**Immersion in Substance-Related and Behavioural Addictions: Neural Systems and Neurochemical Substrates**

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**Abstract:**

**Purpose of review:** Problematic engagement in slot machine gambling has been linked to a state of immersion: heightened attention on the activity (i.e. gambling) at the expense of other mental processing. This review considers the relevance of this state to substance-related addictions, and other behavioural addictions besides disordered gambling. We further evaluate current knowledge on the neural systems and neurochemical substrates implicated in immersion.

**Recent findings:** Prior research has primarily considered immersive experiences from a lens of either dissociation (clinical symptoms indicating detachment from reality) or flow theory (positive psychology and game design). In other forms of addictions, increased dissociative features are observed, often interacting with psychosocial adversity and trauma. Existing work on the neural basis of immersion has been more influenced by the 'flow' conceptualization, and implicates attentional/executive, salience/reward, and default mode brain networks, with regulation by dopaminergic and, potentially, noradrenergic pathways.

**Summary:** Immersion is operationalized as a cognitive attentional state with relevance to a range of addictive disorders. Data on the neural basis of immersion point to brain networks that can be hypothesized to be dysregulated in groups with substance-related and behavioural addictions. Further refinement is needed in measuring immersion and integrating the dissociation and flow perspectives.

**Keywords:** Immersion, Flow, Dissociation, Gambling, Substance Use, PET, fMRI

## 1. Introduction

We all recognize the experience of being completely immersed in an activity (e.g. sports or a good movie): a state of complete absorption in an activity that is often accompanied by losing track of the passage of time and reduced awareness of peripheral stimuli like background conversations or remembering an appointment [1]. In recent years, the field of gambling research has become interested in this state as a factor that may contribute to excessive and harmful use of slot machines, in particular (see [1]*). Across many studies, higher levels of disordered gambling severity were correlated with higher self-reported immersion (e.g. [2]* for meta-analysis). While this state is unlikely to be unique to slot machines, it may be disproportionately linked to fast, digitized forms of gambling, namely land-based Electronic Gaming Machines (EGMs), which include modern slot machine games and online gambling, of which online slot machines are a prime example. Immersion may appeal to people with particular gambling motives -- namely, coping and escape -- and thus can fuel further gambling engagement via negative reinforcement [2,3]. Immersive states could be targeted by regulatory or clinical interventions, such as in-game pop-up messages or psychological techniques, including attentional or mindfulness training [1]. In this way, gambling immersion has broader relevance as an example of the interface between personal vulnerabilities to addictions and product design features, seen within a public health approach to gambling [6,7].

The objectives of this article are to extend this immersion framework by considering two questions. First, to what extent is the state of immersion relevant to other forms of addiction? Second, how does current knowledge on the neural basis of immersion generate testable hypotheses for dysregulation and intervention in addictions? In approaching these questions, we note that earlier research has drawn heavily on two distinct constructs: *dissociation* and *flow.* Dissociation is a clinical construct, comprising a set of symptoms and experiences that are characterized by interruptions or intrusions in one's stream of consciousness. These altered states of consciousness can represent a separation from one's sense of self (depersonalization) or the world (derealization), as well as a disruption of the normal integration of mental processing [2–4]. Dissociation, often conceptualized as a response to trauma, has long-standing theoretical links to addictions [5]. Flow, by contrast, is a construct that originated in positive psychology, to describe a state of effortful absorption and optimal performance in an activity [6]. A recent article from our group asserts that these constructs share cognitive underpinnings, in the heightened attentional focus given to one activity, at the expense of other mental processes [1,7]. Building on Butler's work [8] proposing a continuum from mild, non-pathological dissociation to pathological symptoms (e.g. depersonalization), Murch & Clark [1] hypothesize that gambling severity may also be associated with a transition from a more flow-oriented formulation to more severe disruptions of consciousness and the sense of self, with negative consequences.

