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Review

Electrophysiological correlates of problematic Internet use: Critical review and perspectives for future research

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ABSTRACT

Problematic behaviors have emerged with the exponential development of the Internet access, with some individuals failing to constrain their Internet use despite its negative impact on their daily lives. Recent neuropsychological and neuroscience studies have suggested that problematic Internet use is notably associated with increased cue-reactivity and reduced inhibitory control. This review of the electroencephalography (EEG) literature shows that most studies have found that impaired self-control abilities (i.e., inhibition and error monitoring) are associated with underactivated frontal regions in problematic Internet users (PIUs). However, some EEG studies in the domain have also demonstrated alterations in the processing of Internet-related cues and emotional stimuli. As a whole, these data therefore suggest that both reflective (top-down) and automatic/affective (bottom-up) systems, postulated by dual-process models as being determinants in decision making, are impaired among PIUs. On this basis, new research avenues are proposed to better understand the development and maintenance of problematic Internet use, according to six main directions respectively related to (1) the identification of vulnerability biomarkers, (2) the investigation of possible lower level cognitive impairments, (3) the exploration of core reflective and automatic/affective symptoms, (4) the evaluation of Internet use heterogeneity and comorbidities, (5) the development of new neuroscience strategies and (6) the elaboration of behavioral and cognitive interventions.

Contents

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1. Introduction

The use of the Internet has grown exponentially during the last two decades, initially in Western countries and more recently worldwide, with nearly three billion people now having constant and cheap Internet access (Internet World Stats, 2014). The Internet has thus become an essential component of everyday life for nearly half of humanity and brings positive outcomes to the large majority of its users, notably by facilitating social communication and access to information and knowledge. However, this expansion of Internet availability has also led to the emergence of problematic conducts. This "problematic Internet use" can be broadly defined as an inability to control Internet use despite its severe negative consequences in the daily life (Spada, 2014; Tam and Walter, 2013).

Internet maladaptive use is generally conceptualized as a behavioral addiction that includes core components of addictive behaviors (Kuss et al., 2014). Heterogeneous terms have been used to describe this condition, from "problematic/dysfunctional Internet use" or "pathological Internet use" to "Internet addiction" or "Internet dependence" (Spada, 2014). Although the public health issues associated to problematic Internet use is no longer debatable, the position that it consists in an addictive behavior is largely controversial (Starcevic, 2013). It has for example also been proposed that problematic Internet use rather consists in a maladaptive coping displayed to face negative life events or comorbid psychopathology (Kardefelt-Winther, 2014; Schimmenti and Caretti, 2010). Moreover, it is worth mentioning that the process by which excessive behaviors (especially Internet-related use) tend to be conceptualized has recently received much criticism (Billieux et al., 2015a,b,d; Kardefelt-Winther, 2014; Mihordin, 2012). This process, described as a *confirmative approach* by Billieux et al. (2015c) generally comprises the three following steps. First, based on initial observations (often clinical), an excessive behavior is a priori considered as an addictive disorder without considering potential alternative conceptualizations. Second, diagnostic criteria and related screening tools are developed, based on the substance abuse framework. Third, the neurobiological and psychological correlates of the newly identified behavioral addiction are explored in light of the established risk factors for substance-related addictions. One important problem of such an approach is that it often over-pathologizes the condition under the scope of investigation, as applying substance use criteria to define a behavior (e.g., gaming) often failed to distinguish high involvement (i.e., a passion) from dysfunctional involvement (Charlton and Danforth, 2007; Griffiths et al., 2015). Recently, notwithstanding inconsistencies in classification and limited evidence regarding both the etiology and the course of the condition, Internet gaming disorder has been included in Section 3 of the *Diagnostic and Statistical Manual of Mental Disorders* [5th ed.; *DSM-5*]. This specific section of the DSM-5 is devoted to the conditions that deserve further research prior to define them as established mental disorders. The question whether the Internet is the vehicle or the focus of a disorder in problematic Internet users remains also debated (Potenza, 2015). This even led to the proposal that the term "Internet addiction [. . .] should be replaced by addictions to the Internet-related activities if the pattern of such activities meets the criteria for behavioral addiction" (Starcevic, 2013, page 18). The current "conceptual chaos" that surrounds Internet-related research, which notably complicates the distinction between common behaviors or leisure activities and dysfunctional ones, slows the development of this field, by hampering a reliable comparison across studies, as underlined in recent reviews (Aboujaoude, 2010; Spada, 2014).

In the framework of the current paper, and according to the lack of definitive evidence and consensus regarding the conceptualization, etiology and course of the condition, it has been decided to use the term "problematic Internet users" (PIUs) to describe individuals displaying Internet-related disorders, despite the majority of previous published papers have used the term "Internet addicts". In accordance with recent proposals (Van Rooij and Prause, 2014), problematic Internet use will here be considered as a maladaptive pattern of Internet use involving: (1) an apparent loss of control [globally defined as an inability to stop a behavior when initiated or to refrain from this behavior after a period of abstinence (Lyvers, 2000)] over the use of the Internet, as well as irritability, anxiety, and dysphoric mood during attempts to control it; (2) the occurrence of psychological, social, or professional negative consequences; and (3) the presence of obsessive thoughts and worries when it is impossible to use the Internet (Van Rooij and Prause, 2014).

Beyond the debates related to its definition, the exploration of the psychological, cognitive, and social correlates of problematic Internet use now constitutes a growing research field which already led to a better understanding of this maladaptive pattern (Weinstein and Lejoyeux, 2010). However, despite valuable attempts to identify the unique characteristics of PIUs (e.g., Davis, 2001; Kardefelt-Winther, 2014; King and Delfabbro, 2014), most existing studies do not go beyond the mere reproduction of substance-related criteria (Block, 2008; Ko et al., 2009b; Shapira et al., 2003; Tao et al., 2010; Young, 1998), and the specificity of problematic Internet use remains to be clearly established. Moreover, although there are several longitudinal studies (e.g., Gamez-Guadix et al., 2015; Gentile et al., 2011), most studies are cross-sectional, which prevents any interpretation regarding the direction of causation. Furthermore, these studies rarely take into account possible confounding factors, notably personality traits and comorbid psychopathology. This is a central concern as problematic Internet use appears to be often comorbid with other psychiatric states, especially substance use disorders, depression, and social anxiety (Kuss et al., 2014). Another crucial concern is the measure of problematic Internet use (King et al., 2013; Lortie and Guitton, 2013). Several reliable and psychometrically sound tools have been extensively used to screen for problematic Internet use (Chen's Internet Addiction Scale, Chen et al., 2003; Compulsive Internet Use Scale, Meerkerk et al., 2009; Young's Internet Addiction Test, Young, 1998), but although these tests are standardized and adapted to different languages or cultures, they are self-reported measurements and therefore subject to participant bias. Moreover, the cut-offs frequently used with these scales are too sensitive and not internationally recognized, which has among other resulted in an overestimation of the problematic Internet use's prevalence (Kuss et al., 2014). Finally, the social conception of what is an excessive or problematic use probably varies from one culture to another. Consequently, even though the importance and extent of the phenomenon are now widely recognized, wide-ranging prevalence rates are reported: epidemiological studies show prevalence rates ranging from about 1% to more than 25%, depending on the type of sample included (self-selected versus random), the countries in which the studies were done, and the screening questionnaires and diagnostic criteria used (Aboujaoude et al., 2006; Kuss et al., 2014; Villella et al., 2011).

Despite the above-mentioned debates and the heterogeneity of Internet-related activities [problematic Internet use clearly covering a large range of often unrelated activities (Billieux, 2012; Pawlikowski et al., 2014)], it is now clearly established that problematic Internet use is associated with a wide range of psychological and social negative consequences, namely, increased stress and aggressiveness, interpersonal conflicts, and social isolation, as well as reduced work or academic achievements and reduced well-being (Beard and Wolf, 2001; Kuss, 2013; Kuss and Griffiths, 2011; Kuss et al., 2014). Although several factors have been explored at the cognitive level, such as repetitive thoughts or maladaptive thinking mode (see King and Delfabbro, 2014 for a review), executive control impairments seem to be the crucial factor related to problematic Internet use (Dong and Potenza, 2014). This maladaptive pattern indeed appears related to large deficits in inhibition (Irvine et al., 2013) and decision making (Laier et al., 2014; Sun et al., 2009), as well as to increased impulsivity (Billieux et al., 2011; Billieux et al., 2015d; Meerkerk et al., 2010). These observations probably contributed to the currently dominant proposal that problematic Internet use is characterized by impulse control impairment (Robbins and Clark, 2015; Yau et al., 2012). Accordingly, impulsivity-related deficits are a central feature in the etiology of problematic Internet use, independently of the type of online activity concerned (Billieux and Van der Linden, 2012; Cao et al., 2007a).

Numerous neuroscience studies have recently extended the exploration of problematic Internet use by determining its brain correlates (see Brand et al., 2014; Kuss and Griffiths, 2012; Weinstein and Lejoyeux, 2015; Yuan et al., 2011a; Zhu et al., 2015, for recent reviews). However, and quite surprisingly, the brain characteristics of problematic Internet use have mostly been explored by using neuroimaging, and other neuroscience techniques have been far less used to deepen the understanding of this maladaptive pattern. This contrast is particularly striking regarding electroencephalography (EEG; D'Hondt and Maurage, 2015), as this technique has been fruitfully used for decades to explore substance addiction (Campanella et al., 2014; Littel et al., 2012a). Indeed, EEG, and particularly the event-related potentials (ERP) technique, is considered a reliable tool to determine the brain correlates of addictive disorders and is widely used in experimental and clinical contexts (see McLoughlin et al., 2014; Pogarell et al., 2007 for reviews). Conversely, EEG has to date led to only limited evidence in the context of problematic Internet use, despite its high potential usefulness to complement and deepen neuroimaging results. Accordingly, the central aim of the present paper is to review the available literature related to EEG studies in maladaptive pattern of Internet use, and to propose new research avenues in which EEG might be used to offer innovative insights into the understanding of problematic Internet use.

