







A taxonomy of technology design features that promote potentially addictive online behaviours

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Abstract

Gaming disorder was officially recognized as a disorder of addictive behaviour in the International Classification of Diseases 11th revision in 2019. Since then, other types of potentially problematic online behaviour have been discussed as possible candidates for inclusion in the psychiatric nosography of addictive disorders. Understanding these problematic online behaviours requires further study of the specific psychological mechanisms involved in their formation and maintenance. An important but underdeveloped line of research has examined the ways in which technology design features might influence users' capacity to exert control over how they engage with and use websites and applications, thereby amplifying uncontrolled, and perhaps addictive, use. In this Review, we critically examine the available research on the relationships between technology design features and the loss of control and harms experienced by those who engage in online video gaming, online gambling, cybersexual activities, online shopping, social networking and on-demand TV streaming. We then propose a theory-driven general taxonomy of the design features of online applications that might promote uncontrolled and problematic online behaviours.

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Introduction

The past two decades have been characterized by substantial developments in information and communication technologies, such as smartphones, tablets and laptop computers. These technologies have revolutionized ways of working and living, and have led to substantial changes in numerous aspects of daily life, including communication (for example, social networking sites), information access (for example, up-to-date online news coverage), education (for example, e-learning opportunities), shopping (for example, e-commerce platforms) and entertainment (for example, video games and on-demand streaming services). Although these changes are often considered to be positive, there is growing evidence that the use of information and communication technologies might become harmful to a subgroup of vulnerable individuals who are susceptible to problematic or addictive usage patterns^{1–6}.

Beyond online gambling disorder (considered to be a subtype of gambling disorder), gaming disorder is the only online behaviour currently recognized as an addictive disorder in the International Classification of Diseases 11th revision (ICD-11)⁷. The inclusion of gaming disorder in the ICD-11 was based on epidemiological^{8–10} and neurobiological^{11,12} evidence, including clinical studies¹³ conducted in large samples of patients (supporting the view that dysfunctional involvement in video games should be considered a public health issue) and reports from treatment providers^{14,15} that there has been an increase in demand to reduce the functional impairments generated by uncontrolled gaming patterns in the past decade. Consistent with the operationalization of behavioural addictions (non-substance-related addictive disorders)^{16,17}, gaming disorder is defined in the ICD-11 as persistent gaming behaviour characterized by: impaired control; increasing priority given to gaming over other life interests and daily activities; and continuation or escalation of gaming despite the occurrence of negative consequences. Central to this definition is that video gaming must be associated with distress or substantial functional impairment in daily life¹⁸.

Other types of problematic online behaviour constitute candidates for inclusion in the dominant health classifications such as the Diagnostic and Statistical Manual of Mental Disorders (DSM)¹⁹ and ICD systems, including excessive online shopping¹⁵, compulsive cybersexual activities^{1,20}, and problematic use of social networks and other internet applications^{1,21,22}. These problematic online behaviours might belong to a spectrum of related conditions that share some common etiological mechanisms^{23–25}. Candidate psychological mechanisms include affective, cognitive, motivational and/or interpersonal processes (Table 1).

Whether gaming disorder should be considered a mental disorder remains debatable^{14,26}. For example, it has been argued that its inclusion in ICD-11 might promote moral panic and stigmatize non-problematic gamers, that the evidence for its inclusion remains insufficient, or that alternative conceptualizations (for example, gaming as a coping mechanism) would be more suitable. Moreover, evidence for the clinical relevance of other types of problematic online behaviour is mixed^{1,27–30}, generating criticisms about the conceptualization of these problematic behaviours within the biomedical model of addiction^{31,32}. Nevertheless, available evidence suggests that performing such activities online (instead of offline) places individuals at higher risk of developing uncontrolled and addictive patterns of behaviour associated with negative consequences and functional impairment. For example, online gamblers are more likely to develop harmful gambling patterns compared to those who engage in offline gambling

activities^{33,34}. Similarly, excessive online shopping is associated with greater severity of general compulsive buying-shopping disorder than in-person shopping³⁵, and cybersexual activities are associated with greater functional impairment in patients who exhibit compulsive patterns of sexual behavior³⁶. These results suggest that the nature or structure of the online environment influences the formation and propagation of problematic behaviours.

Previous studies using a network analytical approach provide empirical support for the notion that, although they constitute separate entities (that is, form distinct clusters), problematic online behaviours are associated with each other^{23,37}. This connection is assumed to lie partly in the features and affordances of the medium through which they are performed (that is, internet-related technologies)^{38,39}. For example, according to the Triple A model⁴⁰, over-engagement in cybersex is promoted by accessibility (an unlimited amount of sexual content is constantly accessible), affordability (free or low-cost sexual content), and anonymity (the user perceives their behaviour as undetectable to others). The Triple A model has since been adopted and re-articulated in the context of other potentially problematic online behaviours (such as on-demand streaming of TV series and online shopping)^{41,42}. Beyond the general features of the internet described in the Triple A model, the specific structural characteristics and design of web-based sites and applications (technology design features) might make them habit-forming and potentially addictive, thereby facilitating the onset and perpetuation of problematic online behaviours^{43–47}.

In this Review, we explore the psychological mechanisms through which design features of online applications might challenge users' self-control abilities and lead to problematic usage patterns. First, we summarize the most recent and reliable evidence of relationships between technology design features and loss of control or harms experienced in the context of specific types of behaviour that might become problematic online. Next, we formulate a theory-driven taxonomy that explains how design features might operate, based on reinforcement learning and behavioural control theories^{48,49}. This approach enables us to identify similar and dissimilar mechanisms across different users and digital technology interactions.

Problematic online behaviours

In this section, we summarize how design features promote problematic involvement (characterized by a loss of control and the maintenance of the behaviour despite negative consequences)^{16,17} in online video gaming, online gambling, cybersexual activities, online shopping, social networking and on-demand TV streaming.

