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Trends in
Cognitive Sciences

Review

In search of boredom: beyond a functional account

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Boredom has been characterized as a crisis of meaning, a failure of attention, and a call to action. Yet as a self-regulatory signal writ-large, we are still left with the question of what makes any given boredom episode meaningless, disengaging, or a prompt to act. We propose that boredom is an affective signal that we have deviated from an optimal ('Goldilocks') zone of cognitive engagement. Such deviations may be due to a perceived lack of meaning, arise as a consequence of struggles we are experiencing in attending to a task, or be interpreted as a blunt call to find something different to engage with. Thus, the key to understanding boredom lies in its role in keeping us cognitively engaged.

Highlights

Decades of research has demonstrated that boredom matters. It is a common cognitive-affective experience that affects almost all domains of life.

Although boredom can lead to both positive and negative outcomes, boredom often prompts us to act in ways that are injurious to the self. It is as though the state is so aversive, we seek anything, even hedonically negative actions, to alleviate it.

The study of boredom can offer insights into the nature of self-regulation, learning, and cognitive engagement. It also has the potential to inform artificial intelligence algorithms to maximize efficient learning.

Defining boredom

Over the past few decades, there has been an expansion of boredom research [1]. What was once considered trivial has been shown to be critical for mental and physical health, cognitive functioning, social relationships, academic achievement, and workplace performance [2–17]. This surge in boredom research brings to the forefront the need for a cohesive definition of the experience. Past accounts grounded boredom in existentialist notions of meaning regulation, with feelings of boredom indicative of low situational meaning or a lack of life meaning [18–21]. Cognitive models point to poor attentional control, particularly in circumstances demanding sustained attention [22,23]. Psychodynamic accounts place the blame for the discomfort of boredom on the repression of unmet desires; the bored person is mired in the desperate need for something to engage in, with no idea what might fulfill that desire [24–26].

The proliferation of models of boredom underscores a challenge in defining the experience. Capturing boredom's essence by recourse to a single feature, cognitive, physiological (Box 1), existential, or otherwise, is a fool's errand. Attempts at combining accounts leave us with the challenge of differentiating multiple types of boredom [27]. One solution is to focus on boredom's function: What is it for [28–31]? Accordingly, boredom is either a push to seek novel actions/engagement [28,32], or a call to action [29]. What is missing from these accounts is a mechanism that explains the function: How is boredom transformed into action?

Here we explore several possibilities for that mechanism, from novelty-seeking, to rising opportunity costs, to suboptimal deployment of attention (Figure 1). While each explanation has led to important insights into boredom, what is needed is a mechanistic account that not only captures the phenomenon of boredom but also straddles the gulf between in-the-moment feelings of boredom and the trait propensity to experience the state [33]. To this end, we propose that boredom signals a mismatch between the nature of current inputs (e.g., task demands, engagement level, meaningfulness) and an individual's capacities and desires (e.g., current/future goals, effort, attention, skill required). Consistent with the affect-as-information account [34], boredom has an important informational function insofar as it indicates a mismatch between desired and experienced cognitive engagement. This mismatch prompts actions to address the deviation from

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 https://doi.org/10.1016/j.tics.2023.02.002

some optimal level of cognitive engagement to ultimately eliminate the very experience that informs us of its presence. In short, boredom signals a deviation, affectively and cognitively, from a Goldilocks zone of engagement either with one's external environs or one's own mental states. As such, boredom is a cognitive-affective experience, captured well by the suggestion that boredom is a 'feeling of thinking' [35]. By conceiving of boredom as a regulatory mechanism that maintains cognitive engagement, our model explains and highlights boredom's ability to function as a call to action. Moreover, our model accounts for the trait propensity to experience boredom as a problem of either: a narrowed range of desired engagement (i.e., only specific things will engage the boredom-prone mind) on the one hand, or inappropriately assessing current levels of engagement, value, or reward on the other hand.

We should note that what counts as optimal engagement requires definition. Resource utilization perspectives might suggest that full deployment of resources (a concept which itself requires definition) [36] would count as optimal engagement, although it could be argued that this represents a more extreme experience of engagement, namely, flow [37]. At the very least, engagement is multifactorial, including behavioral, cognitive, affective, and agentic components [38]. Drawing on insights from processing theory [39] and educational psychology [40,41], we consider cognitive engagement to minimally involve psychological investment (i.e., willingness to exert effort) and intentional actions aimed at extracting meaning/information in the pursuit of a goal. This definition permits engagement with either the external environs or one's own internal milieu (e.g., meditation as cognitive engagement). Successful engagement in either domain should preclude boredom. Lastly, our understanding of optimal cognitive engagement highlights the relevance of meaning in the experience of boredom [18,21]. Whether we are able to cognitively engage with a task in a way that fulfills our desires depends (at least partly) on our ability to find meaning in the task.

The drive toward novelty

Boredom has been conceived of as a great motivator, blamed for everything from murder to self-harm[i,ii], alcohol misuse to sadistic behavior, reckless driving to gambling, and sabotage to truancy [42–49]. Boredom's motivating force and its myriad outcomes are consistent with the view of boredom as a call to action [28,29]. Yet the presumption that boredom possesses this function does not offer an explanation as to why. Even if boredom is a call to action, we still need to determine what makes it so.