First, before providing a critical review of EEG studies, the principal findings from neuroimaging studies concerning brain differences associated with problematic Internet use will be summarized. Given that these studies have already been reviewed elsewhere (see Brand et al., 2014; Kuss and Griffiths, 2012; Weinstein and Lejoyeux, 2015; Yuan et al., 2011a; Zhu et al., 2015), only a synthesis of their main results will be provided. Of note, self-control impairments (impaired inhibitory and executive control) have been established as a hallmark of addictive behaviors and impulse-control disorders (Groman et al., 2009). As a consequence, most functional neuroimaging and electrophysiological studies in the field of problematic Internet use have focused on cognitive functions, and particularly on executive control. However, several studies have also investigated affective processing of salient cues, suggesting that cognitive deficits may not be the only facet involved in excessive Internet use, as PIUs also present attentional biases toward stimuli related to online activities (Decker and Gay, 2011; van Holst et al., 2012). Interestingly, dual-process models (Mukherjee, 2010), which are currently influential in addiction research and have recently been applied to the study of maladaptive pattern of Internet use (Dong and Potenza, 2014), state that efficient decision making depends on the interactions between two brain networks, namely, the "reflective system" (mainly relying on orbitofrontal–dorsolateral cortices and involved in thoughtful-controlled conduct) and the "automatic–affective" system (mainly relying on limbic-striatal areas and driving impulsive–automatic conduct, Daw et al., 2005; Hampton et al., 2007). The application of these models to addictive disorders (Stacy and Wiers, 2010; Wiers et al., 2007) suggests that the development and maintenance of these psychiatric disorders relies on a disequilibrium between the two systems, with an under-activation of the reflective network (related to impairments in executive functions, thus hampering the effectiveness of behavioral control) and, conversely, an over-activation of the automatic–affective network (generally leading to emotional disturbances, craving, attentional biases, and increased appetence toward specific stimuli). Current research in addictions has nevertheless focused on the separate exploration of these two systems, and it should be noted that their effective interactions leading to decision making need to be further explored. The proposal initially offered in the dual-process approach (Mukherjee, 2010) is that both systems independently assign a value to a given stimulus and that the behavior in response to this stimulus is driven by a combination of the valuations of the two systems. Furthermore, it has been recently proposed that a third system involving the insula may be crucial, by integrating the inputs related to the two other systems and by incorporating interoceptive signals into the decision-making process (Noel et al., 2013). However, this theoretical proposal has up to now received little empirical evidence and, for the sake of clarity, the presentation of functional neuroimaging and electrophysiological data will thus follow the initial distinction made by dual-process models between reflective and automatic–emotional systems (Mukherjee, 2010).

Second, a research agenda will be proposed by underlining six main domains in which EEG might be used to offer innovative insights into the understanding of problematic Internet use. More precisely, it is proposed that ERP exploration of problematic Internet use would be useful (1) to identify vulnerability biomarkers and detect brain consequences at the early stages of the problematic Internet use; (2) to explore the successive stages of the cognitive continuum, notably to test the hypothesis that the high-level impairments observed in earlier studies (for decision making, inhibition, and error monitoring) might be explained by lower-level perceptive or attentional deficits; (3) to strengthen the understanding of the core symptoms associated with problematic Internet use, notably by exploring emotional processes and cognition-emotion interactions; (4) to better understand the heterogeneity of problematic Internet use by clarifying the convergences and discrepancies between the various types of problematic Internet uses (e.g., online gaming, social networks, cybersex) and the role of comorbidities, as well as by exploring the links between maladaptive pattern of Internet use and substance-related or behavioral addictive disorders (especially gambling disorders); (5) to determine spatio-temporal dynamics of cerebral modifications by associating it to functional Magnetic Resonance Imaging (fMRI), in order to benefit from both the high temporal resolution of EEG and the high spatial resolution of fMRI; and (6) to renew the interventions designed to treat this maladaptive pattern by complementing the available diagnosis tools, as well as by testing the efficiency of rehabilitation programs and optimizing their use in clinical settings.

2. Functional and structural brain modifications in problematic Internet use: Insights from neuroimaging studies

2.1. fMRI

On the one hand, numerous fMRI studies have investigated the cerebral correlates of the reflective system in PIUs by using executive tasks. Several studies have thus reported modifications related to the brain regions involved in response inhibition in problematic Internet gaming. Particularly, increased prefrontal activity has been found in adult (Ko et al., 2014a) and adolescent excessive online gamers (Ding et al., 2014), combined with lower functional connectivity of the fronto-striatal network (Li et al., 2014). Ko et al. (2014a) also found that individuals with problematic Internet gaming had lower activations of the right insula than controls during error processing. Among PIUs, works by Dong et al. (2012b, 2013b, 2014) reported increased activity of the anterior and posterior cingulate cortices while performing a Stroop task (Dong et al., 2012b), as well as increased activation in the anterior cingulate cortex and decreased activation in the orbitofrontal cortex during error processing (Dong et al., 2013b). These authors also showed increased activations during task switching (easy-to-difficult and difficult-to-easy switches during a Stroop task) in superior temporal gyrus, insula and precuneus (Dong et al., 2014). Such results led Dong et al. (2014) to propose that PIUs have to engage more effort in executive control during decision-making, resulting in increased brain activities. A recent study by Seok et al. (2015) has examined the brain correlates of decision making in problematic Internet use and has found that PIUs show more risky decision-making. Centrally, they showed that these risky choices in PIUs were associated with greater anterior cingulate cortex and caudate nucleus activations, as well as reduced ventro-lateral prefrontal activations. On this basis, the authors proposed that modifications in these brain regions, which are involved in conflict monitoring, reward processing and cognitive control, respectively, may constitute biological markers for problematic Internet use. However, the cross-sectional nature of this study hampers to draw any definitive conclusion regarding the causality between problematic Internet use and brain modifications. In line with these results, there is evidence from a probability-discounting task suggesting that PIUs have impaired risk evaluation, which was associated with a decreased activation in the inferior frontal and precentral gyri when performing probabilistic evaluations (Lin et al., 2015c). Dong et al. (2013a) observed that decision making by PIUs was associated with increased activations in the inferior frontal cortex, insula and anterior cingulate cortex, and decreased activations in the posterior cingulate cortex during repeated wins or losses. According to these authors, PIUs may continue to play online because they do not take into account their previous choices and the associated consequences in their current decision. Finally, it was also suggested that a modification of motor processes might be present during cognitive tasks in Internet gaming disorder, as reduced activity of premotor and motor areas have been reported during a Go/NoGo task (Chen et al., 2015).

On the other hand, concerning the automatic–affective system, a study by Dong et al. (2011a) reported that PIUs showed modifications in brains areas associated with reward/punishment processing, globally indexed by increased reward sensitivity (reflected by higher orbitofrontal cortex activation) and conversely with decreased loss sensitivity (shown by reduced anterior cingulate cortex activation). Results appear divergent in adolescent PIUs who are characterized by decreased reward sensitivity both for social and monetary rewards (Kim et al., 2014). Furthermore, several studies found that PIUs displayed increased activity in distributed brain areas (notably several prefrontal and striatal regions, inferior parietal lobe, and posterior cingulate cortex) in response to game-related cues, which correlates with self-reported gaming urges (Han et al., 2010; Ko et al., 2009a, 2013; Liu et al., 2015; Sun et al., 2012). The dorsolateral prefrontal cortex moreover appears to have a particular role in Internet gaming disorder as (1) activations of the right dorsolateral prefrontal cortex and left parahippocampus in response to gaming cues were reduced in individuals with remitted Internet gaming disorder compared with a group presenting current Internet gaming disorder (Ko et al., 2013); (2) activities of the right dorsolateral prefrontal cortex and right superior parietal lobe were increased by gaming cue distraction during a Go/No-Go task performed by individuals with Internet gaming disorder, and were negatively correlated with response inhibition in this group (Liu et al., 2014); (3) cue-induced brain activity in the left dorsolateral prefrontal cortex (among other brain regions such as left occipital lobe and left parahippocampal gyrus) was decreased after 6 weeks of bupropion treatment (a norepinephrine/dopamine reuptake inhibitor already used in the treatment of patients with substance abuse), and so were the craving and the total time spent gaming (Han et al., 2010).

Finally, there is an increasing number of studies investigating brain at resting-state in PIUs. First, Internet gaming disorder in adolescents is associated with higher global cerebral blood flow in a large range of limbic, insular, parietal and frontal regions, as well as lower cerebral blood flow in the left middle temporal and occipital gyri, and in the right cingulate gyrus (Feng et al., 2013). Even though contrasted results were found (Dong et al., 2012c; Kim et al., 2015; Liu et al., 2010), it appears that regional homogeneity at the resting state in Internet gaming disorder is enhanced in sensory-motor areas (cerebellum, brainstem, several frontal regions). Numerous studies have also investigated functional connectivity and have reported reduced connectivity among adolescents presenting Internet gaming disorder, mainly in cortico-striatal circuits and notably involving prefrontal areas (Hong et al., 2013b, 2015; Jin et al., 2015), which reinforces the proposal of an impaired frontal control on the reward system. Two recent studies have also investigated functional connectivity of the posterior cingulate cortex, a major node of the default-mode network (Raichle et al., 2001), in (nonsmokers) adolescents and young adults with Internet gaming disorder. Both studies found increased functional connectivity (Raichle et al., 2001) with cerebellum and reduced functional connectivity with parietal lobules and inferior temporal gyri (Chen et al., 2014; Ding et al., 2013). There are also evidence suggesting that Internet gaming disorder might be associated with reduced functional connectivity in the reflective system and increased functional connectivity in the automatic–affective system [i.e., reward network and limbic areas (Dong et al., 2015; Ko et al., 2015; Zhang et al., 2015)]. In PIUs, it has up to now only been suggested that extensive modifications happen regarding the functional connectivity within cortico-striatal circuits in adolescents, involving both reduced and increased connectivity (Kuhn and Gallinat, 2015; Lin et al., 2015a; Wee et al., 2014), but the heterogeneity of participants and the variability in the methods and analyses conducted do not allow to draw a clear-cut conclusion regarding these resting-state data.

