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Electrophysiological studies in Internet addiction: A review within the dual-process framework

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HIGHLIGHTS

- EEG studies in Internet addiction are reviewed within a dual-process framework.
- Internet addiction is associated with hypo-activated reflective-control system.
- Internet addicts also appear to present an hyper-activated affective system.
- Internet addiction may thus be characterized by an imbalance between systems.
- Future works should explore Internet addiction subtypes and the role of comorbidities.

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ABSTRACT

The increase of pathological Internet use recently led to the identification of an "Internet addiction" disorder. While its diagnosis criteria remain unclear, the behavioral consequences of Internet addiction have been widely explored. Its cerebral correlates have also been investigated using electroencephalography, but obtained results have not yet been integrated in a sound theoretical framework. This paper aims at reviewing these studies and at analyzing their results through a dual-process perspective. A systematic literature search was conducted using Pubmed to identify studies in English exploring neural oscillations and/or event-related potentials in individuals displaying problematic Internet use. The 14 articles finally selected show that Internet addiction shares essential features with other addictive states, mainly a joint hypo-activation of the reflective system (decreased executive control abilities) and hyper-activation of the automatic-affective one (excessive affective processing of addiction-related cues). Despite the currently limited data, dual-process models thus appear useful to conceptualize the imbalance between cerebral systems in Internet addiction. We finally propose that future electrophysiological studies should better characterize this disequilibrium between controlled-deliberate and automatic-affective networks, notably by using event-related potentials paradigms focusing on each system separately and on their interactions, but also by better specifying the potential differences between sub-categories of Internet addiction.

1. Introduction

The excessive use of Internet has recently bloomed, leading to the characterization of an "Internet addiction" (Kuss, Griffiths, Karila, & Billieux, 2014; Spada, 2014). Although not yet included in the standardized classifications of mental diseases, this habit is now broadly considered as a specific addictive disorder, mostly characterized by compulsive Internet use, intense craving when Internet is not available, and deleterious personal/social consequences (Van Rooij & Prause, 2014). However, this definition remains debated and clear diagnosis criteria are lacking. In fact, Internet addiction gathers various activities, some being only available online (web surfing, social networking), while others are reproducing pre-existing offline conducts (online computer games replacing video gaming, online gambling replacing real-life gambling).

Despite this lack of established definition criteria, the psychological (e.g. psychopathological comorbidities, personality traits), cognitive (e.g. attentional or memory biases) and interpersonal (e.g. social isolation, online communication specificities) correlates of Internet addiction have been widely explored (King & Delfabbro, 2014; Kuss, 2013). These behavioral results have been recently renewed by a neuroscience approach which confirmed (by means of fMRI) that Internet addicts (IA) display, in line with other addicted populations, a double modification of brain functioning, i.e. a reduced efficiency of prefrontal areas when engaged in cognitive tasks (Brand, Young, & Laier, 2014) and an increased activation of the reward system when confronted with

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addiction-related stimuli (Ko et al., 2013). In light of these results, it appears that Internet addiction can be integrated in the dual-process framework (Mukherjee, 2010; Noel, Brevers, & Bechara, 2013), proposing that addictive states are characterized by a disequilibrium between under-activated reflective system (involved in the cognitive evaluation of the stimuli, initiating controlled-deliberate responses) and over-activated automatic-affective system (involved in the emotional evaluation of the stimuli, initiating appetitive responses). This disequilibrium might lead to increased automatic arousal and craving when confronted with Internet-related stimuli, combined with a reduced ability to control this urge and inhibit the addictive behavior. Importantly, the exploration of this disorder has not yet fully used the opportunities offered by neuroscience techniques. This is particularly true for electroencephalography (EEG) which might, thanks to its high temporal resolution, efficiently complement the localization data offered by fMRI. The present article thus proposes a comprehensive review of the existing EEG studies in Internet addiction, and integrates them in a dual-process theoretical framework.