Gambling Disorder was recognized as the first non-substance-related addictive disorder in the DSM-5 (APA 2013). In considering the relevance of immersion to other behavioural addictions, we note that gaming disorder (now recognized in the ICD-11), social media addiction [9], smartphone addiction [10], and other conditions associated with problematic use of the internet [11] are each emergent constructs requiring further validation as diagnostic entities. Regardless of one's view on this debate, these activities are intuitively highly immersive and this quality may be a 'vector' to their excessive consumption among some individuals. What about substance addictions? Drug intoxication is associated with a panoply of subjective effects that vary across substances, but commonly include elements of dissociation and detachment from reality [12]*. These dissociative effects may reinforce a coping response to trauma and adversity, which are risk factors for substance addictions [13], and may set up negative reinforcement in a similar manner to that described for slot machine gambling. Notably, this research on immersive states in other forms of addictions is primarily influenced by the dissociation perspective.

Building on this wider relevance to addiction, what is known about the neural basis of immersion? This turns out to be a deceptively complex question, as in brain imaging settings, participants may experience fleeting moments of immersion during many procedures, including the resting state. The original conceptualization of 'flow' by Csikszentmihalyi proposed a number of characteristics of flow-inducing tasks, including difficulty, degree of prior practice or skill, the availability of clear and immediate feedback, and task enjoyment, that would each be expected to modulate task immersion in neuroimaging or psychophysiological designs (see e.g. [6,14,15]). At the same time, immersion is characterized by a *lack* of meta-awareness in the moment, which presents an obstacle for its physiological or neural assessment in real-time. We will consider some of the methodological procedures for eliciting immersion in neuroscience research (see **Table** 1); we note that these techniques are influenced by the flow perspective to a much greater extent than the dissociation perspective [14]. At the current time, there is limited research combining the two objectives of this review: how are the neural sequelae of immersion altered in people with addictions? For example, how could these brain mechanisms be relevant to treatment or recovery in addictions?

## 2. Immersion in Substance-Related and Behavioural Addictions

### *Substance-Related Addictions*

Drugs of abuse elicit a range of subjective effects, including those on mood, alertness, cognition, motivation, and motor function. A common effect across many drugs is a "state of altered identity" [5], often labelled as a dissociative experience. As the best studied example, alcohol consumption causes a range of dissociative effects from 'mind wandering' and 'zoning-out' at lower doses [16], to blackouts at higher doses where there may be a subsequent failure to recall events that occurred during the intoxication [17]. Jacobs' 'general theory of addictions' [5] posited a common dissociative response among all forms of addictions during engagement in the target behaviour. Such 'transdiagnostic' evidence was seen in his study across treatment-seeking individuals with gambling problems, alcohol use disorder, and compulsive over-eating.

Jacobs' theory also proposed childhood affective disturbance as a predisposing factor to these dissociative experiences [5], such that the target behaviour (e.g. gambling) was able to provide a source of escape from psychological distress. Subsequent studies have corroborated this three-way relationship between addictive disorders (either substance-related or behavioural addictions), dissociative experiences, and trauma, for example in the form of childhood adversity or PTSD [18–20]. Patients receiving treatment for alcohol or drug use disorders displayed elevated rates of dissociative disorders and score highly for dissociative experiences [21–24]. (Notably, a diagnosis of a dissociative disorder would exclude a patient whose episodes were limited to states of drug intoxication). These relationships with dissociative symptoms are amplified in patients with substance use disorders with comorbid PTSD [21] or who experienced childhood trauma [23]. However, the causal connections here are less clear: increased dissociative tendencies may be a risk factor for substance use, or alternatively, some individuals may use substances due to a *reduced* dissociative ability in order to facilitate reaching this state (termed the 'chemical dissociation' hypothesis [25,26]). It is also possible that chronic substance use may alter the susceptibility to dissociative experiences [25,26]. In one study, a 'desire to dissociate' scale in a student sample mediated the association between childhood sexual abuse and problematic alcohol use, whereas trait dissociative experiences did not [27]. In line with the chemical dissociation hypothesis, people with comorbid PTSD and substance use disorders showed lower dissociation scores than a group with PTSD but no substance use [28]*. However, in a similar study in people with gambling disorder and comorbid PTSD, higher PTSD symptoms were positively correlated with both dissociation and gambling severity [29]. Interestingly, in community participants with PTSD, gambling disorder, or both, gambling-related dissociation and trauma-related dissociation were elevated in the comorbid individuals, but this was not true of 'trait' (or domain-general) dissociative tendencies [30], suggesting the importance of testing dissociation profiles in relation to different behaviours.

