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Primary publication

Wegmann, Elisa; Steins-Loeber, Sabine (2026): Has light reinforcing effects in humans and may contribute to the development of problematic usage of the internet and digital-based behavioral addictions? : Commentary to the debate: “Wired for habit: Using rodents to understand digital technology-based disorders”, in: Journal of behavioral addictions, Budapest: Akadémiai Kiadó, Online First, pp. 1–5, doi: 10.1556/2006.2025.00417.

1828
AKADÉMIAI KIADÓ

Journal of Behavioral Addictions

DOI:
10.1556/2006.2025.00417

DEBATE: WIRED FOR HABIT: USING RODENTS TO UNDERSTAND DIGITAL TECHNOLOGY-BASED DISORDERS

Has light reinforcing effects in humans and may contribute to the development of problematic usage of the internet and digital-based behavioral addictions?

Commentary to the debate: "Wired for habit: Using rodents to understand digital technology-based disorders"

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Received: September 24, 2025 • Revised manuscript received: March 31, 2026 • Accepted: March 31, 2026

ABSTRACT

This commentary complements the arguments by Tam et al. (2025) and offers a comprehensive approach when considering light conditioning in the context of the development and maintenance of problematic Internet use. Thereby, we illustrate the impact of light on humans also within the context of theoretical considerations and empirical studies. We agree with Tam et al. (2025) that there is a need for a better understanding of habit formation within addictive behaviors and we acknowledge the empirical challenges which are proposed in the article mentioned. At the same time, this commentary emphasizes that light should not be considered as an isolated reinforcer, but rather as a complementary component of other conditioned and cognitive tendencies (e.g., use expectancies), as well within the interplay of further processes in addiction research such as craving, attentional biases, and self-control abilities.

KEYWORDS

behavioral addictions, addictive behaviors, Pavlovian-to-instrumental-transfer, craving, attentional bias

The article by Tam, Stryjska, Gu, and Becker (2025) titled *Operant light self-administration in mice and its relevance to digital technology-based disorders* presents the operant light self-administration paradigm and suggests that this may be a useful paradigm to assess mechanisms of habitual responding to non-drug and non-feeding cues in animals. Interestingly, Tam et al. (2025) also suggest that from a perspective of cross-species research, this paradigm can be helpful to elucidate mechanisms in digital-based technology disorders like problematic Internet use given the important role attributed to habit behavior in the development and maintenance of addictive behavior in humans. We comment here on the article by Tam et al. (2025) from a perspective of human research on affective and cognitive mechanisms in the development and maintenance of problematic Internet use. In doing so, we will include theoretical considerations from addiction research and empirical evidence, as well as specifically discuss the individual suggestions in the context of light conditioning and share further arguments.

Tam et al. (2025) address an important research question, i.e., the role of habit formation in the development of problematic Internet use. As for example outlined by Brand, Antons, et al. (2025), several rewarding activities that are often performed online (e.g., gaming, use of

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social networks, buying-shopping, pornography) may be executed excessively, receive increasing priority in everyday life, and are continued despite negative consequences. For many decades, learning processes and habit formation are considered key mechanisms in the development of substance use disorders. In short, the incentive sensitization theory (e.g., Berridge & Robinson, 2016; Robinson & Berridge, 1993) posits that cues that were repeatedly associated with substance consumption acquire appetitive properties and enhanced incentive salience. The exposure to conditioned substance-associated stimuli elicits conditioned stimulus-associated responses, which motivate instrumental drug seeking behavior. Habit theory (e.g., Everitt & Robbins, 2005, 2016) assumes that drug-seeking is initially goal-directed. However, stimulus-response habits develop as the association between substance-associated stimuli and drug-seeking behaviors strengthens and finally, drug-seeking becomes a compulsion characterized by inflexibility and resistance to experiences of reduced rewarding properties of the drug (Everitt & Robbins, 2016). In recent years, habit formation and habitual responding in addictive behaviors have been discussed controversially. For example, Hogarth (2020) argues that habitual behavior is still flexible and, for example, outcome devaluation procedures are associated with reduced responding.

With the Interaction of Person-Affect-Cognition Execution (I-PACE) model, Brand et al. (2019) formulated a framework focusing on the development and maintenance of behavioral addictions. It is assumed that the interactions between predisposing variables (e.g., impulsivity), affective and cognitive responses to specific stimuli (e.g., cue-reactivity, craving), and deficits in self-control abilities (e.g., reduced inhibitory control) contribute to the development of "seemingly" habitual responding and resulting in addictive behaviors (Brand, Müller et al., 2025). The term "seemingly" habitual (or automatic) refers to addictive behavior in the later stages of the addiction process that is more driven by internal or external stimuli and performed under less cognitive control. This does not necessarily mean that goals and goal-directed behaviors are completely diminished. Habit formation can be considered as a general process in addictive behavior that starts early on and contributes to the development of stimulus-response associations (Brand, Müller, et al., 2025). It may thus increase the likelihood that a specific behavior is executed in specific situations, for example with the goal to avoid negative feelings, which may be activated rather automatically by external or internal stimuli (e.g., stress, negative mood) and the executed behavior "seems" habitual.