Box 1. There is no physiological signature of boredom

There is controversy as to whether or not boredom should be considered a high- or low-arousal experience, a controversy that highlights the limitations of using one facet of boredom, in this case psychophysiology, to explain the phenomenon. One persistent myth regarding boredom is that of the couch potato: an individual driven inactive by boredom. Indeed, an early conceptualization of the state split it into agitated and apathetic boredom [24], a distinction we propagated for a time in our own work [52,102]. Boredom is a motivational state, one most commonly associated with terms such as agitation and restlessness [103]. Furthermore, research shows that boredom is a distinct construct from apathy, the more appropriate state for describing the couch potato [2]. Nevertheless, there is some controversy as to which end of an arousal spectrum, high or low, boredom belongs. On the basis of both physiological data and self-reports, boredom has been seen to be both a high- and low-arousal experience [81,104–109]. More recently, self-report data showed that ratings of both restlessness and sleepiness rose during a boredom mood induction [110]. So which is it? Is boredom high or low in arousal?

One way to resolve this would be to state that boredom is a mixed-arousal experience. This sidestep is unsatisfying if we believe that arousal levels could provide a signature of boredom. Perhaps this is a futile endeavor for all cognitive-affective states. In an ingenious recent study [111] participants were given probes concerning mood that were based on changes in their own physiology (i.e., heart rate changes prompted the probes). Data showed no definitive signatures for distinct affective states. In their hands, boredom was more commonly associated with low arousal, although even in this case, the most common cluster of physiological changes associated with boredom included elevated heart rate (see also [81]).

Functionally, whether boredom is a low-, high-, or mixed-arousal experience may be irrelevant. This is not to suggest that we cannot learn much from psychophysiology about the dynamics of the state. Indeed, it may be the case that dynamic changes in arousal characterize the onset and prolonged experience of boredom in unique ways (Figure I). In the context of our model, such changes may reflect deviations from the Goldilocks zone of cognitive engagement.