*Behavioural Addictions*

While less extreme than the mind-altering effects of psychoactive drugs, internet use and video gaming also elicit immersive and dissociative experiences along with a sense of escape [31–34], and these are also reminiscent of the profile described earlier in gamblers using EGMs. The moderating roles of psychosocial adversity and trauma are also evident in recent studies in groups with behavioural addictions. For example, in a large sample of gamers, both adverse childhood experiences and dissociative experiences predicted the level of disordered video gaming symptoms in structural equation modelling [33]. In a similar design, dissociative experiences, depression and physical aggression predicted internet gaming disorder symptomatology [31]*, with 'body dissociation' having the highest coefficient in the model [31]. In Lee et al. [32], subjects with problematic internet use and dissociative symptoms showed poorer overall mental health than those with problematic internet use without dissociative symptoms. It is notable that the research covered in this section on substance-related and behavioural addictions has almost exclusively approached immersion through a lens of dissociative features. A recent study [35]* has begun to extend these links to the flow construct, classifying experienced users of the smartphone game Candy Crush into those who do or do not 'game to escape'. Larche & Dixon [35] established further correlations between escape gambling and greater flow experiences during video game play, as well as with both higher problematic video gaming and 'boredom proneness', a trait that characterizes a range of externalizing disorders. Other work assessing psychological states associated with slot machine gambling has posited the term ‘dark flow’ as similar to flow, but with an emphasis on negative consequences and excessive consumption that derive from being in this state [36,37].

## 3. Brain Systems

In contrast to clinical research on addictions and their assessment of immersion in terms of dissociative features, the research on the neural substrates of immersion has been informed to a much greater extent by the flow framework. An early hypothesis informed by neurocognitive mechanisms is that of ‘transient hypofrontality’ [38]. Predicated on a distinction between an implicit system for skill automatization and an ‘explicit’ system for top-down executive control and flexibility, Dietrich posited that flow occurs when a practiced skill can be maintained by implicit processes (putatively dependent on the dorsal striatum [14,38]), and this may require the temporary suspension of prefrontal cortical control. There is some evidence for this prefrontal suppression, for example from a study using functional near infrared spectroscopy (fNIRS) to specifically record hemodynamic responses over prefrontal cortex [39]. However, studies using functional magnetic resonance imaging (fMRI) studies with whole-brain coverage indicate additional neural foci [40,41], suggesting that transient hypofrontality is likely an over-simplification. A competing idea, ‘synchronization theory’, ([42] reviewed in [14]), asserts that flow may arise from more efficient and automated connectivity between networks. Both transient hypofrontality and synchronization accounts acknowledge the role of subcortical systems in handling motor control and skill acquisition during flow. More recently, van der Linden and colleagues [43]* posit the involvement of three large-scale networks in flow states - the default mode network, the central executive network, and salience/reward network - based on their established links to self-referential processing, task engagement and attention, and feedback and agency detection, respectively.

The elicitation of immersion in experimental settings is not straightforward, for reasons described in the Introduction (see also [15]). The core procedures used in many of the studies in Sections 3 and 4 are summarized in **Table** 1. One procedure that is well-suited to fMRI uses an unpaced finger-tapping task to identify natural fluctuations in sustained attention and mind-wandering. In this task, the participant is instructed to press a button rhythmically for 8 minutes, in time with a 600 ms metronome that is only presented for the first 10 seconds of the run [44]*. Periods of relatively low inter-tap variance, indicating 'in-the-zone' attention, were associated with greater activity in the default mode network, whereas periods in which the rate of tapping was more variable ('out of the zone' attention) were related to increased activity in the dorsal attention and salience networks. Notably, greater coupling of the medial prefrontal cortex and posterior cingulate cortex nodes in the default mode network with the anterior insula in the salience network was seen during higher out-of-zone attention [44], highlighting the role of connectivity dynamics in the "waxing and waning of (attentional) focus" (p. 1836). These data are broadly in line with the 'synchronization theory' of flow discussed earlier (see [14]). We note that substantial evidence exists for dysregulation of these networks and their functional connectivity, in both gambling disorder and substance use disorders [45–51].

