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RESEARCH ARTICLE

The knowns and unknowns of boredom: a review of the literature

Quentin Raffaelli[1] · Caitlin Mills[1] · Kalina Christoff[1,2]

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Abstract Despite the ubiquitous nature of boredom, the definition, function, and correlates of boredom are still poorly understood. In this review, we summarize the "known" (consistent evidence) and "unknown" (inconsistent evidence) correlates of boredom. We show that boredom is consistently related to negative affect, task-unrelated thought, over-estimation of elapsed time, reduced agency, as well as to over- and under-stimulation. Activation of the default mode network was consistent across the few available fMRI studies, while the recruitment of other brain areas such as the hippocampus and anterior insular cortex, was a notable but less consistent correlate of boredom. Other less consistent correlates of boredom are also reviewed, such as the level of arousal and the mental attributions given to fluctuations of attention. Finally, we identify two critical factors that may contribute to current inconsistencies in the literature and may hamper further progress in the field. First, there is relatively little consistency in the way in which boredom has been operationalized across studies to date, with operationalizations of boredom ranging from negative affect paired with under-stimulation, over-stimulation, to negative affect paired with a lack of goal-directed actions. Second, preliminary evidence suggests the existence of distinct types of boredom (e.g., searching vs. apathetic) that may have different and sometimes even opposing correlates. Adopting a more precise and consistent way of operationalizing boredom, and arriving at an empirically validated taxonomy of different types of boredom, could serve to overcome the current roadblocks to facilitate further progress in our scientific understanding of boredom.

Keywords Boredom · Arousal · Task-unrelated thought · Default network · Hippocampus · Anterior insula

Introduction: what is boredom?

Boredom is known by many names: "anguish, ennui, tedium, the doldrums, humdrum, the blahs, apathy, listlessness, stolidity, lethargy, [and] languor" (Brodsky 1989), to name a few. While boredom is a commonly understood term in the colloquial sense, it is much more difficult to operationally define, and even harder to measure for empirical purposes. Part of this difficulty may stem from the fact that its connections to other important psychological phenomena are poorly understood: How is boredom related to arousal? Does mind-wandering lead to boredom, or does it help us escape from it? And how does boredom relate to time perception, mood, and fatigue?

Over the last few decades, researchers have advanced answers to some of these questions through correlational work, and in some cases by experimentally inducing boredom. However, there is still an active debate about what boredom actually is, and what its signature markers are. To this end, the current paper presents a comprehensive review on the neural, cognitive, and behavioral correlates of boredom across multiple domains including, psychology, neuroscience, and education. Our main goal is to provide a roadmap for researchers who wish to better understand boredom and further investigate boredom and its various correlates.

✉ Kalina Christoff
kchristoff@psych.ubc.ca

[1] Department of Psychology, University of British Columbia, 2136 West Mall, Vancouver, BC V6T 1Z4, Canada

[2] Centre for Brain Health, University of British Columbia, 2211 Wesbrook Mall, Vancouver, BC V6T 2B5, Canada

Table 1 Overview of consistent and inconsistent correlates of boredom

Proposed correlate	Consistent/ inconsistent	Direction (increased boredom is associated with)
Attention		
Stimulation/task difficulty	Consistent	Over- and under-stimulation
Task-unrelated thoughts	Consistent	More task-unrelated thoughts
Attributions of attention	Inconsistent	Task-unrelated thoughts appraised as boredom vs. boredom arises after boredom ensues
Time perception	Consistent	Over-estimated time perception
Agency	Consistent	Reduced agency
Affect		
Valence	Consistent	Negative affect
Arousal	Inconsistent	High vs. low arousal
Brain regions		
Default mode network	Consistent/probable	Activation in MTL and vmPFC
Hippocampus	Inconsistent	Activated in 1/3 studies vs. deactivated in 1/3 studies
Anterior insula	Inconsistent	Activated in 1/3 studies vs. deactivated in 1/3 studies
Fatigue	Probable	More fatigue/sleepiness
Mood	Probable	Negative mood

