

Review Article

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Psychological and neuroscientific advances to understand Internet Use Disorder

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Abstract: Internet Use Disorder (IUD; previously referred to as “Internet addiction”) has been considered an emerging public health issue. However, the topic is debated and remains highly controversial. Furthermore, the inclusion of a *Gaming Disorder* diagnosis in ICD-11 by the World Health Organization have rekindled debates on the nature of behavioral addictions. Against this background, the present review aims to provide readers with a summary on the current state of diagnostic approaches, risk factors and neurobiological models of IUD. Moreover, and in this context, the present work will include an outlook on smartphone use disorder (often referred to as “smartphone addiction”).

With respect to neurobiological underpinnings of IUD, different approaches including molecular genetics and neuroimaging have been employed. Here we will focus on magnetic resonance imaging (MRI) studies in particular. In doing so, we will outline limitations of the available literature and provide an outlook for future research questions, which aim to integrate IUD with other behavioral and substance-based addictions.

Keywords: Internet addiction, Internet Use Disorder, Smartphone addiction, gaming disorder, magnetic resonance imaging

Zusammenfassung: Internet-Nutzungsstörung (INS; in der jüngeren Vergangenheit zumeist als „Internet-Sucht“ benannt) stellt ein viel diskutiertes Thema weltweit dar. Besonders mit der Aufnahme der Diagnose *Gaming Disor-*

der im ICD-11 der Weltgesundheitsbehörde ist das nächste Level einer oftmals emotional geführten Debatte über die Natur der Verhaltenssuchte erreicht worden. Um den Leser aktuelle Einsichten in den aktuellen Stand der Dinge bezüglich dieses Themenbereiches zu vermitteln, wird in der vorliegenden Übersichtarbeit zunächst zusammengefasst, was über die INS bekannt ist und auch wie sich das Störungsbild entwickelt. Zusätzlich wird versucht, das relativ neue Phänomen der Smartphone-Nutzungsstörung (für viele eher bekannt als „Smartphone-Sucht“) in dem großen Themenkomplex der INS zu verorten.

Über diese theoretischen und diagnostischen Aspekte hinausgehend, gibt der vorliegende Artikel eine Übersicht über neurowissenschaftliche Erkenntnisse, die dabei helfen, die INS besser zu charakterisieren. Viele unterschiedliche Methoden der Neurowissenschaften wurden bereits eingesetzt, um die biologischen Grundlagen der INS zu entschlüsseln. Die Magnetresonanztomographie (MRT) stand dabei in der Vergangenheit besonders im Fokus, so dass Befunde aus der MRT-Forschung auch im Fokus dieses Übersichtsartikel stehen werden. Der Artikel endet mit Limitationen der aktuellen empirischen Forschung. Zusätzlich wird ein Ausblick auf die nächsten Schritte in dem lebhaften Forschungsfeld der INS gegeben.

Schlüsselwörter: Internet-Sucht, Internetnutzungsstörung, Smartphone-Sucht, Computerspiel-Sucht, Gaming Disorder, Magnetresonanztomographie

1 Background

The study of “Internet addiction” started scientifically with the landmark publication of Kimberly Young (1996), who described the case of a 43 year old woman being “hooked-up” to the Internet. The case report describes symptoms that strongly overlap with symptom-level criteria for (non-)substance use disorders, which led to significant impairments in daily life. Since then, considerable progress has been achieved, not only regarding the scientific discussion on the nature of “Internet addiction,” but also with respect to the increasing digitization

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of societies around the globe. As just one example, fast and low cost broadband Internet connections, as well as mobile Internet access have facilitated nearly instant transfer of huge data packages, thus allowing the streaming of video, massive multi-player online games, as well as voice-to-voice and peer-to-peer video communication. Moreover, the World Wide Web (WWW), arguably the most important Internet application to date, has evolved from a digital platform, where users passively consume content (or write e-mails peer to peer), to an increasingly interactive platform, allowing users to publish and promote their own content (even at the scale of peer to masses). The so-called interactive Web 2.0 paved the way for social media platforms such as Facebook, and in doing so, changed considerably both the world we live in, as well as how we interact with others. The importance and prevalence of social media in our world today, is illustrated, for instance, by 2.3 billion monthly active Facebook users (statista.com, 2019), or the more than one billion WeChat users in 2018 (Montag et al., 2019). These social media platforms not only impact how we communicate with one another, but also how we present ourselves to online platforms, clearly facilitating processes of social comparison that affect an Internet user's self-esteem (Vogel et al., 2014).