A more established paradigm for eliciting flow in physiological studies relies on Csikszentmihalyi's concept of the 'flow channel' as a point of balance between the challenge or difficulty of the task, and the participant's level of skill or performance (also see [15]). This is often referred to as the skill-challenge balance [15,52,53], and it can be operationalized experimentally by identifying each participant's personal level of ability and then tailoring the task around that difficulty level to create easier ("boredom") or more difficult ("overload") conditions, as well as an optimal 'balanced' condition for inducing flow. Some studies use only 2 of these 3 conditions to enhance the number of repetitions. Cognitive tests such as verbal fluency [39], arithmetic [41,54], or video games, such as Tetris [55] and Candy Crush [35,56] have been used in this approach.

Measuring regional cerebral blood flow with perfusion imaging during arithmetic task performance across these 3 conditions, greater activity was observed in the balanced condition (promoting flow) in the putamen, inferior frontal gyrus, and parietal lobe, which are nodes in the salience and central executive networks. Lower activity was seen in the flow condition in the medial prefrontal cortex and anterior cingulate cortex, parts of the default mode network, and in the amygdala [54]. The amygdala was also implicated in an individual differences analysis, where higher flow scores were related to lower regional blood flow and blood oxygen level dependent activity in the amygdala and the medial prefrontal cortex [41,54]. This activity adhered to quadratic (U-shaped) patterns that were highest (inferior frontal gyrus, caudate nuclei, parietal lobe, dorsal raphe nucleus, thalamus, cerebellum) or lowest (anterior cingulate cortex and medial prefrontal cortex, posterior cingulate cortex, amygdala) in the flow condition, compared to boredom and overload conditions [41]. Using a similar procedure with fNIRS, prefrontal cortical subregions were examined while participants played a Tetris game under flow and boredom conditions [57]. In the flow condition, haemodynamic responses were greater in the ventrolateral PFC [58] in the final 30 seconds of the game, whereas greater activity was seen in the dorsolateral PFC [59,60] and frontal pole immediately following the flow state. These data are challenging to reconcile with the 'transient hypofrontality' hypothesis described earlier and likely point to differential contributions of distinct prefrontal subregions.

Another fMRI study recorded activity during a first-person shooter video game [40] and conducted a retrospective behavioural analysis of game performance (based on video content) to infer a number of dimensions of flow, such as periods of heightened focus (e.g. phases of active fighting versus time between rounds) and periods of challenge-skill balance (successful = killing your target, failures = being killed in the game). This study found stronger activity in the putamen and caudate, anatomical regions that make up the dorsal striatum, as well as in the motor cortex, during challenge-skill balance (i.e. to successful kills). During periods of heightened focus, reduced activity was observed in the anterior cingulate cortex and orbitofrontal cortex, and greater activity in the precuneus, cerebellum, and visual system [40]. Importantly, conjunction analyses across multiple dimensions of flow revealed activation of a motor network comprising thalamus and premotor areas, suggesting that heightened immersion in the game may derive from integrating action and awareness during the activity [40].

In contrast to the emphasis in clinical research on the dissociation perspective, neuroscience studies to date have been shaped primarily by the flow account and much less is known about the neural sequelae of dissociation. Clinically, dissociation is conceptualized in a defense cascade mechanism as an adaptive response to a traumatic experience. One of the most severe clinical expressions is the dissociative subtype of PTSD, which may be precipitated by repeated trauma-induced activation of the fear network [61]. In a large group of women with a history of trauma, including people with and without PTSD, higher levels of dissociation in response to trauma-related images were related to lower functional connectivity between the amygdala and the anterior insula [62]. In the same study, using neuropsychological testing with neutral stimuli, high and low dissociation subgroups performed better or equally well. Thus, this study again points to neurocircuitry within the salience network, but it is not clear whether their fMRI connectivity results can be reconciled with flow studies testing the synchronization hypothesis [14], which were mostly in healthy participants. A notable methodological difference in this study is the use of trauma-related stimuli to elicit the effects of interest. More work is needed to distinguish dissociation in the context of trauma ('dissociating from') versus intoxication in the context of addictions ('dissociating to') [4,27,30]. Another fMRI study comparing individuals with PTSD with and without dissociation focused specifically on the pedunculopontine nucleus (PPN), a part of the reticular activating system in the brainstem, using resting-state functional connectivity with the PPN set as the seed region [63]. Participants with the dissociative subtype displayed greater connectivity of the PPN with the amygdala, parahippocampal gyrus, anterior cingulate cortex, and the ventromedial prefrontal cortex [63]. The reticular activating system also includes the locus coeruleus and dorsal raphe nucleus, and is involved in attention, arousal, regulation of muscle tone, and the ability to focus [64], functions that are highly relevant to threat processing and dissociative states. Future research may further interrogate these structures using high-resolution techniques.