2.2. *Structural MRI*

Wide-range brain structure modifications have also been reported in problematic Internet use. First, reduced cortical thickness of the orbitofrontal cortex was observed in adolescents showing problematic Internet use (Hong et al., 2013a) or Internet gaming disorder, this reduction being correlated with impaired cognitive control (revealed by a color-word Stroop task; Yuan et al., 2013). Yuan et al. (2013) also reported that cortical thickness was reduced in insula, lingual gyrus, right postcentral gyrus, entorhinal cortex and inferior parietal cortex, and increased in the left precentral cortex, precuneus, middle frontal cortex, inferior temporal and middle temporal cortices. Atrophy in gray matter among individuals with Internet gaming disorder has been reported for various brain regions, including the right orbitofrontal cortex, bilateral insula and right supplementary motor area (Weng et al., 2013), the left precentral gyrus (Sun et al., 2014), the bilateral amygdala (Ko et al., 2015), the bilateral inferior frontal gyrus, left cingulate gyrus, insula, right precuneus, and right hippocampus (Lin et al., 2015b). The study by Weng et al. (2013) even observed that gray matter volumes of the right orbitofrontal cortex and bilateral insula were correlated with self-reported Internet addiction symptoms. Conversely, higher gray matter volumes have also been reported in intense Internet gaming in the left ventral striatal region of adults

(Kuhn et al., 2011), and in the right inferior, middle temporal and right parahippocampal gyri of young adults (Sun et al., 2014). Interestingly, beyond the mere differences between individuals with Internet gaming disorder and controls, Han et al. (2012) showed that the main differences between individuals with Internet gaming disorder and unproblematic professional gamers were their respective increased gray matter volume of the left thalamus and the lateral cingulate gyrus. Conversely to Internet gaming disorder, where both increased and decreased brain volumes have been reported, gray matter appears specifically reduced in adolescent PIUs, particularly in the left anterior cingulate cortex, left posterior cingulate cortex, left insula, and left lingual gyrus (Zhou et al., 2011), and in the bilateral dorsolateral prefrontal cortex, supplementary motor area, orbitofrontal cortex, cerebellum, and left rostral anterior cingulate cortex (Yuan et al., 2011b). Kuhn and Gallinat (2015) also found a significant negative association between the Internet Addiction Test score and the gray matter volume of the right frontal pole in PIUs.

White matter modifications have also been recently reported in individuals with Internet gaming disorder, revealing lower density in the inferior frontal gyrus, insula, amygdala, and anterior cingulate cortex (Lin et al., 2015b). A previous study has also found reduced fractional anisotropy in the right parahippocampal gyrus of adolescents with problematic Internet use (Yuan et al., 2011b). Lin et al. (2012) extended these results to large areas of the brain of PIUs including orbitofrontal white matter, corpus callosum, cingulum, inferior fronto-occipital fasciculus, corona radiation, internal and external capsules. Fractional anisotropy values in the left external capsule were negatively correlated with self-reported Internet addiction symptoms. Interestingly, Weng et al. (2013) also found that individuals with Internet gaming disorder showed reduced fractional anisotropy in the right genu of corpus callosum, bilateral frontal lobe white matter, and right external capsule (fractional anisotropy values of the right external capsule being correlated with the intensity of excessive Internet use). However, while these authors did not find any higher fractional anisotropy in PIUs, this was observed by Dong et al. (2012a) in individuals with Internet gaming disorder at the level of left posterior cingulate cortex and thalamus, this latter being correlated with the severity of Internet gaming disorder. Similar increased fractional anisotropy were found by Yuan et al. (2011b) in the left posterior limb of the internal capsule for adolescents with problematic Internet use.

2.3. Molecular imagery

Several studies have suggested the existence of neurobiological abnormalities in individuals with Internet gaming disorder and PIUs. While the seminal positron emission tomography study by Koepp et al. (1998) revealed intense striatal dopamine release during online gaming in non-problematic players, Kim et al. (2011) reported that PIUs exhibited reduced D2 dopamine receptor availability in the striatum, which was negatively correlated with Internet Addiction Test scores. Consistently with this finding, a single-photon emission computed tomography study found a decreased level of dopamine transporter expression in the striatum of PIUs (Hou et al., 2012). Moreover, glucose metabolism in individuals with Internet gaming disorder was found to be increased in the right middle orbitofrontal gyrus, left caudate nucleus, and right insula and decreased in the bilateral postcentral gyrus, left precentral gyrus, and bilateral occipital regions compared with non-problematic gamers (Park et al., 2010). Tian et al. (2014) also recently found in individuals with Internet gaming disorder a decreased glucose metabolism in the prefrontal, temporal, and limbic systems as well as a dysregulation of striatal D2 receptors, which were correlated with duration of excessive online gaming. These authors also reported that a low level of striatal D2 receptors was positively correlated with decreased glucose metabolism in the orbitofrontal cortex. Taken together, these results suggest that problematic Internet use could be associated with dysregulation of dopaminergic systems, involving in particular the orbitofrontal cortex and the striatum (Zhu et al., 2015). Importantly, it should be noted that some biases in the results of these studies could come from the fact that practice [only Tian et al. (2014) report the capacity of Internet game playing as an inclusion criterion] and pleasure in doing these online activities were not assessed among participants and thus putatively differed between groups.

3. Electrophysiology in problematic Internet use: A critical review

A synthesis of the electrophysiological literature on maladaptive patterns of Internet use (summarized in Table 1) is proposed, presenting the results related to reflective and automatic–affective systems of the "dual-process" models (Mukherjee, 2010). First, evidence of deficits in cognitive processes involved in controlled, deliberate behaviors can be found in a study conducted by Yu et al. (2009), which used an auditory oddball paradigm where participants had to detect the appearance of rare stimuli among sequences of frequent ones by pressing a response key. On the one hand, the authors explored gamma-band activity (ranging from 30 to 50 Hz) by means of time-frequency analysis of the EEG signal based on a factorial procedure (i.e., non-negative matrix factorization method). This analysis showed reduced gamma-band activities in PIUs, particularly in the parietal region, this deficit being interpreted as a reduced ability to synchronize and integrate information coming from different brain regions. On the other hand, deficits were also shown at the behavioral level [longer reaction times (RT) for detecting rare stimuli] in PIUs, and were associated with a reduced and delayed P300 component. The authors globally interpreted these deficits as reflecting memory impairments in PIUs, as P300 can be related to high-level cognitive abilities, including memory. However, due to the low sample size (10 PIUs and 10 matched controls) and the lack of control variables (psychiatric comorbidities, psychotropic medication, type of online activity concerned), these results have to be taken cautiously. In another study on a larger sample and with stronger control of comorbidities, Ge et al. (2011) provided a more detailed analysis of ERP evoked during an auditory oddball task, in which they reported measures for N1, N2, P2, P3a, and P3b. Results did not reveal deficits for amplitude in PIUs, but longer latencies were reported for the N2, P3a and P3b components, suggesting impaired attentional (N2–P3a) and working memory (P3b) abilities in PIUs. Unfortunately, this study did not specify the subtype of maladaptive pattern of Internet use presented by participants, and the electrophysiological recording method chosen was very far from established quality standards for ERP studies (as all components were measured on the same electrode, namely Cz). Importantly, while the authors interpreted P300 modifications as exclusively indexing memory dysfunctions, the oddball paradigm used did not require a strong memory load. As the P300 in oddball tasks has also been considered as reflecting other cognitive abilities (e.g., decision-making or inhibition stages) rather than being a pure measure of working memory, this deficit might also reflect more global impaired cognitive abilities in PIUs.

ERP studies also clearly showed that PIUs are impaired in prepotent response inhibition. On the one hand, two sources of data report congruent results concerning conflict monitoring deficits in problematic Internet use. The first was brought forward by studies that used Go/NoGo tasks (Dong et al., 2010; Zhou et al., 2010), i.e., tasks measuring response inhibition (e.g., Bari and Robbins, 2013), in which participants are required to produce a simple motor response when confronted with Go trials (e.g., the letter

Table 1
Description and main results of EEG studies in chronological order.

Reference	Population	Subtype of Internet behavior	Controls for comorbidities	Design	Results	Conclusion
Thalemann et al. (2007)	15 individuals with IGD (15 males; *M* = 28.75 years; ICM-10 and Questionnaire of Differentiated Assessment of Addiction) 15 HCs (15 males; *M* = 25.73 years)	Online videogames	Smoking and alcohol consumption	Passive perception of game-related or non-game-related pictures	B: No measure EEG: Increased LPC for game-related pictures	Increased sensitivity to addiction-related cues in IGD
Yu et al. (2009)	10 PIUs 10 HCs	Not specified	None	Auditory binary oddball paradigm	B: Longer RT ERP: Reduced P300 amplitude, longer P300 latency Reduced gamma-band activities (300 ms, parietal)	Problematic Internet use affects information coding and integration in the brain
Dong et al. (2010)	12 PIUs (12 males; *M* = 20.47 years; IAT ≥ 7) 12 HCs (12 males; *M* = 20.19 years; IAT < 4)	Not specified	Neurological or psychiatric disorders Psychological variables (Symposium Checklist-90 and 16PF)	Go/NoGo with letters	B: No significant difference EEG: Lower NoGo-N2 amplitude Higher NoGo-P3 amplitude, longer NoGo-P3 peak latency	Impairment of conflict detection ability in PIUs
Zhou et al. (2010)	26 PIUs 26 HCs	Not specified	None	Go/NoGo with 8 two-digit numbers	B: Higher impulsivity (BIS-11) Higher false alarm rate, lower hit rate EEG: Reduced NoGo N2 amplitude	Problematic Internet use is part of the compulsive-impulsive spectrum disorder
Dong et al. (2011b)	17 PIUs (17 males; *M* = 21.09 years; IAT ≥ 6) 17 HCs (17 males; *M* = 20.78 years; IAT < 4)	Not specified	Neurological or psychiatric disorders Psychological variables (Symposium Checklist-90 and 16PF)	Color-word Stroop task	B: Longer RT in incongruent conditions More response errors in incongruent conditions EEG: Reduced MFN deflection in incongruent conditions	Impairment of executive control ability in PIUs
Ge et al. (2011)	41 PIUs (21 males; *M* = 32.5 years; IAT ≥ 5) 48 HCs (25 males; *M* = 31.3 years)	Not specified	Excluded patients: 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 Patients with other Axis I comorbid disorders were not excluded	Auditory binary oddball paradigm	B: No measure EEG: Longer N2, P3a, P3b latencies Reduced P3a-P3b latencies after 3-month CBT (PIUs)	Longer latencies in Internet addiction is corrected after 3-month CBT
He et al. (2011)	14 PIUs (14 males; *M* = 20.5 years; mean IAT = 7.6) 14 HCs (14 males; *M* = 20.6 years; mean IAT = 1.8)	Not specified	PIUs: medications known to affect the central nervous system and dependency on tobacco, alcohol, drugs, or other substances HCs: current or past neurological or psychiatric illness	Passive visual detection paradigm	B: Target monitoring equally good in both groups EEG: Smaller P1 amplitude over the left temporal–occipital area Reduced difference in N170 amplitude between face and non-face-related information	PIUs have deficits in the early stage of face-perception processing