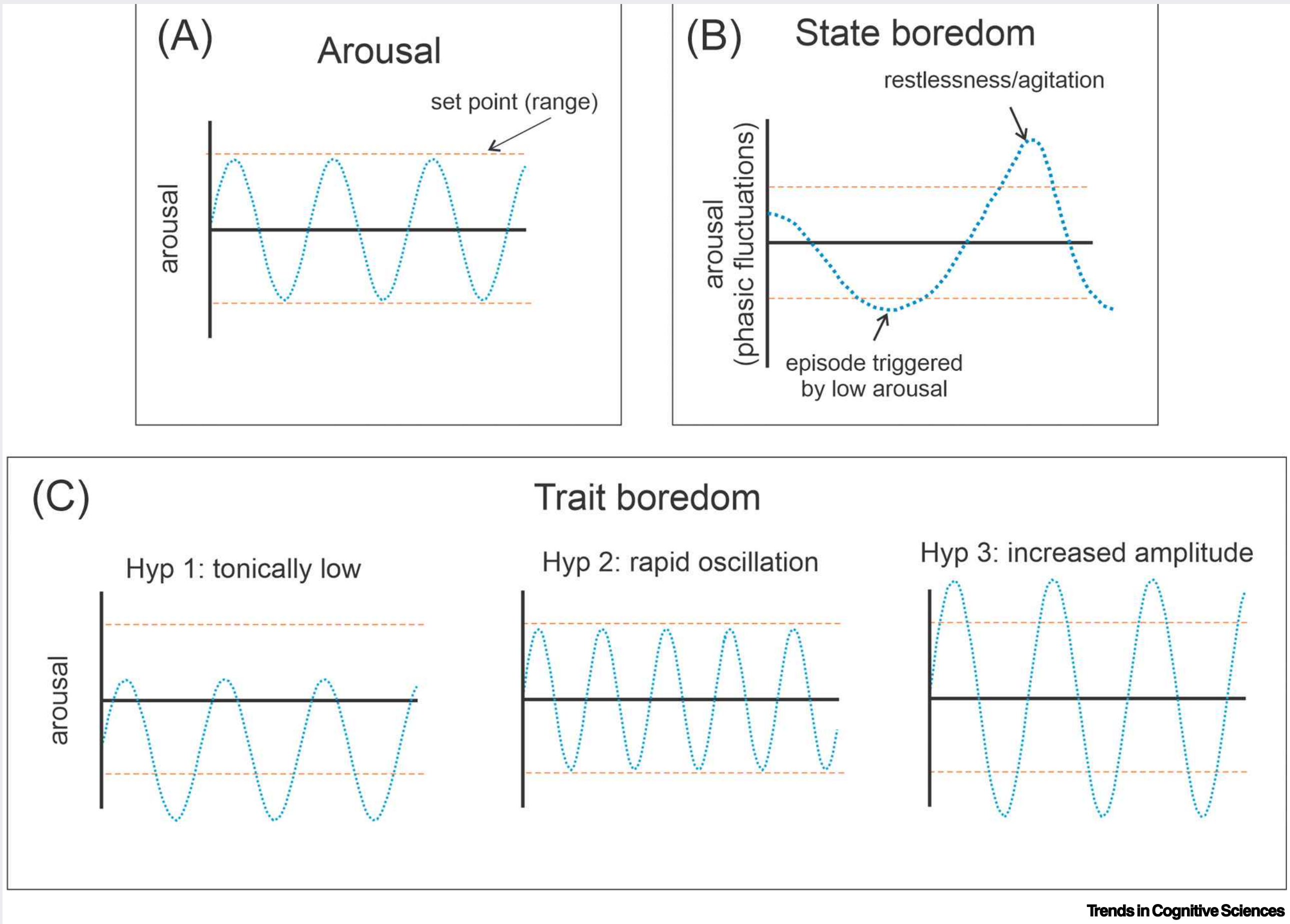

Figure I. Hypothetical role of arousal in boredom. (A) A theoretical set point for fluctuations in arousal, indicative of an optimal range for engagement. (B) Hypothetical changes in arousal for a single boredom episode, triggered by low arousal, but becoming high arousal when the event is unresolved. (C) Hypothetical patterns of arousal for highly boredom-prone individuals – left = chronically low arousal; center = abnormally rapid oscillations between high and low arousal states; right = differences in amplitude (presumably outside some optimal set point shown in the broken orange line; hypotheses 2 and 3 need not be mutually exclusive).

Furthermore, pursuing individual differences in the regulation of arousal may tell us much about the trait propensity to be bored (Figure I). What is clear, is that arousal (or changes in arousal) is not vital to either the definition [27] or the function of boredom. As with accounts that rely solely on meaning regulation, attention, or novelty-seeking, any account of boredom grounded exclusively in arousal will fail to fully capture the nuances of the experience.

Could novelty-seeking be the key to understanding boredom's motivational and behavioral outcomes? One account [28] argues that boredom's motivating force is underwritten by a need to seek affectively novel states, as any current affective experience wanes in intensity. That is, the need for novelty is not merely the search for something 'new', but a response to the diminished intensity of a current affective experience [28]. To substantiate this claim, researchers showed that bored participants sought out novel experiences, ones that were affectively different than their current experience, even if the novel experiences were hedonically negative [32] (Figure 1). Accordingly, boredom heightens one's need for novelty, which in turn drives boredom's ability to initiate change.

Novelty-seeking offers a plausible explanation as to why boredom so often leads to harmful or maladaptive outcomes. The need for novelty and the resultant desire for something distinct