Perhaps one of the most important accelerators towards a "digital society" was the introduction of multi-purpose mobile computing devices (smartphones), such as the iPhone in 2007, which rapidly became a huge market success and led to investments of several other companies into development of similar devices. The iPhone may at least be partly responsible for the overwhelming number of 2.71 billion smartphone users around the globe in 2019 (statista.com, 2019). Smartphone users are able to access the Internet and online services from nearly anywhere in the world. This led to major improvements in everyday life, including the possibility to access information from anywhere or to chart a course in an unknown territory. Currently, the global Internet penetration rate is around 56 %; more than half of mankind has access to the Internet (internetworldstats.com, 2019). For a general research timeline at the dawn of the Internet of Things, please see Montag & Diefenbach (2018).

More than twenty years after the initial case report from Young describing "Internet addiction", the very term "Internet addiction" still remains a matter of ongoing debate, both in the public and scientific community alike. In parallel, many researchers prefer the terms *problematic Internet use* or *Internet Use Disorder* (for an overview, see also the edited volume on Internet addiction by Montag & Reuter, 2017a). Further yet, another frequently used term that

can be found in the literature is *cyber addiction*. Of note, the term *problematic Internet use* is in itself not optimal, because it can describe either a person in transition from normal Internet usage to potentially pathological use (with specific symptom criteria for a diagnosis still to be defined in this area) or describe the spectrum end. Although this development partly adheres to recent dimensional conceptualization of psychiatric disorder, a unified definition of a symptom-criteria based cut-off for *Internet Use Disorder* (IUD) would improve transparency in the literature on addictive Internet use. Although no consensus on symptoms underlying IUD exists, prominent contributions in the field argue that *preoccupation with the Internet* and *withdrawal symptoms when not being online* might be considered as core symptoms of IUD (Tao et al., 2010). Along with negative repercussions in private and professional areas of a person's life that result from one's own online usage, these symptoms would also mirror core symptoms that have been defined for substance use disorders and other behavioral addictions, e. g. pathological gambling (for details on diagnostic issues see also next section). The term *Internet Use Disorder* has been proposed by Brand et al. (2016) in their I-PACE model, to better understand the aetiology of IUD. Use of the IUD nomenclature (instead of "Internet addiction"), can clearly be seen as a response to inclusion of the term *Internet Gaming Disorder* in section III of DSM-5 issued by the American Psychiatric Association (APA; more on the I-PACE model in section III). Importantly, the term IUD fits with recent developments that recognize a diagnosis called *Gaming Disorder* in the latest version of ICD-11 issued by the World Health Organization (WHO, 2018). Of note, further diagnostic issues with respect to IUD and the related topic "smartphone addiction" are presented in the supplement. For co-morbidities of IUD please see the works by Peterka-Bonetta et al. (2019) and the meta-analysis by Ho et al. (2014).

2 The Case of Gaming Disorder in ICD-11: a controversy

With the inclusion of *Internet Gaming Disorder* (IGD) as an emerging disorder in section III of DSM-5 in 2013, convergent research categories were for the first time published, defining an initial working model for diagnostic criteria of a specific IUD (Petry & O'Brien, 2013). Nine criteria were proposed in detail (preoccupation, withdrawal, development of tolerance, loss of control over gaming, loss of interest in earlier preferred activities/hobbies, lying about gaming, putting relationships at risk because of gaming,

playing video games to overcome anxiety, and continuing game play with the knowledge that it has negative consequences). According to DSM-5, out of these nine criteria, five need to be met to fulfill the diagnosis of an IGD. To better understand IGD and its potentially detrimental effects on mental health, these symptom criteria stimulated a large body of research, both in terms of psychometrics (Pontes & Griffiths, 2015) as well as underlying neurobiology (Yao et al., 2017). Covering both, the current scientific literature as well as clinical treatment demand (e.g. are patients actually searching for treatments, are specific treatment options available?), the WHO decided to include Gaming Disorder in the draft of the ICD-11 (final inclusion decision to be reached in May 2019; WHO, 2018).

On the WHO's website, the new diagnostic category *Gaming Disorder* is described as "being characterized by impaired control over gaming, increasing priority given to gaming over other activities to the extent that gaming takes precedence over other interests and daily activities, and continuation or escalation of gaming despite the occurrence of negative consequences." As for other diagnostic categories, a timeframe for the symptoms and functional impairments (usually >12 months; significant impairments in everyday life) need to additionally be fulfilled for the clinical diagnosis. Please see also the new work by Pontes et al. (in press) providing a first self-report questionnaire assessing Gaming Disorder according to the proposed WHO framework.

