third revised manuscript received: April 23, 2017; accepted: June 11, 2017)

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*Background and aims:* Internet addiction (IA) was recently defined as a disorder tagging both the impulse control and the reward systems. Specifically, inhibitory deficits and reward bias were considered highly relevant in IA. This research aims to examine the electrophysiological correlates and autonomic activity [skin conductance response (SCR) and heart rate] in two groups of young subjects ( $N = 25$ ), with high or low IA profile [tested by the Internet Addiction Test (IAT)], with specific reference to gambling behavior. *Methods:* Oscillatory brain activity (delta, theta, alpha, beta, and gamma) and autonomic and behavioral measures [response times (RTs) and error rates (ERs)] were acquired during the performance of a Go/NoGo task in response to high-rewarding (online gambling videos and video games) or neutral stimuli. *Results:* A better performance (reduced ERs and reduced RTs) was revealed for high IAT in the case of NoGo trials representing rewarding cues (inhibitory control condition), probably due to a “gain effect” induced by the rewarding condition. In addition, we also observed for NoGo trials related to gambling and video games stimuli that (a) increased low-frequency band (delta and theta) and SCR and (b) a specific lateralization effect (more left-side activity) delta and theta in high IAT. *Discussion:* Both inhibitory control deficits and reward bias effect were considered to explain IA.

**Keywords:** Internet addiction, brain oscillations, autonomic activity, rewarding, gambling

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### INTRODUCTION

Addiction refers to a process whereby a behavior, which can function both to produce pleasure and provide escape from internal discomfort, and is employed in a pattern characterized by (a) recurrent failure to control the behavior and (b) continuation of the behavior, despite significant negative consequences (Goodman, 1990). Two main cognitive functions have been emphasized as major components in the development and persistence of addictive states (e.g., Luijten et al., 2014). Indeed, the incentive salience properties of the addiction-related stimuli as well as a deficit in inhibitory skills are core mechanisms of addictive behavior (the dual-process model; Field & Cox, 2008; Wiers et al., 2007). On the one hand, the phenomenon of increased salience may be due to an impaired mechanism of reward, able to induce a sort of “reward bias” for potential rewarding cues, such as substance, but also video games or gambling stimuli (Park & Lee, 2011; Yen et al., 2012). Reward motivation significantly correlates with drug addiction (Balconi, Finocchiaro, & Canavesio, 2014; Knyazev, 2010). The reward deficit syndrome was proposed as a possible contributing factor to the development of substance abuse disorders (Cao, Su, Liu, & Gao, 2007), since

addiction may be related to greater receptiveness to the reinforcing effect of drugs and other similar rewarding stimuli (Logan, Cowan, & Davis, 1984; Vitaro, Arseneault, & Tremblay, 1999). On the other hand, altered inhibitory skills have led authors to consider addiction as an impulse control disorder (Dell’Osso et al., 2008; Dong, Lu, Zhou, & Zhao, 2010; Shapira, Goldsmith, Keck, Khosla, & McElroy, 2000).

Response inhibition, as assessed through Go/NoGo tasks, can be defined as the act of withholding or terminating a behavioral response, and is considered to be governed by a cognitive inhibitory process (Logan et al., 1984). A strong relationship between reduced impulse control and addictive behaviors, such as pathological gambling, substance, and alcohol abuse, was evidenced (Barnes, Welte, Hoffman, & Dintcheff, 2005; Moeller et al., 2001; Vitaro et al., 1999). Accordingly, it was shown in substance abusers [heroin addicts (Yang, Xiong, Kojic, & Cynader, 2009), cocaine users (Waters, Marhe, & Franken, 2012), alcohol users

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(Noël et al., 2007), and tobacco smokers] that they (a) show a drug cue-reactivity, manifested by a processing enhancement in the brain striatal regions related to motivation and reward and (b) typically fail to inhibit drug-oriented behavior even when the consequences are deleterious.

Addictions “without substances,” also called behavioral addictions [like gambling or Internet addiction (IA)] show similar patterns (Luijten et al., 2014). In this paper, we focus on IA, which was classified as one category of behavioral addiction, representing a specific impairment that involves online and/or offline computer misuse (Grant, Potenza, Weinstein, & Gorelick, 2010; Han, Lyoo, & Renshaw, 2012; Zhou et al., 2011). At the neurocognitive level, it is suggested that the “bad balance” between these two components, that is, reward sensitivity and impulsiveness, may have an important role to play in explaining IA (Caseras, Avila, & Torrubia, 2003). IA was considered as an impulse disorder or at least related to impulse control disorder (Beard & Wolf, 2001; Dawe & Loxton, 2004). There is consistent evidence at this respect both at the structural and functional levels (see Kuss & Griffiths, 2012 for review). Current data indicate that, compared with controls, brain regions associated with reward, addiction, craving, and emotion [such as nucleus accumbens, amygdala, insula, and orbitofrontal cortex (OFC)] are increasingly activated during game play and presentation of game cues while furthermore, Internet addicts were found to have decreased gray matter volume in regions mediating cognitive control [such as supplementary motor area and dorsolateral prefrontal cortex (DLPFC)]. As impairment in inhibitory control is classically considered as the cornerstone of addictive states, most electroencephalogram (EEG) studies in IA focused on the reflective system, while concerning the automatic-affective system, it has to be underlined that current data remain very preliminary due to the small number of available studies (see D’Hondt & Maurage, 2017 for review).