2. EEG studies in Internet addiction: a review

2.1. Method

A systematic literature search was conducted on Pubmed (U.S. National Library of Medicine) using the keywords [(electroencephalography or electroencephalogram or "event-related potentials" or EEG or ERP) and ("Internet addiction" or "Internet dependence" or "pathological Internet use" or "excessive Internet use")] (Fig. 1). The "related articles" tool in Pubmed database and the reference list of selected studies were also used to identify additional articles. No publication dates were imposed, but the final search was performed in February 2015. To be included in the review, studies had to: (1) compare individuals displaying a problematic use of Internet with controls, (2) use tasks or a resting-state paradigm, and (3) analyze neural oscillations and/or event-related potentials (ERP). After reviewing all abstracts, two articles (Chuang, 2006, a study interested in massively multiplayer online role-playing game-induced seizures; Yuan, Qin, Liu, & Tian, 2011, a review) did not meet these criteria and were excluded. Finally, articles written in a language other than English were excluded (Yu, Zhao, Wang, Li, & Wang, 2008; Zhao, Yu, Zhan, & Wang, 2008; Zhu, Li, Du, Zheng, & Jin, 2011). The 14 articles finally selected are listed in Table 1 together with the characteristics of the samples and the diagnostic criteria.

2.2. Reflective system

As impairment in inhibitory control is classically considered as the cornerstone of addictive states, most EEG studies in IA focused on the reflective system. First, Zhou et al. (2010) evaluated inhibitory control by a Go-NoGo task where participants (26 IA, 26 controls, mean age: 22 years old) were confronted with two-digit numbers and had to react to Go stimuli (e.g. "10") and refrain from answering to NoGo ones (e.g. "50"). IA showed higher self-reported impulsivity and reduced N2 amplitude in NoGo trials. Given that N2 component reflects conflict monitoring process, this suggests that conflict detection ability is modified in IA. The same result was observed in another Go-NoGo study (Dong et al., 2010) controlling for the presence of comorbid psychiatric and neurological disorders [12 IA for whom diagnostic was based on Internet Addiction Test (Young, 1998) and 12 controls (mean age: 20.3 years old)]. IA also presented enhanced and delayed NoGo P3, this NoGo P3 reflecting response evaluation during inhibitory tasks. Taken together, these studies suggest that Internet addiction is linked with a globally reduced ability to stop prepotent behaviors. The same team (Dong et al., 2011) used similar diagnosis criteria and control of comorbidities to measure ERP during a Stroop test (i.e., naming the ink color of congruent or incongruent color words) in 17 IA and 17 controls (mean age: 20.9 years old). The study focused on the medial frontal negativity (MFN, occurring 400–500 ms after stimulus), which is increased in response to incongruent stimuli compared to congruent