After inclusion of Gaming Disorder in ICD-11, the gaming industry (among others) complained about the premature nature of this proposal (e.g. nytimes.com, 2018). Although some in the research field share this view, the *International Gaming Response Consortium* led by King (2018) responded in a commentary, that aside from this discussion, ample evidence exists that excessive gaming leads to problems in afflicted persons and a diagnosis (perhaps to be revised in the near future with respect to the aforementioned criteria), will facilitate prevention activities and treatment options for those affected by excessive gaming. Importantly, it must be emphasized that the full diagnostic symptoms for *Gaming Disorder* are only met by a relatively small number of individuals. Although large-scale studies investigating the new criteria by ICD-11 in the population are still missing, applying the criteria from DSM-5 suggests that "only" 0.3–1% of the general population may be affected (see 1.16% in Germany by Rehbein et al., 2015). However, prevalence rates may be considerably increased in certain demographic groups (e.g. adolescents).

3 Models to understand Internet Use Disorders

Several frameworks have been put forward to understand the aetiology of IUD. In order to come up with a complex framework and given the brevity of this review, we will only focus on the earlier mentioned I-PACE model drawing in parts on the work of Davis (2001) and Dong & Potenza (2014). The acronym I-PACE stands for Interaction of Person-Affect-Cognition-Executive Variables, all contributing to the development of Internet Use Disorder. Among the P variables, personality traits such as low conscientiousness, low self-directedness and higher impulsivity, might represent a vulnerability factor for the development of excessive Internet usage. Although self-directedness is not explicitly mentioned, it might be included in a revision of the I-PACE model, because it has been shown with cross-cultural research, that low self-directedness is robustly associated with higher IUD

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symptomatology across cultures (Sariyska et al., 2014; for a general introduction into personality see Montag & Panksepp, 2017). The chance of developing an IUD is even greater, if together with a person's vulnerable personality traits, a history of psychiatric disorder can be observed. What then follows (outgoing from the P variables) is a process of habit formation, that is accompanied and reinforced by emotional reactions towards Internet cues and one's own experience when using online applications (A), together with the development of cognitive maladaptive thoughts (C), and low executive functioning (E), resulting in high bottom-up brain activity (high "hot activity" of the brain, or strongly wanting to use the Internet), when a person is confronted with his/her relevant online cue, and finally, low top-down regulation (low "cold activity" of the brain – hence, emotional brakes are not working properly). This will be elaborated upon with regards to our current neuroscientific understanding in the next section. Importantly, the I-PACE model lacks a molecular perspective on IUD. Beyond the dominance of MRI studies in the field of neuroscientific IUD works, it will therefore be important to also factor in the molecular underpinnings of IUD. Here, work by Montag et al. (2016) could supplement the I-PACE model.

4 Neurobiological basis: initial findings on the neurobiological basis of Internet Use Disorder

Different research strategies and methodological approaches have been employed to delineate the neurobiological basis of IUD, including molecular genetic (Montag et al., 2012; Montag & Reuter, 2017b) and endocrinological approaches (Bibbey et al., 2015), as well as brain imaging approaches such as electroencephalography (Lee et al., 2014) or magnetic resonance imaging (MRI). In line with the proposed symptomatic overlap between IUD and (non-)substance use disorders, particularly the loss of regulatory control and habitual use despite negative consequences, accumulating evidence from a growing number of MRI-based neuroimaging studies reported brain structural and functional alterations in IUD that partly resemble alterations observed in (non-)substance use disorders (for a detailed overview see also excellent recent reviews by Yao et al., 2017).

Based on a wealth of evidence from animal models and, more recently human neuroimaging research, sub-