Brain imaging studies also stressed the importance of the prefrontal cortex (PFC) in addictive behaviors mainly through its involvement in a higher-order executive function as well as its regulatory function on limbic rewarding regions (Balconi & Finocchiaro, 2015; Baler & Volkow, 2006; Bechara, 2005; Chen et al., 2015; Dawe & Loxton, 2004; Knyazev, 2010). More specifically, addictive states were defined by (a) hyperactivity in the emotional system, mediated by frontal and medial structures, such as OFC, anterior cingulate cortex, and amygdala, which exaggerated the rewarding impact of external reinforcing cues; (b) anomalous brain activity in DLPFC, which predicted the long-term consequences of a given action (Balconi & Finocchiaro, 2015); and (c) dysfunctions in the mesolimbic dopaminergic reward system, which can support conditioned attention allocation for dependence-associated stimuli rendering them especially salient (Adinoff, 2004), as already reported in substance abusers and impulsive individuals (Adinoff, 2004; Limbrick-Oldfield, van Holst, & Clark, 2013; Scheres, Milham, Knutson, & Castellanos, 2007). In this view, PFC was implicated in reward bias and whereas the left PFC was shown to be more implicated in approach-related and rewarding conditions, the right PFC was found to be more involved in withdrawal-related motivations and inhibitory mechanisms (Balconi & Mazza,

2009, 2010; Davidson, 2004; Harmon-Jones, 2004). Both approach and withdrawal motivations are paralleled by the reward and punishment contingencies, as shown in a recent EEG study, which revealed a specific more left (reward-related) or right (punishment-related) higher brain responsiveness (Balconi, Brambilla, & Falbo, 2009a; Balconi, Falbo, & Conte, 2012).

However, with specific reference to IA, limited studies explored the relationship between addiction, impulsivity, and brain activity by focusing on EEG (Kamarajan et al., 2004). Ample range of brain oscillations were previously used to test brain correlates of different types of addiction (Balconi & Finocchiaro, 2015; Balconi, Finocchiaro, & Canavesio, 2015; Finocchiaro & Balconi, 2015). Specifically, delta band responses were assumed to mediate signal detection and decision-making (Başar, Başar-Eroğlu, Karakaş, & Schürmann, 1999, 2001; Schürmann, Başar-Eroglu, Kolev, & Başar, 2001), whereas theta functions were mainly attributed to different cognitive processes, such as inhibitory mechanisms (Başar, Başar-Eroğlu, et al., 2001; Harper, Malone, & Bernat, 2014; Klimesch, Doppelmayr, Stadler, et al., 2001; Klimesch, Doppelmayr, Yonelinas, et al., 2001). It was also found that in some specific addiction behavior (i.e., alcohol dependence), patients showed significant reduction in delta and theta power during NoGo trials as compared with controls. This reduction was prominent at the frontal region and suggests a deficient inhibitory control and information-processing mechanism. Furthermore, both higher frequency bands (i.e., beta and gamma) have been found to be associated with response inhibition. Two EEG studies assessed reflective system in IA about online computer gaming by investigating resting-state activities, which reflect non-task-related cognitive mechanisms (Andrews-Hanna, Reidler, Huang, & Buckner, 2010; Greicius & Menon, 2004). A first study showed a decreased absolute power in the beta band (Choi et al., 2013) in IA, previously related with task-related impulsivity observed in attention-deficit hyperactivity disorder patients (Snyder & Hall, 2006). IA also presented increased absolute gamma band power. Moreover, changes in gamma band have also been associated with impulsivity (Barry, 2009). Resting-state fast-wave brain activity thus appears to be associated with impulsivity in online computer gaming.

Finally, systemic blood pressure, pulse rate, and skin conductance were considered potential biological markers of arousal modulation related to the salience of a specific context or cue (Tupak et al., 2014). Among the others, skin conductance response (SCR) provides a useful measure of the limbic function (Furmark, Fischer, Wik, Larsson, & Fredrikson, 1997; Lang, Davis, & Öhman, 2000). The significance of this measure for arousal modulation and attentional functions was previously demonstrated (Balconi & Pozzoli, 2008; Balconi, Brambilla, & Falbo, 2009b) as it may be considered a useful marker of the salience/relevance of some cues. Indeed, autonomic measures are generally related to the attentional and motivational significance of the eliciting context. The advantage of acquiring both the autonomic (arousal-related) and the central (EEG cortical-related) activities in studying IA stands in the possibility to better elucidate the reciprocal interplay of the two compartments and to better describe the existence