| Method name | Perspective | Description |
|---|---|---|
| Skill-challenge balance [35,41,54–57] | Flow | This approach tailors the difficulty of a task to each participant's personal level of ability. Different conditions may then be created that are easier ("boredom"), more difficult ("overload"), or precisely at ("flow") that level of performance. These studies have used cognitive tasks such as mental arithmetic, but also video games including Tetris and Candy Crush. |
| Video content analysis [40] | Flow | A retrospective content analysis of video game play was conducted, coding five factors of flow: skill-challenge balance, concentration on activity, direct feedback of results, clear goals, and control over activity. |
| Trait measures of flow (e.g. Swedish Flow Proneness Questionnaire [41,65–67]) | Flow | Self-reported measures of flow to assess the general tendency to experience flow in different aspects of life, e.g. at work or school, during leisure activities, and during household maintenance. |
| State measures of flow (e.g. Flow State Scale / Dimensions of Flow Dimension [41,54,57]) or immersion [68,69] | Flow, dissociation, immersion | Self-reported, retrospective ratings of flow, dissociation or immersion, as experienced in relation to an experimental task (e.g. after a session of slot machine gambling). |
| Finger Tapping Task [44] | Immersion | Participants were asked to tap fingers in a rhythm, and distinguish 'in the zone' and 'out of the zone' periods of performance based on tapping variability. |

**Table 1** Experimental methods used to investigate immersion.

## 4. Neurochemical Substrates

Immersion may also have a characteristic neurotransmitter signature. Recent research on this question has focused on dopamine, a neurotransmitter that also has long-standing links to drugs of abuse and addiction [70], although we note below that norepinephrine is another candidate that has received far less attention. Using positron emission tomography (PET) scans with the [11C]-raclopride tracer in healthy volunteers, higher scores on the 'flow proneness scale' was related to higher levels of dopamine D2 receptors in the dorsal striatum [65]. Together with age, the trait-like tendency to experience flow states (across multiple activities) explained 57% of the variance in dopamine binding [65]. The locus of this effect in the dorsal striatum is consistent with links in the previous section to skill acquisition and habit formation, as well as in PET research on individuals with Gambling Disorder, in whom increased amphetamine-induced dopamine release (measured with the dopamine D3-preferring ligand 11C-(+)-PHNO) in the dorsal striatum was correlated with increased gambling tendencies, including higher bet size on a slot machine task [71]. By contrast, greater dopaminergic release in the ventral striatum was associated with higher impulsiveness [71,72], a differentiation that may reflect distinct phenotypes among gamblers for immersion and impulsivity (c.f. Blaszczynski & Nower's Pathways Model [73]).

Recent genetic work has also linked a dopamine D2 receptor polymorphism to flow proneness [66]. The C957T polymorphism of the D2 receptor encoding gene (rs6277) on chromosome 11 accounts for 18% of the variance in striatal D2 receptor binding [74]. The T allele, which has been associated with lower levels of D2 binding, was linked to lower levels of flow proneness – a finding that is broadly congruent with the raclopride PET study of flow proneness [65]. It should be noted that in the genotyping study their result was restricted to certain flow domains in relation to particular activities (studying and working, rather than leisure activities). This domain-specificity represents a neglected aspect of flow research and would benefit from replication attempts using pre-registered designs [66,67]. Lastly, a structural imaging study in a large (n = 680) Japanese sample found a positive correlation between greater gray matter volume of the dorsal striatum and total flow proneness [67], which was interpreted as supporting the link to dopaminergic functioning.

