Brain oscillations, inhibitory control mechanisms and rewarding bias in web addiction. Two opposite young subjects' clusters?

Michela Balconi[1,2] - Irene Venturella[1,2] - Roberta Finocchiaro[1,2]

[1] *Research Unit in Affective and Social Neuroscience, Catholic University of the Sacred Heart, Milan, Italy*

[2] *Department of Psychology, Catholic University of the Sacred Heart, Milan, Italy*

DOI: http://dx.doi.org/10.7358/neur-2018-023-bal1 michela.balconi@unicatt.it

ABSTRACT

Internet Addiction (IA) is considered a subtype of impulse control disorder, and a behavior related to rewarding system deficits. However whether and how impulse control deficits are related to in rewarding mechanisms is actually unexplored. The present research aims to examine the neural correlates of deficits in inhibitory control and the rewarding mechanisms in IA in a sample of young people. Internet Addiction Inventory (IAT) was applied to a sub-clinical sample. Secondly, cortical oscillations (frequency bands) and personality trait (Behavioral Inhibition System, BIS; Behavioral Activation System, BAS) were considered to explain IA. Oscillatory brain activity (delta, theta, alpha, beta and gamma) and response times (RTs) were monitored during the performance of a Go/NoGo task in response online gambling videos, videogames or neutral stimuli. BAS, BAS-R (BAS-Reward subscale), BIS and IAT predicted the low-frequency band variations, although in an opposite direction: reduced delta and theta and RTs values were found for higher BAS, BAS-R and IAT, in the case of NoGo for gambling and videogames stimuli; in contrast increased delta and theta and RTs values were observed for higher BIS. Two potential different young subjects' clusters were suggested: with low inhibitory impulse control and rewarding bias (higher BAS and IAT); and with impulse hyper-control (higher BIS).

Keywords: Internet Addiction; frequency band; BIS-BAS; rewarding; gambling

1. Introduction

Internet addiction (IA) has been considered a public health issue (Zhou et al., 2011) that involves online and/or offline computer use (Han, Lyoo, & Renshaw, 2012). It was suggested that IA should be classified as one category of "behavioral addiction" considering its natural course, clinical symptoms, tolerance, comorbidity, and neurobiological aspects (Grant, Potenza, Weinstein, & Gorelick, 2010). Other authors have referred to IA as a subtype of impulse control disorder (Dell'Osso et al., 2008; Dong, Lu, Zhou, & Zhao, 2010; Shapira, Goldsmith, Keck, Khosla, & McElroy, 2000). Indeed, some studies revealed the correlation between low impulse control and other addictive behaviors, such as pathological gambling, substance and alcohol abuse, mainly in young population. More specifically, Barnes, Welte, Hoffman and Dintcheff (2005) found that lower impulse control is a significant predictor of alcohol misuse for females and delinquency for males. Vitaro, Arseneault and Tremblay (1999) used a prospective-longitudinal design to investigate whether measuring low impulse control in youngers could predict engagement in gambling in adolescence. Moeller et al. (2001) found that impulsivity is a significant predictor of cocaine use and treatment retention. Based on this evidence researchers believe that IA is an impulse disorder or at least related to impulse control disorder (Beard & Wolf, 2001; Young & Rogers, 1998) since other addiction categories may share similar neuropsychological and personality characteristics with IA (Choi et al., 2014). Cao, Su, Liu and Gao (2007) reported that adolescents with IA were more impulsive than controls as measured by both the Barratt Impulsiveness Scale-11 (BIS-11) and the Go-Stop impulsivity paradigm and response inhibition paradigm (Cao et al., 2007). In addition, the 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, Cowan, & Davis, 1984).

In line with this perspective, some researchers have provided electrophysiological evidence obtained from individuals with IA. For example, Dong et al. (2010) investigated response inhibition in subjects with IA by recording event-related potentials (ERPs) during a Go/NoGo task. The authors reported that the IA group exhibited lower NoGo-N200 amplitude and higher NoGo-P300 amplitude than did the normal group (Colrain et al., 2011; Dong et al. 2010). More generally, previous studies using time-frequency analysis related to the event-related potentials in response to target detection have found significant differences between different types of addictions and control subjects (Andrew & Fein, 2010; Jones et al., 2006).

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). Brain oscillations were previously used to test brain correlates of different types of addiction, although in a reduced number of cases focusing on an ample range of brain oscillations (Balconi & Finocchiaro, 2015; Balconi, Finocchiaro, & Canavesio, 2015; Balconi & Pozzoli, 2005; Finocchiaro & Balconi, 2015). Recent research has documented increased mid-frontal theta-band activity during demands of response inhibition (Barry, 2009; Kamarajan et al., 2004; Kamarajan et al., 2006; Kirmizi-Alsan et al., 2006; Yamanaka & Yamamoto, 2010), indicating that theta activity may reflect inhibitory processes. Moreover, in line with findings indicating that joint theta and delta activity underlies several ERP components (Başar, Başar-Eroğlu, Karakaş, & Schürmann, 1999), some studies report delta-band activity underlying the NoGo-N2 and P3 responses, with delta-NoGo activity having a more central topographic distribution compared to delta-Go data (Barry 2009; Kamarajan et al., 2004, 2006; Kirmizi-Aslan et al., 2006). It was also found that in some specific addiction behavior (i.e. alcohol dependence) patients showed a significant reduction in delta and theta power during NoGo trials as compared to controls. This reduction was prominent in the frontal region (Kamarajan et al., 2012). The decreased delta and theta power associated with NoGo processing perhaps suggests a deficient inhibitory control and information-processing mechanism. Moreover, the slow alpha rhythm (8-10 Hz) has been reported to be modulated as a function of attentional demands (Basar, Schürmann, Başar-Eroglu, & Karakaş, 1997; Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998; Klimesch, Doppelmayr, Pachinger, & Ripper, 1997a), and fast alpha activity (10–12 Hz) has been found to be a mediator of semantic memory processes as well as stimulus-related aspects (Klimesch, 1996; Klimesh et al., 1997a; Klimesch, Doppelmayr, Schimke, & Ripper, 1997b; Klimesch, Schimke, & Schwaiger, 1994), and response to rewarding stimuli (Balconi & Finocchiaro, 2016). Further, oscillatory gamma responses were shown to be involved in visual perception and cognitive integrative function (Basar, Başar-Eroglu, Karakaş, & Schürmann, 2001a; Başar, Schürmann, Başar-Eroglu, & Demiralp, 2001b; Basar-Eroglu, Strüber, Kruse, Başar, & Stadler, 1996a; Başar-Eroglu, Strüber, Schürmann, Stadler, & Başar 1996b; Schürmann, Basar-Eroglu, & Basar, 1997). Both higher frequency bands (i.e. beta and gamma) have been found to be associated with response inhibition.

Another factor that seems to be implicated in addiction was related to the rewarding effect and "reward bias" of potential rewarding cues, such as substance, but also videogames or gambling task condition in the case of IA. Indeed brain-imaging studies of addictive behaviors have identified a key involvement of the prefrontal cortex (PFC) through its regulation of the limbic reward regions as well as its involvement in a higher-order executive function (Chen et al., 2007; Knyazev, 2010). Thus, addictive behavior may be explained by more receptiveness to the reinforcing effect of rewarding stimuli. Indeed, high reward sensitivity was shown to contribute to drug abuse vulnerability (Balconi & Finocchiaro 2015; Baler & Volkow 2006; Bechara & Van Der Linden, 2005; Dawe & Loxton, 2004). Three underlying types of dysfunctions have been identified in the case of reward vulnerability: hyperactivity in the emotional system, mediated by frontal and medial structures, such as the orbitofrontal cortex (OFC), anterior cingulate cortex (ACC) and amygdala, which exaggerate the rewarding impact of external reinforcers; anomalous brain activity in the prefrontal cortex (and mainly the DLPFC), which predicts the long-term consequences of a given action (Balconi & Finocchiaro, 2015, 2016; Bechara & Martin, 2004). A third component seems also to be associated with specific dysfunctions in the dopaminergic mesolimbic reward system which can elicit conditioned attention allocation for dependence-associated stimuli rendering them especially salient (Adinoff, 2004). Indeed, deficient mesolimbic reward system and prefrontal cortex activation is reported in substance abusers and impulsive individuals (Limbrick-Oldfield, van Holst, & Clark, 2013; Scheres, Milham, Knutson, & Castellanos, 2007).