of anomalous response behavior to the external stimuli. Indeed, recent research underlined the anomalous response by SCR in pathological decision-making (Bechara & Damasio, 2002; Dixon, Harrigan, Sandhu, Collins, & Fugelsang, 2010; Trotske, Starcke, Pedersen, Müller, & Brand, 2015). However, whether and how web addiction is related to rewarding mechanisms in response to Go/NoGo on one hand and how impulse control deficits are related to reward mechanisms on the other hand are actually unexplained (Kamarajan et al., 2008). Moreover, no previous research monitored these three levels (electrophysiological correlates, autonomic measures, and behavioral performance) all together to furnish a complete overview of the control and reward deficits (Balconi & Finocchiaro, 2016). To test this reward bias and control deficits based on IA construct in this research, attentional inhibitory task (Go/NoGo task) was performed. Internet Addiction Inventory (IAI, Young, 1998) was applied to distinguish between high IA or low IA profile, during the performance in response to specific potentially rewarding cues (videos representing online gambling and video games) or neutral contexts (as sport game). Second, cortical oscillations (frequency bands) were considered as predictive components to explain a potential web addiction profile. Moreover, systemic SCR and heart rate (HR) were recorded as potential biological markers of deficit in inhibitory control and rewarding mechanisms.

Therefore, we hypothesized that an inhibitory control deficit should be reported for increased IA profile (higher IA), mainly for NoGo trials regarding gambling cues (inhibitory control condition). In this case, a behavioral attentional bias was expected [reduced response times (RTs) and reduced error rates (ERs) for gambling category]. In addition, we expected a decreased low-frequency bands (mainly delta and theta) and increased SCR and HR in higher IA when compared with lower ones. These modulations were seen as, respectively, a marker of deficit in the

inhibitory system, as a rewarding bias as well as a signal of the arousing power of the gambling category. In addition, a frontal EEG asymmetry was expected, related to appetitive rewarding conditions (rewarding cues), with a heightened reward bias reflected in a left frontal activity (more reward-related, suggesting that the activation of one system will result in the inhibition of the former).

## METHODS

### Participants

A total of 25 volunteers participated in this study ( $M = 24.77$ ,  $SD = 0.99$ , age range = 20–25 years, 15 women). All subjects were undergraduate students at the Catholic University of the Sacred Heart, Milan and were right-handed, with normal or corrected-to-normal visual acuity. Exclusion criteria were history of psychopathology for the subjects or immediate family members. No specific neurological or psychiatric pathologies were observed by clinical colloquium. Other addictive behaviors were excluded from the sample. A specific questionnaire was submitted to explore the drug use by the subjects to complete the Internet Addiction Test (IAT) measurement.

### Measures

In the experimental task, the stimuli consisted of two capital white letters (M and W; size of  $500 \times 400$  mm) in Times New Roman font and three background pictures (gambling-related, video games-related, and neutral contexts) (Figure 1) displayed on a 15-in. monitor. A total of 20 volunteers, matched for age and sex with the experimental group, evaluated these pictures for gambling- and video games-related context, considering four dimensions: relevance,



Figure 1. Go/NoGo task. Each trail consisted of the presentation of a background picture (neutral, gambling, and video games) for 500 ms, then the letter M or W appeared in the center of this picture for 200 ms. All the sessions were randomized

familiarity, valence, and arousing power (for more procedure details, see [Balconi & Finocchiaro, 2016](#)). On this basis, 18 pictures were selected and categorized into three types: six neutral stimuli, six gambling-related stimuli, and six pictures for video games-related condition.

IAT ([Young, 1998](#)) was developed according to the diagnostic criteria of the DSM-IV for pathological gambling, and it was adapted for the diagnosis of IA. It specifically explores the addiction for the Internet users, considering both the style of users, their mood during the Internet use, the impact of Internet use on the life styles, the quantitative and qualitative features of Internet use, and so on. Its validity and reliability were largely tested. The questionnaire consists of 20 items measured with 4-point Likert scale (ranging from “never” to “always”). The score was valued according to the cut-off: score between 0 and 30 (none): Internet usage below the average; score between 31 and 49 (mild): an average Internet user, who can sometimes happen to surf the net a bit too long but without losing control of the situation; score between 50 and 79 (moderate): the person already has several problems because of the Internet and it should reflect on the impact these issues have on his life; and score between 80 and 100 (severe): the use of the Internet is excessive and causing considerable problems to the person. The Cronbach’s  $\alpha$  coefficient was from .79 to .93 (49.68). Two subgroups of subjects were created based on this total score: high IAT with score more than 60 ( $N = 12$ ,  $M = 78.97$ ;  $SD = 5.43$ ) and low IAT with score less than 40 ( $N = 13$ ,  $M = 37.08$ ;  $SD = 5.03$ ). Gender was balanced across group. We successively explored the specific content (program, applications, etc.) of Internet users to better characterize their profiles. They showed a specific penchant for video games (such as sport video games), gambling situations (such as video-poker or similar), and social media. Therefore, we were able to better qualify the nature of their addiction and to put the adequate stimulus condition.