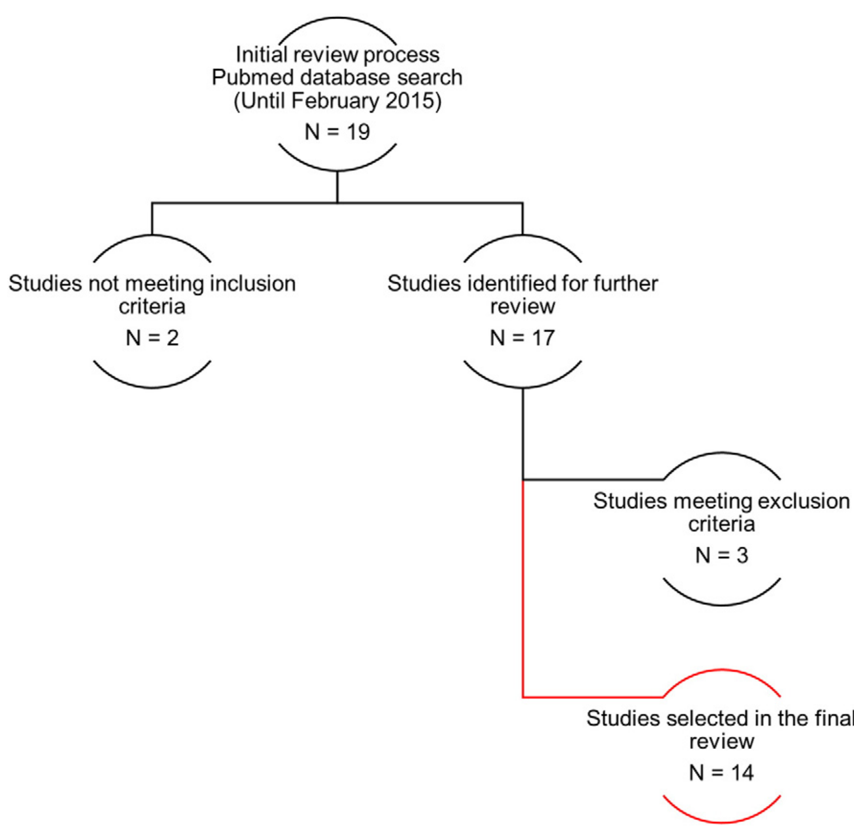

Fig. 1. Flow diagram illustrating the article selection process.

Table 1
Characteristics of included studies[1].

Study	Sample (number of male participants; mean age)	Internet addiction diagnosis	Internet addiction subtype	Reported comorbidities
Choi et al. (2013)	21 IA (12; 23.33 years) 20 HC (11; 22.40 years)	IA: IAT ≥ 70; mean Internet hours: per day = 5.95, per week = 45.95 HC: Internet hours per day <2	Online computer gaming	4/21 IA with DSM-IV criteria for depressive disorder HC: no history of any psychiatric disorder exclusion criteria for all subjects: head injury, alcohol or substance abuse, seizure disorder, and psychotic disorder
Dong, Zhou, and Zhao (2010)	12 IA (12; 20.47 years) 12 normal university students (12; 20.19 years)	IAT IA ≥ 7 HC < 4	Unspecified	Control for neurological or psychiatric disorders Control for psychological variables (SCL-90 and 16PF)
Dong, Zhou, and Zhao (2011)	17 IA (17; 21.09 years) 17 normal university students (17; 20.78 years)	IAT IA ≥ 6 (Mean = 6.71) HC < 4 (Mean = 2.73)	Unspecified	Control for neurological or psychiatric disorders control for psychological variables (SCL-90 and 16PF): depression, anxiety, obsessive–compulsive, hostility, somatization, phobic anxiety, and psychoticism
Duven, Muller, Beutel, and Wolfling (2015)	14 pathological online gamers (14; 24.29 years) 13 casual online gamers (13; 23.31 years)	Addiction diagnosis by a clinical psychologist AICA-S Pathological online gamers ≥7 (mean gaming hours per day = 7.18 during school time; 9.04 during holidays) Casual online gamers: 0–3 (mean gaming hours per day = 1.08 during school time; 1.92 during holidays)	Online computer gaming	SCL-90-R: no significant difference between groups on depressiveness
Ge et al. (2011)	41 IA (21; 32.5 years) 48 HC (25; 31.3 years)	IA diagnosed by two consultant psychiatrists and IAT ≥ 5	Unspecified	Excluded IA: pregnant, serious medical conditions, unstable psychiatric features (suicidal ideation), history of psychosis, mania, or organic mental syndrome, substance abuse or dependence within the previous 6 months, with the exception of nicotine dependence IA with other Axis I comorbid disorders were not excluded.
He, Liu, Guo, and Zhao (2011)	14 excessive Internet users (14; 20.5 years) 14 HC (14; 20.6 years)	IAT Excessive Internet users: mean = 7.6, (mean Internet hours per day = 6.2) HC: mean = 1.8 (mean Internet hours per day = 2.2)	Unspecified	Excessive Internet users: control for medications known to affect the central nervous system and for dependency on tobacco, alcohol, drug or other substances. HC: control for neurological or psychiatric disorders
Lee et al. (2014)	17 IA with depression (13; 21.24 years) 18 IA without depression (12; 23.44 years) 34 HC (25; 23.59 years)	IA: IAT ≥ 70, mean Internet hours: per day >4, per week >30 HC: Internet hours per day <2	Online computer gaming	DSM-IV (SCID): depression and ADHD diagnostics Exclusion criteria: injury, alcohol or substance abuse, seizure disorder, or psychotic disorder HC and IA without depression: no family history of depression
Littel et al. (2012)	25 excessive online gamers (23; 20.52 year) 27 HC (10; 21.42 years)	VAT: Excessive online gamers (mean gaming: days per week = 5.05 days, hours per day = 4.67) > 2.5 HC (mean gaming: days per week = 0.58 days, hours per day = 0.47) <1.5	Online computer gaming	Control for addictions (alcohol, smoking, illicit drugs)
Thalemann, Wolfling, and Grusser (2007)	15 excessive online computer gamers (15; 28.75 years) 15 casual players controls (15; 25.73 years)	Excessive online computer players (mean playtime = 4.31 h per day), 3 addiction criteria according to the ICM-10 and measured by the QDAS Casual gamers (mean playtime = 0.25 h/day)	Online computer gaming	Control for smoking and alcohol consumption