Therefore, reward motivation significantly and directly correlates with drug addiction Balconi, Finocchiaro, & Canavesio, 2014; Knyazev, 2010). At this regard, a strong relationship was also shown between impulsivity, drug-dependence and Behavioral Activation System (BAS) and Behavioral Inhibition System (BIS) (Dawe & Loxton, 2004). Indeed, BIS and BAS measures represent a usable construct to test subjective reward-sensitivity based on neurophysiological correlates (Balconi, Brambilla, & Falbo, 2009a, 2009b; Balconi, Falbo, & Brambilla, 2009c; Balconi, Falbo, & Conte, 2012; Balconi & Mazza, 2009a, 2009b, 2010; Carver & White, 1994; Fowles, 1980; Gray, 1981; Gray & McNaughton, 2003). Previous findings provide support for the role of Gray's BAS in mediating approach behavior and dependence as associated with the drive to consume rewarding substances or to be exposed to rewarding conditions (Balconi et al., 2015; Blum et al., 2000; Dawe & Loxton, 2004; Smillie, Loxton, & Avery, 2011). The cortical correlate of BIS/BAS system is the PFC, and, whereas the left PFC was shown to be more implicated in approach-related motivations and rewarding conditions, the right PFC was found to be more involved in withdrawal-related motivations and inhibitory mechanisms (Balconi & Mazza, 2009a, 2010; Davidson, 2004; Harmon-Jones, 2004). Both approach and withdrawal motivations are paralleled by the reward and punishment contingencies (Balconi & Pozzoli, 2005, 2008). Indeed, frontal EEG asymmetry has been hypothesized to relate to appetitive (approach-related) and aversive (withdrawal-related) motivation and emotion, with heightened approach tendencies reflected in left frontal activity and heightened withdrawal tendencies reflected in relative right frontal activity (Kamarajan et al., 2008).

However whether and how impulse control deficits are related to in rewarding mechanisms is actually unexplored and unexplained. The purpose of the present study was to examine the neural correlates of deficits in inhibitory control and impulsive behavior, from one hand, and the underlying rewarding mechanisms, from the other hand, in online decisional processes by using potentially addictive stimuli. Specific and predictive measures of potential AI (as measured by Internet Addiction Inventory, IAT, Young, 1998) were applied to characterize a sub-clinical sample of healthy subjects. Secondly, cortical oscillations (frequency bands) and personality trait (BIS/BAS) were considered as predictive components to explain a potential web addiction profile. In addition, anxiety measure (STAY-Y2) was considered. A subclinical sample of young subjects was selected and potential internet addiction behavior was explored by using behavioral measures (response times, RTs) during the performance of a Go/NoGo task in response to specific potentially rewarding cues (videos representing online gambling, videogames or control contexts such as sports games). Oscillatory brain activity in different frequency bands was monitored through an ample range of oscillations: delta, theta, alpha, beta and gamma.

As revealed by previous analysis on different forms of addiction, it was supposed that the inhibitory control deficits should be reported in the case of increased AI profile (higher AI questionnaire scores), mainly in response to NoGo trials (inhibitory control condition), with decreased low-frequency bands (mainly delta and theta) as marker of deficit in inhibitory system. Moreover, BAS and BIS trait was considered as predictor of rewarding bias related to the potential rewarding cues. Indeed, reward sensitivity as reported by BAS (and BAS-reward, BAS-R subscale) may be informative on the behavioral bias in responding to potential rewarding (and addictive) cues. In contrast, BIS profile may more directly suggest a higher control and the activation of the inhibitory functions, with a less “unbalanced” (less rewarding-related) behavior in response to Go/NoGo task. Finally, these two levels (respectively the inhibitory control and impulse regulation on one hand; the reward-sensitivity on the other hand) may be integrated each other, since addiction involves a combination of cognitive, motivational, and emotional states, which have been found to be mediated by brain oscillations, and mainly in the theta and delta bands. Therefore, a decreased low-frequency bands (reduced inhibitory control) should be paralleled by increased BAS values mainly in response to NoGo and more rewarding (gambling contexts) cues. In contrast, increased BIS values should be mirrored by an increased low-frequency bands, as an expression of a higher control (or over-control) activity and increased request for an inhibitory behavior when a NoGo performance is necessary. Finally, anxiety level should be directly related to these factors, with a concomitant higher anxiety level in the case of dysfunctional (less controlled and more reward-bias related) behavior.

2. Method

2.1 Subjects

Twenty-two volunteers took part in the study (age range 19-25, M = 24.16, Sd = 0.90, thirteen women and seventeen men). All subjects were undergraduate students at the Catholic University of Milan and were right-handed, with normal or corrected-to-normal visual acuity. Exclusion criteria were history of psychopathology (Beck Depression Inventory, BDI-II, Beck et al., 1996) for the subjects or immediate family members. No specific neurological or psychiatric pathologies were observed by clinical colloquium. They gave informed written consent for participating in the study, and the research was approved by the Ethical Committee of the institution where the work was carried out.

2.2 Procedure

The participants signed the informed written consent and then they sat on a comfortable chair in front of a Pc screen (1280/1024 pixel). The Pc was placed approximately 80 cm from the subject, with a visual horizontal angle of 4° and a vertical angle of 6°. They were instructed to the Go/No-Go task, prior to record EEG data. They were informed that the task consisted of four sessions and that at the beginning of each session would appear a black screen with instructions indicating which letter (M or W) represented the Go (press the button) and which the No-Go (do not press the button) condition. Also, they were allowed to rest until manually initiating the next block. In order to familiarize with the task, the participants completed a short session of 20 trials (70 % Go and 30% NoGo) on a black background. After the Go/No-Go task, the participants were submitted to a debriefing phase, with the post-evaluation questionnaires (IAT; BIS/BAS; STAI-Y; BDI-II).

2.3 Stimuli

In the experimental task the stimuli were two capital white letters (M and W; size of 500x400 mm) in Times New Roman font and background pictures (gambling-related, videogames-related and neutral contexts) (figure 1) displayed on a 15-inch monitor. During a pre-testing phase, 40 pictures were selected from the Internet, and balanced for dimension, brightness and net color with adobe Photoshop 8.0. After that, 30 voluntaries, matched with age and sex with the experimental group, evaluated these pictures for gambling- and videogames-related context, considering four dimensions: relevance, familiarity, valence and arousing power. Participants were asked to rate on a scale of five points: from zero "not at all" to five "extremely", the following questions for each picture: 1) How much the picture could be related to gambling/(or videogames)? 2) How much time do you spend in the activity represented by the picture? 3) Could you indicate the degree of pleasantness/unpleasantness of the picture? 4) Could you indicate the degree of emotional involvement that you feel because of the picture? Finally, 18 pictures were selected and categorised into four types: 6 pictures with low scores on gambling and video games relatedness and emotional levels were selected for neutral condition (e.g. various sport scenes not related to gambling or video-games); 6 pictures with high scores on relevance, valence (positive) and arousal (high) were selected for gambling-related condition (e.g. simulating interfaces gambling sites online) and 6 pictures for video games-related condition (e.g. the most famous and recent video games online).

2.4 Go/No-Go task

The Go/No-Go task which was a modified version of the experimental task used by Petit, Kornreich, Noël, Verbanck and Campanella (2012). The task was composed of four blocks of 120 stimuli per each, which were divided into 84 Go trials and 36 No-Go trials for each session. The blocks consisted of randomised presentation of background pictures from three different contexts: gambling (G), videogames (VG) and neutral (N) for 500 ms, then the letter M or W appeared in the center of this background picture for 200 ms, successively the initial background picture came back for 1300 ms (figure 1). Therefore, participant had a maximum of 1500 ms to press the button before the next letter appear. The letters were presented in a random order to ensure the same amount as a percentage of the trials Go (70%) and No-Go (30%) for each block and category. In order to familiarize with the task, before the first session, a black screen with instructions reported which letter (M or W) represented the Go (M, press the button) and which the No-Go (W, do not press the button). 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 No-Go stimulus. Moreover, they were asked to reduce moving and blinking during the task in order to diminish the interferences during the EEG registration. Each participant completed a total of 480 trials.

Figure 1. Go/No-Go task. Participants performed 4 blocks of 120 stimuli per each, divided in 84 Go trials and 36 No-Go trials. Each trial consisted of the presentation of a background picture (neutral, gambling and videogames) for 500 ms, then the letter M or W appeared in the center of this picture for 200 ms, successively the background screen remained for 1300 ms before to start another trial with a different background picture. (All the sessions were randomised using the software E-Prime)

2.5 BIS/BAS scores

BIS and BAS scores were calculated for each subject (Leone, Pierro, & Mannetti, 2002). The evaluation included 24 items (20 score-items and four fillers, each measured on four-point Likert scale), and two total scores for BIS (range = 7-28; 7 items) and BAS (range = 13-52; 13 items). BAS also includes three subscales (Reward, 5 items, Drive, 4 items, and Fun Seeking, 4 items). The questionnaire was submitted to the subject after completion of the experimental phase. Based on these measures, two total scores (BIS and BAS total) and three BAS subscale scores were calculated. The mean and standard deviation values for each scale were, respectively: for BIS: 16.32(1.12); BAS: 36.67(1.76); Reward: 14.08(1.56); Drive: 14.55(1.43); Fun Seeking: 15.21.01(1.70). Finally, Cronbach's alpha was calculated for BIS (0.85) and BAS (0.82) and separately for each BAS subscale (Reward 0.85; Drive 0.79, and Fun Seeking 0.81).

2.6 IAT scores

Internet Addiction Test (IAT) was designed by Young (1998), according to the diagnostic criteria of the DSM-IV for pathological gambling and it was adapted for the diagnosis of Internet Addiction. The questionnaire consists of 20 items measured with 5 steps Likert scale, ranging from "never" (0) to "always" (5). Once the subject has answered all the questions, the numbers of response were summed. The score is 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, which 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; score between 80 and 100 (severe): the use of the Internet is excessive and is causing considerable problems to the person. The Cronbach's alpha coefficient is from 0.75 to 0.92 (Laconi, Rodgers, & Chabrol, 2014; Young, 1998). *S*ubjects self-administrated the questionnaire after completion of the experimental task. The mean and standard deviation value for the group was: M = 37.75 (11.03).