In human studies, several tasks has been used to study habit formation, for example, the two-step task (Daw, Gershman, Seymour, Dayan, & Dolan, 2011), contingency degradation tasks (e.g., Liljeholm, Tricomi, O'Doherty, & Balleine, 2011; Shanks & Dickinson, 1991), outcome devaluation tasks (e.g., Steins-Loeber et al., 2020), or the motor learning sequence task (e.g., Grundmann et al., 2025). However, regarding behavioral addictions, there are at present (at least) two challenges. Firstly, human studies on learning processes and habit formation with stimuli and reinforcers that are not drug-related or food-related are scarce and only few paradigms have been proposed and validated. For example, Vogel et al. (2018) reported the relevance of learning processes and automatized behavior for online gaming and online shopping using a Pavlovian-to-Instrumental Transfer Paradigm with application-related stimuli. Only recently, Schmid et al. (2025) presented data on the validity and reliability of a short Pavlovian-to-Instrumental Transfer Paradigm to assess mechanisms of habit formation, again in online gaming and online shopping. Second, there is at present no animal model to investigate habit formation in problematic Internet use (or behavioral addiction). Against this background, Tam et al. (2025) make an important contribution to a better understanding of theoretical considerations and empirical results in addictive behaviors by presenting the operant light self-administration paradigm. This paradigm builds on the observation that in rodents brief light pulses (or an increase in light) serve as positive reinforcer. This was already found by Stewart (1960). In short (see also Figure 1 in Tam et al., 2025), in the operant light self-administration paradigm a mouse is placed in an otherwise dark operant chamber. Performing an instrumental response (e.g., lever pressing) results in a few seconds of light. The hedonic value of light in mice thereby seems to rely on the retina that conveys light signals to subcortical circuits involved in reward and affective processing. The hedonic value is modulated by several neurotransmitters including dopamine, glutamate, and opioids. Under certain conditions, light can be as reinforcing as addictive drugs.

Wrapping up these theoretical and empirical considerations, it raises the question if the operant light self-administration paradigm helps to understand learning processes and mechanisms of habit formation assumed to be relevant for problematic Internet use? Based on preliminary findings that the total smartphone screen time per day of young adults is reduced by at least 20–50 min when gray-scale filters are applied (e.g., Dekker & Baumgartner, 2023), Tam et al. (2025) propose three different ways in which light may contribute to excessive use of digital devices, which we would like to address against the background of specific affective and cognitive mechanisms of problematic Internet use: Firstly, light is a primary reinforcer and intrinsically rewarding; secondly, light serves as a Pavlovian conditioned cue associated with other primary reinforcers and thus serves as a conditioned incentive for responding; thirdly, light causes a general increase in responsiveness due to a change in arousal, alertness, or affective state.

Regarding the first suggestion, we assume that under certain conditions, light may indeed serve as a primary reinforcer. For example, fear of darkness is common in children with 20–30% of children reporting severe nighttime fears (Kopcsó, Láng, & Coffman, 2022). In adults, nighttime outdoor environments are perceived as less pleasant and darkness provokes feelings of fear for personal safety (Toet, Houtkamp, & Vreugdenhil, 2016). As outlined by Kopcsó and Láng (2014) fear of darkness is more common in

women than men and associated with cognitive style and attachment quality. It may be a relevant clinical condition (named nyctophobia or achluophobia) that persists from childhood to adulthood and may severely impact daily life. While darkness may thus be associated with anxiety disorders, there may also be an association with affective disorders. Thus, the positive effect of bright light therapy for individuals suffering from seasonal or non-seasonal depression as well as bipolar disorders is well documented (Geoffroy et al., 2025; Penders et al., 2016). Although the putative mechanisms encompass chronobiology, homeostatic sleep processes, wake systems, and monoaminergic neurocircuits, there is also evidence suggesting a retinothalamic-frontocortical pathway in mammals that mediates the effects of light on neural pathways of mood and behaviors (Geoffroy et al., 2025). Nevertheless, there is a significant lack of studies on light effects in humans, and based on our current knowledge, we consider it unlikely that the primary reinforcing effects of light alone contribute to the development of problematic Internet use illustrated by experiencing loss of control over the behavior. Rather, we assume that a general action tendency (e.g., using the smartphone) within the context of reinforcement does not automatically lead to habitual behavior tendencies or an addictive behavior, but more likely that effects of light could represent a complementary aspect in the interaction of further affective and cognitive mechanisms (e.g., cue-reactivity, craving; see second suggestion below).