Table 1 (*Continued*)

Reference	Population	Subtype of Internet behavior	Controls for comorbidities	Design	Results	Conclusion
Littel et al. (2012b)	25 individuals with IGD (23 males; *M* = 20.52 years; Videogame Addiction Test) 27 HCs (10 males; *M* = 21.42 years)	Online videogames	Addictions (alcohol, smoking, illicit drugs)	Go/NoGo with letters	B: Faster RT on NoGo trials More errors on NoGo trials No speed-accuracy trade-off EEG: No differences on Pe and N2, P3 Reduced ERN amplitude	Increased impulsivity in IGD at self-reported, behavioral, and electrophysiological levels
Zhu et al. (2012)	39 PIUs in the "electroacupuncture (EA)" group (25 males; 20.98 years) 36 PIUs in the "psycho-intervention (PI)" group (27 males; 22.53 year) 37 PIUs in the "comprehensive therapy (CT = EA + PI)" group (27 males; 22.48 years)	Not specified			B: After treatment, all groups had lower Internet addiction score (even more in EA) and higher scores of short-term memory capacity span EEG: Delayed and enhanced P300 latency in the EA group and enhanced MMN in the CT group	Improvements of the cognitive function of PIUs by CT through a faster pre-attentive sensory discrimination (MMN) and a greater resource mobilization (P3) during information processing
Choi et al. (2013)	21 PIUs (12 males; *M* = 23.33 years; IAT ≥ 70) 20 HCs (11 males; *M* = 22.40 years)	Online videogames	4/21 PIUs fulfilled *DSM-IV* criteria for depressive disorder HCs: any psychiatric disorder Exclusion criteria for all subjects: head injury, alcohol or substance abuse, seizure disorder, and psychotic disorder	Resting-state EEG during eyes closed	B: High impulsivity (BIS-11) Impaired inhibitory control (stop signal task) EEG: Lower absolute power on the beta band Higher absolute power on the gamma band EEG activities significantly associated with severity of internet addiction and extent of impulsivity	Resting-state fast-wave brain activity is related to impulsivity in PIUs
Zhou et al. (2013)	23 PIUs (17 males; *M* = 25 years; Young's Diagnostic Questionnaire for Internet Addiction, YDQ) 23 HCs (17 males; *M* = 25 years)	Mixed (online videogames, web surfing, cybersex, social networking)	*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.	Modified Erikson flanker task	B: Faster RT More errors EEG: Reduced ERN amplitude at frontal and central sites	Reduced response monitoring and increased impulsivity in PIUs
Lee et al. (2014)	17 PIUs with depression (13 males; 21.24 years; IAT ≥ 70) 18 PIUs without depression (12 males; *M* = 23.44 years; IAT ≥ 70) 34 HCs (25 males; 23.59 years)	Online videogames	Exclusion criteria: injury, alcohol or substance abuse, seizure disorder, or psychotic disorder HCs and PIUs without depression: family history of depression	Resting-state EEG during eyes closed	B: Higher impulsivity (BIS-11) in PIUs with and without depression EEG: PIUs without depression: reduced absolute delta and beta powers in all brain regions PIUs with depression: increased relative theta and reduced relative alpha power in all regions	Decreased absolute delta and beta powers are neurobiological markers of problematic Internet use
Wang et al. (2014)	15 PIUs (14 years; Adolescent Pathological Internet Use Scale >3,15) 15 HCs (14 years; Adolescent Pathological Internet Use Scale < 3.15)	Not specified	Diseases of the brain, ingestion of stimulant medications that might influence brain function and prior participation in any similar EEG experiments Participants were left-behind children	Binary pain detection task on pictures	B: No measure EEG: No group differences on N1-LPC No differences in P2-N2 between pain and non-pain images in PIUs, but difference in controls	Reduced empathy for pain in PIUs

Table 1 (*Continued*)

Reference	Population	Subtype of Internet behavior	Controls for comorbidities	Design	Results	Conclusion
Duven et al. (2015)	14 individuals with IGD (14 males; *M* = 24.29 years; AICA-S, CSV-S) 13 HCs (13 males; *M* = 23.31 years)	Online videogames	Scl-90-r (Franke, 2002): no significant difference between groups on depressiveness	Reward-seeking computer game (token search)	B: Higher amount of computer gaming (AICA-S) Higher craving and cognitive involvement with computer games EEG: Longer N100 latency and increased N100 amplitude Reduced P200 and P300 amplitudes	Divergent processing of reward stimuli in IGD

Abbreviations: AICA-S, Scale for the assessment of Internet and computer game addiction (Wöfling et al., 2011b); B, Behavioral; CBT, cognitive behavioral therapy; CSV-S, Scale for the assessment of pathological computer-gaming (Wöfling et al., 2011b); ERN, error-related negativity; HCs, healthy controls; IAT, Internet Addiction Test (Young, 1998); IGD, Internet gaming disorder; LPC, late positive complex; MFN, medial frontal negativity; MMN, mismatch negativity; PIUs, problematic Internet users; RT, reaction time.

"X") while ignoring NoGo trials (e.g., the letter "O"). Using this paradigm, Zhou et al. (2010) and Dong et al. (2010) found that PIUs showed reduced N2 amplitude in NoGo trials as compared with healthy controls. According to Dong et al. (2010), the N2 component reflects an early sub-process of response inhibition, namely, conflict detection (see also Randall and Smith, 2011). The second source of evidence was furnished by Dong et al. (2011b), who recorded the medial frontal negativity (MFN) during the color-word Stroop test, centrally measuring conflict monitoring and response inhibition (MacLeod, 1991). In this paradigm, the MFN (occurring between 400 and 500 ms after stimulus onset) is supposed to reflect conflict detection, as its amplitude is increased for incongruent stimuli compared with congruent ones. PIUs showed longer RT than controls, more error responses and reduced MFN amplitude during incongruent trials. The authors also found a significant negative correlation between RT and MFN amplitude when considering all participants together. These results thus suggested that conflict monitoring ability is impaired in this population, which shows lower executive control abilities. On the other hand, Dong et al. (2010) also found an enhanced and delayed NoGo-P3 in PIUs compared with controls. Despite the absence of group differences regarding the error rates related to this Go/NoGo task, the authors interpreted this result as showing an impairment at a later stage of response inhibition (compared with an earlier deficit at the NoGo N2 level), namely, the evaluation of response inhibition (or the efficient response inhibition). Moreover, these studies did not mention the subtype of maladaptive pattern of Internet use included in their sample, only offered a limited control of psychopathological comorbidities and did not control for the influence of psychotropic medication. Furthermore, deficits of executive functions in PIUs are also suggested by modifications in error monitoring. A recent study by Zhou et al. (2013), proposing a stricter control of psychiatric and neurological comorbidities, found a reduced amplitude of the fronto-central error-related negativity (ERN) in PIUs as compared with controls during a modified Eriksen flanker task (based on the processing of a central stimulus while ignoring congruent or incongruent flankers, and repeatedly used to measure inhibitory control in addictive states, Luijten et al., 2014). Higher error rates were also observed in PIUs, thus suggesting an increased impulsivity in this group, but as PIUs also presented faster RT, these results might index a speed-accuracy trade-off rather than a genuine inhibition impairment (Luijten et al., 2014). As no reliable measure was proposed in this study regarding the intensity of the maladaptive pattern of Internet use and the presence of behavioral impulsivity, it regrettably did not allow to explore the specific influence of these variables on electrophysiological results, and error monitoring modifications could thus be partly related to unmeasured psychological or cognitive factors unrelated to Internet-related activities.