Definitions and functions of boredom

Many definitions of boredom exist, arising from different schools of thought (for a review, see Eastwood et al. 2012). While there are many similarities across definitions, the differences center around various contextual and explanatory factors (Malkovsky et al. 2012). Psychodynamic psychologists, such as Lipps (1904, cited in Lewinsky 1943), originally considered boredom to be the unpleasant feeling resulting from an unfulfilled need for psychic stimulation. This unfulfillment can occur due to either a lack of stimulation or a state of mind preventing the bored individual from selecting and engaging in a stimulating activity (Fenichel 1953). Existentialist theories suggested that boredom results from the emptiness following feelings of meaninglessness (Frankl 1992). The resulting absence of will causes inaction, which is experienced as unpleasant and devoid of all emotions except for the feeling of boredom. Arousal theorists view boredom as the outcome of a mismatch between the need for arousal and the level of arousal provided by the environment (O'Hanlon 1981), while cognitivists consider boredom to be an interaction between a non-stimulating environment and an individual's impaired ability to concentrate (Fisher 1993).

The first attempt to provide a common definition was made by Mikulas and Vodanovich (1993). They proposed that boredom can be defined as "a state of relatively low arousal and dissatisfaction, which is attributed to an inadequately stimulating situation". The most commonly employed definition of boredom at this point, however, is the one formulated by Eastwood and colleagues (Eastwood et al. 2012, p. 482): "an aversive state of wanting, but being unable, to engage in satisfying activity".

Using this definition by Eastwood et al. (2012), boredom has been proposed to have a unique function as an adaptive emotion (Bench and Lench 2013). That is, boredom is an emotional cue that one needs to pursue a goal different from what one is currently pursuing. Once a person reaches the aversive state of being unable to engage in a satisfying activity, boredom signals the need to look for something different. More specifically, Bench and Lench (2013) propose that boredom might arise during times when goals are blocked or when strong emotions (e.g., happiness or sadness) fade. In this sense, boredom can be viewed as a functionally adaptive emotion that helps us continuously reorient our goals.

While the current definitions and functional accounts of boredom have fostered the study of antecedents and consequences of boredom, the "gold standard" markers of boredom remain unclear. Beyond the signature negative valence of boredom, there is much less consistency with respect to other potential correlates. The aim of this review is therefore to synthesize the existing literature to identify those correlates of boredom that are "known" (that is, have been consistently observed) and those that are as of yet "unknown" (that is, are inconsistently observed).

In what follows, we discuss the state of the literature in each of five domains of work, each representing proposed markers or correlates of boredom: attention, time perception, agency, dimensions of affect, neural correlates, mood, and fatigue. For each domain, we discuss whether the current literature reflects a picture of relatively consistent or inconsistent correlates of boredom (see Table 1 for a summary). Finally, consistent with the definitions of boredom discussed so far, this review encompasses the correlates of boredom as a transient state, rather than boredom as a trait.

Boredom as an attentional failure

Attentional failures are generally related to boredom (Eastwood et al. 2012; Gerritsen et al. 2014). In this section, we discuss evidence supporting the mismatch hypothesis, which proposes an account of how task requirements and attentional capacity are related to boredom. We also discuss how attributions of attentional failures may influence the subjective experience of boredom.

Mismatch hypothesis

According to arousal theorists, boredom arises when there is a mismatch between task requirements and attentional capacity (Berlyne 1960; Csikszentmihalyi 1975, 1990). Specifically, boredom will occur when attention is not maintained at an optimal level of arousal (Gerritsen et al. 2014; Pattyn et al. 2008). This can be when a task is too simple, resulting in under-stimulation (Eastwood et al. 2012), or too difficult, resulting in over-stimulation (Carriere et al. 2008). While boredom occurs at either end of the spectrum (over- or under-stimulation), the ability to pay attention requires optimal levels of arousal—a phenomenon known as the Yerkes–Dodson law (1908). Similarly, the state of flow (which can be conceptualized as the opposite of boredom) requires a task that is challenging enough but not too difficult (Csikszentmihalyi 1975, 1991).

Indeed, there is some experimental evidence that optimal levels of challenge can promote engagement (Freeman et al. 2004). Freeman et al. (2004) employed a yoked-control design in which difficulty levels during a vigilance task were dynamically adjusted using an engagement index (based on EEG frequencies). In a negative feedback condition (consistent with the mismatch hypothesis), the number of stimuli decreased when the engagement index went up, and increased when the engagement index went down. A positive feedback condition received the opposite treatment: the number of stimuli increased when the engagement index went up, and decreased when it went down. The yoked-control counterparts received the same number of changes in stimuli, but in a random fashion. Importantly, only the positive feedback condition, which may have promoted over- or under-stimulation, showed a vigilance decrement.