(continued on next page)

Table 1 (*continued*)

Study	Sample (number of male participants; mean age)	Internet addiction diagnosis	Internet addiction subtype	Reported comorbidities
Wang, Ge, Zhang, Liu, and Luo (2014)	15 IA (14 years) 15 non addicts (14 years)	APIUS IA > 3.15 Non-addicts <3.15 points	Unspecified	Left-behind children control for diseases of the brain, ingestion of stimulant medications that might influence brain function and prior participation to any similar EEG experiments.
Yu, Zhao, Li, Wang, and Zhou (2009)	10 IA 10 HC	IA diagnosed by the Institute of Psychology of Tianjin University	Unspecified	None
Zhou, Yuan, Yao, Li, and Cheng (2010)	26 pathological Internet users 26 HC	Pathological Internet use	Unspecified	
Zhou, Li, and Zhu (2013)	23 IA (17; 25 years) 23 HC (17; 25 years)	IA: YDQ > 6; mean Internet hours per day = 11.01	Mixed (pornography, online computer gaming, web surfing, social networking)	Control for DSM-IV axis I disorder or personality disorders, smoking, alcohol or substance dependence, neurological disorders, head injury or systemic disease affecting the central nervous system
Zhu et al. (2012)	39 IA in the "electroacupuncture (EA)" group (25; 20.98 years) 36 IA in the "psycho-intervention (PI)" group (27; 22.53 year) 37 IA in the "comprehensive therapy (CT = EA + PI)" group (27; 22.48 years)	Diagnostic meeting the standard of IA according to APA EA group (mean Internet hours per day = 5.88) PI group (mean Internet hours per day = 6.08) CT group (mean Internet hours per day = 6.05)	Unspecified	Exclusion criteria: mental disorders other than IA, history of drug addiction, counter-indications of EA or hyper-sensitivity to EA, pregnant or lactating.

[1] 16PF = Sixteen Personality Factor Questionnaire (Schneewind, Schröder, & Cattell, 1985); AICA-S = Assessment of Internet and Computer game Addiction (Wölfling, Müller, & Beutel, 2011); APIUS = Adolescent Pathological Internet Use Scale (Lei & Yang, 2007); HC = healthy controls; IA = Internet addicts; IAT = Internet Addiction Test (Young, 1998); QDAS = Questionnaire of Differentiated Assessment of Addiction (Grüsser et al., 2007); SCID = Structured Clinical Interview for the DSM-IV (First, Gibbon, Spitzer, Gibbon, & Williams, 1996); SCL-90 = Symptom Checklist-90 (Derogatis, Rickels, & Rock, 1976); VAT = Videogame Addiction Test (Van Rooij, Schoenmakers, van den Eijnden, Vermulst, & van de Mheen, 2012); YDQ = Diagnostic Questionnaire for Internet Addiction (Brard & Wolf, 2001).

ones and is therefore associated with conflict detection. IA had longer reaction times (RTs), more errors and reduced MFN amplitude in incongruent conditions, which confirms that IA show impaired executive control ability.