As a whole, results obtained from the assessment of self-control abilities in PIUs could thus be interpreted as revealing a general pattern of executive impairment in this population, a lack of cognitive inhibition, and more specifically an impaired behavioral monitoring and self-error detection. However, contrasting results have been observed by Littel et al. (2012b), as these authors, though confirming the reduced amplitude of the ERN and showing higher behavioral error rates for NoGo stimuli in PIUs, showed preserved ERP correlates of response inhibition (NoGo N2-P3), whereas deficits of these components have been reported in impulsive–control and addictive disorders (Morie et al., 2014; Petit et al., 2014). Nonetheless, it should be noted that Littel et al. (2012b) tested a specific subpopulation of PIUs (namely, excessive online gamers), suggesting that a different pattern of results could emerge in accordance with subcategories of maladaptive pattern of Internet uses. Despite this interesting focus on a specific subtype of problematic Internet use, Littel et al. (2012b) did not control for the presence of other substance-related or behavioral addictive states, which could have strongly influenced the link between excessive Internet use and error monitoring. Moreover, this study did not report a specific analysis of the post-error responses, which might have offered a complementary view on the error monitoring modifications observed in PIUs (e.g., increased attention for the trials immediately following an error). In a recent study, Choi et al. (2013) investigated EEG resting state in PIUs and observed differences from healthy controls in fast-wave brain activity, i.e., decreased absolute power in the beta band, which has previously been related to impulsivity in patients with attention deficit hyperactivity disorder (Snyder and Hall, 2006), and increased absolute gamma band power, usually associated with impulsivity or impaired response inhibition (Barry et al., 2010; Romer Thomsen et al., 2013). As this first study did not efficiently control for comorbid depressive state, the same team (Lee et al., 2014) replicated this experiment to assess the impact of comorbid depression in the results observed for PIUs, by comparing EEG resting-state activities between depressed PIUs, PIUs without comorbid depression, and matched healthy controls. They replicated their results by showing that PIUs without depression had lower absolute beta power than controls; they also found that these participants had lower absolute delta power than controls and depressed PIUs in all brain regions. Conversely, depressed PIUs had increased relative theta and decreased relative alpha power in all regions as compared with the other groups. This led to the conclusion that comorbid depression in problematic Internet use may be associated with increased slow-wave activities, whereas decreased absolute delta and beta powers may constitute the neurobiological markers that differentiate pure problematic Internet use from comorbid states. To sum up, data concerning the reflective system show that PIUs could be, in line with what has been described for substance-related addiction and gambling disorders, characterized as presenting a "loss of control". Indeed, the most reliable results in this field is the presence of control monitoring difficulties, which appear to be present in different subtypes of problematic Internet uses including online gaming (Littel et al., 2012b) but also cybersex and web surfing (Zhou et al., 2013).

Moreover, as mentioned earlier, several studies have also revealed deficits in PIUs that can be related to the automatic–affective system described by dual-process models. In particular, Thalemann et al. (2007) showed that excessive online gamers, in comparison to casual gamers, presented an increased sensitivity to Internet-related cues (but not to non-Internet-related and alcohol-related pictures). This was revealed by an increased amplitude of the late positive complex (LPC) at parietal sites when participants were specifically confronted with game-related screenshots, which replicates earlier studies in substance-related dependence (e.g., Dunning et al., 2011) and gambling disorders (e.g., Wolfling et al., 2011a). It has been supposed that the LPC component is functionally equivalent to the P300 component in that it reflects the activation of processing resources (Kok, 1997). In this experimental context, the LPC may reveal a modified affective and motivational appraisal of the stimuli, suggesting that Internet-related cues lead to a conditioned emotional arousal in problematic online gamers. It should nevertheless be underlined that, as this study used a paradigm based on passive viewing without specific task to perform, the actual psychological and cognitive activities presented by each participant during the experiment (e.g., mind-wandering) remained uncontrolled, and group differences might thus be partly related to these uncontrolled cognitive processes.

This increased sensitivity to disorder-related stimuli in PIUs appears to be concomitant with a reduced sensitivity toward other types of rewarding cues in this population. This conclusion can be drawn from the results of the study conducted by Duven et al. (2015), who compared patients presenting Internet gaming disorder with casual online gamers in a task consisting in a computer game in which the participants had to find tokens. Responses of problematic online gamers were characterized by a delayed and enhanced N100, as well as a reduced P200 and P300. Given that facilitated processing of stimuli by multimodal presentation (Stekelenburg and Vroomen, 2007; van Wassenhove et al., 2005) has been associated with shorter peak latencies and smaller amplitudes (Stekelenburg and Vroomen, 2007; van Wassenhove et al., 2005) and that an enhanced N100 is thought to reflect enhanced attention toward the stimulus (Van der Lubbe et al., 2012), Duven et al. (2015) concluded that problematic online gamers needed more capacity for the initial orienting toward rewards that were not directly related to their disorder (as the game did not involve typical video game-related stimuli, such as game screenshots, but rather low-motivating stimuli, i.e., tokens). Conversely, reductions in the amplitudes of later components, notably P300, might reveal decreased sensitivity toward rewards (Wu and Zhou, 2009), in which problematic online gamers engage less resources than do casual gamers, suggesting a reduced arousal toward non-gaming-related cues. Here again however, the absence of control for sensory-motor and cognitive abilities across groups does not allow to exclude that some of the differences observed between groups at the electrophysiological level are due to variations in baseline visuo-spatial, motor or attentional abilities involved in this high-demanding task.

Interestingly, Wang et al. (2014) have also shown that the affective processing of negative stimuli is impaired in young PIUs. These authors used a binary decision task that required participants to detect the presence or absence of pain in pictures; they found that PIUs did not present an increased amplitude of the N2–P2 for pain stimuli compared with non-pain stimuli, as observed among controls. Thus, contrary to the results observed for reward stimuli with problematic online gamers, the initial orienting toward stimuli and the later activation of resource processing were not affected during pain processing. Yet, the authors surprisingly concluded that the cognitive processing of pain and the empathy for pain were impaired in PIUs. This unjustified conclusion is further challenged by the very specific population chosen (left-behind Chinese teenagers, presenting large-range psychopathological comorbidities which have been only partly controlled for), hampering any generalization toward a more global population of PIUs. Finally, He et al. (2011) used a passive visual detection paradigm in PIUs to assess early perceptual steps in the processing of facial stimuli, a critical feature in human social interactions. First, the authors observed that the P1 amplitude, both for faces and non-face-related information (i.e., pictures of tables), was significantly reduced in left occipito-temporal areas in PIUs as compared with controls. This result suggests that early visuospatial processing could be disrupted in PIUs. Then, when comparing the N170 amplitude between face and non-face-related information, the authors found a reduced N170 face effect in PIUs compared with controls. This suggests that the visual expertise stage of information processing may also be impaired in PIUs. The poor matching between experimental (pictures of faces) and control (pictures of tables) stimuli regarding perceptual complexity however weakens this conclusion, as group differences on the N170 might also be explained by differences in complex stimuli processing rather than in visual expertise for faces per se. These results nevertheless led the authors to conclude that the processing of social stimuli could be altered in PIUs, and that social impairments observed in this population could be due to defects arising as early as the perceptual steps of information processing.

Despite these encouraging results, it has to be underlined that the current data regarding the affective-automatic system remain highly scarce. The two latter mentioned studies (He et al., 2011; Wang et al., 2014) have explored the affective part of this system but in a greatly indirect way: empathy for pain and passive viewing of emotional faces can indeed not be considered as directly measuring emotional abilities, and this subsystem should thus be more thoroughly and specifically explored. Concerning the automatic subsystem, a strength of the available results (Duven et al., 2015; Thalemann et al., 2007) is that they are based on strongly established paradigms (cue-reactivity and reward processing) and on valid ERP measures, but they only offer partial electrophysiological confirmation of the over-activated automatic processing of addiction-related stimuli. The very limited number of studies and their heterogeneity regarding experimental population and procedure do not allow formulating strong assumptions concerning the modifications related to the automatic–emotional system in PIUs.

Beyond the usefulness of EEG, and particularly ERP, to identify impairments in patients, their use as a fully-fledged tool in the treatment of psychiatric diseases is currently a focus of attention (Campanella, 2013). This is also already the case in the field of problematic Internet use, as recent studies used ERP recordings to assess the possible benefits of clinical interventions. Indeed, effects of three-month cognitive behavioral therapy have been evaluated through P3a and P3b measurements (Ge et al., 2011). Results have shown that the latencies of these components were reduced in patients after therapy (suggesting a putative electrophysiological effect of this rehabilitation technique), but the absence of control group do not allow to exclude an influence of spontaneous recovery (independent from therapeutic intervention) on the ERP modifications observed. Moreover, Zhu et al. (2012)

assessed the impact of therapy that combined electroacupuncture and psycho-intervention; they were notably able to relate observed cognitive improvements to changes in the mismatch negativity and P3 components. These results clearly suggest that electrophysiological tools might offer promising ways to reliably evaluate the efficiency and brain correlates of psychological, medical, or pharmacological interventions for problematic Internet use. However, these studies offered very few details regarding the characteristics of the clinical programs applied (e.g., content of therapeutic sessions, specific cognitive, motivational or affective processes targeted), and surprisingly omit to mention the actual effect of these programs on problem-related behaviors (e.g., frequency and intensity of Internet use) and psychological variables (e.g., well-being, anxiety or depression) as well as their relations with ERP modifications. It is thus impossible, on the basis of these preliminary studies, to determine the causal links between therapeutic interventions, ERP changes and problematic Internet use evolution. Moreover, the ERP design used appear very vague (unstandardized acquisition procedure, low number of electrodes used in ERP analyses, and unusual statistical processing), and the lack of control for psychopathological comorbidities hamper to actually conclude that the electrophysiological modifications observed can indeed be attributed to the treatment proposed (or at least partly to spontaneous changes in comorbid states or neurocognitive functions).

As a whole, the large majority of EEG studies in PIUs have investigated the reflective system, which is involved in the cognitive evaluation of the stimuli initiating controlled, deliberate responses through the assessment of long-term consequences. These studies have found deficits of decision-making abilities in PIUs, indexed by P3 alterations (Ge et al., 2011; Yu et al., 2009), which can be linked to self-control impairments, at least at two levels: (1) inhibition, both for conflict detection [indexed by N2 (Dong et al., 2010; Zhou et al., 2010) and MFN (Dong et al., 2011b) changes] and for response evaluation [evidenced by NoGo-P3 (Dong et al., 2010) modifications]; and (2) error monitoring [reflected by ERN impairments (Littel et al., 2012b; Zhou et al., 2013)]. Conversely, few EEG studies on problematic Internet use have investigated the automatic–affective system, which is involved in the emotional evaluation of the stimuli and the initiation of automatic–appetitive responses based on associative learning (stimulus-response link). Modifications have been demonstrated for the processing of (1) Internet-related cues, indexed by increased LPC (Thalemann et al., 2007); (2) negative stimuli, reflected by changes in N2–P2 during pain processing (Wang et al., 2014); (3) positive stimuli, shown by N100–P200–P300 modifications during reward processing (Duven et al., 2015); and (4) social stimuli, shown by alterations of P1 and N170 in response to faces (He et al., 2011). These initial results are globally consistent with observations obtained in addictive behaviors, indicating that (1) salience attribution to Internet-related cues is increased (Field et al., 2013); (2) sensitivity to natural rewards is decreased, notably in gambling disorder (Sescousse et al., 2013); and (3) there are strong impairments in the processing of emotional and interpersonal stimuli (D'Hondt et al., 2014a).