### Procedure

The participants sat on a comfortable chair in front of a PC screen (1,280 × 1,024 pixel). The PC was placed approximately 60 cm from the subject, with a visual horizontal angle of 4° and a vertical angle of 6°. They were instructed to complete the Go/NoGo task, prior to record EEG data. The Go/NoGo task was a modified version of the experimental task used by [Petit et al. \(2012\)](#) (see [Balconi & Finocchiaro, 2016](#) for this version) and it was composed of four blocks of 120 stimuli per block, which were divided in 84 Go trials and 36 NoGo trials for each session. The blocks consisted of randomized presentation of background pictures from three different contexts: gambling (G), video games (VG), and neutral (N) for 500 ms. Successively, the letter M or W appeared in the center of this background picture for 200 ms, and then the initial background picture came back for 1,300 ms ([Figure 1](#)). Therefore, participant had a maximum of 1,500 ms to press the button before the next letter appears. A successive 3,000 ms intertrial interval was included. The letters were presented in a random order to ensure the same amount as a percentage of the trials Go (70%) and NoGo (30%) for each block and category.

Participants were required to press a button as fast as possible, when they saw the Go stimulus appearing at the center of the screen and to withhold the response for the NoGo stimulus. Moreover, they were asked to reduce moving and blinking during the task to control EEG artifacts during registration. Each participant completed a total of 480 trials. To familiarize with the task, the participants completed a short session of 20 trials (70% Go and 30% NoGo) on a black background. After completing the Go/NoGo task, the participants were submitted to a debriefing phase, with the post-evaluation questionnaires (IAT, State-Trait Anxiety Inventory-Form Y, and Beck Depression Inventory-II).

### Statistical analysis

*EEG recordings and data reduction.* EEG recordings were performed with a 32-channel DC amplifier (SynAmps system) and acquisition software (NeuroScan 4.2). An Electro-Cap with Ag/AgCl electrodes was used to record EEG from active scalp sites referred to the earlobes (10/20 system of electrode placement) ([Jasper, 1958](#); [Pfurtscheller, 1992](#)). Data were acquired using a sampling rate of 500 Hz, with a frequency band of 0.01–50 Hz. The onset was considered the appearance of the image. An offline common average reference was successively computed to limit the problems associated with the signal-to-noise ratio ([Ludwig et al., 2009](#); [Pascual-Marqui, 2002](#)). In addition, two electrooculogram (EOG) electrodes were sited on the outer canthi to detect eye movements. The impedance of the recording electrodes was monitored for each subject prior to data collection, and was always maintained below 5 k $\Omega$ . After performing EOG correction and visual inspection, only artifact-free trials were considered (rejected epochs 2%). The signal was visually scored, and portions of the data that contained artifacts were removed to increase the specificity. Blinks were also visually monitored. Ocular artifacts (eye movements and blinks) were corrected using an eye-movement correction algorithm that employs a regression analysis in combination with artifact averaging ([Pascual-Marqui, Michel, & Lehmann, 1994](#); [Semlitsch, Anderer, Schuster, & Presslich, 1986](#)). The digital EEG data were band-pass filtered in the following frequency bands: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (14–20 Hz), and gamma (20–40 Hz) (band-pass filtering 96 dB/octave roll-off, warm-up filter left and right to 100 ms). To obtain a signal proportional to the power of the EEG frequency band, the filtered signal samples were squared ([Palmero-Soler, Dolan, Hadamschek, & Tass, 2007](#); [Pfurtscheller, 1992](#)). An average absolute power value for each experimental condition was calculated, using the time window of 0–500 ms. The fast Fourier transform method (Hamming window: length 10%) was used to obtain estimates of spectral power ( $\mu\text{V}^2$ ) in the 1 Hz frequency bins for each electrode site. Spectral power values were averaged across all epochs within a single baseline and were then transformed to power density values for the different frequency bands. All power density values were log-transformed to normalize the distribution of the data after the subtraction.

*Autonomic data.* Biopac MP 150 system (Biopac Systems Inc., Goleta, CA, USA) was used to record the autonomic activity. Electrocardiography (ECG) was recorded

continuously in lead 1 from two electrodes attached to the lower wrist, with the positive pole on the left arm and the negative pole on the right one. One more reference electrode was placed over the left ankle. The ECG signal was sampled at 1000 Hz with the Biopac Acknowledge 3.7.1 software (Biopac Systems Inc.) according to the manufacturer's guidelines. ECG was converted to HR in number of beats per minute. The signal was low-pass filtered at 35 Hz and high-pass filtered at 0.05 Hz for motor and ocular artifacts. The electrodes for SCR were attached to the distal phalanges of the first and second finger of the left hand. SCR was recorded using two Ag/AgCl electrodes and an isotonic gel. The signal was sampled at 1000 Hz and low-pass filtered at 10 Hz for motor, ocular, and biological artifacts. SCR elicited by each stimulus was continuously registered with a constant voltage. It was defined as the largest increase in conductance during image presentation, with a cut-off of at least 0.4  $\mu$ S in amplitude with respect to baseline (pre-stimulus) mean values scored prior to task onset. The highest peak amplitude of SCR was on average at 4.1 s post-stimulus onset, within a mean beginning and ending of the peak included between 3.4 and 4.8 s.

### Ethics

All participants gave informed written consent for participating in the study, and the research was approved by the Ethical Committee (Department of Psychology) of the institution, where the work was carried out. The study procedures were carried out in accordance with the Declaration of Helsinki.