Online video gaming

Video games are a highly diverse form of digital entertainment. The complex and dynamic nature of games makes them challenging to classify^{50,51}, and researchers have categorized games and their main elements in many different ways. Games differ according to genre (shooting, role-playing or strategy), platform (personal computer, console or smartphone), mode (player-versus-player or player-versus-environment), online connectivity (online or offline), objective (collecting, building, capturing or destroying) and monetization patterns (freemium, one-time payment, upfront payment with in-game purchases or subscription). Games can fulfil players' desires to experience different emotions, satisfy psychological needs (such as autonomy and competence) and escape reality⁵². Modern video games offer unlimited play experiences, with large worlds and role-playing elements, complex narratives and characters, episodic and randomly generated

content, and/or systems that regulate players' progression to keep them playing longer and more regularly⁵³. The variety of gaming products and services also makes it challenging for researchers to study the potential influence of such features on players' behaviour, including uncontrolled gaming patterns.

Some of the main rewarding elements of gaming can be understood with reference to operant conditioning. Many video games employ one or more reinforcement schedules⁵⁴ to encourage the individual to play longer or maintain a regular gaming pattern. For example, there might be variable ratio reinforcement, such that a player receives a desired reward (for example, a rare item) after repeating an in-game action (for example, killing an enemy) a variable and unpredictable number of times. At the same time, there might be fixed ratio reinforcement whereby the player receives a reward (for example, in-game currency) for each enemy killed. Thus, the player will become motivated both to acquire the rare item on the variable ratio schedule and to collect in-game currency on the fixed ratio schedule. Both fixed and variable ratio schedules elicit high rates of responding and contribute to continued engagement because players will cyclically acquire one reward type and then work toward acquiring the other.

Some features (such as in-game avatars) are designed to facilitate the formation of an identity and emotional bond to the game or aspects of the game^{55,56}. Some games encourage players to form a psychological attachment to virtual items, actions and identities, particularly in online games that simulate 'ownership' of virtual goods^{57,58}. Indeed, some gamers value their digital collections of games and virtual achievements as others would value material goods⁵⁹. For these players, such games are not simply a form of entertainment; games also facilitate acquisition of 'sacred' items that provide personal satisfaction and have meaning.

In-game purchasing schemes enable players to acquire virtual goods in video games, usually via small monetary payments. Spending on 'loot boxes' (a popular type of microtransaction)⁶⁰ is positively associated with problem gaming⁶¹ and problem gambling symptoms⁶². Some in-game monetization schemes, particularly those found in 'free-to-play' games on mobile devices, are designed to repeatedly solicit or 'nudge' the player to make in-game purchases^{63,64}. Players might respond favourably to monetization options and time-limited offers to resolve unmet in-game needs. For example, purchasing an item to bypass an obstacle might satisfy the need to reach in-game goals in an expedient fashion⁶⁴. Some of these in-game purchasing schemes might be viewed as predatory because they disguise or withhold the true long-term cost of the activity until players are already financially and psychologically committed⁶⁵. Thus, such features can reinforce uncontrolled and addictive habits in gaming, particularly among users with self-regulation and decision-making difficulties (for example, an inhibitory control deficit or difficultly delaying pursuit of an immediately available online reward, respectively)⁶⁶.

Research on problem gaming in relation to structural characteristics has found that game characteristics, such as realistic graphics, novel rewards and surprise mechanics (for example, loot boxes or video-game-related purchases with a random outcome)⁶⁷, tend to increase a player's enjoyment or increase the time spent gaming^{50,68-72}. Problem gaming rates also differ according to game genre. Specifically, players of massive multiplayer online games tend to score higher on measures of problem gaming symptoms than players of other types of video game^{73,74}. These players also score higher on measures of novelty-seeking⁶⁴, depression⁷⁵, social anxiety⁷⁶ and lower on measures of self-esteem⁷⁵, compared with players of other online games.

Table 1 | Candidate psychological mechanisms involved in the development and maintenance of problematic online behaviours

	Processes	Definition	Refs.
Affective	Emotion dysregulation	Impaired ability to efficiently recognize, differentiate and modulate emotional experiences	205,228-238
	Craving	The overwhelming desire and urge towards the addictive behaviour that jeopardizes control attempts	239-242
	Cue reactivity	Physiological, emotional and cognitive responses to stimuli relevant to the online activity	101,243-246
	Reward sensitivity	Increased tendency to detect, pursue, learn from and derive pleasure from positive stimuli	247-250
Cognitive	Inhibitory control impairments	Reduced top-down control of behaviour	66,127,242,251
	Decision-making impairments	Preference for short-term rewarding behaviours despite negative long-term consequences	66,127,242,251
	Attentional biases	Increased awareness of stimuli in the environment that are relevant to the online activity	66,127,242, 252,253
	Dysfunctional cognitions	Distorted cognitive beliefs or irrational use expectancies	55,57,253-256
Motivational	Examples of specific motivations beyond entertainment	Curiosity and sexual education (cybersexual activities)	114
		Personal enrichment (on-demand TV streaming)	3
		Bonding with others (gambling apps)	257
	Negative reinforcement motivations	Alleviating negative emotional states arising from stressful contexts or adversities in life and escaping from everyday problems	114,258-262
Interpersonal	Social anxiety	Overwhelming fear of social situations	5,239,263-265
	Attachment style	Internalized mental representation of the self and others in close relationships	266
	Feelings of isolation and loneliness	-	267-269
	Deficiencies in self-other differentiation	Impaired ability to experience a sense of self as a separate individual in relationships with others	270

These results suggest that online multiplayer games might attract more vulnerable players.

In summary, the evidence on problem gaming or gaming disorder and game design suggests that more complex, endless and socially driven games enable or promote higher rates of problem gaming. Some player vulnerabilities (such as high impulsivity, risk-taking, and comorbidity with psychopathological symptoms) might increase the risk of gaming disorder for certain game types or genres. However, the current research base is limited by its reliance on cross-sectional data. Thus, these studies do not provide insight into how gaming problems develop, and whether any specific game design features have a formative influence on the onset and progression of gaming disorder symptoms.