PIUs thus appear to display impairments of both systems involved in decision making, according to the dual-process models. These results are congruent with recent addiction models and further suggest the possibility of an imbalance between these two systems. However, available data have to be considered as very preliminary, as the current literature suffers from strong methodological limitations, notably low sample sizes and questionable use of electrophysiological tools (e.g., low number of electrodes used in ERP analysis, use of experimental designs not adapted to ERP, atypical analyses of EEG data). Centrally, the heterogeneity of problematic Internet use should be far more taken into account in future works. Indeed, as illustrated in Table 1, studies have up to now chosen to promote a global approach of maladaptive pattern of Internet use (as more than the half of the studies reviewed did not mention the subtype of Internet-related behavior in their sample) or to focus on a specific activity (namely online gaming). These variations across the samples included led to contradictory results regarding the core processes involved, for example regarding inhibitory processes where opposite observations have been made between participants with unspecified Internet maladaptive pattern (Dong et al., 2010, 2011b; Zhou et al., 2010) and online gamers (Littel et al., 2012b). An experimental and theoretical switch should thus be rapidly performed to go beyond the consideration of maladaptive pattern of Internet use as a unitary phenomenon and to explore the commonalities and differences across problematic Internet use's sub-categories, as underlined in the following section.

4. Perspectives for future research

4.1. Identifying vulnerability markers and measuring early consequences

Earlier studies focused on populations presenting installed problematic Internet use and provided the first insights regarding cerebral correlates of extreme Internet habits. However, they totally neglected the exploration of early problematic Internet use and of the brain modifications already present at the beginning of the maladaptive pattern, particularly in youth. A first perspective is thus to use electrophysiological techniques among at-risk people or young people presenting problematic Internet use to explore maladaptive pattern's early markers and answer two crucial questions.

First, are ERP a useful predictive tool for the development of problematic Internet use and what are the electrophysiological risk markers of this maladaptive pattern? Some risk factors might be identifiable before problematic Internet use or even before any excessive Internet use, thus offering new avenues for early therapeutic interventions. However, such risk factors remain unrevealed in behavioral addictions and ERP studies might help their identification, particularly regarding the role of electrophysiological biomarkers in substance addiction. Indeed, heritability of substance addiction is high (Kendler et al., 2008), particularly in alcohol-dependence where clear ERP vulnerability markers have been identified. More specifically, at-risk individuals (children of alcohol-dependent parents) present P300 modifications before any personal alcohol consumption (Porjesz et al., 2005), P300 thus being considered a reliable alcohol-dependence endophenotype (Singh and Basu, 2009). As P300 is impaired in problematic Internet use, it might constitute a biomarker of this maladaptive pattern, but no electrophysiological study has been conducted in at-risk populations (i.e., children of PIUs) or among children at early stages of Internet use. Future ERP studies should thus identify the electrophysiological vulnerability indexes of Internet use.

Second, does problematic Internet use lead, before any detectable behavioral effect, to early brain modifications which might increase vulnerability? The cognitive consequences of problematic Internet use are usually explored by neuropsychological testing (Brand et al., 2014). Such approach has been applied in substance addictions to explore their long-term effects, but also to specify the early cognitive consequences of addiction. For example, binge drinking, considered a potential first step toward alcohol-dependence, is associated with neuropsychological deficits for attention and memory (Hermens et al., 2013). Interestingly, this behavioral exploration has been extended by electrophysiological studies (Crego et al., 2010; Maurage et al., 2009) showing that binge drinkers present altered ERP components (particularly the

P300) before any detectable cognitive impairment. These studies offered decisive fundamental (by clarifying the roots and early consequences of addictive states) and clinical (by promoting the rehabilitation of these early cognitive deficits) contributions. Such combined neuropsychological–electrophysiological approach might thus identify the early consequences of excessive Internet use and detect the electrophysiological modifications related to problematic Internet use appearing before any notable behavioral change.

In summary, this first perspective proposes a thorough electrophysiological investigation of two still unexplored stages of problematic Internet use related to (1) the identification of vulnerability biomarkers present before the appearance of problematic Internet use among at-risk children; (2) the detection of early brain consequences among young people starting excessive Internet use. Finally, ERP studies should develop longitudinal explorations to determine the causal link between electrophysiological modifications and problematic Internet use, and answer the following question: Are the electrophysiological deficits in PIUs due to the brain consequences of excessive Internet use or do they index the cerebral modifications preceding or facilitating the development of this maladaptive pattern?

4.2. Determining low-level cognitive impairments

As high-level cognitive impairments (particularly for executive functions) are considered as a hallmark of problematic Internet use, earlier electrophysiological explorations mostly explored the ERP related to decision making (P300), inhibition (MFN, NoGo N2), error monitoring (ERN), and motivational treatment (LPC). This focus however left other cognitive stages almost entirely unexplored, notably those related to early stimuli processing steps. Only four studies have explored early visual or auditory processing, reporting contradictory results: Increased amplitude and delayed latency for visual N1 in PIUs were recently described (Duven et al., 2015), whereas earlier studies reported preserved visual (Wang et al., 2014) and auditory (Ge et al., 2011) N1. Moreover, He et al. (2011) found a reduced P1 amplitude and N170 face amplitude effect in PIUs. The current lack of knowledge on these early perceptive and attentional processes is problematic, as they constitute an essential preliminary step for conducting efficient higher level cognitive steps. Future ERP studies should thus clarify the potential impairments of early stimulus processing among PIUs.

Indeed, ERP technique possesses a high temporal resolution, allowing the detailed investigation of successive cognitive steps. Stimulus processing can be globally separated into three successive steps: stimulus perception, attribution of attentional resources and decision making (Rugg and Coles, 1995). An impairment in the early steps hampers the correct execution of subsequent ones (Luck and Kappenman, 2013). Interestingly, electrophysiological deficits in early perceptive (N1–P1) and attentional (N2–P2) stages have been identified in many psychiatric disorders like schizophrenia (Campanella and Guerit, 2009) and in substance-related addiction like cocaine addiction (Bauer and Easton, 1996) or alcohol-dependence (Cadaveira et al., 1991), these low-level deficits influencing the impairment found in later stages (D'Hondt et al., 2014b; Maurage et al., 2007). Evaluating these first processing steps is thus crucial to correctly interpret higher-level deficits: The deficits observed earlier in problematic Internet use for the electrophysiological components related to high-level cognitive functions might partly result from impaired perceptive-attentional stimulus processing rather than from a deficit of these high-level stages per se.

Exploring early processing stages might also be useful for deepening the understanding of attentional biases in PIUs. Neuroimaging studies have identified a specific sensitivity toward addiction-related cues among PIUs, associated with limbic-striatal over-reactivity (Han et al., 2011; Ko et al., 2013; Park et al., 2010). This hypersensitivity has been related to attentional biases (i.e., the preferential processing of disease-related stimuli), which have been widely explored in anxiety (Hope et al., 1990; Mathews and MacLeod, 2002), substance addiction (Field and Cox, 2008) and gambling disorders (Brevers et al., 2011), and are known to play a role in the development and maintenance of psychiatric disorders (Amir et al., 2008; Wiers et al., 2013). However, ERP correlates of attentional bias have been explored in only one study in PIUs, focusing on online gamers (Thalemann et al., 2007). Further exploration is thus needed to understand the brain correlates of this preferential processing for online activity-related stimuli. ERP could particularly clarify whether attentional biases are mostly related to increased basic perceptive processing (e.g., higher general arousal toward these stimuli), biased attribution of attention (e.g., automatic mobilization of attentional resources by these stimuli), and/or higher level cognitive modifications (e.g., increased mnesic activation or reduced inhibition toward these stimuli).

In conclusion, upcoming ERP studies should thus explore perceptive and attentional processes in PIUs to determine their involvement in high-level cognitive deficits and the presence and nature of attentional bias.

4.3. Renewing the investigation of core symptoms

As reviewed above, while EEG studies suggest that both systems postulated by dual-process models (Dong and Potenza, 2014) are impaired in PIUs, most earlier works have focused on the reflective system. It thus appears urgent to deepen the electrophysiological exploration of the automatic–affective system and of its interactions with the reflective one. The automatic–affective system can actually be divided in automatic (associated with response to stimuli that acquired positive or aversive value through learning) and affective (ensuring core emotional decoding) subsystems (Bechara, 2005; Bechara and Damasio, 2005). Concerning the automatic subsystem, the previous section already stressed the need to determine the brain correlates of disorder-related stimuli preferential processing. Concerning the affective subsystem, future studies should determine which level of affective processing is impaired in PIUs.

Indeed, emotional effects are influencing the successive EEG processing steps, particularly for visual perception. These emotional modulations start at perceptive stage (P1, Olofsson et al., 2008; Vuilleumier and Pourtois, 2007) where they are thought to be driven by rapid analysis of coarse visual information (Alorda et al., 2007; Pourtois et al., 2005; Vlamings et al., 2009), particularly in peripheral vision (Bayle et al., 2009; D'Hondt et al., 2013; Rigoulot et al., 2011; Rigoulot et al., 2012). Emotional pictures also elicit an early posterior negativity (EPN, Flaisch et al., 2008; Junghofer et al., 2001; Schupp et al., 2003; Schupp et al., 2004) which is proportional to pictures' arousal level (Boucher et al., 2015; D'Hondt et al., 2010; Peyk et al., 2008; Schupp et al., 2006) and reflects automatic "natural selective attention" (Olofsson et al., 2008). Exploring EPN in PIUs could thus clarify the cerebral correlates of the affective system. Emotional modulations are also detected for P300 (Hajcak et al., 2010; Olofsson et al., 2008): P3a and P3b amplitudes are increased by unpleasant or arousing pictures (Delplanque et al., 2006). This result has also been reported for the late positive potential, related to memory formation (Hajcak et al., 2010; Olofsson et al., 2008). As a whole, studying affective processing in PIUs by ERP would determine whether defects in the processing of emotional and/or disorder-related stimuli occur at perceptual, attentional or memory levels.