2.7 STAI-Y scores

The State and Trait Anxiety Inventory (STAI, Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) was used to assessed anxiety: the "Y" form is the most popular version, and it is composed by two axes: Y1 for state anxiety and Y2 for trait anxiety, both consisting of 20 multiple-choice items; all items are measured with a four steps Likert scale (from "almost never" to "almost always"). The total STAI score is between 20 and 80 with a threshold value of 40 predictive of anxiety symptoms. According to a scalar criterion, it is also possible to define the severity level of anxious: 40 to 50 mild, 50 to 60 moderate, up to 60 severe. The coefficient of consistency of the scale varies from 0.86 to 0.95 (Spielberger et al., 1983). Subjects self-administered the questionnaire after the experimental task, for the final analyses it was considered the scores of trait anxiety (STAI-Y2) (M = 46.45; Sd = 2.10).

2.8 EEG recordings and data reduction

During task execution, EEG recordings were performed with a 64-channel DC amplifier (SYNAMPS system) and acquisition software (NEUROSCAN 4.2). An ElectroCap 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 to 50 Hz. An off-line common average reference was successively computed to limit the problems associated with the signal-to-noise ratio (Ludwig, Miriani, Langhals, Joseph, & David, 2008; Pascual-Marqui, 2002). Additionally, two 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 below 5 kΩ. After performing EOG correction and visual inspection, only artifact-free trials were considered (rejected epochs, 3%). The signal was visually scored, and portion of the data that contained artifacts were removed to increase 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 (Balconi & Caldiroli, 2011; Pascual-Marqui, Michel, & Lehmann, 1994; Semlitsch, Anderer, Schuster, & Presslich, 1986). The digital EEG data (from all 64 active channels) were bandpass filtered in the following frequency bands: delta (0.5-4), theta (4-8), alpha (8-12 Hz), beta (14-20), and gamma (20-40) (band-pass filtering 96 dB/octave rolloff, 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 msec. A fast Fourier transform method (Hamming window: length 10%) was used to obtain estimates of spectral power (μV^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 into power density values for the different frequency band. All power density values were log transformed to normalize the distribution of the data after the subtraction.

2.9 LORETA

To localize the source of neural activity, we used the low-resolution electromagnetic tomography (sLORETA) method (Crean, de Wit, & Richards, 2000; Pascual-Marqui et al., 1994; Pascual-Marqui, 2002; Proverbio, Riva, & Zani, 2010) It solves the inverse problem based on the assumption that the smoothest possible activity distribution is the most plausible one. Specifically, an improved version of standardized weighted sLORETA was applied (swLORETA) (Palmero-Soler et al., 2007). This method computes the current density (A/m^2) according to the digitized probability atlas as the linear, weighted sum of the scalp electric potentials, and it assumes neither a limited number of dipolar point sources nor distribution on a known surface. Topographical voltage maps of bands were made by plotting color-coded isopotentials obtained by interpolating voltage values between scalp electrodes at a specific time interval (0-500 msec.). The source space used 5-point grid spacing (the distance between two calculation points), and the estimated signal to noise ratio (SNR, which defines the regularization) was 3. In the present research, we calculated source localization for every subject and condition. Voxel-wise nonparametric statistics were used. Direct comparisons were successively conducted between the Go/NoGo condition.

3. Results

3.1 Data analysis

The statistical analyses were subdivided into four steps: a first set of correlational analysis finalized to explore the relationship between to BIS/BAS, IAT and STAI measures. A second set of ANOVAs, applied respectively to the dependent measures of RTs and frequency band oscillations, in response to Go/NoGo task and different stimulus condition. A third set of analysis finalized to explore the cortical localization of the frequency bands (sLORETA). Finally, a set of stepwise multiple regressions was applied to BIS/BAS and IAT measures as predictors of RTs and cortical oscillations modulations.

3.2 Correlational analyses

Pearson's correlation analysis (across-subject correlations) was applied reciprocally to BIS/BAS, IAT and STAI measures. There was a significant positive correlation between BIS and IAT (r = .491; p < .01) and BAS and IAT (r = .513; p < .01). In addition, BAS-Reward subscale was highly correlated with IAT (r = .581; p < .001). Moreover, BAS was related with STAI (r = .514; p < .01). Finally, IAT was positively related with STAI (r = .487; p < .01). No other Pearson value was statistically significant.

3.3 ANOVAs

3.3.1 RTs

The behavioural measures of RTs were subjected to a two-way repeated measures ANOVA, in which the within-subjects factors Go/NoGo (2) and stimulus (3) were applied to the RTs. Errors associated with inhomogeneity of variance were controlled by decreasing the degrees of freedom using the Greenhouse-Geiser epsilon. A significant main effect was found for Go/NoGo ($F(1,21) = 13.19$, $P = 0.001$, $\eta^2 = .42$), stimuli ($F(2,21) = 11.87$, $P = 0.001$, $\eta^2 = .40$), and Go/NoGo x stimuli ($F(2,40) = 14.30$, $P = 0.001$, $\eta^2 = .44$) (Fig 2). About the main effects, Go condition revealed reduced RTs compared with NoGo. Moreover, as revealed by post-hoc analysis (contrast analysis for ANOVA, with Bonferroni corrections for multiple comparisons), reduced RTs were found for gambling more than videogames ($F(2,21) = 11.87$, $P = 0.001$, $\eta^2 = .40$) and neutral stimuli ($F(2,21) = 11.87$, $P = 0.001$, $\eta^2 = .40$). In addition videogames differed from neutral stimuli ($F(2,21) = 11.87$, $P = 0.001$, $\eta^2 = .40$), with reduced RTs for the former. About the significant interaction effects, simple effects revealed reduced RTs for videogames ($F(1,21) = 9.43$, $P = 0.001$, $\eta^2 = .36$) and gambling stimuli ($F(1,21) = 11.11$, $P = 0.001$, $\eta^2 = .38$) in Go more than NoGo condition. In addition, gambling stimuli condition showed decreased RTs more than videogames and neutral stimuli in Go (respectively ($F(1,21) = 7.16$, $P = 0.001$, $\eta^2 = .35$), ($F(1,21) = 9.06$, $P = 0.001$, $\eta^2 = .36$), ($F(2,21) = 8.45$, $P = 0.001$, $\eta^2 = .37$); and in NoGo ($F(1,21) = 10.43$, $P = 0.001$, $\eta^2 = .40$); ($F(1,21) = 8.92$, $P = 0.001$, $\eta^2 = .37$). No other effect was statistically significant.

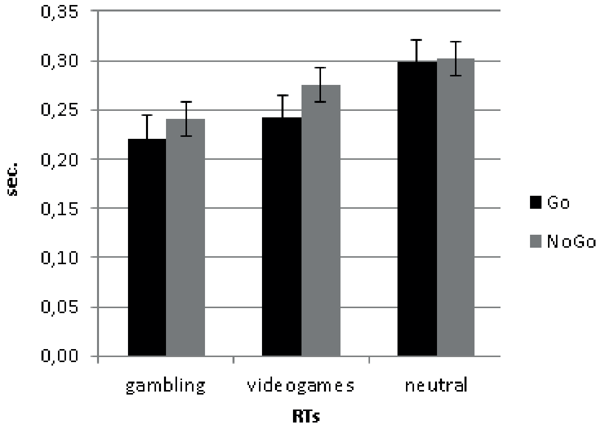

Figure 2. RTs mean values as a function of stimulus type and Go/NoGo task

3.3.2 Frequency band analysis (delta, theta, alpha, beta, gamma)

Each frequency band was subjected to a four-way ANOVA, in which the within-subjects Go/NoGo (2), stimuli (3), localization (4), and lateralization (2) were applied to the dependent variable of band power (Table 1). Localization (four sites: frontal, central, temporo-parietal, and occipital) and lateralization (three sides: left, central, and right) factors were considered in applying statistical analysis. Specifically, we measured left, central and right frontal (F3, Fz, F4), middle-central (Cz, C3, C4), temporo-parietal (P3/T7, Pz, P4/T8; the left and right localizations were obtained as the mean value of parietal and temporal sites) and occipital (Oz, O1, O2) brain activity.

For delta, significant condition ($F(1,21) = 8.16$, $P = 0.001$, $\eta^2 = .37$) and stimuli ($F(1,21) = 8.90$, $P = 0.001$, $\eta^2 = .37$) main effects were found (Figure 3a). Indeed, delta power was higher for NoGo than Go condition. Moreover, condition x stimuli ($F(1,21) = 9.13$, $P = 0.001$, $\eta^2 = .39$) and lateralization x localization ($F(1,21) = 8.11$, $P = 0.001$, $\eta^2 = .35$) interaction effects were significant. Specifically, as shown by post-hoc comparisons, delta increased in response to NoGo condition for gambling stimuli ($F(1,21) = 7.09$, $P = 0.001$, $\eta^2 = .34$) and videogames ($F(1,21) = 8.32$, $P = 0.001$, $\eta^2 = .37$) than neutral stimuli. For the second interaction effect, delta was more frontally and right distributed than the other cortical sites (for all paired comparisons $P \leq 0.001$).