Online gambling

Along with gaming disorder, gambling disorder is the sole behavioural (non-substance-related) disorder classified as an addiction¹⁹. Importantly, new forms of online gambling sites and applications feature a large panel of ready-to-consume and time-limited incentives. These incentives include sign-up email bonuses, smartphone notifications on bonus bets, free bet happy hours, multi-bet offers, improved odds and cash-out offers (reviewed previously⁷⁷). Qualitative and quantitative studies suggest that these wagering-inducement strategies lead to decreased perceived control while gambling⁷⁸, and might represent a risk factor for the development of gambling-related harm^{79–81} and relapse in those seeking treatment for gambling⁸².

Among the new types of online gambling opportunities, sports betting is becoming increasingly popular, in particular among adolescents and young adults⁸³. In most industrialized countries, it is now possible to bet, at every moment, on almost every sport event. In addition to this around-the-clock availability of betting opportunities, there is high exposure to sports betting advertisements^{84–86}. Consequently, a large number of individuals (including children and adolescents) are directly (through television advertisements and smartphone notifications) or incidentally (through teams that feature sports betting sponsors on their jerseys) exposed to sports betting messages⁸⁷. A key feature of sports betting advertising is that it relies on narratives that trigger perceived control over and social acceptance of sports betting⁸⁶. Moreover, viewing more sports betting advertisements in real life is associated with increased recall of sports betting sponsors (names and logos on team jerseys)^{88–95}, symptoms of gambling disorder⁹⁶ and greater betting intention^{77,96,97} among adolescents. Hence, because children and adolescents seem particularly sensitive to catchy slogans, humour and music featured in sports betting advertisements^{94,98}, narratives that trigger perceived control over and social acceptance of sports betting might modulate their perception of gambling and lead them to believe that sports betting is a normal activity in which most sports fans participate⁹⁴.

The ability to place sports bets at any time and in many places might influence how sports cues (such as a game schedule) are processed. Indeed, neural responses to sports cues differ according to whether or not these cues represent a gambling opportunity^{99,100}. For example, one study found increased brain activation within the hippocampus, caudate nucleus, anterior insula and orbitofrontal cortex when participants were asked to choose whether or not they wanted to bet on a sporting event compared to when they were asked whether or not they wanted to watch the sporting event⁹⁹. These regions play a key role in cognition, emotion and memory processes that are triggered by addiction-related cue reactivity (reviewed previously¹⁰¹). Easy and

constant access to sports betting online might cause all sports cues to be processed as betting-relevant, which might trigger actual betting behaviour and lead to problem gambling.

Another neuroimaging study showed that in frequent online sports bettors, greater problem gambling severity and lower trait-self-control (the ability to pursue abstract and distal goals when faced with competing concrete and proximal goals)^{102,103} were associated with higher neural reactivity to sports events that were made unavailable for betting (that is, were blocked)¹⁰⁰. These results suggest that sports bettors' neural reactivity to gambling unavailability might be a relevant marker of sports betting-related harms. The convenient and easy access to sports betting might also increase non-planned betting (betting on action contingencies during the sports game, or live betting). Indeed, live betting is very common in young men who score high on general trait impulsivity^{80,104} or sensation-seeking¹⁰⁵, and live betting gambling habits are positively associated with symptoms of gambling disorder^{80,104,106,107}.

Taken together, these findings suggest that the hyper-accessibility of sports betting, the design features of sports betting apps, and the content and frequency of sports betting advertisements increase gambling-related harms.

Cybersexual activities

The Internet has revolutionized the way sexuality (and in particular pornography) is expressed and/or consumed, and multiple devices (laptops, tablets and smartphones) permit easy and constant access to a wide range of cybersexual activities from any location^{108–110}. Cybersexual activities include various internet and/or smartphone-mediated behaviours involving human sexuality including (but not limited to) watching pornography, having sexual chats or watching Xcams (live sex on the Internet), using specialized internet websites (or apps) to find offline sexual partners, engaging in virtual reality pornography, playing sexually explicit videogames, or sending and receiving 'sexts'^{109,111–113}. Indeed, 'cybersexual activities' is an umbrella term for distinct behaviours that can be performed in diverse ways (alone or with partners), driven by heterogeneous motives (sexual arousal, mood management or anonymous fantasizing; reviewed previously¹¹⁴), and associated with different user profiles¹¹⁵.

Cybersexual activities are widely practised among adults¹⁰⁸, and high pornography consumption is not necessarily problematic¹¹⁶. However, in a minority of vulnerable users uncontrolled involvement in cybersexual activities can be impairing and associated with negative consequences such as conflicts with significant others, compulsivity, addiction-like symptoms (strong urges or cravings, tolerance-like phenomena such as gradual increase in extreme pornography engagement or consumption to experience a constant arousal level, or constant preoccupation), or moral incongruence (misalignment between moral beliefs about sexual behaviour and actual sexual behaviour)^{108,113}. To date, there is no diagnosis specific to pathological cybersexual behaviours. However, the ICD-11 framework allows pathological and functionally impairing engagement in cybersexual activities to be diagnosed as compulsive sexual behaviour disorder¹¹⁷.

Design features implemented in cybersexual websites or apps include algorithm-based recommendations of content, personalized notifications (such as informing users when specific content is available), advanced search functionality (such as identifying all content featuring a specific actress or actor on a specific website), or rating and commenting on content by other users^{118–120}. These design features suggest that cybersexual products (especially online pornography)

are optimized for predicting and responding to user preferences and behaviour, which might promote over-involvement and a potential loss of control over engagement (thereby increasing the amount of time spent on cybersexual websites), especially in vulnerable populations (such as adolescents). Developments in cyber-sexuality in the past fifteen years include artificial erotic agents, such as virtual partners, erotic chatbots or sex robots¹⁰⁹. Research that investigates how exposure to such artificial intelligence influences sexual behaviours, and whether they present new risks for developing addictive patterns of use, is needed.