Optimal levels of difficulty are also important in educational contexts, which might be ideally structured to maintain optimal levels of challenge. Starting with materials that require simple connections in kindergarten (e.g., describing the physical world in geometric shapes), challenge is built up incrementally as mastery is acquired over time (e.g., learning trigonometry in high school). Vygotsky's (1978) zone of proximal development captures this idea perfectly. From a developmental perspective, a child's level of cognitive development should adequately match the difficulty of a task, providing an optimal level of challenge, or else it would be judged "too boring" (Englert et al. 1994). For example, boredom was strongly correlated with being both under-challenged and over-challenged in a math class (Daschmann et al. 2011). Similar tendencies might be manifested in the fast renewal rate of toys for younger children, or the highly specific age that is recommended for various games and toys. The wooden fire truck that was fun at age four may eventually be deemed boring by the child who has now turned six because it no longer elicits a stimulation level that matches the child's current stage of cognitive development. Critically relevant for educational outcomes, boredom has been linked to academic underachievement (Pekrun et al. 2010; Wegner et al. 2008). Students who are under-stimulated are more likely to experience boredom and high achieving students have a propensity to get bored at school (Larson and Richards 1991; Kanevsky and Keighley 2003; Moneta and Csikszentmihalyi 1996; Robinson 1975).

In sum, insufficient or excessive task difficulty are consistent predictors of boredom: boredom is likely to arise when the task is too easy (under-stimulation) or when it is too difficult (over-stimulation). In addition, boredom stemming from over-stimulation and under-stimulation may be qualitatively different subtypes, consistent with the distinction drawn by Goetz. et al. (2014)—a distinction that is important to consider in future research.

Task-unrelated thoughts

Task-unrelated thoughts[1] are considered a hallmark of attentional failures, and thus are often directly connected to the experience of boredom (Critcher and Gilovich 2010; Cunningham et al. 2000; Eastwood et al. 2012; Steinberger et al. 2016). Indeed, task-unrelated thoughts are sometimes used to corroborate successful boredom inductions (Danckert and Merrifield 2016; Mann and Cadman 2014), and are considered to be a consistent correlate of boredom (i.e., boredom is related to an increased frequency of task-unrelated thoughts).

[1] Although many studies refer to task-unrelated thought as mind-wandering, we attempt to use more precise terminology here by referring to what most of the studies are truly measuring: task-unrelated thoughts. See Christoff et al. (2016) for a more detailed discussion.

Attributions of attention

It has also been hypothesized that the relationship between boredom and task-unrelated thoughts can be explained based on how an individual interprets attentional failures: a task is more likely to be experienced as boring when individuals make an appraisal that their attention is not sufficiently engaged by a task (Bench and Lench 2013; Carriere et al. 2008; Daniels et al. 2015; Mercer-Lynn et al. 2014; Pattyn et al. 2008). Specifically, Critcher and Gilovich (2010) argued that negative task appraisals are made after task-unrelated thoughts have occurred and reached metacognitive awareness. One might then make appraisals about the task that are consistent with a state of boredom (e.g., 'non-satisfying'; 'not able to engage'; 'I shifted my attention towards an internal stream of thought'). Critcher and Gilovich also propose that appraisals of boredom may depend on the content of the task-unrelated thoughts, such that boredom is less likely if current concerns are the subject of an task-unrelated thought rather than some negative task appraisal. However, it is also possible that task-unrelated thoughts are an outcome of boredom, resulting from a search for new goals (Bench and Lench 2013), or an escape from boredom when one cannot meaningfully engage in the current task, yet needs to continue performing it. Thus, it is unclear if boredom is a product of the appraisals made about the task-unrelated thoughts themselves or if task-unrelated thoughts arise once boredom has already ensued.

Finally, the extent to which an individual can identify the cause of attentional failure may influence whether they judge the task as boring (Damrad-Frye and Laird 1989). In an experiment in which participants were exposed to an inaudible, moderate, or loud auditory distraction, those in the inaudible condition judged the task more boring and less pleasant. Indeed, this suggests that boredom is influenced by perceptions and attributions of the current task. In this experiment, when it was possible to blame attentional disruptions on task-unrelated auditory distractors, the task was experienced as less boring.