## RESULTS

### ERs

The behavioral measures of ERs (number of errors out of the total of trials) were subjected to a three-way repeated-measures ANOVA, with between-subject IAT (2), and the within-subject factors Go/NoGo (2) and stimuli (3) applied to the ERs. We preliminarily applied a distinct analysis comparing the two categories (incorrect stop/go, considering the respective percentage). Since no significant differences were found, we considered the total ERs in the final second analysis. Errors associated with inhomogeneity of variance were controlled by decreasing the degrees of freedom using the Greenhouse–Geisser epsilon. Post-hoc analysis (contrast analysis for ANOVA, with Bonferroni corrections for multiple comparisons) was applied in case of significant effects. The significant effects were found for stimuli [ $F(2, 24) = 10.16, P = .001, \eta^2 = .40$ ] and IAT  $\times$  Go/NoGo  $\times$  stimuli [ $F(2, 72) = 11.23, P = .001, \eta^2 = .42$ ] (Figure 2a). As revealed by post-hoc analysis (contrast analyses for repeated measure ANOVA), reduced ERs were found for gambling and video games [ $F(2, 24) = 9.56, P = .001, \eta^2 = .39$ , respectively] than neutral stimuli. About the interaction effect, simple effects revealed decreased ERs for video games [ $F(1, 24) = 9.30, P = .001, \eta^2 = .38$ ] and gambling stimuli [ $F(1, 24) = 8.97, P = .001, \eta^2 = .33$ ] in Go condition for high IAT more than low IAT. Similarly, decreased ERs were

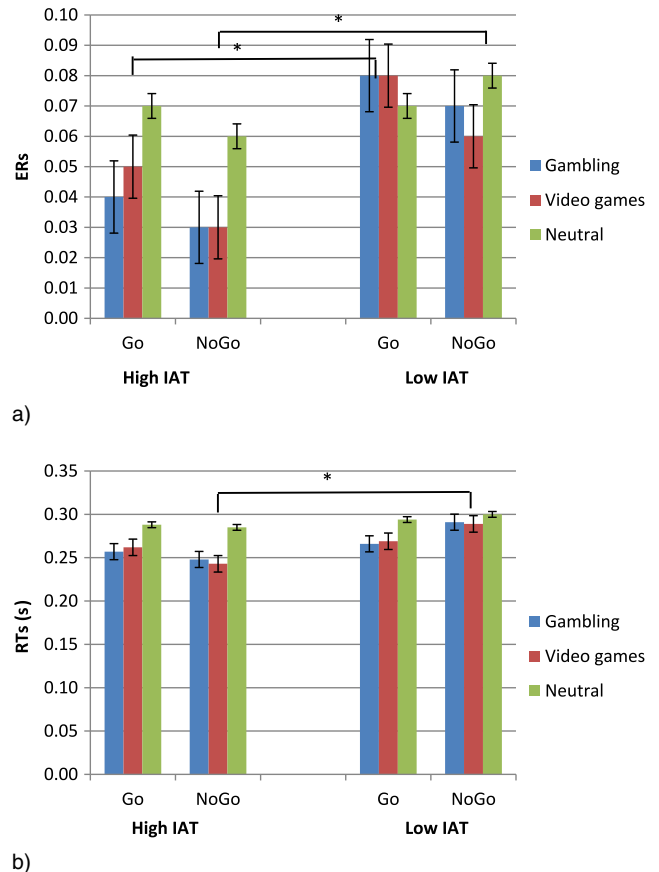


Figure 2. (a) ER values as a function of stimulus type and Go/NoGo task. (b) RT values as a function of stimulus type and Go/NoGo task.  $*P \leq .01$

found for video games [ $F(1, 24) = 8.70, P = .001, \eta^2 = .33$ ] and gambling stimuli [ $F(1, 24) = 8.55, P = .001, \eta^2 = .32$ ] in NoGo condition for high IAT more than low IAT.

### RTs

RTs were subjected to a three-way repeated-measures ANOVA (IAT  $\times$  Go/NoGo  $\times$  stimuli).

The significant effects were found for stimuli [ $F(2, 24) = 9.43, P = .001, \eta^2 = .38$ ] and IAT  $\times$  Go/NoGo  $\times$  stimuli [ $F(2, 48) = 10.07, P = .001, \eta^2 = .40$ ] (Figure 2b). Lower RTs were found for gambling and video games than neutral stimuli. About the significant interaction effect, simple effects revealed lower RTs for video games [ $F(1, 24) = 9.51, P = .001, \eta^2 = .36$ ] and gambling stimuli [ $F(1, 24) = 7.56, P = .001, \eta^2 = .30$ ] in NoGo condition for high IAT more than low IAT.

### Brain oscillations

Each frequency band was subjected to a five-way ANOVA, in which the IAT (2), Go/NoGo (2), lateralization (2), stimuli (3), and localization (4) were applied to the dependent variable of band power. Localization (four sites: frontal, central, temporo-parietal, and occipital) and lateralization (three sides: left, central, and right) were calculated.

Specifically, we measured left, central, and right frontal (F3, Fz, and F4), middle-central (Cz, C3, and C4), temporo-parietal (P3/T7, Pz, and P4/T8), and occipital (Oz, O1, and O2) brain activity.