stance-related addictions have been reconceptualized during the last decade as a chronically relapsing disorder of the brain. This disorder is characterized by dysregulations in the brain's motivational circuitry that manifest in regional- and addiction stage-specific changes in striato-limbic-frontal brain systems. The transition from initially voluntary use, towards habitual and ultimately addictive use is accompanied by neuroplastic maladaptations in these circuits, which mediate exaggerated salience and compulsive-like habitual responses to the drug itself and drug-associated cues. Concomitant dysregulations in the prefrontal cortex, a region engaged in executive functions, are thought to mediate progressive impairments in top-down regulatory control over behavior (Koob & Volkow, 2016). The striatal system lies at the core of this circuitry and contributes to both the acute reinforcing effects of potentially addictive drugs, as well as the transition from voluntary to escalating and ultimately addictive use (Everitt & Robbins, 2016). The complex contributions of the striatum to different facets of the addictive process are reflected in the complex functional organization of this structure. Overall, ventral regions of the striatum play a key role in reward and reinforcement processing, whereas dorsal parts of the striatum strongly contribute to cognitive functions and habit formation (Haber, 2016). In line with emerging perspectives on psychiatric disorders as network-level disorders, accumulating evidence suggests that the core behavioral symptoms of habitual use and loss of behavioral control in substance use disorders are mediated by network level dysregulations in cortico-striatal circuits (Zimmermann et al., 2017). The striatum exhibits strong bi-directional connections with nearly the entire cortex. In line with the specific behavioral characteristics of the striatal subregions, the ventral part has strong connections with the ventral anterior cingulate and orbitofrontal cortex, both of which are engaged in reward processes, whereas the dorsal part exhibits strong connections with prefrontal regions that are engaged in regulatory control (Haber, 2016; Zhao et al., 2019). Overall, the different functions and circuitries of the striatal subregions may mediate different aspects of the addictive process, and together, promote the transition towards habitual-like drug seeking and loss of behavioral control (Robbins et al, 2012; Zhou et al., 2018).

Accumulating evidence from animal models and human neuroimaging studies, suggests that cortico-striatal circuits play a particularly important role in the transition to addiction via associative learning processes. Studies in substance use disorders have provided compelling evidence, that cues repeatedly paired with the drug acquire

their excessive motivational significance via operant and instrumental learning processes, which are mediated by drug-induced dysregulations in the cortico-striatal circuitry (Koob & Volkow, 2016; Everitt & Robbins, 2016). Studies in patients with substance use disorders consistently reported exaggerated striatal reward-related reactivity towards drug-associated cues (Kühn & Gallinat, 2011), possibly at the expense of natural rewards (Zimmermann et al., 2018) along with concomitantly decreased frontal activity during executive control processes. Together, these changes are considered to promote drug seeking and take over as the main motivational drive, without adequate regulatory control over behavior. With respect to behavioral addictions, similar changes have been observed. For instance, a recent review of Internet Gaming Disorder (IGD) literature by Yao et al. (2017) reported that IGD subjects, relative to healthy reference populations, demonstrated “hyperactivation in the anterior and posterior cingulate cortices, caudate, posterior inferior frontal gyrus (IFG) which were mainly associated with studies measuring reward and cold-executive functions; and, (2) hypoactivation in the anterior IFG in relation to hot-executive function, the posterior insula, somatomotor and somatosensory cortices in relation to reward function.” (p. 313). Thus IGD-mediated neural alterations partly resemble alterations previously observed in other addictive disorders. In particular, when confronted with IUD-related cues, mounting evidence suggests that IUD patients, on the one hand, respond with an exaggerated response in striatal reward processing areas of the brain. On the other hand, deficits in regulatory executive functions/implicit learning abilities (e.g. Sariyska et al., 2017) may reflect deficits in regulatory control. Covering the available imaging literature, Brand et al. (2014, p. 1) concluded that “findings on reductions in executive control are consistent with other behavioral addictions, such as pathological gambling. They also emphasize the classification of the phenomenon as an addiction, because there are also several similarities with findings in substance dependency.”

In addition to reports focusing on functional changes in brain cortico-striatal areas, several studies have documented structural alterations in these systems when investigating individuals with substance-use disorders. Most have compared indices of gray matter integrity, (particularly gray matter volume and density), between individuals with chronic substance use and healthy reference groups and reported a relative decrease in gray matter in the substance using group (e.g. Daumann et al., 2011). Recent quantitative meta-analyses of the available literature confirmed notable gray matter reductions in corti-

co-striatal regions and to a lesser extent limbic regions, across substance-using populations, including patients with alcohol use disorder (Xiao et al., 2015), stimulant use disorder (Ersche et al., 2013) and chronic cigarette smokers (Sutherland et al., 2016). In line with observations of substance-related addictions, a growing number of studies reported gray matter deficits in excessive Internet users, with a recent meta-analysis confirming that individuals with IGD demonstrate decreased gray matter in frontal regions engaged in executive functions (Yao et al., 2017).