It is frequently acknowledged that the specific design features of cybersexual activities (for example, continuously exposing users to their preferred stimuli based on past tracked online behaviour) contribute to their addictive potential and/or promote loss of control and compulsivity^{121–123}. However, empirical research is scarce and supporting evidence is mainly indirect. For example, engaging in cybersexual activities is associated with higher functional impairment in individuals with compulsive sexual behaviour disorder³⁶. Qualitative studies suggest that specific design features (for example, algorithm-based recommendations and advanced search functionalities) promote loss of control and compulsivity in those who engage in problematic cybersexual behaviour^{124–126}. Problematic use of online pornography is also associated with greater attentional biases toward sexual stimuli, poorer inhibitory control and executive functioning, and impaired decision-making abilities compared to individuals without problematic pornography use (reviewed elsewhere¹²⁷). These results suggest that inherent characteristics and features of cybersexual activities (for example, infinite and immediately accessible sexual content) interact with individual vulnerabilities (for example, low impulse control) to promote problematic usage patterns.

Online shopping

Empirical research on the structural determinants of problematic online shopping is limited^{5,128,129}. Previous studies have noted that the easy accessibility, availability (ability to shop 24 hours a day, 7 days a week), anonymity (ability to shop without face-to-face contact), and convenience (ability to shop without leaving home) of online environments might contribute to the onset and maintenance of problematic online shopping^{130,131}. However, there has been less discussion on the specific features (advertising pop-ups, time-limited discount offers, flexible payment options, and points programmes) that might fuel problematic use of e-commerce platforms^{130,132,133}.

One study that applied a descriptive auditing method to 50 Australian-based entertainment, social network, online merchandise, and news and media websites identified time-limited offers (a feature that is also relevant to online gaming and gambling) involving countdown meters (which often provide false information), display of product sell counts, indicators of limited product left, and product recommendations based on other customers' purchases as structural elements designed to stimulate instant and reckless purchases⁴⁵. These findings might constitute a preliminary base for further empirical research assessing the impact of e-commerce platform design features on uncontrolled online shopping.

Social networking

Social networking services include messaging apps (such as WhatsApp, WeChat and Snapchat) and social networking platforms (such as Facebook, YouTube, Instagram, Twitter, Pinterest and TikTok) that allow users to interact, create, share and consume content. Social networking

services are designed to prolong time spent on such applications^{44,134,135}, and might promote problematic smartphone usage patterns^{136–140}. Specifically, the constant availability of smartphones might encourage repeated checking of social networking accounts, especially among vulnerable individuals with low self-control¹⁴¹.

A few preliminary theoretical reports describe relevant design features that might keep social networking services users engaged over extended periods of time or get them continuously coming back. These include infinite scrolling (the ability to scroll down through content that does not end)^{44,135}, the 'newsfeed' that matches a user's interests (derived from machine learning algorithms applied to the user's previous interactions with the platforms)⁴⁴, the 'like' feature^{44,45} and the 'double tick' function (two grey ticks indicating that a message has been received, which turn blue when the message has been read)⁴⁴.

These claims are supported by qualitative research (usually based on interviews with social networking service users). According to this research, the group setting on messaging apps induces continuous engagement and creates social pressure to reply to received messages quickly, which is amplified by the 'double tick' function¹⁴². Moreover, temporarily available information (for example Instagram 'stories' that are deleted after a certain amount of time) and trending information (for example popular hash-tags) motivate users to continually check their social networks owing to a fear of missing out (FOMO) on updates or potentially important information¹⁴². Finally, 'likes' and repost or forward functions (for example 'retweets' on Twitter) that provide users with real-time updates on the number of people reacting to their posts, continuous information renewability (new information generated in the 'newsfeed' since one's last logon), and push notifications (sounds and images notifying users when relevant information is available) encourage automatic checking behaviour and loss of control over time spent engaging with social networking services, which interferes with daily life tasks, sleep, work and offline social interactions^{46,142}. These findings are consistent with previous research demonstrating that push notifications act as relevant external cues that prompt more usage sessions in problematic smartphone use¹⁴³.

On-demand TV streaming

Online streaming platforms enable 24-hour immediate access to all episodes of released seasons of a TV show, from anywhere and on any device with an internet connection. Consequently, binge-watching (watching multiple episodes of a TV series in one viewing session)³ has become the new standard for viewing content¹⁴⁴. The widespread adoption of binge-watching has been attributed to the on-demand nature of streaming and the technological design features of streaming platforms¹⁴⁵, including notifications about the release of new TV series¹⁴⁶, algorithm-based content recommendations^{147,148}, the autoplay or post-play feature (countdown to the automatic start of the next episode)^{149,150}, accelerated viewing¹⁵¹, smart download (automatic download of episodes to queue for upcoming viewing)¹⁵² and playback mode (omission of episode recaps or the ability to skip opening credits)¹⁵⁰.

Preliminary qualitative evidence (derived from focus groups with binge-watchers) suggests that the design features described above are perceived to encourage continuous on-demand streaming of TV series and make it difficult to stop binge-watching^{41,153–156}. In particular, easy and convenient access to abundant TV series across multiple devices (TV, smartphones, tablets, laptops and computers) facilitates unplanned and uncontrolled TV consumption^{41,153,154}. The autoplay or post-play feature is generally reported as the biggest challenge to self-control in binge-watching^{153,155,156}. Other design features, including push

notifications, algorithm-based recommendation and playback mode, encourage further binge-watching sessions^{154,156}.

Convergence between online behaviours

In the previous section, we summarized how technology design features might promote uncontrolled engagement in distinct types of online behaviours. However, the growing interlinking of information and communication technologies, media content, activities, services and products, owing to the evolution and popularization of the internet^{157–159} has led to increasing overlap between initially distinct web-based applications. For example, shopping advertisements appear in social networking services and gambling-like features such as loot boxes are embedded in video gaming and social networking services^{157,160}. Crucially, sophisticated machine learning algorithms applied to a user's previous interactions with the website, platform or application, and derived personalized push notifications or recommendations encourage loss of control across different online behaviours^{46,124–126,142,154,156}. Indeed, tracking and continuously updating individual preferences via the collection (and exploitation) of behavioural data might be a common structural feature connecting problematic online behaviours. Such data collection allows service providers to maintain users within 'online interactive loops' to maximize data collection and refine these profiling analyses^{22,161}, thereby optimizing information and recommendation tailoring. Such technical systems also clearly point to economic motives for exploiting these features when designing web-based applications and interfaces^{162–166}.