For delta, significant stimuli [ $F(1, 24) = 8.90, P = .001, \eta^2 = .37$ ] main effect was found (Figure 3a). Indeed, delta power was higher for NoGo than Go condition. Moreover, IAT  $\times$  Go/NoGo  $\times$  stimuli  $\times$  lateralization  $\times$  localization [ $F(1, 96) = 9.18, P = .001, \eta^2 = .38$ ] interaction effect was significant. Specifically, as shown by post-hoc comparisons, delta increased in response to NoGo condition for gambling stimuli [ $F(1, 24) = 7.09, P = .001, \eta^2 = .34$ ] and video games [ $F(1, 24) = 8.32, P = .001, \eta^2 = .37$ ] than neutral stimuli in high IAT. Moreover, delta was more frontally and left distributed than the other cortical sites for gambling and video games in high IAT (for all paired comparisons,  $P \leq .001$ ).

For theta, significant IAT [ $F(1, 24) = 8.98, P = .001, \eta^2 = .37$ ] and localization [ $F(1, 24) = 7.61, P = .001, \eta^2 = .35$ ] main effects were observed. As shown in Figure 3b, theta power was higher for NoGo than Go condition and it was more frontally distributed. Moreover, IAT  $\times$  stimuli  $\times$  Go/NoGo  $\times$  lateralization  $\times$  localization [ $F(1, 96) = 10.77, P = .001, \eta^2 = .41$ ] interaction effect was significant. Specifically, as shown by post-hoc comparisons, theta increased in response to NoGo condition for gambler stimuli [ $F(1, 21) = 8.31, P = .001, \eta^2 = .37$ ] and video games [ $F(1, 21) = 6.09, P = .001, \eta^2 = .373$ ] than neutral stimuli within the left hemisphere in high IAT.

For alpha, beta, and gamma, no significant effects were found.

Autonomic measures

HR and SCR measures were analyzed with two-way repeated-measures ANOVAs (IAT  $\times$  Go/NoGo  $\times$  stimuli). For SCR interaction effect, IAT  $\times$  Go/NoGo  $\times$  stimuli was significant [ $F(1, 48) = 8.12, P = .001, \eta^2 = .36$ ] (Figure 4). Increased SCR values were found for high IAT in NoGo for gambler stimuli [ $F(1, 24) = 8.16, P = .001, \eta^2 = .36$ ] and video games [ $F(1, 24) = 7.88, P = .001, \eta^2 = .33$ ] than neutral stimuli. For HR, no effect was statistically significant. In addition, high IAT showed increased SCR in NoGo for gambling stimuli [ $F(1, 24) = 7.15, P = .001, \eta^2 = .33$ ] and video games [ $F(1, 24) = 7.12, P = .001, \eta^2 = .33$ ] when compared with low IAT.

DISCUSSION

This research aimed at exploring the deficits observed for the rewarding and the inhibitory control mechanisms in IA. Cortical brain oscillations, autonomic activity, and behavioral measures were simultaneously considered to analyze the impaired behavior in response to online stimuli (gambling, video games, and neutral cues), when a decisional process (Go/NoGo task) was submitted. A main effect was found in relationship with brain oscillations (an increase