The second suggestion refers to light serving as a Pavlovian conditioned cue associated with other primary reinforcers and thus serving as a conditioned incentive for responding. We think it is very likely that every time an instrumental response leads to a psychologically significant outcome, some stimuli are present that have the chance to become associated with either the outcome or the response or both. Consequently, in instrumental learning scenarios, multiple associative mechanisms may be at play simultaneously. This scenario may well apply to problematic Internet use. For example, every time someone receives or opens a message on the smartphone this will be accompanied by an increase in light of the display and other primary cues, for example sounds and vibration (see also Wegmann, Stodt, & Brand, 2018). However, focusing on the light on the display, this might be not unrelated to other cognitive processes such as specific expectations or reward experiences towards the online behavior. The I-PACE model emphasizes that the behavioral manifestation is associated with specific use expectations and the experience of positive and negative reinforcements (e.g., gratification and compensation) (Brand et al., 2019; Brand, Müller, et al., 2025). This could indicate that although the light represents a reinforcing aspect, the actual reinforcer is rather the content of the message such as receiving "Likes" for a picture (Sherman, Hernandez, Greenfield, & Dapretto, 2018), feelings of social connectedness, or other rewarding aspects. However, although not a primary reinforcer as suggested by Tam et al. (2025), we agree that light may be associated with the incentive value of this reinforcer and may acquire incentive properties itself.

This argumentation is also reflected by the third suggestion that light causes a general increase in responsiveness due to a change in arousal, alertness, or affective state. As already mentioned, not only light itself, but also its association with reinforcing aspects of the application outlined before will probably result in light enhancing arousal and, for example, attention allocation to the digital devise. Thus, higher arousal or alertness may be associated with higher cue-reactivity and craving as an indicator of a problematic online behavior. Increased sensitivity to behavior-associated cues and the resulting desire to engage in the behavior (= craving) is a central mechanism of behavioral manifestation in both substance-related addiction and behavioral addiction (Starcke, Antons, Trotzke, & Brand, 2018). In a comprehensive study by Antons et al. (2025), individuals with problematic Internet use showed an increased sensitivity including arousal, urge, and craving responses to application-related stimuli (i.e., distal cues like starting pages not illustrating the rewarding aspects directly) compared to individuals with non-problematic or risky online behavior. This also underscores the interplay between general sensitivity and actual desire related to a behavior which is already problematic. However, theoretical models do not consider this mechanism in isolation; the relevance of cue-reactivity is reflected in other cognitive mechanisms such as attentional bias and specific inhibitory control (Berridge & Robinson, 2016; Brand et al., 2019; Brand, Müller, et al., 2025; Field & Cox, 2008; Stacy & Wiers, 2010): Confrontation with behavior-specific stimuli is associated with shifts in implicit processes (e.g., Chen et al., 2018; Kessling, Schmidt, Brand, & Wegmann, 2023; Liu et al., 2024) or difficulties in inhibitory control as part of self-control, also already discussed within the context of problematic usage of the Internet (e.g., Müller et al., 2025; Nikolaidou, Fraser, & Hinvest, 2019). Keeping this in mind, we assume that more generalized stimuli such as light could contribute to a general action tendency and, within the context of a problematic behavior, it might be an indicator of the interplay between several affective and cognitive processes.

Taken together, there are a number of shortcomings associated with the transfer of this paradigm to humans. Most importantly, although the theoretical considerations and methodological approach presented by Tam et al. (2025) are important and exciting aspects in the context of problematic Internet use, we do not agree that light may be a primary reinforcer in humans. However, we agree for light as a complementary component in conjunction with other (conditioned) reinforcement processes and within the interplay of affective and cognitive processes. Thus, the increase in light may be associated with affective and cognitive responses to other stimuli related to the application resulting in a generally higher increase of affective response and trigger positive outcome expectancies. Against this background, this approach can make a substantial contribution to a better understanding of these various constructs, especially when discussing the impact of habit formation in addictive behaviors. Thereby, we have the impression that it is important to consider a) the transferability of animal

studies to humans in terms of translational psychological aspects, b) the differences when transferring results from a general, unproblematic usage of digital technologies to a problematic use, and c) above all, other relevant processes such as expectations, rewards, and attentional biases and self-control abilities and their interplay within this specific context.

Funding sources: The work of EW and SSL on this article were carried out in the context of the Research Unit ACSID, FOR2974, funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 411232260.

Authors' contribution: EW and SSL equally conceptualized the manuscript. SSL wrote the first draft of the manuscript and EW added further arguments. All authors contributed to and have approved the final manuscript.

Conflict of interest: The authors declare no conflict of interest.

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