One shortcoming of these studies is that they did not report information regarding the specific subtype of Internet behaviors presented by the IA. Yet, Littel et al. (2012) found contrasting results when they compared 25 excessive online gamers [diagnosed using the Videogame Addiction Test (Van Rooij et al., 2012)] to 27 controls (mean age: 20.9 years old) using Go-NoGo. No group differences between this subtype of IA (controlled for other addictions) and controls were found for NoGo N2 and P3. When exploring error-monitoring components, they however found that excessive gamers exhibited reduced amplitude of the error-related negativity (ERN), appearing 50–100 ms after an erroneous response and indexing response monitoring (the ability to detect and take into account one's own error). ERN impairments are often observed in executive dysfunctions and addictions (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Potts, George, Martin, & Barratt, 2006) and are thus seen as indexing impaired reflective system. Higher impulsivity and error rates for NoGo trials were also reported, these measures being correlated with ERN alterations. Recently, these findings have been extended to a sample of 23 participants (mean age: 25 years old) reflecting the multiple facets of behaviors regrouped in Internet addiction [as measured by the Diagnostic Questionnaire for Internet Addiction (Brard & Wolf, 2001)], and that was controlled for comorbid neurological, psychiatric and other addictive disorders (Zhou et al., 2013). As compared to the 23 controls, IA showed faster RTs but lower accuracy and reduced ERN amplitude in a modified Eriksen Flanker task (requiring to detect the direction of a central arrow while ignoring incongruent flankers). This result shows a general pattern of impulsivity in Internet addiction, and specifically impaired behavioral monitoring and self-error detection.

More classical explorations of the P300 component, globally associated with high-level cognitive processing related to the reflective system, have also been done in IA with auditory oddball paradigms. However, the results of these studies have to be taken with precaution due to methodological limitations. First, Yu et al. (2009) showed longer RTs for detecting rare stimuli (high-tone sounds) among a succession of frequent ones (low-tone sounds) in IA, related to a global P300 deficit (reduced amplitude and longer latencies). Nonetheless, their study included a low sample size (10 IA, 10 controls, mean age: 22 years old), there was no control of comorbidities and no specification regarding Internet addiction subtype. Then, Ge et al. (2011) found no deficit for amplitude but longer latencies for the N2, P3a and P3b components, which was interpreted as reflecting impaired attentional (N2–P3a) and working memory (P3b) abilities in IA. However, even if the sample size was larger (41 IA and 48 controls, mean age: 31.3 years old) and the comorbidities controlled for, Internet addiction's subtypes remained unspecified and not evaluated by validated questionnaires. Moreover, these results should be taken cautiously as no methodological explanation was given regarding ERP recording and selection, and as all components have been measured on the same electrode (Cz). Finally, in the auditory oddball, the P300 is classically considered as reflecting the decision-making stage before starting the motor-response rather than a memory stage, and these P300 deficits could thus also be interpreted as indexing impaired decision-making.

Of note, this study (Ge et al., 2011) also conducted a second ERP measure in IA to explore the effect of a three-month cognitive-behavioral therapy. P3a–P3b latencies were reduced after therapy, suggesting a significant electrophysiological effect of this rehabilitation. More recently, another study (Zhu et al., 2012) evaluated P300 and mismatch negativity (MMN) changes among IA (mean age: 21.9 years old) before and after treatment with electroacupuncture (EA, 39 IA), psycho-intervention (PI, 36 IA) and both methods (Comprehensive Therapy, CT, 37 IA). Internet addiction score (based on a diagnosis conducted by a psychiatrist) was lowered in all groups, but P300 latency was delayed and enhanced in the EA group while MMN amplitude was increased in the CT group. The authors suggested that these ERP changes rely on the cognitive improvements induced by therapy with a faster pre-attentive sensory discrimination (MMN) and a greater resource mobilization (P3) during information processing.

Finally, two EEG studies assessed reflective system in IA who played online computer gaming by investigating resting-state activities, which involve a specific network of brain regions ("default mode network") and reflect non-task related cognitive processes (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 (21 IA, 20 controls, mean age: 22.8 years old, without strict control of comorbidities), previously related with task-related impulsivity observed in ADHD patients (Snyder & Hall, 2006). IA also presented increased absolute gamma band power, while changes in gamma band have also been associated with impulsivity (Barry et al., 2010; Romer Thomsen et al., 2013). Resting-state fast-wave brain activity thus appears to be associated with impulsivity in Internet addiction (online computer gaming) and differences within those EEG resting-state activities could constitute neurobiological markers for the pathophysiology of Internet addiction. However, as IA presented higher depression and anxiety scores, these comorbidities might have influenced the results. Interestingly, Lee et al. (2014) compared EEG resting-state activities of 17 IA (online computer gamers) with comorbid depression, 18 IA without depression and 34 matched controls (mean age: 22.9 years old). IA without depression had: (1) lower absolute beta power than controls, replicating the results presented above; (2) lower absolute delta power than controls and depressed. Moreover, depressed IA had (1) increased relative theta, and (2) decreased relative alpha power. This led to the conclusion that comorbid depression in excessive online computer gaming may be associated with increased slow-wave activities, already reported in depression alone (Adler, Bramesfeld, & Jajcevic, 1999; Morita et al., 2013). Decreased absolute delta and beta powers may therefore be neurobiological markers that differentiate pure Internet addiction from comorbid states.