For theta, significant condition ($F(1,21) = 8.92$, $P = 0.001$, $\eta^2 = .37$) and localization ($F(1,21) = 7.87$, $P = 0.001$, $\eta^2 = .35$) main effects were observed. As shown (Figure. 3b) theta power was higher for NoGo than Go condition and it was more frontally distributed. Moreover, condition x stimuli ($F(1,21) = 10.73$, $P = 0.001$, $\eta^2 = .42$) interaction effect was significant. Specifically, as shown by post-hoc comparisons, theta increased in response to NoGo condition for gambler stimuli ($F(1,21) = 8.31$, $P = 0.001$, $\eta^2 = .37$) and videogames ($F(1,21) = 6.09$, $P = 0.001$, $\eta^2 = .373$) than neutral stimuli. For alpha, a significant condition effect was found ($F(1,21) = 8.56$, $P = 0.001$, $\eta^2 = .36$). Indeed, there was a significantly decreased alpha in response to NoGo compared with Go condition. For beta and gamma no significant effects were found.

3.4 sLORETA analysis

For delta and theta, the algorithm localised the cortical source generators respectively in the right DLPFC for delta and in the DLPFC for theta when NoGo was compared with Go condition ($t = 6.44$, $p \leq 0.01$; BA9 $x = 5$, $y = 43$, $z = 14$; $t = 6.93$, $p \leq 0.01$; BA9 $x = 2$, $y = 44$, $z = 17$).

For alpha, a significant differential activation comparing Go/NoGo was found more in the DLPFC ($t = 5.60$, $p \leq 0.01$; BA10 $x = 1$, $y = 52$, $z = 6$). In contrast, no significant differences were found for beta ($t = 1.22$, $p = 0.15$) and gamma ($t = 1.09$, $p = 0.22$).

Table 1. Mean power of frequency bands (only significant interaction effect, in bold significant values) as a function of condition, stimuli, localisation and lateralization

	frontal						central					
	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)
delta	left		central		right		left		central		right	
Go												
gambling	2.33[a]	0.45	2.40	0.23	2.65	0.37	2.50	0.22	2.52	0.12	2.59	0.11
videogames	2.45	0.34	2.77	0.18	2.65	0.22	2.78	0.17	2.41	0.15	2.49	0.20
neutral	2.12	0.31	2.22	0.26	2.08	0.26	1.67	0.25	2.07	0.20	2.10	0.28
NoGo												
gambling	2.70	0.16	2.88	0.32	3.44	0.27	2.44	0.43	2.16	0.15	2.30	0.34
videogames	2.77	0.29	2.96	2.38	3.14	0.15	2.44	0.15	2.29	0.21	2.38	0.18
neutral	2.20	0.32	2.30	0.44	2.33	0.12	2.39	0.20	2.31	0.18	2.30	0.26
theta												
Go												
gambling	2.16	0.19	2.09	0.29	2.10	0.34	2.06	0.15	2.12	0.23	1.88	0.17
videogames	2.20	0.29	2.08	0.34	1.98	0.12	1.77	0.17	2.09	0.25	1.90	0.16
neutral	2.09	0.30	1.90	0.30	1.95	0.24	1.80	0.32	2.01	0.31	1.98	0.20
NoGo												
gambling	3.02	0.20	2.98	0.38	2.90	0.44	2.21	0.23	2.10	0.36	1.32	0.22
videogames	3.11	0.23	3.02	0.33	2.86	0.41	2.45	0.28	2.40	0.38	1.99	0.18
neutral	2.90	0.43	2.89	0.30	2.77	0.38	2.50	0.35	3.09	0.40	3.01	0.18
alpha												
Go												
gambling	2.44	0.34	2.38	0.29	2.39	0.33	2.22	0.29	2.50	0.22	2.41	0.49
videogames	2.12	0.20	2.33	0.22	2.20	0.30	2.16	0.23	2.31	0.20	2.27	0.40
neutral	2.02	0.19	2.10	0.22	2.19	0.28	2.07	0.29	1.97	0.30	1.90	0.34
NoGo												
gambling	2.02	0.20	1.90	0.15	1.88	0.19	1.80	0.23	1.56	0.27	1.50	0.15
videogames	2.10	0.29	1.89	0.33	1.80	0.17	1.76	0.31	1.55	0.43	1.44	0.32
neutral	1.98	0.22	1.77	0.29	1.78	0.29	1.70	0.15	1.50	0.44	1.41	0.20

	temporo-parietal						occipital					
	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)
delta	left		central		right		left		central		right	
Go												
gambling	2.50	0.13	2.40	0.21	2.33	0.11	2.42	0.15	2.55	0.22	2.39	0.20
videogames	2.52	0.20	2.44	0.17	2.46	0.14	2.51	0.12	2.51	0.20	2.36	0.24
neutral	1.90	0.32	1.95	0.33	2.04	0.29	2.11	0.17	1.90	0.29	1.98	0.39
NoGo												
gambling	2.31	0.21	2.15	0.32	2.22	0.15	2.30	0.21	2.17	0.20	2.22	0.21
videogames	2.39	0.17	2.40	0.20	2.50	0.23	2.40	0.18	2.38	0.16	2.37	0.27
neutral	2.42	0.18	2.30	0.16	2.42	0.19	2.48	0.24	2.31	0.17	2.15	0.17
theta												
Go												
gambling	2.13	0.34	1.16	0.15	1.19	0.23	2.02	0.23	2.18	0.20	2.01	0.12
videogames	1.87	0.44	1.77	0.27	1.55	0.15	1.60	0.10	2.09	0.34	1.90	0.15
neutral	1.80	0.29	1.84	0.22	1.84	0.12	1.12	0.29	1.86	0.15	1.95	0.25
NoGo												
gambling	1.77	0.45	1.32	0.56	1.87	0.32	1.56	0.33	1.90	0.55	1.98	0.21
videogames	1.88	0.34	1.63	0.55	1.78	0.30	1.86	0.23	1.60	0.29	1.98	0.16
neutral	2.65	0.33	2.62	0.50	2.70	0.29	2.50	0.22	2.53	0.20	2.41	0.18
alpha												
Go												
gambling	2.38	0.17	2.09	0.22	1.90	0.27	1.88	0.33	1.77	0.39	1.54	0.29
videogames	2.30	0.16	2.29	0.28	1.78	0.30	1.99	0.22	1.90	0.30	2.08	0.22
neutral	1.98	0.25	2.05	0.25	2.10	0.28	2.12	0.39	2.18	0.20	2.07	0.19
NoGo												
gambling	1.45	0.20	1.40	0.16	1.44	0.44	1.34	0.15	1.22	0.28	1.34	0.22
videogames	1.42	0.30	1.20	0.20	1.30	0.13	1.32	0.32	1.28	0.39	1.30	0.34
neutral	1.32	0.37	1.34	0.34	1.27	0.21	1.20	0.29	1.09	0.27	1.22	0.39

[a]= μVolt

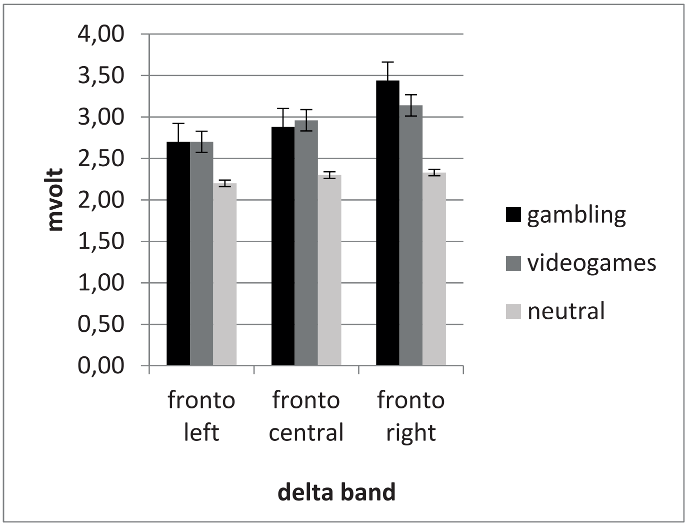

Figure 3a. Delta power modulation as a function of stimulus type and Go/NoGo task

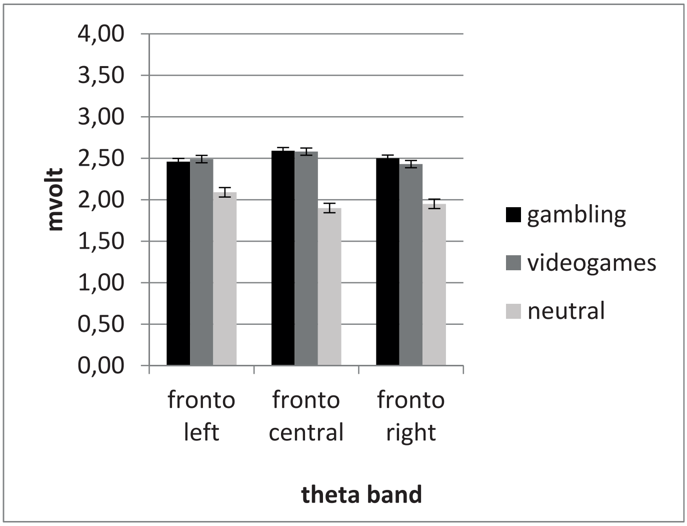

Figure 3b. Theta power modulation as a function of stimulus type and Go/NoGo task

3.5 Regression analysis

Distinct multiple regression analyses were performed for each band and condition. Since sLORETA showed significant effect between conditions within the prefrontal cortex, regression analyses were performed on this cortical area. Predictor variables were BAS/BAS-R subscales, BIS, and IAT and predicted variables were frequency band in Go or NoGo condition from one hand; RTs variations on the other hand. Table 2 reports the correlations between predictors and predicted variable (R), the explained variance (R^2), and the regression weights (β) for the regression equation.