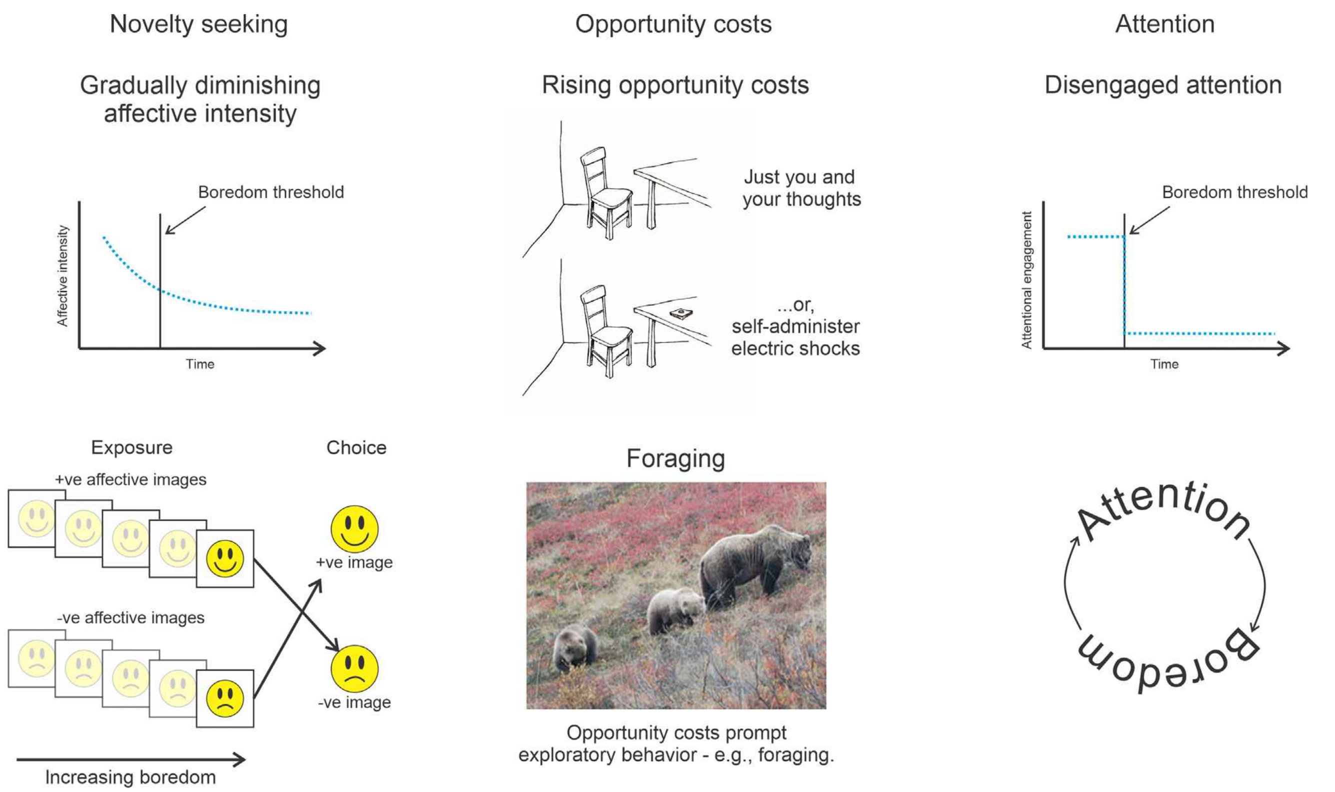

Figure 1. Schematic representation of three prominent models of boredom. Left panel: Under the novelty-seeking account, boredom signals diminishing affective intensity of our current state at some threshold. Research shows that when bored by a stream of either positively or negatively valenced stimuli, participants tend to choose the opposite valence to attend to, indicative of a novelty preference [32]. Middle panel: Under the opportunity costs account, boredom signals that the cost of foregoing other activities is high. Thus, we experience a situation as boring because it is associated with high opportunity costs (i.e., our involvement with it requires that we forsake other activities that are less effortful, more desirable, or more engaging). Situations associated with high opportunity costs can even lead to self-harm behavior, if such behavior is thought to lead to a reduction of those costs [45]. The image below highlights a prominent task in mammals, foraging, in which opportunity costs are a driver of exploratory behavior. This account suggests that boredom can drive exploratory actions. Right panel: Attentional accounts of boredom suggest that the inability to effectively engage attentional resources is associated with boredom. The circular schematic below highlights the challenge of determining the causal arrow of this account (i.e., does boredom lead to attention failures or vice versa?).

from one's current state makes bored individuals willing to choose negative, even harmful experiences. The claim that novelty-seeking is central to boredom is also consistent with findings showing that situations lacking in novelty (e.g., repetitive tasks) typically give rise to boredom [50] and with reports that the highly boredom-prone express a stronger preference for novelty [51,52].

There are, however, important challenges to this account. First, boredom is distinguished from other negative emotions insofar as it involves the appraisal that one's situation or life lacks meaning [18,21,53,54]. Asserting that boredom's character and outcomes are solely accounted for by a heightened need for novelty would require us to explain the role of perceived meaninglessness entirely in terms of novelty. But novelty and meaningfulness are distinct: novel situations can lack meaning (e.g., experimental art, foreign languages) and meaningful situations do not have to be novel (e.g., regular family meals). Experimental work corroborates the distinction: boredom can arise in complex situations (e.g., demanding academic contexts), ones which presumably contain novel features but resist attempts at meaning-making [55].

Second, recent findings suggest there are limits to the explanatory power and scope of novelty-seeking when it comes to boredom. First, novelty-seeking may not always alleviate boredom [56]. If so, boredom's presence cannot always be attributed to a need for novelty. Second, the desire for novelty is not the only factor driving boredom's outcomes [57]. Other factors (convenience, meaning, autonomy, and effort) are also relevant [58–65]. Third, this explanation fails to account for how familiar situations or tasks, especially those that engender the experience of flow [37], do not lead to boredom. Finally, if novelty-seeking were an optimal solution to boredom, it does little to explain the boredom-prone individual's failure to launch into action [61]. To be sure, there will be some circumstances in which constraint prevents action, but presumably the search for novelty is not especially onerous.

The need for novelty only partially explains boredom. Boredom, both as a state and trait, has been connected to the twin drives of exploration and exploitation [31]. Agents need both to exploit known resources and explore their environs. They must negotiate these demands in a manner advantageous to them; although exploration is beneficial, one cannot neglect known resources. Boredom relates to both drives, first as an uncomfortable feeling alerting us to the presence of insufficient (cognitive) exploitation, and second as a prompt to explore [31,35,66]. The suggestion that boredom is intimately connected to novelty-seeking captures an important aspect of boredom's relationship to exploration: novelty-seeking is instrumental in motivating exploration. Still, an account of boredom that focuses only on novelty-seeking does little to explain boredom's connection to exploitation. It leaves unaddressed the question of how the desire for novelty interacts with other known features of boredom (e.g., poor attentional control, meaninglessness, autonomy, effort, fatigue). It does not explain why some familiar tasks are not boring. Nor does it offer an account as to why novel situations, characterized by cognitive overload, are oftentimes boring [67–69]. Furthermore, it seems implausible that we could be in a perpetual state of novelty-seeking. Not only would this forego the benefits of exploiting known resources, but it would also undercut the value of novelty, leading to habituation.

Rising opportunity costs

An alternative account of boredom suggests the state signals rising opportunity costs [31,36]. That is, any given activity comes encumbered with the cost of forgoing others. As we write this (thoroughly engaging) article, we could be playing with our children or watching our favorite TV show. In this view, boredom signals rising opportunity costs: what I am doing now is not engaging, anything else would be better. Because rising opportunity costs are associated with negative phenomenology, agents are moved to pursue the reduction of such costs.

This notion received support from a recent study [70] in which people sat in an empty room with nothing but their thoughts to entertain them. While some reported the experience to be pleasant [71], many found it unpleasant, so much so that they were willing to self-administer electric shocks (Figure 1). This was replicated in studies inducing boredom and other affective states, such as sadness [45,72,73]. In these studies, boredom led participants to shock themselves more frequently than did sadness. While it could be argued that self-administering an electric shock could be driven by a desire for novelty, participants had received shocks before commencing the experiment and had indicated a willingness to pay money not to experience them again [70]. When taken together with the finding that rates of self-administered shocks were higher in boredom versus sadness inductions, this result can be interpreted to reflect a role for boredom signaling high opportunity costs. Just why such high opportunity costs should evoke self-harm is not entirely clear [31,36].