As cognition and emotion constantly interact (Pessoa, 2013), future ERP studies should go beyond the independent exploration of the two systems to evaluate their interactions, which are critical for adaptive decision making (Mukherjee, 2010). First, several gambling tasks are particularly adapted to study these interactions, notably the Iowa gambling task (IGT; Bechara et al., 1994) and the balloon analogue risk task (BART; Lejuez et al., 2002). These tasks allow the investigation of two main successive ERP components related to feedback processing (which is critical for adaptive decision making, Cui et al., 2013; Kobor et al., 2015): (1) Feedback-related negativity (FRN), sensitive to the delivery of unpredicted reward or negative outcome (Holroyd et al., 2003; Pfabigan et al., 2011). The FRN has been used as an index of sensitivity to reward expectation (Euser et al., 2011; Franken et al., 2010; Munoz et al., 2012) or outcome evaluation (Euser et al., 2013; Fein and Chang, 2008) in the addiction domain, but it may reflect the detection of an error in reward prediction or of salience prediction errors (Hauser et al., 2014; Parvaz et al., 2015; Talmi et al., 2013). The FRN might constitute a potential biomarker in psychopathology (Talmi et al., 2013), as it is enhanced in individuals with higher executive performance (Kobor et al., 2015); (2) P3, that is supposed to reflect a higher level of feedback processing or the cognitive evaluation of overall salience (Wu and Zhou, 2009). The reduction of this component might be a vulnerability marker for substance abuse (Euser et al., 2013). Future studies should thus investigate FRN-P3 modifications in PIUs during feedback processing following risky decision making. Second, new experimental strategies could be developed to explore systems' interactions in PIUs. Future ERP studies should investigate interactions between affective processing and (1) attention, using the emotional Stroop task (Gonzalez-Villar et al., 2014; Williams et al., 1996); (2) conflict monitoring, using the emotional Go/NoGo paradigm (Messerotti Benvenuti et al., 2014); (3) error monitoring, using face or word emotional flanker tasks (Kanske and Kotz, 2011; Munro et al., 2007); and (4) working memory, using an emotional N-back task based on verbal or spatial working memory (Li et al., 2006).

To summarize, the reflective system is clearly impaired in PIUs, but data remain sparse concerning the automatic–affective system and nonexistent concerning systems' interactions. Several already existing tasks or adaptations of validated tasks appear relevant for an in-depth exploration of these two facets, and particularly for determining whether PIUs are characterized by an imbalance between systems, which is at the heart of addiction. Ultimately, such research is necessary to clarify whether PIUs can be considered within the spectrum of addictive disorders.

4.4. Understanding maladaptive pattern heterogeneity, comorbidities, and the links with addiction

PIUs subtypes share commonalities [e.g., search for anonymity, avoidance of real-life interactions, obsessive thoughts when offline (Winkler et al., 2013)] but are distinguishable at various cognitive and psychological levels. A current challenge is thus to explore this heterogeneity by determining the commonalties and discrepancies between these sub-categories (Billieux et al., 2015d; Robbins and Clark, 2015) and by identifying the influence of psychopathological comorbidities (Cash et al., 2012). Another crucial question is related to disentangling the neuropsychobiological processes that PIUs share with other behavioral or substance-related addictions, as they frequently co-occur (Kuss et al., 2014).

PIUs subtypes are underlain both by shared risk factors (involved in all problematic online activities, e.g., poor executive control) and by specific risk factors (involved in the etiology of certain problematic online activities, e.g., social skills impairment). Dysfunctional online behaviors thus constitute a related but distinct spectrum of maladaptive patterns, rather than a unitary "Internet addiction" (Billieux, 2012; Starcevic, 2013). These behaviors seem to share a common background (particularly executive control deficits), but also present fundamental differences regarding motivations (e.g., social affiliation, achievement, immersion, escapism), preferential stimuli, and interpersonal difficulties (Aboujaoude, 2010; Billieux et al., 2013; King and Delfabbro, 2014). However, these differences should be directly tested by comparing larger samples of diverse PIUs subtypes (e.g., cybersex, online games, social networking), notably at the electrophysiological level. Indeed, as ERP are efficient to detect subtle impairments in general problematic Internet use, they could help going beyond this first step by identifying the common and distinct brain correlates of PIUs subtypes. It might for example be hypothesized that PIUs with strong cognitive demands (e.g., competitive multiplayer online gamers) will present fewer deficits in high-level cognitive ERP components than PIUs with low cognitive involvement (e.g., social network excessive use). Another hypothesis might be that the ERP correlates of attentional biases will be more marked in habits with specific visual stimulations (e.g., sex pictures for cybersex or game screenshots for videogame, Brand et al., 2011) than in behaviors unrelated to such precise stimuli (e.g., online chatting or web browsing).

Concerning comorbidities, the limited control offered in earlier studies for these psychopathological states hampers to precisely distinguish, in the deficits presented by PIUs, the specific contribution of problematic Internet use from the global influence of these comorbidities. Problematic Internet use indeed often jointly occurs with depression (Bernardi and Pallanti, 2009), general anxiety (Ko et al., 2012) or social anxiety (Weinstein et al., 2015), which influence cognitive and cerebral processing (Hansenne, 2000). For example, the deficits for high-level components (P300, ERN, LPC) in PIUs might result from co-occurring anxious or depressive states, strongly modulating these waves (Pogarell et al., 2007). Future studies should thus control these psychopathological comorbidities to ensure that the deficits emphasized are genuinely related to problematic Internet use. A further step, already initiated (Lee et al., 2014), is to directly compare "pure" PIUs with PIUs also presenting comorbidities. Such approach has been conducted in other addictions, where it allowed the disentanglement of specific consequences of addictive disorders from those due to comorbidities (Maurage et al., 2008).

Concerning the frequent presence of other addictive states among PIUs, the dominant diagnosis-focused approach led to a separate exploration of the cerebral correlates related to each condition. This approach is now outdated as addictive comorbidities are very frequent in psychiatric disorders (Widiger and Samuel, 2005), particularly in problematic Internet use (Grusser et al., 2005; Wood et al., 2004). An alternative to the diagnosis-focused perspective is the transdiagnostic approach (Kinderman et al., 2013) focusing on psychological processes rather than on diagnoses. ERP, by allowing the exploration of specific cerebral processes independent of the related diagnosis, are useful to promote this paradigmatic change in addiction. Earlier studies in PIUs have suggested that this condition shares crucial cognitive deficits with addiction (e.g., impaired inhibition), and future explorations could use ERP to explore the common cerebral deficits involved in various types of addictions.

As a whole, problematic Internet use has been mostly considered a unitary and isolated clinical entity in earlier ERP studies, but future studies should explore (1) the heterogeneity of PIUs by clarifying the convergences and divergences between their subtypes; (2) the influence of psychopathological comorbidities; and (3) the links between problematic Internet use and other addictive disorders, in a transdiagnostic framework focusing on psychological processes (Billieux et al., 2015a).

4.5. Toward a combined use of EEG and fMRI

The current limits related to the available neuroimaging and electrophysiological literature mentioned above lead us to propose three main new research avenues in problematic Internet use. First, several important methodological limitations related to earlier studies should be further considered. Almost all neuroscience studies in the field were based on a cross-sectional design. As mentioned in the Introduction section, this hampers to clearly establish the causal link between problematic Internet use and brain modifications (Starcevic, 2015) and may contribute to a publication bias, minor brain differences being invalidly interpreted as resulting from excessive Internet use. Future studies should thus use longitudinal research designs in order to investigate the direction of these relations, even if this method does not totally rule out possible third-variable effects. Another methodological limit is that, among the neuroimaging and electrophysiological studies reviewed in this paper, none has considered the brain influence related to the repeated practice of the behaviors associated with problematic Internet use. It can indeed be hypothesized that PIUs develop perceptive and motor expertise related to their Internet use. The neural plasticity following this specific learning (Debarnot et al., 2014), which has been frequently observed in other repeated behaviors [e.g., following sport (Hanggi et al., 2015) or music (Bengtsson et al., 2005) training], is a possible confound when exploring brain modifications in PIUs, and it should thus be considered in future studies. Preliminary studies have found that action video game experience affects oculomotor control (West et al., 2013), which further stresses the need to investigate probable low-level motor and perceptive brain modifications that could be attributed to practice or expertise rather than to problematic Internet use per se. The effects of these possible practice-induced brain changes on both systems postulated by dual-process models should also be investigated.

Second, the large majority of studies reviewed in the present paper reported group differences, but it can be proposed that the magnitude of the differences may present large individual variations across PIUs, and it thus appears important to consider reported group results with caution. The large heterogeneity of activities associated with problematic Internet use and the lack of firm diagnostic criteria have already been underlined, both aspects being potential sources of variability in the results. Moreover, as noted by Starcevic (2015) concerning the study by Seok et al. (2015), there is sometimes a large variability regarding the frequency and intensity of Internet use among participants included in a same group of PIUs. One important mean to consider this probable variability is to perform individual analyses. Relevance of this strategy for addictive states has been illustrated in a recent study by Maurage et al. (2015), in which the authors found significant group differences on two false belief tasks, alcohol-dependent individuals presenting “Theory of Mind” difficulties as compared to healthy controls. However, when performing individual analyses, this deficit was only present in less than half of the alcohol-dependent patients. Similarly, a study on pathological gambling (Billieux et al., 2012) using both between-groups (i.e., case-control) and intra-group (i.e., within the pathological gamblers) analyses revealed that only 40% of pathological gamblers displayed an actual impairment on a laboratory task measuring inhibitory control, despite an overall statistically-significant group impairment. These results clearly illustrate the inter-individual variability regarding cognitive and emotional deficits in patients presenting excessive behaviors, and the need to go beyond the mere observation of group differences.