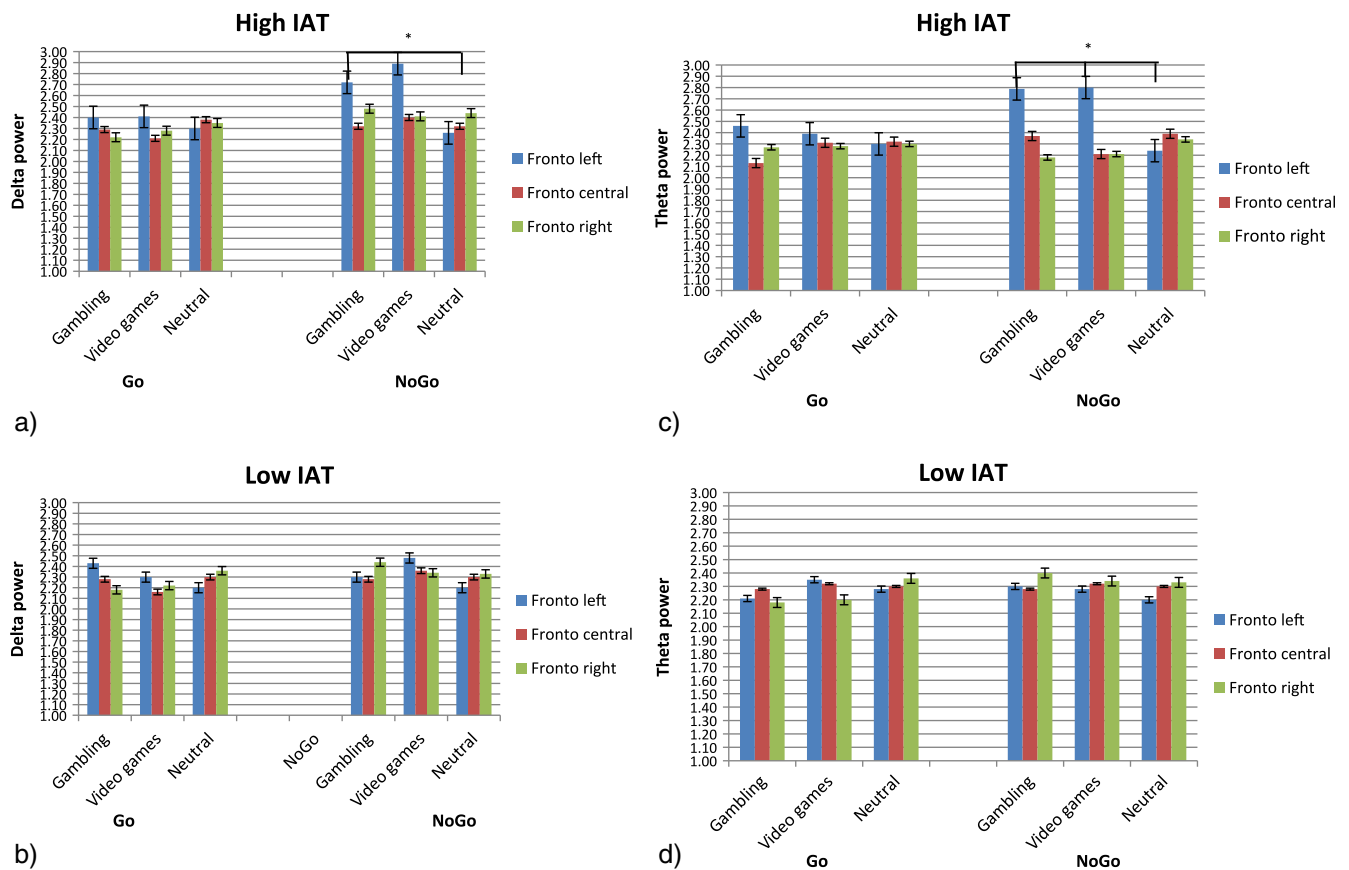


Figure 3. Delta (a and b) and theta (c and d) power modulation as a function of high/low IAT, stimulus type, and Go/NoGo task. \* $P \leq .01$

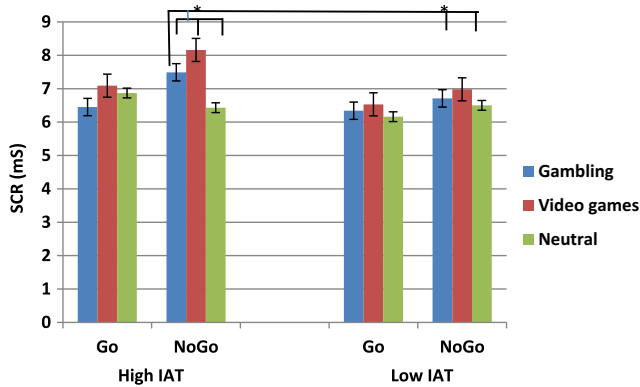


Figure 4. SCR measures as a function of high/low IAT, stimulus type, and Go/NoGo task. \* $P \leq .01$

in delta and theta low-frequency bands) and autonomic measures (increased SCR), when a more controlled behavior was required (NoGo condition) in response to rewarding cues (gambling and video games). This specific effect was modulated by IAT, with increased delta and theta for high IAT subjects. They also showed a better performance (reduced ERs and RTs) in NoGo condition (mainly for RTs) for rewarding cues. Moreover, EEG confirmed a prefrontally lateralized activation effect within the left hemisphere. Indeed, for the EEG component, frequency band data (theta and delta modulation) indicated that rewarding cues (gambling and video games) led to an increased activity over the left PFC more for high IAT. About the first effect, high IAT revealed an increased low-frequency response in concomitance to inhibitory process, when NoGo task was performed. The observed increase in delta, and in the low-frequency bands activity in general, is consistent with previous observations with Go/NoGo task data (Barry, 2009; Kamarajan et al., 2004, 2006; Kirmizi-Alsan et al., 2006; Yamanaka & Yamamoto, 2010), as well as other control-related processes, such as response error and feedback processing (Bernat, Nelson, Steele, Gehring, & Patrick, 2011; Cavanagh, Zambrano-Vazquez, & Allen, 2012; Cohen, Elger, & Ranganath, 2007; Gehring & Willoughby, 2004; Trujillo & Allen, 2007; Yordanova, Falkenstein, Hohnsbein, & Kolev, 2004). This increased brain activity for low-frequency bands was found in response to specific categories, such as gambling and video games stimuli. The significant impact of such categories may reveal the necessity for the subjects to highly control and suppress their behavior in response to specific, more “sensitive” Internet contexts and potentially “rewarding” categories compared with neutral ones. It was also underlined that delta band activity was associated with some cognitive functions, including reward processing (Bernat et al., 2011; Nelson, Patrick, Collins, Lang, & Bernat, 2011). In addition, it was showed that delta modulation depends on activity of motivational systems and participates in salience detection (Knyazev, 2007). Therefore, theta and delta may be responsive-relevant rewarding cues and their modulation may be related to a reward bias. In terms of the significance of delta and theta reduction, impulsivity was also previously indicated as a crucial contributing factor for this variation in

low-frequency bands. Specifically, neurocognitive models of addiction disorders often implicate impulsivity as a major component, and they reported a significant role for low-frequency bands as cortical marker of this deficit in impulse control. This result may also stress that NoGo condition with potentially “rewarding” cues may more consistently and directly activate the subjective necessary resources needed to “inhibit” or suppress automatic responses.