In a more direct test of the opportunity cost model, researchers had two groups of participants spend time in a room with nothing but their thoughts [74]. The first group had nothing to distract their attention. The second group were in a room with a range of activities (e.g., a half-finished Lego© puzzle) that, had they been allowed, they could have engaged with, that is, participants could look, but not touch. Reports of boredom and the desire to engage were higher in this room than in the empty room.

Behavior in this study was monitored by spy-cam. Many participants broke the rules and engaged with the objects in the room that contained them, or, contrary to instructions, left their seats and did various things (e.g., pacing) in the empty room. Such rule-breaking is a rational response to rising opportunity costs. Indeed, in multiple studies, it has been shown that the highly boredom-prone were more likely to break social distancing rules during the pandemic [75–77] (Box 2). Restrictions of normal activities were, for the highly boredom-prone, difficult to adhere to when other avenues for action, however transgressive, signaled unbearable opportunity costs.

There are several challenges to the opportunity cost model. First, it is often the case that we must engage in tasks even when opportunity costs are high (e.g., filing tax returns). Without context, opportunity costs become a blunt tool (Figure 1) and fail to account for the many outcomes of boredom. Second, in considering the conundrum of boredom for the highly boredom-prone, just as with novelty-seeking, we are unable to explain the failure to launch [61]. That is, although boredom-prone individuals recognize the call to action signaled by boredom, they often fail to engage in meaningful actions or, when they do, they engage less than desirable options[i,ii]. Opportunity costs do little to account for this failure.

Furthermore, opportunity costs are not a unique specifier of boredom. Increasing feelings of effort or fatigue also signal rising opportunity costs [36] but such experiences are not equivalent to boredom. In addition, this account does not explain the many other facets of boredom, pointedly the attentional challenges commonly associated with both the state and trait [5,23,52]. Why would a rise in opportunity costs necessarily lead to failures of attention? Suggesting that such failures are themselves indicative of rising opportunity costs renders the explanation redundant.

Box 2. Locked in: boredom in the pandemic

At the onset of the global coronavirus disease 2019 (COVID-19) pandemic, there was a pervasive sense that a wave of boredom was poised to descend upon us. As lockdown measures were imposed throughout much of the world, Google searches for the term ‘boredom’ rose dramatically in both Europe and the USA [112], with some even comparing the experience to that of first-time prisoners [113]. Once we actually got down to the business of measuring boredom as a function of pandemic constraints, our intuitions were supported. Across many countries, self-reported boredom did rise in the early stages of the pandemic [114]. And the changes were consequential, with rises in boredom, loneliness, and psychological distress, all associated with elevated challenges for mental health and life meaning [115–117]. Some even showed that rates of alcohol and marijuana use increased [118], presumably in part, as a response to being bored. We even over-ate out of boredom, although this has been shown to be true in non-pandemic times too [60,119]. Beyond the consequences of increased feelings of boredom (i.e., state boredom), the pandemic was also challenging for the highly boredom-prone. Those low in self-control and high in boredom proneness tended to break the rules of social distancing even 1 year into the experience [75–77]. So, boredom was consequential from a public health perspective on multiple levels.

But what can we learn from this experience about boredom? It seems that expectations of what engagement and agency we may be able to achieve in any given situation are critical. Perhaps the prospect of an explosion of boredom actually turned out to be more of a trickle [114], but it nevertheless established expectations of what life under constraints would be like. For those who planned for their boredom [120], or those who found productive outlets when bored [117], mental health outcomes were better. Indeed, recent work suggests that merely anticipating the negative affective sequelae of boredom makes the impending experience worse, whereas normalizing it has the opposite effect [3]. This is supported by work during the pandemic showing that the trait disposition to boredom worsened mental health outcomes, whereas positive coping strategies mitigated them [121]. In the context of our model, this highlights the key role played by expectations for cognitive engagement. When met, outcomes tend to be better. When unmet, boredom is at least one potential negative outcome.

Boredom's struggles with attention

One of the most persistent findings regarding boredom is the involvement of attentional difficulties (Figure 1) [5,22,23,52,78,79]. Phenomenological, cognitive-behavioral, physiological, and neurological evidence suggests boredom is intimately related to the deficient deployment of attentional resources. Attentional difficulties and tasks that place heavy demands on attentional resources have been repeatedly found to give rise to boredom [5,53]. First-person descriptions and lay characterizations of boredom articulate it in terms of a struggle to sustain attention [55,80]. Physiological and neurological correlates of boredom are suggestive of impaired attention [81–84]. Individuals with compromised attentional abilities report elevated levels of boredom [85–88][iii]. Attentional difficulties may even arise on account of one's experience of boredom [5]. Boredom and attention are thus intimately related. But does this mean that we can locate boredom's essence entirely in the workings (or mis-workings) of attention?