About frequency bands, as shown in table 2, BAS and BAS-Reward measure accounted for delta power in NoGo, with reduced delta values for gambling and videogames stimuli. Similarly, increased IAT values explained delta decreasing in response to these stimuli categories. On the contrary, BIS significantly accounted for the variance of delta, with a significant increased BIS which explained the concomitant delta increasing in response to videogames and gambling stimuli. No other effect was statistically significant.
Similarly about theta, BAS and BAS-Reward measures accounted for theta power in NoGo, with reduced values for gambling and videogames stimuli. Also increased IAT values explained delta decreasing in response to these stimuli categories. BIS significantly accounted for the variance of theta, since increased BIS values explained delta increasing in response to videogames and gambling stimuli. No other effect was statistically significant.

About RTs, BAS, BAS-R and IAT increased values predicted a significant RTs reduction in NoGo condition in response to gambling and videogames stimuli. No other effect was statistically significant.

*Table 2. Regressions analysis: BIS/BAS and IAT as predictor variables and frequency bands/RTs variations as predicted variable, for each stimulus category. Only significant values were reported (for NoGo condition in frontal areas) * p: .05 ** p:.01*

	delta				*theta*				*RTs*			
	BAS	*BAS-R*	*BIS*	*IAT*	*BAS*	*BAS-R*	*BIS*	*IAT*	*BAS*	*BAS-R*	*BIS*	*IAT*
gambling												
R^2	.32	.64	.80	.98	.29	.49	.76	.93	.27	.44	.49	.75
β	.33	.37	.30	.35	.22	.29	.30	.17	.12	.22	.17	.37
std error	.19	.18	.27	.28	.33	.30	.27	.29	.18	.30	.18	.19
t	2.90**	2.92**	1.70*	1.76*	3.30**	2.77**	3.05*	2.55**	2.88**	1.58*	1.07	2.91**
videogames												
R^2	.37	.62	.81	.98	.33	.68	.81	.97	.25	.46	.50	.73
β	.40	.33	.17	.30	.28	.20	.38	.37	.21	.25	.22	.26
std error	.28	.18	.22	.25	.24	.30	.32	.30	.31	.32	.21	.22
t	3.22*	2.96*	1.89	1.80	2.99*	3.48*	1.71	2.60*	2.55*	2.10*	.96	2.51*
neutral												
R^2	.09	.18	.26	.31	.10	.19	.30	.38	.08	.12	.18	.23
β	.41	.37	.22	.26	.24	.24	.32	.29	.28	.20	.28	.20
std error	.28	.25	.28	.25	.30	.31	.37	.33	.35	.35	.21	.30
t	.88	.81	.93	.78	.90	.94	.78	.64	.70	.54	.40	.31

4. Discussion

The present research aimed to explore the contribution of inhibitory mechanisms deficits and rewarding bias in IA. IAT, brain oscillations and BIS/BAS were used as integrated measures to test brain activity and behavioral response toward online stimuli (gambling; videogames; neutral cues) when a Go/NoGo task was submitted. Three main effects were elucidated and discussed. Firstly, one of the main effects was found due to the increasing of low-frequency bands (delta and theta) in relationship to the inhibitory system response (NoGo condition), when a more controlled behavior was required. This effect was more directly related to some stimuli categories, such as gambling and videogames.

Secondly, the contribution of BAS/BIS and IAT measures was demonstrated in online task. Indeed, as reported by regression analysis, they affected the subjects' performance on both brain oscillations and RTs levels. In fact BAS and BIS predicted the low-frequency band variations, although in an opposite direction: reduced delta and theta values were found for higher BAS and BAS-R in the case of inhibitory control condition (NoGo) mainly for gambling and videogames stimuli; in contrast increased delta and theta values were observed for higher BIS in response to NoGo condition and gambling/videogames stimuli. Also, RTs was modulated by BAS with decreased RTs for NoGo and gambling/videogames stimuli. Thirdly, IAT was shown to be a significant co-factor in explaining the brain oscillations variations, in concomitance with BIS/BAS.

A first main effect was observed with regard to frequency band modulation, specifically for the low-frequency bands delta and theta. Indeed subjects revealed an increased low-frequency response in concomitance to inhibitory process, when NoGo task was performed. An increased brain activity was signaled also by the general decreased alpha in response to NoGo condition. As shown in previous research (Harper, Malone, & Bernat,. 2014) NoGo condition is generally associated with increased delta band activity, relative to Go stimuli (Harper et al., 2014). Thus, 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; Cohen, Elger, & Ranganath, 2007; Gehring & Willoughby, 2004; Trujillo & Allen, 2007; Yordanova, Falkenstein, Hohnsbein, & Kolev, 2004). Specifically, previous work has detailed delta band activity associated with some cognitive functions, including reward processing (Bernat et al., 2011; Nelson, Patrick, Collins, Lang, & Bernat, 2011), target detection (Gilmore, Malone, Bernat, & Iacono, 2010; Schürmann, Başar-Eroglu, Kolev, & Başar, 1995), commission of motor errors (Cavanagh et al., 2012; Yordanova et al., 2004), and reward magnitude (Bernat, Nelson, & Baskin-Sommers, 2015). In contrast to the delta effects exhibited in a gambling-feedback task, where theta and delta were sensitive to different stimuli (theta-loss and delta-gain; Bernat et al., 2011), in other cases delta activation was sensitive to the same experimental effect as theta (i.e., greater for NoGo stimuli). The cortical generators of this effect were more frontally and centrally localized and this brain activity may dually reflect motor/cognitive inhibition and stimulus context updating (Smith, Johnstone, & Barry, 2008).However, a new and interesting result of the present research was that, for the first time, this increased brain activity for low-frequency bands was mainly found in response to specific categories, such as gambling and videogames stimuli. Similarly, the performance (RTs) was affected by both task condition and stimuli: indeed, whereas in general a reduction of RTs was revealed in response to Go than NoGo condition, videogames and even more gambling stimuli registered the lowest RTs values. In this case a sort of facilitation effect, with an increased performance for more salient stimuli, may be suggested. In addition, an interesting and specific result was present in response to gambling stimuli, which showed the best performance (lower RTs) compared to the other categories. Therefore, whereas the inhibitory mechanisms may have required more cognitive resources to control the explicit behavior (with increased delta/theta for NoGo condition), the subjective performance may present a systematic temporal gain mainly for the most salient category (gambling) with a probable more “immediate” and “impulsive” response.

However, at this regard a relevant effect should be attributed to the motivational components (BIS/BAS) and the internet addiction profile (IAT), as shown by the regression analysis. A first general effect was related to decreased theta and delta in relationship with increased BAS, BAS-R and IAT measures. In contrast with the general tendency observed for the whole sample, the finding of the present research indicated that delta/theta activity was partially suppressed in higher BAS, BAS-R and IAT at more anterior regions during NoGo trials. As revealed in previous research, the reduced responses in delta, as well as theta, are likely to show some deficits in cognitive functions that are mediated by these oscillatory processes. Specifically, this fact may suggest that these subjects may present anomalies for some cognitive functions in governing inhibitory mechanisms, as well as dysfunctional frontal neural substrates that mediate these functions. A body of neuropsychological evidence supports this view, by showing a wide range of cognitive limitations including attention, working memory, encoding and retrieval processes and other deficits of executive functions, included the controlled and planned behavior related to delta and theta variations (Kamarjan et al., 2004).

In terms of the significance of delta and theta reduction, also impulsivity was previously reported as an explicative factor. 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. However a second potential explanation of the present results is related to the significance of the stimuli category (gambling and videogames), that is the proper rewarding effect of such stimuli. Indeed a significant finding of the present study is that higher BAS showed a significant reduction in theta activity, and secondly in delta activity when these potential rewarding cues were presented (Kamarajan et al., 2012). Brain oscillations of different frequency bands have been shown to have specific functional significance (Balconi et al., 2009, 2015; Balconi, Finocchiaro, & Canavesio, 2014; Başar et al., 1999). Reward processing as unfolded during a Go/NoGo task involves a combination of behavioral, cognitive, motivational, and emotional states, which have been found to be mediated by brain oscillations in the theta and delta bands (Kamarajan et al., 2008). In addition, prior findings, from both neuroimaging and electrophysiological studies, have reported dysfunctional neural reward systems in different forms of addictions (such as alcohol abuse and dependence). Many fMRI studies have identified the areas involved in reward processing in healthy subjects (Delgado, Locke, Stenger, & Fiez, 2003; Delgado, Miller, Inati, & Phelps, 2005; Knutson, Fong, Bennett, Adams, & Hommer, 2003; Marco-Pallares, Müller, & Münte, 2007; McClure York, & Montague, 2004), and a few imaging studies have documented the impairments in the key brain areas of reward circuitry in alcoholics (de Greck et al., 2009; Makris et al., 2008; Wrase et al., 2007). Overall, these topographic differences in addiction during reward processing may indicate a possible dysfunction in the neural reward circuitry. (Diekhof, Falkai, & Gruber, 2008), have outlined the neural mechanisms underlying reward processing and decision-making processes in the healthy brain as well as pathophysiological alterations in the neural reward system observed in addictive and mood disorders. Integrating both dimensions as possible mechanism for addiction and drug-seeking behavior, Schoenbaum, Roesch and Stalnaker (2006) reasoned 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).