In sum, boredom is consistently correlated with over- and under-stimulation, as well as with task-unrelated thoughts. However, it remains unclear how attributions of task-unrelated thoughts relate to the experience of boredom. Does boredom arise when making negative attributions about a task after experiencing task-unrelated thoughts, or are task-unrelated thoughts a product of being bored? Investigations assessing the more fine-grained temporal dynamics of an entire episode of boredom might help answer some of these open questions.

Time perception

One of the more consistent correlates of boredom is slowed time perception (the well-known everyday experience of time passing too slowly). The subjective estimation of elapsed time is referred to as 'psychological time' (Grondin 2001). Boredom has been associated with an over-estimation of elapsed time (Bench and Lench 2013; Danckert and Allman 2005; Eastwood et al. 2012; Mercer-Lynn et al. 2014). For example, when people are led to believe that they spent more time than they estimated on a task, they report higher levels of boredom (London and Monell 1974). Furthermore, individuals who scored high on trait-level boredom measures were more likely to overestimate how much time they spent on a task, while those with low proneness to boredom were more likely to underestimate that duration (Danckert and Allman 2005).

Although slowed time perception is a consistent correlate of boredom, it is not clear why they are related. Some authors suggest that time perception may be important for maintaining motivation to perform a task (Conti 2001) and for the experience of pleasure (Rolls 1999). Alternatively, Zakay (2014) suggests the experience of time passing slowly is a signal communicating to the executive system that action ought to be taken to remedy the current unfulfilling state.

Distorted time perception may also be linked to the changes in physiological arousal associated with boredom (discussed in detail below). An over-estimation of time can be associated with increased physiological arousal, induced by either perceptual stimulation (presentation of fast repeated visual or auditory series of stimuli), physiological manipulation (alteration of body temperature), or pharmacological manipulation (administering a psychostimulant; Buhusi and Meck 2005; Meck 1996).

Agency

The feeling of agency is also a consistent negative correlate of boredom (Martin et al. 2006; Mercer-Lynn et al. 2014; Pekrun et al. 2010, 2002, 2014; Steinberger et al. 2016). Agency can be thought of as the ability to freely determine what tasks or actions one will undertake (Snibbe and Markus 2005). Similarly, in their review, Eastwood and colleagues (2012) describe constraint in terms of individuals having to "do what they do not want to do or cannot do what they want to do" (p. 488). Further, Eastwood et al. (2012) view constraint as integral to the experience of boredom. It is also one of the cognitive components proposed by Hill and Perkins (1985) in their model of boredom, and has been mentioned as a potential factor that induces boredom (Fenichel 1951; Geiwitz 1966; Hill and

Perkins 1985; Mikulas and Vodanovich 1993; Vodanovich and Kass 1990).

Empirical evidence for the relationship between agency and boredom comes from findings that voluntarily engaging in a task appears to lower estimation of time spent on the task. When one group of participants performs a task by choice while another group performs the same task but with no choice, participants who did not choose the task showed increased levels of boredom (as measured via time perception) compared to participants performing the same task by choice (Troutwine and O'Neil 1981).

Dimensions of affect

Boredom has long been viewed as an affective state (Bench and Lench 2013; Goetz et al. 2007, 2013; Pekrun et al. 2010; Smith and Ellsworth 1985). Affective states can be characterized by two orthogonal dimensions: valence (i.e., pleasantness) and arousal. This two-dimensional space has been referred to as the Circumplex Model of Affect (Posner et al. 2005; Russell 1980). Where does boredom fall in this two-dimensional space?

Valence

Feelings of unpleasantness, or negative valence, are reliably associated with boredom (Goetz et al. 2007, 2014; Pekrun et al. 2010; van Tilburg and Igou 2016). This is the case across domains: in the laboratory (van Tilburg and Igou 2012), educational classrooms (Goetz et al. 2013), workplaces (Fisher 1998; van Hooff and van Hooft 2014), or in everyday life (Steinberger et al. 2016). Though unpleasant, the negative feelings of valence are typically mild in nature, rather than being extremely aversive (e.g., Fisher 1993; Goetz et al. 2007). Such findings are consistent with Plutchik's (2001) description of boredom as a mild version of disgust, where disgust is typically marked with more intense negative valence. This is also consistent with findings from Smith and Ellsworth (1985), where boredom was found to involve a less unpleasant feeling compared to that felt during anger, frustration, contempt, and sadness.