One recent attentional account of boredom [23] suggests it is characterized by the presence of attentional shifts instigated by inadequate engagement. Accordingly, inadequate attentional engagement occurs when there is a mismatch between task demands and the level of attention deployed. The model vacillates between treating poor attentional engagement as the typical (but not necessary) cause of (or condition for) boredom or as a critical facet of the experience. Others have struggled to determine the exact role of attention in boredom. In a study that correlated state boredom ratings with attentional errors on a sustained attention task [5], results showed that initial ratings were uncorrelated with attentional errors early in the task. However, the relation was significant and positive after the first block of trials, implying that failures of attention led to boredom. However, on subsequent blocks, prior boredom ratings did correlate with subsequent errors, suggestive of a reciprocal relation between boredom and attention [5]. Thus, it is unclear whether inadequate attentional engagement should be considered a cause or an effect of boredom (Figure 1).

If these accounts of boredom as attentional disengagement are to be understood as an explication of the common antecedents of boredom, then they only make partial progress in articulating the mechanism underlying boredom. Boredom could be caused by suboptimal attentional engagement, even though it is not itself an attentional phenomenon. The question is whether we should treat suboptimal deployment of attention as both a necessary and sufficient condition for experiencing boredom. Such a view entails that poor attentional engagement gives rise to boredom and that every experience of boredom is associated with this type of (dis)engagement. It would render boredom an essentially attentional phenomenon.

There are challenges for such a purely attentional account of boredom. For one, the claim that poor attentional engagement is sufficient for experiencing boredom ignores other antecedents, most notably perceived meaninglessness [18,19]. Moreover, experimental evidence indicates that boredom arises even when individuals do attend to tasks. For instance, activities that require sustained attention (e.g., operating a war drone)[iii] are reportedly boring. Even though bored individuals may commit more errors on such tasks, it can hardly be argued that attention is completely absent.

If boredom arises when attention is (at least partially) engaged, then there is more to boredom than the inability to attend. Attention may wander while bored, but it does not disappear. That is, in cases of boredom during which subjects' attention is objectively engaged, what gives rise to boredom is the fact that subjects' attention is not adequately engaged. Thus, a proper explication of boredom requires more than a determination of whether one is capable of paying attention or not. Among other things, it requires a specification of the phenomenology of the subjects' attentional engagement (e.g., Is it effortful or not?) and their attitudes and expectations regarding attentional efforts (Are they willingly paying attention or not? Is the task perceived as meaningful/ valuable?) [19].

Attentional accounts offer important insights into boredom by relating the experience to cognitive (attentional) engagement. Still, if they remain purely attentional, they are incomplete insofar as they do not specify what it means to be cognitively or attentionally engaged in an (in)adequate manner. What matters for boredom is not merely the absence of engagement but the absence of an engagement that is, relative to the experiencing agent, proper, adequate, or desirable.

Deviation from the Goldilocks zone

Boredom is a cognitive-affective experience facilitating optimal cognitive engagement. Our model is based on a simple, intuitive premise: it feels good to have our cognitive resources actively engaged with the world. That is, our model suggests that agents regulate behavior to maintain cognitive engagement with the world within some optimal range: a Goldilocks zone specified by a range of values that determines what counts as optimal engagement. Boredom is not the only signal we have drifted from an optimal zone of engagement (others might include anxiety, frustration, and effort), but it is an important one.

Conceiving of boredom in this fashion entails that it arises when there is a mismatch between current and desired levels of cognitive engagement. We concede that there are likely circumstances where a person would seek challenges that push them beyond their current skillset; in a sense outside of the optimal cognitive engagement zone. In our view, this does not represent a 'mismatch' between desired and actual outcomes, if the goal is to stretch one's limits. Rather, the optimal engagement zone is only breached when the expectation of how much one's skills will be stretched is not met (either because the task was too easy or too hard than initially desired). Moreover, our model requires that agents capable of experiencing boredom possess expectations as to what counts as optimal engagement. They must also be capable of monitoring current levels of engagement to compare those to expectations. This threefold process (desired levels of engagement, monitoring, comparison) accounts for and synthesizes extant findings, yields testable predictions, and suggests avenues for future research.

First, the model accounts for the richness and diversity of boredom's antecedents. Any task or circumstance that fails to satisfy desired levels of cognitive engagement is a potential antecedent of boredom. This consequence is in line with reports that cognitively unengaging situations reliably give rise to boredom [81,89–91] and with previous findings indicating that perceived meaninglessness is an important component of boredom [18,21]. Yet it also explains the observed variability of the antecedents of boredom. Given that so much depends on an agent's antecedent level of desired engagement, not all monotonous or repetitive situations would necessarily be experienced as boring. This represents a testable hypothesis if one imagines an experiment in which desired or expected levels of engagement are manipulated prior to the completion of tasks that themselves vary in repetitiveness.

Second, the emphasis on prior expectations regarding a desired level of engagement is consistent with the purported role of appraisals in the experience of boredom [22,92,93]: the way one appraises a situation affects whether or not it meets their standards of cognitive engagement. Indeed, one explanation of the empty room experiment [74] (i.e., where individuals in a room with activities that promised but did not deliver cognitive engagement reported more boredom than those in a room with no such activities) is that the experimental condition altered expectations regarding engagement. This could be more directly tested by manipulating participants' expectations explicitly prior to exposing them to an experience replete with or lacking opportunities for engagement. In addition, proposed mitigation strategies of boredom (e.g., calls for cognitive reappraisal or gamification) can be understood as strategies to change one's expectations regarding engagement thereby facilitating the retrieval of meaning [92,93].