In addition to dopamine, norepinephrine may also play a role in flow states via its involvement in attentional processing and vigilance [43]. The locus coeruleus-norephinephrine system's proposed involvement in attentional biases, including its role in engagement versus disengagement, and often in the context of appetitive learning, including addictions [75], may contribute to immersion in addictive disorders. Neuromodulatory interactions between dopamine and norephinephrine may also help to elaborate this hypothesis. We concur with van der Linden et al [43] that there are not yet any direct studies of the norepinephrine system in relation to flow (or immersion), and this may partly reflect the relative lack of selective PET ligands for characterizing norepinephrine transmission in human subjects.

## 5. Conclusion

Immersion is a psychological construct from gambling research that appears to hold translational value in the context of other addictive disorders, including substance use disorders in which related subjective experiences during intoxication may contribute to drug reinforcement and behavioural (technological) addictions that provide a source of escape. Although some inroads have been made to characterize the neural mechanisms that support this state [14,38], this remains a small field. We have identified some experimental procedures that can be used to investigate immersion in neural and/or physiological studies, informed by research on sustained attention / mind wandering and manipulating the challenge-skill balance within the classic model of the 'flow channel' [6] (see **Table** 1). Studies using these procedures implicate a number of a large-scale brain systems, namely the central executive network, the salience/reward network, and the default mode network, although their directional relationships with flow states are less clear, such that findings to date do not arbitrate unequivocally between the long-standing neurocognitive hypotheses of transient hypofrontality [38] versus enhanced connectivity / synchronization [14,42]. Neurotransmitter studies also indicate links with dopamine transmission, although it is notable that these studies have primarily used trait questionnaire measures of 'flow proneness' rather than task-related state measures, which limits their comparability. Nevertheless, research using a range of methodologies has implicated dorsal striatal involvement in particular, a finding that hints at underlying mechanisms involving automatization of motor routines and habit formation. Further testing of the differential contributions of nigrostriatal dopamine (into dorsal striatum, involved in action selection) versus the mesolimbic dopamine pathway (into ventral striatum, implicated in reward and reinforcement learning) will be vital for understanding the emotional consequences of immersion, where the latter may be considered as being encompassed in Csikszentmihalyi's [6] original concept of flow as autotelic (i.e. intrinsically rewarding).

In characterizing immersion in relation to addictive disorders, we have described research adopting two quite distinct frameworks, that of dissociation and flow. Indeed, it is our thesis that immersion, as an attentional state in which the person loses track of time and their surrounding environment, represents a common ground between these more established constructs from clinical psychology and positive psychology, respectively (see [1]). Studies of the neural basis have predominantly used procedures from the flow perspective, and are conducted in healthy volunteers. Gold & Ciorciari note that "these automated stimulus response procedures [...] require many hours of highly dedicated practice" (p. 9) [14] and, sadly, this degree of repetition also holds for addictive disorders, but at the same time, there are aspects of the flow framework that are less compatible with substance-related addictions in particular, such as the balance between challenge and difficulty. Likewise, although dissociation is recognized as a continuum [8,14], it is poorly understood to what extent specific clinical phenomena, such as depersonalization, occur specifically in relation to addictive behaviours like slot machine gambling or in the context of recreational ('everyday') flow. A recent clinical study of severe dissociation in the context of PTSD has highlighted possible roles for the pedunculopontine nucleus and reticular activating system in dissociation. These brain regions have traditionally been at the limits of the resolution of fMRI, but may also contribute to immersion in addictive disorders potentially through arousal processes, and connectivity with limbic circuitry and higher cortical areas. We note that these perspectives and insights provided by neuroscience may hold clinical implications for addiction treatments, including the importance of identifying trauma-related comorbidities, novel avenues for therapy based on attentional [76] or arousal training, or mindfulness-based or cognitive behavioural therapies [77], and the potential for brain stimulation techniques, such as transcranial Direct Current Stimulation to modulate flow (e.g. [78]).

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