Third, beyond the separated use of neuroimaging and electrophysiology to explore the brain correlates of problematic Internet use, future studies should also try to combine EEG and fMRI in a same experimental design. The combination of these methods appears to be a methodological challenge that has been overcome, as several EEG systems now allow to perform electrophysiological recordings in a magnetic environment. Furthermore, analyses strategies have been developed to correct the artifacts induced by the MRI environment on EEG recordings. Simultaneous EEG-fMRI is thus a promising method to simultaneously benefit from two efficient and complementary neuroscience methods. On the one hand, EEG allows direct measurement of brain functioning with high temporal resolution. On the other hand, fMRI provides an indirect assessment of brain activity with high spatial resolution through the investigation of hemodynamic changes. Even if methods of analysis are still under development, simultaneous EEG-fMRI recording is notably useful to unravel brain network structure and functioning associated with different sensory, motor and cognitive processing in healthy and clinical populations (Mulert, 2013; Murta et al., 2015). Applied to the investigation of problematic Internet use, this method would help to evolve toward a more integrated view of brain functioning in PIUs. In particular, it may be a good way to clarify the current controversies between electrophysiological and neuroimaging results (e.g., delayed or reduced ERP components but increased activity observed by means of fMRI), by directly exploring the relations between structural and functional impairments in PIUs.

4.6. Renewing the therapeutic approach

ERP might also constitute an efficient tool to improve treatment in PIUs. Current therapeutic approaches focus on pharmacological treatments [using antidepressants (Dell'Osso et al., 2008; Han et al., 2010) and psychostimulant drugs (Han et al., 2009)] or psychological rehabilitation [cognitive–behavioral therapy (Bai and Fan, 2007; Cao et al., 2007b; Young, 2007) and/or social skills training (Shek et al., 2009)]. Prophylactic interventions improving the control of Internet use among adolescents have also been tested (Du et al., 2010). A recent meta-analysis (Winkler et al., 2013) showed that these treatments significantly decrease the time spent online and/or increase psychological or social well-being, but also underlined that the methodological limits and the heterogeneity of treatments currently hamper to definitely establish the efficiency of these treatments. Despite the potential interest of electrophysiological techniques for treatment has been entirely ignored in previous reviews (King et al., 2011; Peukert et al., 2010; Winkler et al., 2013), ERP could constitute a promising clinical tool in PIUs.

First, ERP could be used to individualize neuropsychological interventions among PIUs. Indeed, the available psychological treatments merely apply cognitive–behavioral or social skill programs initially developed in other addictions and do not focus on the specific cognitive deficits impaired in PIUs [e.g., executive control or error monitoring (Brand et al., 2014)]. Neuropsychological programs rehabilitating these specific abilities should thus be developed [as recently proposed in addiction (e.g., Houben et al., 2011)], and ERP might be helpful to further spot impaired processing stages. ERP could also help individualizing treatment: As cognitive impairments are heterogeneous in PIUs, individually measuring their ERP correlates would help to focus rehabilitation programs on the exact deficits presented by each patient, thus leading to tailored therapeutic intervention.

Second, electrophysiological techniques might index the efficiency and long-term effect of therapeutic interventions, as illustrated by two studies mentioned above (Ge et al., 2011; Zhu et al., 2012). The temporal precision of ERP recordings could be used to extend this approach by determining the effect of a specific intervention on a specific process. For example, a test–retest measure of the error monitoring (ERN) or impulsivity (P3b) ERP components would offer a precise evaluation of neuropsychological rehabilitation focused on these processes. More generally, combining electrophysiological and neuropsychological measures to improve specific cognitive functions constitutes a promising tool, as proposed in other psychiatric conditions (Campanella, 2013).

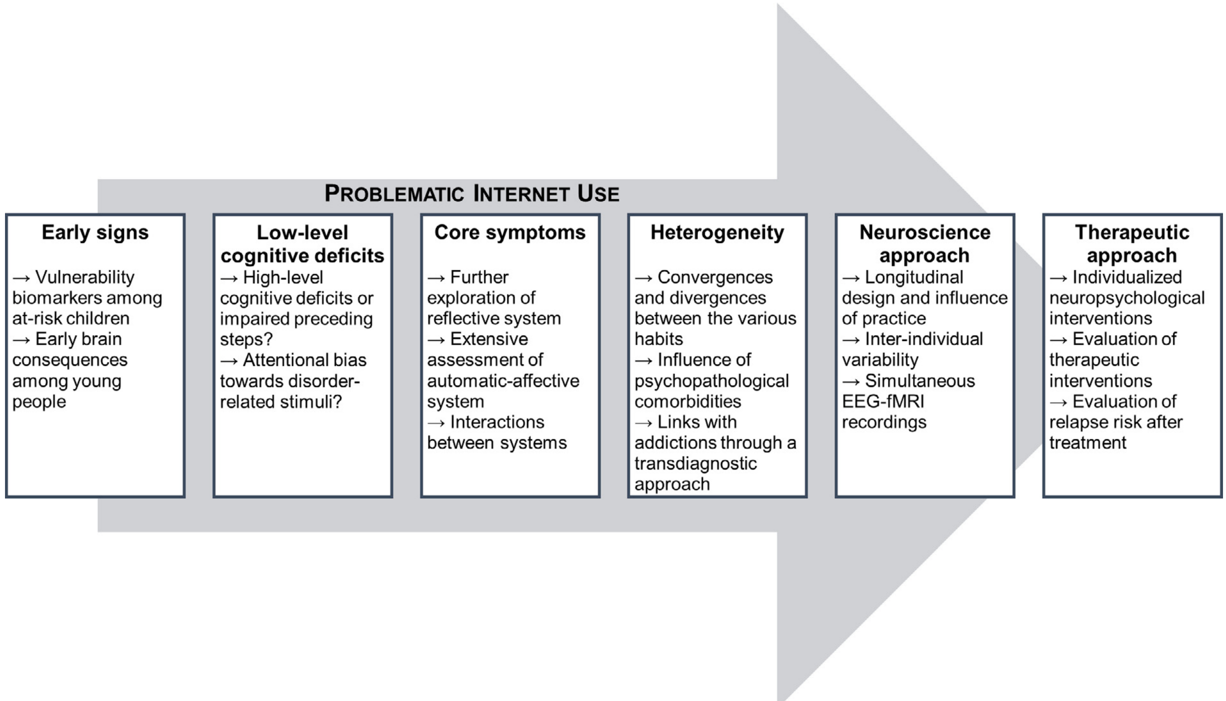

Fig. 1. Schematic illustration of the main research avenues proposed for future EEG research in the domain of problematic Internet use.

Third, ERP measures might evaluate relapse risk after treatment. Neuroimaging studies have used volumetric measures of the medial frontal cortex to predict relapse in alcohol-dependence (Rando et al., 2011). Comparable relapse-prediction indexes exist in ERP, a reduced P300 amplitude when confronted with alcohol-related pictures being correlated with lower relapse risk in alcohol-dependence (Petit et al., 2015). Similar ERP indexes should be tested in problematic Internet use to evaluate relapse risk individually and to adapt treatment duration and intensity accordingly.

Beyond these three proposals promoting electrophysiological tools in clinical settings, many other ERP usages could improve and extend the treatment of problematic Internet use. Some might be directly inspired from other disorders (e.g., using ERP measures to improve differential diagnosis or detect comorbidities), but more innovative uses, specifically related to PIUs, should also be tested (e.g., using ERP to identify specific brain impairment related to each PIUs subtype and to develop rehabilitation programs focused on these deficits).

5. Conclusion

The main aim of this article was twofold: first, to offer an exhaustive review of the available literature regarding electrophysiological explorations of PIUs, and second, to offer new research avenues in order to urge future studies to deepen the exploration of the electrophysiological correlates of problematic Internet use. The literature review of EEG studies in this domain led to two main conclusions. The first is that despite its heuristic value, this tool has been, until now, neglected in the domain. The second is that the few EEG studies that have been conducted were focused on the exploration of self-control abilities, strengthening the idea that problematic Internet use is mostly an impulse-control disorder. It is however worth noting that PIUs are not only characterized by top-down executive deficits: Growing results also suggest that this condition is associated with hyperactivation of the impulsive bottom-up system, which supports its conceptualization within the addictive-disorder spectrum. From a comprehensive review of the literature, avenues for further EEG research have been proposed to improve the diagnosis of PIUs, disentangle its underlying psychoneurobiological processes, and develop its treatment. These perspectives are synthetized in Fig. 1.

In conclusion, beyond the mere replication of investigations in substance-related addiction, it is essential to develop a new electrophysiological exploration of problematic Internet use, on the basis of hypotheses and experimental approaches that take into account the uniqueness of this condition, along with its potential subtypes. Notably, this promising perspective could help to clarify the "conceptual chaos" currently surrounding problematic Internet use, particularly in association with the absence of valid etiological models and uniform diagnosis criteria. Indeed, despite calls to consider "Internet addiction" a new psychiatric condition (e.g., Block, 2008), the American Psychiatric Association has decided that evidence is currently too scarce to include it as a new disorder in the *DSM-5* (American Psychiatric Association, 2013), and Internet gaming disorder has been included instead in Section 3 of the *DSM-5* (American Psychiatric Association, 2013; Petry and O'Brien, 2013). Deepening the exploration of the brain correlates related to this maladaptive pattern could thus constitute a crucial step toward determining the validity of the criteria currently proposed to define Internet gaming disorder (Ko et al., 2014b; Rehbein et al., 2015) and thus toward clarifying the pertinence of its inclusion as a genuine disorder in future disease classifications.

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