Theory-driven classification

Our review of the available scientific literature reveals a dearth of systematic, theory-driven research on the design features of online applications, websites and digital environments that facilitate loss of control over online behaviours. Online product development requires little knowledge of underlying psychological processes because massive deployment allows learning by trial and error: design features that increase the frequency of online behaviour, time-on-device or spending (and therefore revenue) will be maintained, whereas those that do not will be abandoned^{157,167,168}. Because deploying technologies that increase the frequency of online behaviours might be harmful to some users, it is important to understand how these design features operate. However, such understanding is hindered by informational asymmetry: technology providers accumulate massive amounts of information about their users, whereas users (and researchers) have neither access to such information, nor an understanding of how it enables the manipulation of their behaviour in a progressively personalized manner.

To start closing this gap, we propose a theory-driven general taxonomy of design features that influence uncontrolled online behaviours based on the interaction between 'model-free' and 'model-based' mechanisms underlying learning and behavioural control (Fig. 1). In model-based learning, mental models of the world are elaborated and updated as experience with the outcomes of behaviour is accumulated. These mental models are then used to anticipate immediate and delayed consequences of possible choices (for example, the expected outcomes of online gambling, gaming or watching pornography versus abstaining from these behaviours)^{169,170}. Thus, model-based control is based on computing and comparing expected utilities. By contrast, model-free learning consists of the accrual of cached values (values that have been assigned to choice options) that become associated with choice options through previous experience with these options

and subsequent feedback. These cached values subsequently drive model-free behaviour control. Importantly, unlike automatic (cue-driven) versus voluntary (goal-driven) dual-system models of self-regulation, model-free and model-based modes of control are not mutually exclusive, but can operate in parallel. Most behaviours are therefore controlled in a mixed manner^{171–173}. Moreover, both model-free and model-based mechanisms can promote uncontrolled or addictive behaviours. For instance, a decision to start gambling can be simultaneously motivated by an automatic tendency to approach gambling devices (model-free factor) and the expectancy of wins (model-based factor).

In this section, we elaborate on this taxonomy and classify the technology design features that might promote problematic online behaviours described above into model-free and model-based categories (Table 2).

Design features that exploit model-free processes and control

Habit formation and incentive sensitization are two well known examples of learning that mostly depend on model-free processes^{174–176}. In animal models, goal-driven instrumental behaviours can eventually turn into habits – stereotyped, cue-triggered behaviours, mostly insensitive to outcome value – after repeated training under certain reinforcement schedules (such as the variable interval schedule^{177,178}, in which a response is reinforced only after a variable and unpredictable time interval has passed since the last reinforcer was delivered). Incentive sensitization (intense cue-driven 'wanting') is hypothesized to be caused by the repeated overstimulation of mesolimbic and mesocortical dopaminergic pathways¹⁷⁹. Such overstimulation progressively increases the incentive value of environmental cues associated with the addictive agent. In other words, these cues progressively become 'motivational magnets' because they acquire the power to hijack attentional resources and trigger an increasingly intense craving response (an overwhelming desire and urge towards the addictive behaviour), jeopardizing control attempts. Importantly, this overstimulation can be caused by addictive drugs^{180,181} as well as other reinforcers when their delivery is highly unpredictable^{182–184}.

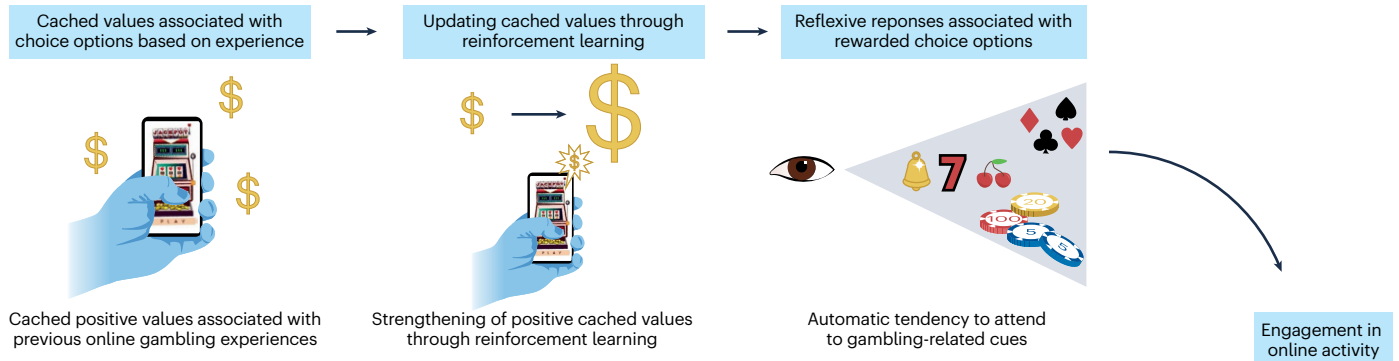
Comparing habit versus incentive sensitization models of compulsion in addictive disorders, and the algorithmic specificities of these learning processes, is beyond the scope of this article (and reviewed elsewhere¹⁸⁵). The key point here is that, in both cases, exacerbated model-free learning might result in gradually more inflexible, stereotyped and cue-driven behaviours. This view is consistent with the finding that a pre-existing imbalance favouring model-free over model-based control is a vulnerability factor for the development of addictive behaviours¹⁸⁶.