Arousal

While most work suggests that boredom has a negative valence, the findings on relations between arousal and boredom are much less consistent. Strictly speaking, boredom does not quite fit the Circumplex Model of Affect because it is unclear exactly where it falls on the arousal dimension. Boredom is sometimes characterized as a low arousal affective state (Mikulas and Vodanovich 1993; also see Hebb 1955; Titz 2001), and sometimes as a high arousal state (e.g., Bench and Lench 2013; Berlyne 1960; Sommers and Vodanovich 2000). Below we summarize the literature on two measures of arousal: subjective reports and autonomic arousal as measured by heart rate and electrodermal activity.

Subjective reports of arousal

There is some evidence that boredom is correlated with low arousal (Geiwitz 1966; van Tilburg and Igou 2016). For example, Geiwitz (1966) induced boredom and found that participants reported lower levels of attention and arousal, as assessed by questions about sleepiness and tiredness. Evidence that boredom is a low arousal state also comes from findings that boredom is correlated with low effort and reduced attention. While not measures of arousal per se, both variables are related to arousal (Pekrun et al. 2002; Smith and Ellsworth 1985). For example, Pekrun et al. (2002) proposed that boredom is generally a negative-deactivating emotion in which students experience low arousal and reduced attention which ultimately leads to superficial processing in educational settings. While they acknowledge that there are times when boredom might be a high arousal state, no direct evidence for this type of boredom was provided so it is unclear when it would arise.

While the Circumplex Model of Affect (Russell 1980) assumes two underlying dimensions of affect (valence and arousal), additional appraisal dimensions may also be relevant (Smith and Ellsworth 1985). In addition to the valence (pleasantness) appraisal, some of the relevant appraisal dimensions from Smith and Ellsworth (1985) include attentional activity, control of the situation, anticipated effort, etc. Of all the negative emotions, boredom was the only one that was "passive," not requiring an increase in activation or any exertion. Boredom was also the lowest scoring emotion on their scale of attentional activity, suggesting that boredom entails lower-activation. Although they did not explicitly measure the arousal dimension, their findings are more in line with the idea that boredom is a low-arousal state.

Autonomic arousal

Based on the subjective reports of lower arousal during boredom, autonomic arousal (i.e., heart rate and electrodermal activity; EDA) might be expected to display the same pattern. Instead, much (but not all) of the research on autonomic arousal suggests that boredom is a high arousal state.

London et al. (1972) provided some of the first evidence that boredom is related to an increase in autonomic arousal. They investigated two measures of autonomic arousal (EDA and heart rate). Increased EDA, which measures the electrical properties of the skin, was found in a boredom condition (induced by a sustained attention task) in comparison to an interesting condition (writing stories in response to pre-specified themes). Heart rate showed the same pattern, increasing in a boredom condition (writing "cd" over and over) compared to an interesting condition (write stories based on pictures from a magazine; London et al. 1972). Since then, other studies have replicated the finding that boredom produces an increase in autonomic arousal using similar experimental paradigms (Lundberg et al. 1993; Ohsuga et al. 2001).

Trait-level boredom (i.e., boredom proneness) has also been linked to increased heart rate. Boredom proneness is considered to be a trait-level disposition to boredom and is often measured using the Boredom Proneness Scale (Farmer and Sundberg 1986). Merrifield and Danckert (2014) asked participants to watch a boring video and then rate the video for boringness. After accounting for participants' boringness rating, those who scored higher on the Boredom Proneness Scale also displayed higher heart rate level (Merrifield and Danckert 2014). Their findings provide further support for the conclusion that boredom, even at a trait-level, is related to a state of higher arousal.

Alternatively, boredom may influence heart rate and EDA in dissociable, opposite directions. This is known as the directional fractionation hypothesis (Lacey 1959; Lacey and Lacey 1970), which posits that EDA decreases during boredom, while heart rate increases. In support of the directional fraction hypothesis, Frith and Allen (1983) found that lower EDA was related to decreases in attention. The same pattern was then found in an experimental study by O'Connell et al. (2008) in which participants either completed a Self-Alert Training session (autonomic arousal biofeedback training) or a placebo condition (playing the video game Tetris). Participants in the Self-Alert Training condition made fewer errors and had higher EDA during a sustained attention, whereas the placebo condition made more errors and were associated with reductions in EDA over the task (O'Connell et al. 2008). On the other hand, previous work suggests that decreases in attention may also be related to increases in heart rate. This conclusion is in part based on the close relationship between attention and heart rate, where heart rate slows down during periods of high attention (Coles 1972).