Third, framing boredom in terms of cognitive engagement opens up novel ways to link state and trait. Recent descriptions of boredom proneness suggest a triumvirate of factors: increased frequency and intensity and a sense of meaninglessness [33]. Although these three factors provide a clear connection between trait and state boredom, no attempt has been made to articulate the mechanism for this connection; Why should the highly boredom-prone experience the state more frequently and intensely? Our account offers a framework to explore this connection. Specifically, desired engagement levels represent a baseline mental model of how the world should be. Prior experiences may set that model to a level that makes actual engagement challenging for the highly boredom-prone. That is, it is plausible that for the highly boredom-prone the range of activities that count as engaging are more narrowly defined than for those low in boredom proneness (Box 1), a distinction that would explain elevated levels of frequency/intensity of experiencing the state. As for what counts as meaningful, this too will be established by prior experiences and may set the bar too high for the highly boredom-prone, such that all experiences require (relative to the non-boredom-prone) higher levels of meaning. Alternatively, it may be the case that highly boredom-prone individuals do not appropriately process value or reward or fail to sufficiently update progress towards a goal. If so, their experience of boredom could indicate a deviation from optimal cognitive engagement due to poor monitoring, a faulty comparison process, or both. Moreover, compromised or suboptimal processing/updating would explain the frequent, intense experience of state boredom and the perceived lack of meaning.

What we propose is not without precedent. In an attempt to explain motivation, one theory developed in the late 1950s [94] suggested that humans are driven towards effective engagement, so-called effectance motivation. It does not just feel good to be engaged with the world, it feels good to demonstrate our agency, to show that when we act, there are consequences that we brought about. Relaxation provides a counter to this in that we can feel engaged, say while reading a detective novel on the beach, without needing to be effecting actions or outcomes on the world. This highlights our point that boredom signals a need to be engaged, but that engagement can encompass a wide range of activities. This places goal pursuit and expectations at the heart of the experience. If I desire relaxation and expect that the Michael Connelly drama will do the trick, then no further outcomes are required. In contrast, if I want to see progress in some goal (get this draft to my colleague), I will need to engage differently with the world. Consequently, I establish different expectations of what will and will not count as engagement.

An account of boredom resting on the need to maintain optimal cognitive engagement has advantages over the aforementioned models of boredom. It does not rely on a unidirectional change in events, nor does it insist there is a sole cause (or essence) of boredom. Understood as a cognitive-affective signal of deviation from optimal engagement, our account underscores that boredom is dynamic (Box 3), responding to the workings of various mechanisms (setting and adjusting expectations, monitoring and comparing engagement levels), but also to ongoing changes in the agent's environment. Moreover, our account synthesizes insights from previous models of boredom. Perceived meaning, attentional resources, opportunity costs, and the desire for novelty are all relevant, as they affect the comparison between desired and current levels of cognitive engagement.

What constitutes a deviation from an optimal zone of engagement becomes a matter for further research (see Outstanding questions). Past work suggests a range of possibilities, none of which are mutually exclusive. In fact, the question of additivity is important: Is boredom more likely

Box 3. Predictive coding, dark rooms, and robots

Predictive coding models of the brain postulate that organisms engage in a constant process of prediction error minimization [122–124]. Such models have been extolled for their ability to unify cognition, perception, and action and to offer insights into unsolved issues within the cognitive and medical sciences. Yet, predictive coding models face an obvious objection. If the brain engages predictive coding mechanisms to guide action, then organisms ought to seek out maximally predictable environments (e.g., a dark room) and remain there [125].

Understood literally, the dark room problem admits an easy solution [126]. Organisms do not retreat into dark rooms because such environments are surprising, insofar as they violate basic homeostatic expectations and requirements [127–130]. This retort, however, only raises a deeper issue with predictive coding. Even if most organisms do not take refuge in dark rooms, the imperative to minimize prediction error is at odds with the variety of exploratory and curiosity-driven behaviors they display [131]. Predictive coding models suggest that valuable states are those that are predictable (i.e., ones the organism has learned to associate with minimization of prediction error through the use of approximate Bayesian inference). But then why would agents ever seek to explore their environments, play, or be curious?

Boredom offers one solution to this puzzle [69]. Insofar as boredom signals a deviation from cognitive engagement, it is tied to predictive learning and error minimizing. More specifically, following insights from computational models of intrinsic motivation [131] and predictive coding models of affective valence [132,133], we suggest that boredom relates both to the presence of prediction error (i.e., violation of prior expectations regarding engagement) and to the rate of change of this error. Consequently, boredom measures how the satisfaction of expectations regarding cognitive engagement changes over time.

The proposal makes evident how boredom can arise in dynamically changing situations. As a situation becomes more predictable, it increasingly affords fewer opportunities for engagement. Unpredictable situations do the same: they do not allow the harvesting of meaningful information and thus deny the possibility of cognitive engagement [67]. Critically, in both instances (monotony and maximum entropy) it is the persistence of the circumstances that boredom responds to. On the contrary, situations that are typically characterized as engaging (e.g., an engrossing lecture, a stimulating conversation, or a challenging game) are precisely those that allow organisms to maximize error reduction regarding expectations of cognitive engagement; indeed, cognitively immersive experiences (e.g., states of flow [37]) meet our expectations for cognitive engagement continuously. By connecting boredom to the presence and rate of change of prediction error, we have a solution to the more difficult version of the dark room problem: boredom motivates exploratory and curiosity-driven behaviors because it is through such behaviors that organisms minimize error.