However, due to the cross-sectional nature of most included studies, differences observed between individuals with substance use disorders, or with IGD, and those of healthy controls may reflect adaptations mediating the addictive process, or alterations associated with an increased risk for escalating use that preceded onset of the disorder. In a previous study, we assessed brain structure in early users of amphetamine-type stimulants and demonstrated that decreased gray matter volume in the dorsal striatum, amygdala and prefrontal region predicts escalation of stimulant use during the subsequent two years (Becker et al., 2015). This finding suggests that some of the previously observed differences in gray matter between substance users and healthy controls, indeed represent markers of an increased vulnerability, rather than addiction-associated adaptations. To determine whether the cross-sectionally observed cortico-striatal gray matter decreases in IGD precedes the onset of excessive Internet use, we recently employed a combined cross-sectional longitudinal design in excessive Internet gamers and in gaming naïve controls (Zhou et al., 2019). To specifically determine gray matter changes related to excessive Internet gaming and to the development of addictive use, *massively multiplayer online role playing game (MMORPG)-naïve participants* were randomized to either six weeks of daily MMORPG gaming or to a control group that remained gaming-naïve. Brain structural data and the level of online video gaming addiction were assessed at study inclusion and after six weeks of training. Confirming the findings from previous cross-sectional studies, we observed that excessive gamers (also investigated in this study) presented lower posterior right orbitofrontal gray matter volume relative to the gaming-naïve group at study inclusion. Analysis of the longitudinal data, revealed that online video gaming addiction levels increased in the gaming-naïve subjects (being now in the gaming intervention group) during the six weeks of gaming, while left orbitofrontal volumes decreased (also in the excessive gamer group). This could suggest that reductions of prefrontal gray matter represent a direct con-

sequence of Internet gaming, rather than predisposing alterations.

Although most previous studies of brain structural alterations related to excessive Internet use focused on IGD (or broader Internet addiction; please see problems in diagnostics described in the supplement), some initial studies have begun to explore structural alterations associated with excessive use of social media. A recent study from our research team examined associations between problematic use of the social media/messenger app WeChat and gray matter in Chinese students (Montag et al., 2018b). We observed that higher levels of addictive WeChat use symptoms were associated with lower gray matter volume in the subgenual anterior cingulate, a region critically engaged in behavioral and emotional regulation. Furthermore, more frequent (but not more addictive) use of the app's payment function was associated with lower gray matter volumes of the nucleus accumbens, a core reward processing node in the ventral striatum. Decreased gray matter volumes of the nucleus accumbens have also been associated with longer and more frequent Facebook use (Montag et al., 2017). Taken together, this suggests that partly overlapping gray matter deficits in frontal regions engaged in executive control and in striatal regions engaged in motivational functions might be observable across the addictive use of different Internet channels. This also emphasizes the need to differentiate changes related to excessive and addictive use. Further studies are needed to assess whether these findings can be transferred to the broader area of smartphone use disorder/addiction. Initial evidence from EEG studies confirm that SUD might also be associated with deficits in executive functions (Chen et al., 2016), and also changes in brain cortical areas due to daily finger training that accompanies use of a touch display (Gindrat et al., 2015).

5 Limitations

In the past, discussions have too often wrongly labeled and stigmatized everyday life activities with terms such as “addiction”. Among these are examples such as being addicted to excessive book reading or to viewing television (Finn, 1992; Millner, 2012). This problem appeared partly because of using a confirmatory approach that is too narrow in studying behavioral addictions, such as simply testing symptoms from recognized disorders such as alcoholism or gambling disorder and transferring it to a possibly new “addiction area”. Applying process models such as the I-PACE by Brand et al. (2016) represents a step

towards counteracting use of narrowed views. On the other side, researchers should generally be aware not to pathologize everyday life (Billieux et al., 2015). One such example is a report stressing terms such as “Tango addiction” (Targhetta et al., 2013), which probably used the term addiction too loosely.

Although the study of behavioral addiction is an important and timely endeavor (Potenza et al., 2018), many obstacles must be overcome to better understand the nature of these excessive human behaviors. This task will not be easy, because problematic behaviors more and more meld together (e. g. loot boxes that are now planted in video games). If a game player buys such a loot box, a surprise such as better armor or new life energy is provided. This example shows how gambling elements mix with gaming elements in video games. Finally, we wish to emphasize, that in the present review we did not address therapeutical interventions. In particular, cognitive behavioral therapy has been shown to be successful in treating patients with IUD (King et al., 2011; Winkler et al., 2013). As such, both the treatment of patients and psychodiagnostics will profit in the future from Psychoinformatics (Montag et al., 2015a; 2016; Montag, 2019, Montag & Elhai, in press). Application of computer science methods in IUD research and treatment will help paint a more refined picture of actual online usage, which may be a highly relevant means to reflect on one's own online behavior (Lin et al., 2015; Montag et al., 2015b).

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Bionotes



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