2.3. Automatic-affective system

The results presented above globally confirm the proposal that IA present impaired cognitive control and altered reflective system. Nevertheless, the focus on this system led to a very limited exploration of the automatic-affective system in Internet addiction, as only four ERP studies have been conducted. The first one (Thalemann et al., 2007) recorded the Late-Positive Complex (LPC) among 15 online game addicts [as measured by the Questionnaire of Differentiated Assessment of Addiction (Grüsser et al., 2007)] and 15 casual gamers (mean age: 27.24 years old) during a cue-reactivity paradigm consisting in the passive viewing of game-related (online game screenshots) or non-game-related pictures. Groups did not differ for non-game related pictures, but IA showed increased amplitude of the LPC at parietal sites for game-related pictures. As the LPC indexes the affective and motivational appraisal of the stimuli, this result suggests that cues associated with computer game lead to a conditioned emotional arousal in IA.

The LPC was also recorded in a later study (Wang et al., 2014) evaluating the influence of Internet addiction on empathy for pain in left-behind Chinese teenagers [15 IA evaluated by the Adolescent Pathological Internet Use Scale (Lei & Yang, 2007), 15 controls, mean age: 14 years old]. Using a binary decision task (i.e. determining the presence or absence of pain in pictures) without controlling psychiatric comorbidities, the authors postulated a strict link between ERP components and the successive stages of pain empathy processing, associating N1 component with autonomic, low-level pain processing, N2–P2 components with the cognitive processing of pain leading to pain empathy, and LPC with the explicit judgment of pain. No group differences were observed for N1 and LPC components, but a group-stimulus interaction was found for N2–P2: a tendency towards increased amplitude for pain stimuli compared to non-pain stimuli was found among controls but not in IA. These results led the authors to conclude that the cognitive processing of pain and empathy for pain are impaired in IA.

A third study (Duven et al., 2015) investigated emotional processes in IA by exploring reward processing in 14 patients with Internet gaming disorder [measured by the Assessment of Internet and Computer game Addiction scale (Wölfling et al., 2011)] and 13 casual online gamers (mean age: 23.8 years old), while controlling for comorbidities using the Symptom Checklist-90 (Derogatis et al., 1976). The task was a computer game where participants had to find tokens in a virtual environment, ERP being time-locked to reward (i.e. to the moment following token discovery). Results revealed that pathological gamers showed delayed and enhanced N100 as well as reduced P200 and P300 in response to the gaming reward. The authors suggested that pathological online gamers: (1) use more resources for the initial orienting towards reward as indexed by changes in N100, and (2) invest less attention in evaluation of the reward as reflected by reductions in later components' amplitudes, notably P300. This pattern could thus constitute the electrophysiological substrate of tolerance process towards non-addiction-related rewards in this population.

Finally, He et al. (2011) used a passive visual detection paradigm to investigate face processing in excessive Internet users [14 IA, diagnosed using the Internet Addiction Test (Young, 1998), 14 controls, mean age: 20.5 years old]. Problematic users showed reduced: (1) P1 amplitude in left occipito-temporal areas, both for faces and objects, suggesting a globally impaired early visuo-spatial processing; (2) N170 amplitude effect (faces versus objects), suggesting an impaired visual expertise processing. Though they cannot directly be related to the "affective-automatic" system, these results are interesting as they suggest that possible deficits in the processing of social stimuli (i.e. faces) could arise from early perceptual steps, as recently suggested in other addictive states (i.e., alcohol-dependence; D'Hondt, Lepore, & Maurage, 2014).