Moreover, experimental research suggests that the unpredictability of rewards, and the impossibility of reducing such unpredictability with experience, promote perseverative and cue-driven addiction-like behaviour^{187,188}. The irreducibility of uncertainty is maximal in random-ratio reinforcement schedules, in which the probability of reward for each response is independent of previous reinforcement history. This type of reinforcement schedule is implemented in most gambling devices (the outcome of each bet is independent of the outcome of previous bets) and has been theoretically and empirically linked to their addictive potential^{187–190}.

Random-ratio reinforcement schedules are also present in video games, social networking services and other internet apps, where non-monetary rewards such as 'likes', 'retweets' or notifications are unpredictable^{191,192}. Unpredictable availability of rewards is also an

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a Model-free mechanisms



b Model-based mechanisms

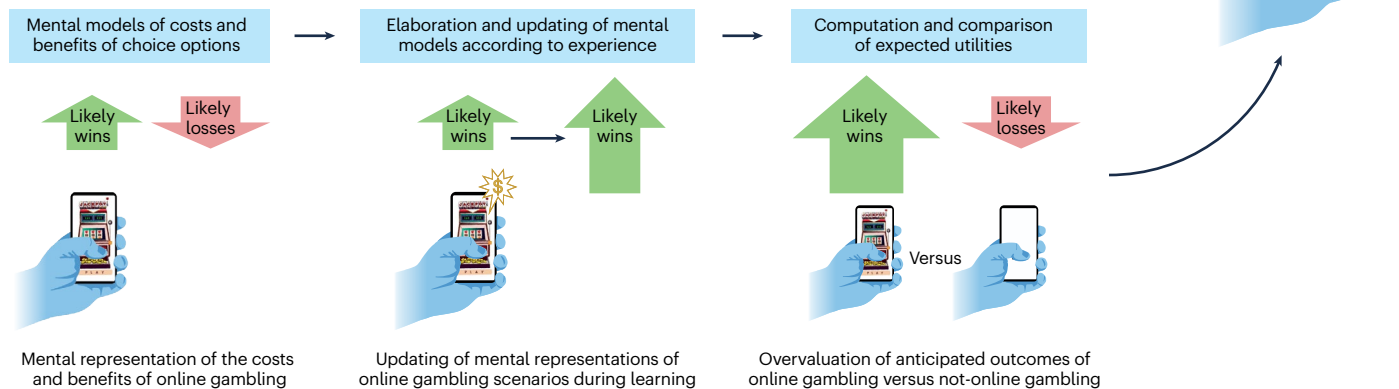


Fig. 1 | Model-free and model-based mechanisms underlying problematic online behaviour. Model-free mechanisms (part a) and model-based

mechanisms (part b) underlying the decision of whether or not to engage in an online activity, using online gambling as an illustrative example.

ingredient of randomly distributed happy hours in online gambling, and special offers in online shopping (such as free shipping or free gifts). Unfortunately, despite their apparent ubiquity and likely role in problematic online behaviours (Table 2), we are unaware of any formal analysis of design features related to reinforcement schedules in domains other than gambling. Notably, loot boxes are increasingly present in commercial video games¹⁹³. The structure of loot box reinforcement schedules has not been thoroughly investigated, but loot boxes have been discussed in relation to variable ratio reinforcement schedules^{191,194}, and their consumption is associated with problem gambling¹⁹⁵.

Internet-based environments can also present cues that trigger potentially problematic behaviours. These triggers can be considered design features that promote loss of control. As described above, cue reactivity (physiological, emotional and cognitive responses to relevant stimuli) is a salient feature of gambling disorder. If irreducibly uncertain reinforcement is at least partially responsible for the development of cue-driven and inflexible behaviours, as suggested by theoretical proposals^{183,184} and empirical evidence¹⁸², gambling devices that implement such reinforcement schedules could exploit these cues. The personalization of push notifications or advertisements in nearly all online activities can be considered individualized or personalized

cues that might generate even more craving and therefore compulsive behaviours. For example, intense craving generated by pop-ups about limited special offers for a specific product on e-commerce sites could lead to compulsive buying. Unfortunately, results from attempts to determine whether or not craving is central to the development of chronic problems in behavioural domains other than gambling are inconclusive, as these studies mostly rely on self-report methods in which craving-related items use generic terminology such as 'urge' or 'desire' (for example, 'sometimes, I feel an irrepressible urge to play')¹⁹⁶ that could refer to different underlying constructs in different behavioural domains^{197,198}.

Design features that exploit model-based learning processes

The model-free learning processes described above (habit learning and incentive sensitization) are involved in gambling problems^{182,199,200}. However, their role in other candidate behavioural addictions is less clear. Moreover, other mechanisms related to model-based control might also cause substantial functional impairment (and therefore serve as targets for prevention)²⁰¹.

Model-based control involves comparing the benefits and costs of the potentially problematic activity with those of alternatives (such as disengagement in the activity or engagement in other behaviours).

Table 2 | Digital technology design features that might reduce users' control

Online behaviour	Model-free design features		Model-based design features			
	Reinforcement schedules	Personalized triggers	Overvaluation of positive outcomes	Features that interfere with deliberation	Partial goal fulfilment	Cognitive biases
Online video-gaming	Random loot boxes; randomly generated content; surprise mechanics	–	Role-playing elements; realistic graphics; in-game achievements	–	Game rewards; in-game purchases	Persistent environment
Online gambling	Random-ratio payment schedules	Advertisements; push notifications; graphics and sounds	Improved odds; free bets	Multi-bets; cash-out opportunities	Sequential bets	Near-misses; control buttons
Cybersexual activities	–	Push notifications; AI-based algorithms; personalized recommendations	Visual partners; chatbots	–	–	–
Online shopping	Free gifts; free shipping	Pop-up product recommendations; new product alerts	–	Time-limited discounts; limited product left alerts	Points programmes	–
Social networking	Likes; repost or forward functions	AI-based algorithms; push notifications	Hashtags; group settings; 'double-tick' function	–	Infinite scrolling; information renewability	Temporarily available information
On-demand TV streaming	Infinite scrolling	AI-based algorithms; pop-up recommendations; playback mode	Graphics and sounds; chatrooms; top-10-rated series	Autoplay; smart download	Progress bar	–

Importantly, such comparison does not imply that the choice is necessarily rational or advantageous in the long term: several mechanisms can lead to a choice option that simultaneously presents the highest subjective value and long-term negative consequences²⁰².