The value of boredom in guiding exploratory behavior raises the question of whether it would be desirable for robots or autonomous artificial intelligence (AI) to be capable of being bored. On the one hand, robots supplant humans in tasks where monotony makes the work unbearable, the capacity to attend untenable, and the possibility of errors high. On the other hand, AI researchers have argued that a boredom algorithm might be necessary to enhance autonomous learning [134–136]. A robot capable of boredom could discover activities that match its expectations and steer away from those that do not, ultimately making them more human; less efficient workers, but more independent learners.

when current affective ratings dip below some intensity level [28], attention is disengaged [22], and the circumstance is seen as meaningless [18]? Is boredom more likely at the lower or upper bounds of optimal engagement? These are testable hypotheses. We do contend that deviation from an optimal zone of engagement is not merely about matching tasks to skills [19,23]. Rather, it is about current experiences failing to meet expectations for engagement. We caution against overly restrictive understandings of optimal cognitive engagement. For instance, if novelty were the sole determinant of optimal engagement, then any experience or event that could somehow maintain a sense of novelty would never lead to boredom. This seems unlikely. An ever-changing milieu could be seen as lacking in meaning and hence boring precisely because our expectations for optimal cognitive engagement include desiderata beyond novelty [35,91].

Lastly, even though research has shown a connection between boredom and the perception of time [95–98], to our knowledge, this connection has not played a major role in models of state or trait boredom. Our model invites a reexamination of the role of time. Both the duration of tasks and our perception of the passage of time could be strong determinants of our expectations regarding optimal cognitive engagement and progress towards goals. As such, time becomes an important influence on, and not merely a corollary of, the experience of boredom.

Concluding remarks

Boredom is a nontrivial, ubiquitous human experience [99]. In the past, research has struggled to define the experience and to unambiguously delineate its antecedents. Here we suggest a solution to these challenges. If indeed it feels good to be optimally engaged with the world, boredom then represents a signal that we have deviated from optimality. Our model allows us to encompass a rich and varied array of potential causes of deviation from an engaged state, ranging from suboptimal deployment of attention, to a diminished sense of meaning, and changes in perceived reward, novelty, value, or even time on task. The model obviates the need to settle longstanding debates in the literature regarding the psychophysical signature of the state; we no longer need boredom to be either a high- or low-arousal state, but are free to explore how a variety of changes in psychophysiology might signal deviation from optimal engagement. Indeed, by conceiving of boredom functionally and not in relation to any specific neurophysiological state, our model becomes applicable to the study of animal [100,101] and even machine boredom (Box 3). Finally, we can reframe the trait disposition to experiencing boredom as a struggle to maintain engagement, either through boundaries for cognitive engagement that are unnecessarily restrictive, or through dysfunctional processing of value, reward, and effort with respect to established goals.

Acknowledgments

This work was supported by a Natural Sciences and Engineering Research Council of Canada grant to J.D.

Declaration of interests

No interests are declared.

Resources

[i] www.theatlantic.com/national/archive/2013/08/we-were-bored-so-we-decided-to-kill-/278858/

[ii] www.washingtonpost.com/world/2019/06/05/niels-hoegel-german-nurse-admits-killing-patients/

[iii] www.motherjones.com/politics/2013/06/drone-pilots-reaper-photo-essay/

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Outstanding questions

Does boredom signal deviation at both the lower (presumably driven by monotony and low arousal) and upper bounds of cognitive engagement (perhaps driven by challenges in meaning-making and associated with restlessness and agitation)?

How do our perceptions of external circumstances, as being low in reward, value, or meaning, interact with internal states (e.g., sensations of lethargy, restlessness, or effort) to inform the experience of boredom?

Do those high in boredom proneness represent reward/value/meaning/effort differently compared with those low in boredom proneness?

What does it mean to be low in boredom proneness? Do these individuals have lower need for reward, meaning, etc., or are they fundamentally better at engaging their cognitive resources?

Although research shows boredom to be a distinct cognitive-affective experience, in what ways does it differ from other cognitive-affective states (e.g., anxiety or frustration) in prompting re-establishment of cognitive engagement?

Under what circumstances (if any) would the boredom signal lead to a change in desired outcomes, as opposed to launching the individual into action? This dichotomous avenue for boredom coping (act vs. change expectations) may be critical in explaining boredom proneness.

How does our model of boredom inform applied contexts where boredom is prevalent? Can we reduce boredom in the classroom by better understanding and predicting students' expectations of desired cognitive engagement? Can jobs in which vigilance requirements are high but the rate of change is low (e.g., assembly line work) benefit from our model in establishing new frameworks for cognitive engagement, autonomy, etc.?

Are desired outcomes for engagement implicitly or explicitly maintained? If both kinds of expectations for engagement are feasible, do they lead to distinct kinds of boredom?

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What are the neural correlates of both boredom and engagement? Some work has already hinted at the involvement of the default mode network and insular cortex when bored, but less is known about the dynamics of neural activity for the state of boredom and its opposite, engagement.

What role does agency play in the experience of boredom and what counts as successful cognitive engagement?

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