3. Discussion and conclusion

To sum up, the following conclusions can be drawn from the currently available literature on the electrophysiological correlates of Internet addiction. Regarding the reflective system, the most convincing results are twofold: On the one hand control monitoring difficulties, as evidenced by ERN impairments both in excessive online computer gamers (Littel et al., 2012) and in a sample of IA including the different kinds of associated behaviors (Zhou et al., 2013). On the other hand, the reduction in delta and beta power resting-state waves of excessive online computer gamers (Lee et al., 2014). However, much more effort has to be made at the methodological level concerning the exploration of: (1) inhibition, as contrasted results are obtained between unspecified IA (Dong et al., 2010, 2011; Zhou et al., 2010) and excessive online gamers (Littel et al., 2012); (2) decision making and potential benefit of therapies on this process even if preliminary data are encouraging (Ge et al., 2011; Zhu et al., 2012). Future controlled studies that consider the heterogeneity of Internet addiction and potential effects of comorbidities should therefore be undertaken using validated paradigms that allow to determine IA executive impairments and notably cognitive inhibition deficits.

Concerning the automatic-affective system, it has to be underlined that current data remains very preliminary. Indeed, on the one hand, only two studies (Duven et al., 2015; Thalemann et al., 2007) gave initial confirmation, at the electrophysiological level and by means of validated paradigms (reward processing and cue-reactivity), of the dysregulated automatic processing of addiction-related cues already described at behavioral and neuroimaging levels. On the other hand, the emotional subsystem has up to now been explored in a very indirect way (by means of pain empathy and passive face processing), and only very initial evidence have thus been offered regarding the modifications in the processing of addiction-related and emotional cues. The limited data and the high heterogeneity in the experimental designs used currently hamper the drawing of conclusions regarding the automatic-emotional system.

Despite these limits, results of these EEG studies are interesting when considered in the framework of "dual-process models" (Mukherjee, 2010) as they suggest that (1) both postulated systems might be altered in IA, and (2) Internet addiction shares essential features with other addictions, centrally the heightened impulsivity and executive control deficits. Future EEG studies should thus be explicitly conducted within this theoretical background, particularly to systematically explore the up to now marginally considered "automatic-affective" system using more adapted and specific tasks. The imbalance between systems should also be investigated, as a central proposal of the dual-process model is that, beyond the deficits related to each system, addictions are developed and maintained by the disequilibrium between systems. This imbalance has not been explored in IA, and future EEG studies should use new paradigms requiring both automatic-affective and controlled processes to test the two systems simultaneously and their interactions.

At the methodological level, upcoming works should also explore the electrophysiological specificities of Internet addiction compared to other addictions, and the differences between the heterogeneous habits constituting Internet addiction. This heterogeneity, illustrated by the variations in the diagnostic criteria used and in the Internet addiction's subtypes considered across ERP studies (see Table 1), is a crucial limitation for the development of this research field. Centrally, most studies have up to now considered Internet addiction as a unitary phenomenon (not mentioning the subtype of online activity) or have focused on one specific subtype (mainly online computer gaming), but Internet addiction is actually an umbrella term encompassing very different activities which might have distinct psychological and cerebral correlates. These subtypes should thus be individually explored to clarify their neurocognitive commonalities and specificities. Future studies should also assess the influence of comorbidities, as Internet addiction is frequently associated with other addictive states, depression or anxiety, which are known to influence cognitive and brain functions. The role played by these comorbidities in the deficits observed has not been precisely determined in earlier studies. Moreover, gold standards should be clearly determined concerning the use of electrophysiological techniques in IA, because earlier studies presented technical shortcomings or methodological limits (e.g., limited number of electrodes or unusual choices for data analysis). As earlier studies used very diverse cognitive tasks with variable reliability, gold standards should also be developed regarding the experimental designs to promote validated and theoretically-grounded tasks focusing on specific cognitive processes and efficiently eliciting the explored electrophysiological components. Both the heterogeneity of the population explored and the diversity of the electrophysiological tools used might have led to inconsistent results in earlier works. The combination of these sources of variability might have also led to a publication bias against null findings, which could explain the currently limited number of publications on the topic. Finally, electrophysiological tools should also be used to test the efficiency of psychotherapeutic programs, as initiated by preliminary results (Ge et al., 2011; Zhu et al., 2012).

Conflict of interest

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