Potentially problematic online activity might be favoured over alternatives if its subjective value is high. The outcomes of some online activities become overvalued for many reasons, and are related to individual differences in people's values and needs^{203,204}. For example, removing time cues and including graphics and sounds facilitates immersion or flow states in some continuous activities ('entering the zone' in online gambling, or feeling 'carried away' by narratives in TV series and video gaming)⁵⁰. This immersion is positively reinforcing for people who engage in these activities, but can become a way to escape – and therefore a negative reinforcer – for emotionally vulnerable individuals or people experiencing distress^{205–207} (that is, alleviation of undesirable emotional states serves as a reinforcement for engaging in the online activity). Other design features might also alleviate peer pressure or FOMO, and thereby promote continuous involvement in online behaviours following a similar negative reinforcement logic. For example, chatrooms and presenting top-10-rated series lists on streaming platforms encourage viewers to catch up on the latest series so they can discuss it with friends; group settings and 'double tick' function on messenger apps induce users to reply quickly to received messages for fear of losing popularity among friends or missing important updates.

In terms of positive reinforcement, design features related to social reward ('likes' in social networking, Elo scores that calculate the relative skill levels of players in e-sports, or role-playing elements in video games) can be especially efficacious in motivating people who lack real-world social skills and confidence, and who experience difficulties achieving the same amount of reward in face-to-face interactions^{208–210}. Similarly, problematic attachment to video games might be associated with maladaptive cognitions, including overvaluing the importance of game rewards and an overreliance on gaming for a sense

of self-worth^{211–213}. Qualitative research shows that features such as promotions and time-limited events trigger or facilitate buying loot boxes for players with social-oriented motivations (such as FOMO) or based on the subjective value attributed to digital content²¹⁴. The variety of social motives and their interaction with individual factors make it difficult to review all the possible design features that might relate to them. Crucially, informational asymmetry enables providers to profile their customers using automated artificial intelligence to offer users what they are looking for. If user motives constitute vulnerabilities, these automated processes could become exploitative.

The ability to fully consider the short- and long-term consequences of decisions to make globally advantageous decisions requires time and cognitive resources²¹⁵. Low availability of such resources constitutes a risk factor for problematic online behaviours^{216–218}. Several design features (for instance, autoplay and smart download function in streaming platforms, which make binge-watching quasi-automatic) interfere with the deliberative and controlled processes needed to overcome present-oriented decision-making. Messages that convey a sense of urgency regarding immediately accessible gratifications (such as in time-limited offers that involve countdown meters and limited product left alerts in e-commerce sites or videogames, or multi-bet and cash-out opportunities in online gambling) are designed to encourage individuals to act on the spur of the moment and directly interfere with reflective thinking.

Revealing new possibilities of reward once a previous one has been reached can increase the anticipation of positive consequences, and therefore expected utility. Features that reflect moving goalposts are ubiquitous in video gaming, social networking and on-demand TV streaming, and they keep individuals engaged for longer than planned after initiating the activity. Reaching goals can be extraordinarily rewarding, so allowing progression is central to maintaining motivation²¹⁹. However, online environments often allow only partial satisfaction. Video games rewards come in levels and stages, and completing one level typically allows access to a new one. Infinite scrolling in social

networking sites reveals some desired information, but also offers the never-ending promise of new rewards, as does continuous information renewability. TV series episodes (with viewing progression reflected by a progress bar on streaming platforms) usually end with some big revelation, but only to introduce a new mystery (cliffhanger). Points programmes that reward customers with points for each purchase encourage people to continue online shopping. As reviewed above, these design features have been linked to progression into problematic and addictive online behaviours.

Finally, some design features strengthen specific cognitive biases and foster distorted beliefs. The consequences of distorted beliefs can be far-reaching. Problematic online behaviour will be more likely if the probability of a positive outcome of engaging in, relative to abstaining

from, that activity is overestimated. In other words, beliefs about relationships between behaviours and outcomes become part of the mental models users enact to make value-based decisions. For instance, stop buttons feed the feeling that outcomes in gambling devices are controllable^{220,221}. Losses disguised as wins (for example, a cheering sound when a slot machine pays US\$0.70 back for a US\$1 wager) and near-misses in which unsuccessful outcomes are perceptually close to the jackpot (for example, when two reels of an online slot machine stop on the dollar symbol, and the third reel stops when the dollar symbol is just a position above or below the payoff line) contribute to the false belief that one is progressing or learning something valuable about the game, or artificially reduce perceived losses^{222,223}. Moreover, these beliefs tend to be domain-specific, namely, they refer to the context

Box 1

Implications for prevention and intervention

Uncovering the influence of technology design features in potentially problematic and addictive online behaviours can contribute to the design of efficient prevention tools and policy recommendations to minimize use-related harms across online domains. Evidence-based educational guidelines and prevention plans, as well as awareness-raising campaigns, should promote self-control strategies to help individuals develop safer online behaviours and new healthy habits. However, little is known about the common (model-based or model-free) strategies that users employ to modulate the impact of these self-control-challenging design features or their efficacy at preventing the emergence of potential harms induced by excessive and dysfunctional technology use. Uncovering such self-control strategies would be a critical asset for health professionals and could inform future intervention studies.

There has already been some work along these lines in the context of social networking overuse²⁷¹. Using a naturalistic-qualitative approach, researchers identified six proactive (for example, fully or partially preventing access to social media by leaving one's phone in another room or turning off notifications) and reactive (for example, using 'in-the-moment' self-control, such as finishing an important task instead of checking social media) self-control strategies. Individuals with high trait self-control were better at avoiding social networking overuse than individuals with low trait self-control because they had weaker social networking use habits and, consequently, found it easier to enact self-control strategies²⁷¹. This result is in line with studies showing that better self-control is associated with higher engagement in beneficial habits²⁷², lower daily life involvement in unhealthy habits²⁷³, and less-effortful inhibition of immediately available temptations²⁷⁴. These results suggest that self-control interventions should revolve around building good habits to replace bad ones, rather than resisting short-term temptations^{275,276}. Accordingly, it would be valuable to examine this assumption across the behavioural domains considered here.