Therefore, in the light of earlier reports on reward processing in healthy subjects as well as in addition, decreased theta and delta power in some subjects higher in BAS and mainly BAS-R may suggest a dysfunctional reward circuitry, which might serve as a hallmark feature of future addictive behavior.

Furthermore, because the cortical generators of theta and delta in response to NoGo condition were reported to be in the frontal areas (mainly the DLPFC) decreased theta and delta response can be attributed to an impairment in frontal lobe functioning.

Therefore, based on the present research, we hypothesize that the some inhibitory deficits and reward mechanisms observed in some subjects (higher IAT and BAS) may be due to the implication (and some anomalous activity) of frontal network system: since response inhibition is a function of frontal lobes (Fuster, 1989), the deficient low-frequency oscillatory activity during NoGo condition would imply a frontal lobe dysfunction in terms of processing of rewarding stimuli. Several studies have reported the frontal origin of event-related theta oscillations during cognitive paradigms, and some researches with gambling paradigm found frontal activations (in cingulate cortex) during reward processing (Kamarajan et al., 2008, 2009) in healthy individuals and identified reduced frontal activations in alcoholic individuals (Kamarajan et al., 2010). Additionally, reduced frontal activity was found in subjects with high impulsivity and alcoholism (Chen et al., 2007; Dom, De Wilde, Hulstijn, & Sabbe, 2007) and it was found that impulsivity was associated with theta power (Kamarajan et al., 2008).In contrast, higher BIS showed a different behavior compared with higher BAS. Indeed they revealed an increased prefrontal responsiveness (more delta and theta values) (Hester, Murphy, & Garavan, 2004). This increased prefrontal activity in response to NoGo condition and mainly to more rewarding cues (gambling and videogames) may be related to the necessity to control the impulsive response. That is, to allow functional inhibitory mechanisms and a successful control of their behavior, they adopted a hyper-control strategy with a consistent and significant frontal activity increasing.

Also IAT measure was a significant component in explaining the brain oscillation and behavioral modulation. Indeed it was able to support both the delta/theta and RTs decreasing in inhibitory condition (NoGo) when rewarding cues were presented. It is also interesting to note that both high BAS and BIS subjects showed a significant relationship (correlational analysis) with IAT measure (Balconi, Falbo & Conte, 2012). This trend may suggest different cortical mechanisms underlying the decisional processes in potential dysfunctional behaviors (web addiction). Whereas both under-control and over-control strategies may be predictive of future addictions (for their correlations with IAT), only under-controlled behavior produces a clear inability to regulate the prefrontal activity in terms of balanced delta/theta response. In addition, as shown by anxiety measures, higher BAS values are more directly related to an increased anxiety state (STAI) which may be predictive of a general anxiety disturb (Balconi, Brambilla, & Falbo, 2009a, 2009b; Balconi et al., 2012).

References

Adinoff, B. (2004). Neurobiologic processes in drug reward and addiction. *Harvard Review of Psychiatry, 12*(6), 305-320.

Andrew, C., & Fein, G. (2010). Event-Related Oscillations Versus Event-Related Potentials in a P300 Task as Biomarkers for Alcoholism. *Alcoholism: Clinical and Experimental Research, 34*(4), 669-680.

Balconi, M., Brambilla, E., & Falbo, L. (2009a). Appetitive vs. defensive responses to emotional cues. Autonomic measures and brain oscillation modulation. *Brain Research, 1296*, 72-84.

Balconi, M., Brambilla, E., & Falbo, L. (2009b). BIS/BAS, cortical oscillations and coherence in response to emotional cues. *Brain Research Bulletin, 80*(3), 151-157.

Balconi, M., Caldiroli, C.. (2011). Semantic violation effect on object-related action comprehension. N400-like event-related potentials for unusual and incorrect use. *Neuroscience, 197*, 191-199.

Balconi, M., Falbo, L., & Brambilla, E. (2009c). BIS/BAS responses to emotional cues: Self report, autonomic measure and alpha band modulation. *Personality and Individual Differences, 47*(8), 858-863.

Balconi, M., Falbo, L., & Conte, V. A. (2012). BIS and BAS correlates with psychophysiological and cortical response systems during aversive and appetitive emotional stimuli processing. *Motivation and Emotion, 36*(2), 218-231.

Balconi, M., & Finocchiaro, R. (2016). Deficit in rewarding mechanisms and prefrontal left/right cortical effect in vulnerability for internet addiction. *Acta Neuropsychiatrica, 28*(5), 272-285.

Balconi, M., & Finocchiaro, R. (2015). Decisional impairments in cocaine addiction, reward bias, and cortical oscillation "unbalance". *Neuropsychiatric Disease and Treatment, 11*, 777.

Balconi, M., Finocchiaro, R., & Canavesio, Y. (2014). Reward-system effect (BAS rating), left hemispheric "unbalance"(alpha band oscillations) and decisional impairments in drug addiction. *Addictive Behaviors, 39*(6), 1026-1032.

Balconi, M., Finocchiaro, R., & Canavesio, Y. (2015). Left hemispheric imbalance and reward mechanisms affect gambling behavior: the contribution of the metacognition and cortical brain oscillations. *Clinical EEG and Neuroscience, 46*(3), 197-207.

Balconi, M., & Mazza, G. (2009a). Brain oscillations and BIS/BAS (behavioral inhibition/activation system) effects on processing masked emotional cues.: ERS/ERD and coherence measures of alpha band. *International Journal of Psychophysiology, 74*(2), 158-165.

Balconi, M., & Mazza, G. (2009b). Consciousness and emotion: ERP modulation and attentive vs. pre-attentive elaboration of emotional facial expressions by backward masking. *Motivation and Emotion, 33*(2), 113-124.

Balconi, M., & Mazza, G. (2010). Lateralisation effect in comprehension of emotional facial expression: a comparison between EEG alpha band power and behavioural inhibition (BIS) and activation (BAS) systems. *Laterality: Asymmetries of Body, Brain and Cognition, 15*(3), 361-384.

Balconi, M., & Pozzoli, U. (2005). Morphed facial expressions elicited a N400 ERP effect: A domain-specific semantic module? *Scandinavian Journal of Psychology, 46*(6), 467-474.

Balconi, M., & Pozzoli, U. (2008). Event-related oscillations (ERO) and event-related potentials (ERP) in emotional face recognition: A regression analysis. *International Journal of Neuroscience, 118*(10), 1412-1424.

Baler, R. D., & Volkow, N. D. (2006). Drug addiction: the neurobiology of disrupted self-control. *Trends in Molecular Medicine, 12*(12), 559-566.

Barnes, G. M., Welte, J. W., Hoffman, J. H., & Dintcheff, B. A. (2005). Shared predictors of youthful gambling, substance use, and delinquency. *Psychology of Addictive Behaviors, 19*(2), 165.

Barry, R. J. (2009). Evoked activity and EEG phase resetting in the genesis of auditory Go/NoGo ERPs. *Biological Psychology, 80*(3), 292-299.

Başar, E., Başar-Eroğlu, C., Karakaş, S., & Schürmann, M. (1999). Are cognitive processes manifested in event-related gamma, alpha, theta and delta oscillations in the EEG? *Neuroscience Letters, 259*(3),165-168.

Başar, E., Başar-Eroglu, C., Karakaş, S., & Schürmann, M. (2001a). Gamma, alpha, delta, and theta oscillations govern cognitive processes. *International Journal of Psychophysiology, 39*(2), 241-248.

Başar, E., Schürmann, M., Başar-Eroglu, C., & Demiralp, T. (2001b). Selectively distributed gamma band system of the brain. *International Journal of Psychophysiology, 39*(2), 129-135.

Başar, E., Schürmann, M., Başar-Eroglu, C., & Karakaş, S. (1997). Alpha oscillations in brain functioning: an integrative theory. *International Journal of Psychophysiology, 26*(1), 5-29.

Başar-Eroglu, C., Strüber, D., Kruse, P., Başar, E., & Stadler, M. (1996a). Frontal gamma-band enhancement during multistable visual perception. *International Journal of Psychophysiology, 24*(1), 113-125.

Başar-Eroglu, C., Strüber, D., Schürmann, M., Stadler, M., & Başar, E. (1996b). Gamma-band responses in the brain: a short review of psychophysiological correlates and functional significance. *International Journal of Psychophysiology, 24*(1), 101-112.

Beard, K. W., & Wolf, E. M. (2001). Modification in the proposed diagnostic criteria for Internet addiction. *CyberPsychology & Behavior, 4*(3), 377-383.