It is important to note that most of the evidence supporting the directional fractionation hypothesis used performance on a sustained attention task as the dependent variable rather than a directly manipulating boredom. These studies, however, are nonetheless relevant for considering the correlates of boredom given the close relationship between boredom and decreased attention (Eastwood et al. 2012).

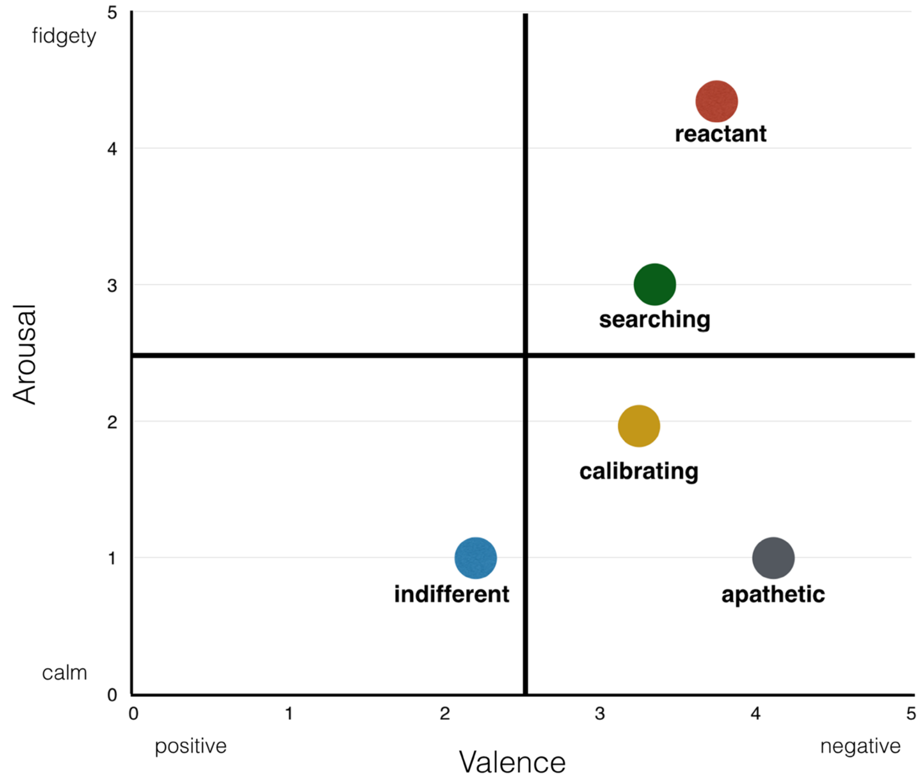
Different boredom types

It is possible that there are different types of boredom, each with a different signature of valence and arousal. Such differences between types of boredom may help reconcile the inconsistency in findings regarding valence and arousal (Goetz et al. 2014). Evidence for the existence of different types of boredom comes from an experience sampling study, in which participants rated their current level of experienced boredom, as well as their current level of arousal and valence (Goetz et al. 2014). Clusters in valence and arousal were used to create five different boredom categories: indifferent, calibrating, searching, reactant, and apathetic boredom (see Fig. 1). Indifferent (more positive valence) and apathetic boredom (more negative valence) were both low arousal states, but differed on the valence dimension. Calibrating (average = 2/5 on arousal scale), searching (average = 3/5 on arousal scale), and reactant boredom (average = ~4.25/5 on arousal scale) were all in the middle of the valence scale, but had markedly different levels of arousal, all three of which had higher arousal than indifferent and apathetic boredom (1/5 on arousal scale).

There are two important points to take away from the Goetz et al. (2014) study. First, the authors suggest that there may be up to five types of boredom, each with distinct levels of valence and arousal. On one hand, this implies that it is critical to know what type of boredom is being induced or measured to properly interpret the findings from a given study, and to draw meaningful comparisons across studies. On the other hand, these findings should be applied cautiously since these five types of boredom may not be entirely consistent with common operationalizations of boredom. For example, boredom is almost never associated with positive valence, which contrasts with the indifferent boredom in Goetz et al. (2014) that was found to be associated with positive valence. Moreover, there are known discrepancies between self-reported levels of arousal and measures of autonomic arousal (Bench and Lench 2013; Eastwood et al. 2012), which indicates that more work needs to be done to verify the validity of these different types of boredom before adopting this five-type classification.