Finally, increased awareness, acceptance of responsibility and direct involvement of service providers in addressing these issues is needed^{43,277}. Thus, stakeholders must work collaboratively to develop, assess and take regulative actions to prevent and minimize

the harm associated with problematic online behaviours. Possible industry-directed regulation initiatives might include legislation that prohibits web-based applications and interfaces from exploiting nudge techniques, or enlisting popular social media influencers to help in promoting healthy online habits.

In general, recommendations for policies to prevent the emergence of problematic and addictive involvement in online activities — and reduce related harms — must be based on a multi-stakeholder approach^{47,278,279} that engages users, their close relatives who can evaluate risks²⁸⁰, researchers, clinicians and community organizations, as well as representatives from industries designing technology²⁸¹ and government bodies regulating it²⁸². All parties should carry out joint efforts to elaborate and implement relevant prevention tools and targeted programmes informed by research evidence.

Policy recommendations to promote healthy patterns of engagement in online activities include (but are not limited to):

- Promoting evidence-based effective and sustainable (model-free/model-based) self-control strategies to help users to regulate online behaviours and minimize potential use-related harms.
- Providing transparent user guidelines on functional and dysfunctional use of online applications and signs of concerning behaviours that might become harmful, including referral to treatment services when needed.
- Developing, implementing and evaluating in-app functions that might support users' self-control, such as warning messages that encourage users to reflect on their long-term goals, that are generated in response to AI-based detection of emerging problematic behaviours.
- Integrating mandatory educational programmes to enhance children and adolescents' digital literacy skills in the public education system.
- Developing, implementing and evaluating awareness campaigns for parents and teachers concerning potential risks resulting from problematic online behaviours.
- Developing, implementing, monitoring and evaluating intervention strategies for individuals exhibiting problematic and addictive involvement in a specific online activity.

and outcomes of the potentially problematic activity. For instance, video games and social networking services stress the importance of the rewards one could be missing by not being online (for example, in virtual worlds in which game-relevant events keep on occurring even when the player is absent, or in social networks in which some content is automatically deleted after a certain time interval) to boost FOMO^{58,66,142}, thus providing fertile ground for activity-related cognitive biases to develop (for example, believing as a gamer that rewarding experiences are only possible online, or that not constantly keeping up with what friends are doing online will reduce one's popularity). The mechanisms driving these beliefs can be embedded into websites, apps and devices in the form of nudges (or dark nudges)^{77,224}, and can also be strengthened by media advertising and direct communication. The link between gambling commercials' content and cognitive biases, and therefore the potentially exploitative use of such biases, has been detailed elsewhere^{85,86}. Similar analysis has not yet been systematically carried out in other domains.

In sum, we posit that engaging in a potentially problematic online activity is always a choice. This choice can be predominantly model-free, that is, made on the basis of cached estimates of the accrued values of previous choices, and therefore mostly reflexive and insensitive to the specificities of the situation that could make it more or less advantageous. An unbalanced reliance on this type of control mode can lead to excessively cue-driven and inflexible behaviours, and manipulations that facilitate model-free control have the potential to turn an instrumental behaviour into an addictive one. However, this is not the only way an initially non-problematic behaviour can turn dysfunctional. Some activities can become problematic (and clinically relevant) through model-based mechanisms simply because their consequences are computed to be more valuable than consequences of abstaining. This relative overvaluing depends on individual features, but technology enables online activities to be adapted to match personal motivations, which might exploit vulnerabilities.

Summary and future directions

In this Review, we have summarized design features of online applications that might promote dysregulated and addictive online behaviours. These design features can be classified in a number of theory-informed (model-free versus model-based) categories, including reinforcement schedules that promote habit formation and incentive sensitization; cues that trigger responses acquired via these model-free processes; features that, in combination with personal needs and values, contribute to overvaluation of the potentially problematic activity and its consequences relative to its alternatives; features that interfere with reflection or deliberation; partial goal fulfilment; and explicit information and decision architectures that strengthen cognitive biases and distorted beliefs about outcome probabilities or their relationship with one's behaviour. Classifying these design features enriches the understanding of the underlying drivers of potentially problematic and addictive involvement in online activities, which can be applied to prevention and intervention efforts that help users to keep or regain control over online behaviours (Box 1).

We identified common psychological mechanisms that might contribute to the development of problematic online behaviours, and the specific design features that promote such mechanisms in different online activities. Future research should further investigate differences and similarities between potentially problematic online behaviours. In accordance with recent calls to conduct qualitative research to clarify potentially problematic and addictive involvement

in online behaviours^{17,225,226}, the focus group method might be particularly relevant to this end²²⁷. Focus groups would also be useful for future investigation of the types of self-control strategy routinely enacted by individuals to regulate their involvement in online activities and their efficacy at preventing the possible emergence of related harms. Further prospective studies would then be needed to examine whether these strategies (and interventions based on them) can help people to develop and maintain healthy online habits.

Obviously, not all mentioned design features have a role in the development of behavioural problems in all online domains considered. However, identifying their specific combinations and behavioural effects contributes to a better understanding of the nature of potentially problematic online behaviours that are currently (and probably misleadingly) grouped together as putative addictive disorders. In other words, investigating how design features have differentially evolved and have, in some cases, become successfully exploitative, can help to overcome the confirmatory approach to studying online addictive behaviours^{31,32} which, by recycling biomedical substance use disorder models to account for excessive online behaviours, is highly reductionistic and tends to pathologize common behaviours while also constraining the scope of relevant prevention and intervention strategies.

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Competing interests

The authors declare no competing interests.

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