Bechara, A., & Martin, E. M. (2004). Impaired decision making related to working memory deficits in individuals with substance addictions. *Neuropsychology, 18*(1), 152.

Bechara, A., & Van Der Linden, M. (2005). Decision-making and impulse control after frontal lobe injuries. *Current Opinion in Neurology, 18*(6), 734-739.

Beck, A. T., Steer, R. A., Brown, G.K. (1996). Manual for the Beck Depression Inventory-II. San Antonio, TX: Psychological Corporation.

Bernat, E. M., Nelson, L. D., Steele, V. R., Gehring, W. J., & Patrick, C. J. (2011). Externalizing psychopathology and gain-loss feedback in a simulated gambling task: Dissociable components of brain response revealed by time-frequency analysis. *Journal of Abnormal Psychology, 120*(2), 352.

Bernat, E. M., Nelson, L. D., & Baskin-Sommers, A. R. (2015). Time-frequency theta and delta measures index separable components of feedback processing in a gambling task. *Psychophysiology, 52*(5), 626-637.

Blum, K., Braverman, E. R., Holder, J. M., Lubar, J. F., Monastra, V. J., Miller, D., ... & Comings, D. E. (2000). The reward deficiency syndrome: a biogenetic model for the diagnosis and treatment of impulsive, addictive and compulsive behaviors. *Journal of Psychoactive Drugs, 32*(sup1), 1-112.

Camara, E., Rodriguez-Fornells, A., & Münte, T. F. (2009). Functional connectivity of reward processing in the brain. *Frontiers in Human Neuroscience, 2*, 19.

Cao, F., Su, L., Liu, T., & Gao, X. (2007). The relationship between impulsivity and Internet addiction in a sample of Chinese adolescents. *European Psychiatry, 22*(7), 466-471.

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology, 67*(2), 319.

Cavanagh, J. F., Zambrano-Vazquez, L., & Allen, J. J. (2012). Theta lingua franca: a common mid-frontal substrate for action monitoring processes. *Psychophysiology, 49*(2), 220-238.

Chen, A. C., Porjesz, B., Rangaswamy, M., Kamarajan, C., Tang, Y., Jones, K. A., ... & Begleiter, H. (2007). Reduced frontal lobe activity in subjects with high impulsivity and alcoholism. *Alcoholism: Clinical and Experimental Research, 31*(1), 156-165.

Choi, J. S., Park, S. M., Roh, M. S., Lee, J. Y., Park, C. B., Hwang, J. Y., ... & Jung, H. Y. (2014). Dysfunctional inhibitory control and impulsivity in Internet addiction. *Psychiatry Research, 215*(2), 424-428.

Cohen, M. X., Elger, C. E., & Ranganath, C. (2007). Reward expectation modulates feedback-related negativity and EEG spectra. *Neuroimage, 35*(2), 968-978.

Colrain, I. M., Sullivan, E. V., Ford, J. M., Mathalon, D. H., McPherson, S. L., Roach, B. J., ... & Pfefferbaum, A. (2011). Frontally mediated inhibitory processing and white matter microstructure: age and alcoholism effects. *Psychopharmacology, 213*(4), 669-679.

Crean, J. P., de Wit, H., & Richards, J. B. (2000). Reward discounting as a measure of impulsive behavior in a psychiatric outpatient population. *Experimental and clinical psychopharmacology, 8*(2), 155.

Davidson, R. J. (2004). What does the prefrontal cortex "do" in affect: perspectives on frontal EEG asymmetry research. *Biological Psychology, 67*(1), 219-234.

Dawe, S., & Loxton, N. J. (2004). The role of impulsivity in the development of substance use and eating disorders. *Neuroscience & Biobehavioral Reviews, 28*(3), 343-351.

De Greck, M., Supady, A., Thiemann, R., Tempelmann, C., Bogerts, B., Forschner, L., ... & Northoff, G. (2009). Decreased neural activity in reward circuitry during personal reference in abstinent alcoholics - A fMRI study. *Human Brain Mapping, 30*(5), 1691-1704.

Delgado, M. R., Locke, H. M., Stenger, V. A., & Fiez, J. A. (2003). Dorsal striatum responses to reward and punishment: effects of valence and magnitude manipulations. *Cognitive, Affective, & Behavioral Neuroscience, 3*(1), 27-38.

Delgado, M. R., Miller, M. M., Inati, S., & Phelps, E. A. (2005). An fMRI study of reward-related probability learning. *Neuroimage, 24*(3), 862-873.

Dell'Osso, B., Hadley, S., Allen, A., Baker, B., Chaplin, W. F., & Hollander, E. (2008). Escitalopram in the treatment of impulsive-compulsive internet usage disorder: an open-label trial followed by a double-blind discontinuation phase. *The Journal of Clinical Psychiatry, 69*(3), 452-456.

Diekhof, E. K., Falkai, P., & Gruber, O. (2008). Functional neuroimaging of reward processing and decision-making: a review of aberrant motivational and affective processing in addiction and mood disorders. *Brain Research Reviews, 59*(1), 164-184.

Dom, G., De Wilde, B., Hulstijn, W., & Sabbe, B. (2007). Dimensions of impulsive behaviour in abstinent alcoholics. *Personality and Individual Differences, 42*(3), 465-476.

Dong, G., Lu, Q., Zhou, H., & Zhao, X. (2010). Impulse inhibition in people with Internet addiction disorder: electrophysiological evidence from a Go/NoGo study. *Neuroscience Letters, 485*(2), 138-142.

Finocchiaro, R., & Balconi, M. (2015). Reward-system effect and "left hemispheric unbalance": a comparison between drug addiction and high-BAS healthy subjects on gambling behavior. *Neuropsychogical Trends, 17*, 37-45.

Fowles, D. C. (1980). The three arousal model: Implications of Gray's two-factor learning theory for heart rate, electrodermal activity, and psychopathy. *Psychophysiology, 17*(2), 87-104.

Fuster, J. M. (1989). *The prefrontal cortex: anatomy, physiology, and neuropsychology of the frontal lobe* (2nd ed.). New York: Raven Press.

Gehring, W. J., & Willoughby, A. R. (2004). Are all medial frontal negativities created equal? Toward a richer empirical basis for theories of action monitoring. Errors, conflicts, and the brain. *Current Opinions on Performance Monitoring, 14*, 20.

Gilmore, C. S., Malone, S. M., Bernat, E. M., & Iacono, W. G. (2010). Relationship between the P3 event-related potential, its associated time-frequency components, and externalizing psychopathology. *Psychophysiology, 47*(1), 123-132.

Grant, J. E., Potenza, M. N., Weinstein, A., & Gorelick, D. A. (2010). Introduction to behavioral addictions. *The American Journal of Drug and Alcohol Abuse, 36*(5), 233-241.

Gray, J. A. (1981). A critique of Eysenck's theory of personality. In *A model for personality* (pp. 246-276). Berlin, Heidelberg: Springer.

Gray, J. A., & McNaughton, N. (2003). *The neuropsychology of anxiety: An enquiry into the function of the septo-hippocampal system* (No. 33). Oxford: Oxford University Press.

Han, D. H., Lyoo, I. K., & Renshaw, P. F. (2012). Differential regional gray matter volumes in patients with on-line game addiction and professional gamers. *Journal of Psychiatric Research, 46*(4), 507-515.

Harmon-Jones, E. (2004). Contributions from research on anger and cognitive dissonance to understanding the motivational functions of asymmetrical frontal brain activity. *Biological Psychology, 67*(1), 51-76.

Harper, J., Malone, S. M., & Bernat, E. M. (2014). Theta and delta band activity explain N2 and P3 ERP component activity in a go/no-go task. *Clinical Neurophysiology, 125*(1), 124-132.

Hester, R., Murphy, K., & Garavan, H. (2004). Beyond common resources: the cortical basis for resolving task interference. *Neuroimage, 23*(1), 202-212.

Jasper, H. H. (1958). The ten twenty electrode system of the international federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371-375.

Jones, K. A., Porjesz, B., Chorlian, D., Rangaswamy, M., Kamarajan, C., Padmanabhapillai, A., ... & Begleiter, H. (2006). S-transform time-frequency analysis of P300 reveals deficits in individuals diagnosed with alcoholism. *Clinical Neurophysiology, 117*(10), 2128-2143.

Kahana, M. J., Seelig, D., & Madsen, J. R. (2001). Theta returns. *Current Opinion in Neurobiology, 11*(6), 739-744.

Kamarajan, C., Porjesz, B., Jones, K. A., Choi, K., Chorlian, D. B., Padmanabhapillai, A., ... & Begleiter, H. (2004). The role of brain oscillations as functional correlates of cognitive systems: a study of frontal inhibitory control in alcoholism. *International Journal of Psychophysiology, 51*(2), 155-180.

Kamarajan, C., Porjesz, B., Jones, K., Chorlian, D., Padmanabhapillai, A., Rangaswamy, M., ... & Begleiter, H. (2006). Event-related oscillations in offspring of alcoholics: neurocognitive disinhibition as a risk for alcoholism. *Biological Psychiatry, 59*(7), 625-634.

Kamarajan, C., Rangaswamy, M., Chorlian, D. B., Manz, N., Tang, Y., Pandey, A. K., ... & Porjesz, B. (2008). Theta oscillations during the processing of monetary loss and gain: a perspective on gender and impulsivity. *Brain Research, 1235*, 45-62.