A systematic lateralization effect was observed for delta and theta in the case of rewarding condition for high IAT subjects. We suggest that, in line with the approach-withdrawal model, prefrontal EEG asymmetry is related to appetitive rewarding cues, with heightened approach and reward bias tendencies reflected in relative left-frontal activity (Balconi et al., 2014). Thus, the specific cortical localization we found may suggest the consistent over-implication of the cortical left PFC system and a concomitant predominance of this brain area in regulating the rewarding behavior in the high IAT subjects. Moreover, the cortical hyperresponsiveness in NoGo condition would imply a frontal lobe dysfunction in terms of processing of rewarding stimuli and the controlled behavior toward them.

Similarly, the behavioral measures (ERs and RTs) were affected by IAT category, stimulus type and task. In fact, a reduction of ERs and RTs was revealed in response to both Go and NoGo condition when the subjects processed video games and even more gambling stimuli. This “facilitation effect” was revealed for high IAT, with an increased performance for more salient stimuli. Therefore, the subjective performance may present a more “immediate” and “impulsive” response and, in concomitance, a better outcome for the most salient category (gambling and video games). This fact could be due to a general increased motivation to respond to high-relevant cues, such as video games and gambling stimuli. This important motivational effect was previously reported (van Holst, van Holstein, van den Brink, Veltman, & Goudriaan, 2012). These results are also in line with the supposition that addicted individuals commonly exhibit a decreased ability to control the desire to obtain drugs (i.e., inhibitory control), despite knowledge about the aversive consequences following drug intake or the low expectation of actual pleasure expected from the drug (i.e., decision-making and reward consequences) (Balconi & Finocchiaro, 2016; Schoenbaum, Roesch, & Stalnaker, 2006).

The autonomic measures as a whole also showed that subjective responses to rewarding cues (gambling and video games) vary eliciting different autonomic patterns. Specifically, SCR was higher for rewarding cues than neutral when inhibitory behavior was required (NoGo). SCR variation is the phasic sympathetic activity that operates such as an index of the arousal and salience dimension of motivation (Amrhein, Mühlberger, Pauli, & Wiedemann, 2004; Balconi et al., 2009a; Balconi, Grippa, & Vanutelli, 2015; Bradley, Cuthbert, & Lang, 1993). In addition, it may elucidate the “emotional cost” induced by the necessity to inhibit their response by subjects more sensitive to rewarding stimuli as high IAT. The present data may partially appear in contrast with previous results, which found a specific decreased SCR in concomitance with “dysfunctional” decisions (as in the

IOWA gambling task) compared with normal subjects who generally show an increased SCR (Bechara & Damasio, 2002; Trotzke et al., 2015). However, it should be noted that in these previous experiments, the anticipatory SCR was generally acquired as a biological signal of functional or dysfunctional behavior in decision-making. In contrast, in this research, an SCR modulation was acquired and observed during the task execution and, for this reason, it should be better considered as a marker of the subject engagement and arousal modification in response to more potentially rewarding and desired condition instead of a sort of anticipatory signal. Future research should better elucidate this point, more directly comparing pre- and post-task SCR variations as an index of potentially different cognitive and emotional mechanisms.

## CONCLUSIONS

To summarize, the present data stressed the importance of both rewarding effect and inhibitory mechanism that highly influence the IAT subjects' responses. Sensitivity to reward and deficit in inhibitory control may have acted as crucial variables in determining the "addiction behavior" in high IAT, when they had to process stimuli that may potentially elicit a compulsive and uncontrolled behavior to obtain the rewarding condition. Therefore, high sensitivity to IAT construct could be considered as a marker of both dysfunctional reward processing and cognitive control mechanisms. More generally, a direct relationship among impulsivity, reward-related behavior, and IA may be suggested, specifically for high IAT. The three levels of analysis, which are brain correlates, autonomic modulation, and behavioral performance, showed significant consistence each other, showing the direct complementarity between more central and peripheral measures.

However, some limitations may be adduced in this research. Indeed, first, the limited number of subjects does not allow an ample generalization of the present data. Second, a more exhaustive analysis of the cortical localization of brain oscillations effect should be provided in future research also using neuroimaging or hemodynamic measures. Third, other experimental tasks should be provided to explore the contribution of control and inhibitory mechanisms in IA, also considering other kind of stimuli to be included and potentially related to addiction behavior. In addition, the engagement of subjects in Go and NoGo tasks should be better explored, considering the role of the emotional behavior in response to more or less rewarding conditions. Finally, the intrinsic link among the cognitive behavior (Go–NoGo performance), the SCR modulation and the brain oscillation variations should be better tested to discover the causal effect of one on another level and their possible causal relationship.

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*Funding sources:* None.

*Authors' contribution:* MB: planned the experiment, supervised the experiment, supervised statistical analysis, and

wrote the paper. RF: realized the experiment, applied statistical analysis, and wrote the paper.

*Conflict of interest:* No conflict of interest to be declared.

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