Kamarajan, C., Rangaswamy, M., Manz, N., Chorlian, D. B., Pandey, A. K., Roopesh, B. N., & Porjesz, B. (2012). Topography, power, and current source density of theta oscillations during reward processing as markers for alcohol dependence. *Human Brain Mapping, 33*(5), 1019-1039.

Kamarajan, C., Porjesz, B., Rangaswamy, M., Tang, Y., Chorlian, D. B., Padmanabhapillai, A., ... & Stimus, A. T. (2009). Brain signatures of monetary loss and gain: outcome-related potentials in a single outcome gambling task. *Behavioural Brain Research, 197*(1), 62-76.

Kamarajan, C., Rangaswamy, M., Tang, Y., Chorlian, D. B., Pandey, A. K., Roopesh, B. N., ... & Porjesz, B. (2010). Dysfunctional reward processing in male alcoholics: an ERP study during a gambling task. *Journal of Psychiatric Research, 44*(9), 576-590.

Kirmizi-Alsan, E., Bayraktaroglu, Z., Gurvit, H., Keskin, Y. H., Emre, M., & Demiralp, T. (2006). Comparative analysis of event-related potentials during Go/NoGo and CPT: decomposition of electrophysiological markers of response inhibition and sustained attention. *Brain Research, 1104*(1), 114-128.

Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *International Journal of Psychophysiology, 24*(1), 61-100.

Klimesch, W., Doppelmayr, M., Pachinger, T., & Ripper, B. (1997a). Brain oscillations and human memory: EEG correlates in the upper alpha and theta band. *Neuroscience Letters, 238*(1), 9-12.

Klimesch, W., Doppelmayr, M., Schimke, H., & Ripper, B. (1997b). Theta synchronization and alpha desynchronization in a memory task. *Psychophysiology, 34*(2), 169-176.

Klimesch, W., Doppelmayr, M., Russegger, H., Pachinger, T., & Schwaiger, J. (1998). Induced alpha band power changes in the human EEG and attention. *Neuroscience Letters, 244*(2), 73-76.

Klimesch, W., Schimke, H., & Schwaiger, J. (1994). Episodic and semantic memory: an analysis in the EEG theta and alpha band. *Electroencephalography and Clinical Neurophysiology, 91*(6), 428-441.

Knutson, B., Fong, G. W., Bennett, S. M., Adams, C. M., & Hommer, D. (2003). A region of mesial prefrontal cortex tracks monetarily rewarding outcomes: characterization with rapid event-related fMRI. *Neuroimage, 18*(2), 263-272.

Knyazev, G. G. (2010). Antero-posterior EEG spectral power gradient as a correlate of extraversion and behavioral inhibition. *The Open Neuroimaging Journal, 4*(1), 114-20

Laconi, S., Rodgers, R. F., & Chabrol, H. (2014). The measurement of Internet addiction: A critical review of existing scales and their psychometric properties. *Computers in Human Behavior, 41*, 190-202.

Leone, L., Pierro, A., & Mannetti, L. (2002). Validità della versione italiana delle scale BIS/BAS di Carver e White (1994): generalizzabilità della struttura e relazioni con costrutti affini. *Giornale Italiano di Psicologia, 29*(2), 413-436.

Limbrick-Oldfield, E. H., van Holst, R. J., & Clark, L. (2013). Fronto-striatal dysregulation in drug addiction and pathological gambling: consistent inconsistencies? *NeuroImage: Clinical, 2*, 385-393.

Logan, G. D., Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit simple and choice reaction time responses: a model and a method. *Journal of Experimental Psychology: Human Perception and Performance, 10*(2), 276.

Ludwig, A., Miriani, R. M., Langhals, N. B., Joseph, M. D., & David, J. (2008). Neuron recordings from microelectrode arrays using a common average reference to improve cortical. *Journal of Neurophysiology, 101*(3), 1679-1689.

Makris, N., Oscar-Berman, M., Jaffin, S. K., Hodge, S. M., Kennedy, D. N., Caviness, V. S., ... & Harris, G. J. (2008). Decreased volume of the brain reward system in alcoholism. *Biological Psychiatry, 64*(3), 192-202.

Marco-Pallarés, J., Müller, S. V., & Münte, T. F. (2007). Learning by doing: an fMRI study of feedback-related brain activations. *Neuroreport, 18*(14), 1423-1426.

McClure, S. M., York, M. K., & Montague, P. R. (2004). The neural substrates of reward processing in humans: the modern role of FMRI. *The Neuroscientist, 10*(3), 260-268.

Moeller, F. G., Dougherty, D. M., Barratt, E. S., Schmitz, J. M., Swann, A. C., & Grabowski, J. (2001). The impact of impulsivity on cocaine use and retention in treatment. *Journal of Substance Abuse Treatment, 21*(4), 193-198.

Palmero-Soler, E., Dolan, K., Hadamschek, V., & Tass, P. A. (2007). swLORETA: a novel approach to robust source localization and synchronization tomography. *Physics in Medicine and Biology, 52*(7), 1783.

Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. *Methods and Findings in Experimental and Clinical Pharmacology, 24*(Suppl D), 5-12.

Pascual-Marqui, R. D., Michel, C. M., & Lehmann, D. (1994). Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. *International Journal of Psychophysiology, 18*(1), 49-65.

Petit, G., Kornreich, C., Noël, X., Verbanck, P., Campanella, S., (2012). Alcohol-related context modulates performance of social drinkers in a visual Go/No-Go task: a preliminary assessment of event-related potentials. *PLoS One, 7*(5):e37466.

Pfurtscheller, G. (1992). Event-related synchronization (ERS): an electrophysiological correlate of cortical areas at rest. *Electroencephalography and Clinical Neurophysiology, 83*(1), 62-69.

Proverbio, A. M., Riva, F., & Zani, A. (2010). When neurons do not mirror the agent's intentions: sex differences in neural coding of goal-directed actions. *Neuropsychologia, 48*(5), 1454-1463.

Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology, 23*(6), 695-703.

Scheres, A., Milham, M. P., Knutson, B., & Castellanos, F. X. (2007). Ventral striatal hyporesponsiveness during reward anticipation in attention-deficit/hyperactivity disorder. *Biological psychiatry, 61*(5), 720-724.

Schoenbaum, G., Roesch, M. R., & Stalnaker, T. A. (2006). Orbitofrontal cortex, decision-making and drug addiction. *Trends in neurosciences, 29*(2), 116-124.

Schürmann, M., Basar-Eroglu, C., & Basar, E. (1997). Gamma responses in the EEG: elementary signals with multiple functional correlates. *Neuroreport, 8*(7), 1793-1796.

Schürmann, M., Başar-Eroglu, C., Kolev, V., & Başar, E. (1995). A new metric for analyzing single-trial event-related potentials (ERPs): application to human visual P300 delta response. *Neuroscience Letters, 197*(3), 167-170.

Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology, 23*(6), 695-703.

Shapira, N. A., Goldsmith, T. D., Keck, P. E., Khosla, U. M., & McElroy, S. L. (2000). Psychiatric features of individuals with problematic internet use. *Journal of Affective Disorders, 57*(1), 267-272.

Smillie, L. D., Loxton, N. J., & Avery, R. E. (2011). Reinforcement sensitivity theory, research, applications, and future. *The Wiley-Blackwell Handbook of Individual Differences*, 101-131.

Smith, J. L., Johnstone, S. J., & Barry, R. J. (2008). Movement-related potentials in the Go/NoGo task: the P3 reflects both cognitive and motor inhibition. *Clinical Neurophysiology, 119*(3), 704-714.

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., Jacobs, G. A., (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Trujillo, L. T., & Allen, J. J. (2007). Theta EEG dynamics of the error-related negativity. *Clinical Neurophysiology, 118*(3), 645-668.

Vitaro, F., Arseneault, L., & Tremblay, R. E. (1999). Impulsivity predicts problem gambling in low SES adolescent males. *Addiction, 94*(4), 565-575.

Wrase, J., Schlagenhauf, F., Kienast, T., Wüstenberg, T., Bermpohl, F., Kahnt, T., ... & Heinz, A. (2007). Dysfunction of reward processing correlates with alcohol craving in detoxified alcoholics. *Neuroimage, 35*(2), 787-794.

Yamanaka, K., & Yamamoto, Y. (2010). Single-trial EEG power and phase dynamics associated with voluntary response inhibition. *Journal of Cognitive Neuroscience, 22*(4), 714-727.

Yordanova, J., Falkenstein, M., Hohnsbein, J., & Kolev, V. (2004). Parallel systems of error processing in the brain. *Neuroimage, 22*(2), 590-602.

Young, K. S. (1998). *Caught in the net: How to recognize the signs of internet addiction--and a winning strategy for recovery.* New Jersey, Hoboken: John Wiley & Sons.

Young, K. S., & Rogers, R. C. (1998). The relationship between depression and Internet addiction. *CyberPsychology & Behavior, 1*(1), 25-28.

Zhou, Y., Lin, F. C., Du, Y. S., Zhao, Z. M., Xu, J. R., & Lei, H. (2011). Gray matter abnormalities in Internet addiction: a voxel-based morphometry study. *European Journal of Radiology, 79*(1), 92-95.