Furthermore, individuals in the experience sampling study by Goetz et al. (2014) tended to report the same category of boredom over time. This may suggest that there are consistent individual differences in the way people experience boredom, whereas one person might experience low arousal boredom, others might experience high arousal boredom. Although such individual differences have not yet been validated with measures of autonomic arousal, assuming that individuals experience boredom in a uniform way may be hampering our understanding and further research into boredom.

Fig. 1 Re-creation of Goetz et al's (2014) five different types of boredom based on two experience sampling studies



Neural correlates

Brain regions

Only three published studies so far have used neuroimaging to measure the neural correlates of boredom. All three studies reported activation in parts of the default mode network (DMN), while activation of other regions of brain was less consistent.

Ulrich et al. (2014) investigated the neural correlates of flow. Boredom (operationalized as under-stimulation through the performance of very easy arithmetic problems) and anxiety (operationalized as over-stimulation through the performance of difficult arithmetic problems) were used as comparison conditions. The arithmetic problems in the flow condition were adjusted to ability, providing optimal levels of difficulty. All conditions were completed while undergoing perfusion MRI. Compared to the flow condition, the boredom condition yielded greater activation in the medial prefrontal cortex (mPFC), as well as in a cluster of areas in the medial temporal lobe (MTL), including left amygdala, hippocampus and parahippocampal gyrus.

In another study, participants played a first-person shooter video game and filled a questionnaire measuring their level of positive and negative affect before and after each 12-minute scan session (Mathiak et al. 2013). Boredom was operationalized as a drop in valence (i.e., becoming more negative) combined with a sustained period of non-goal-directed activity (e.g., no goal-directed moves being made in the game for 10 s). Analyses were then completed by assessing the fMRI response during low goal-directed activity with affect changes (where a positive to negative affect represented a bored state).

Boredom was associated with bilateral activation in the ventromedial PFC (vmPFC) and insula. In addition, the right precuneus and hippocampus were deactivated during boredom, prompting the authors to suggest that the hippocampus and precuneus might play a role in counteracting boredom. However, this finding should be interpreted cautiously for a number of reasons. First, the reduction in activity in the hippocampus contrasts the findings of the Ulrich et al. (2014) study where boredom, there induced by under-stimulating arithmetic problems, was associated with an increase in hippocampal activation. Second, while Mathiak et al. operationalized boredom as a passive state with negative affect, it is unclear whether participants actually experienced boredom. For example, a negative and passive state may also be confusion or frustration at points when the game became more difficult.

A third experiment recorded brain activity under four conditions: (1) resting state, (2) performing a sustained attention task, (3) watching a low-content video of people hanging clothes (i.e. boring condition), and (4) watching an interesting nature documentary (i.e. interesting condition; Danckert and Merrifield 2016). The first three conditions (resting state, sustained attention, and boring video) elicited higher level of self-reported boredom and mind wandering (both questions assessed on a scale from 0 to 8 about how bored they were/how much they mind wandered during the task) compared to the interesting video condition. Independent component analyses were then used to identify clusters of regions of activation that were either correlated (co-activated) or anti-correlated (when one region is activated, the other has reduced activation) with the DMN. Findings revealed similar clusters of correlated activity in the default mode network (DMN) in the boring, sustained attention, and resting state tasks. The size of clusters and spatial patterns of the correlated activity was reported to be "consistent across the majority of participants" (Danckert and Merrifield 2016, p. 6). More specifically, the consistently activated regions of the DMN included bilateral activation of the posterior cingulate cortex and precuneus, as well as bilateral activation in the lateral temporal cortex and mPFC. Indeed, this study provides further evidence that the DMN may play a key role during states of boredom, when attention might be directed towards internal thoughts.

One of the novel findings in Danckert and Merrifield's (2016) study was the differential patterns of activation observed in the anterior insular cortex across the four conditions. First, activity in the insula was correlated with DMN activation during the interesting condition, which was proposed to indicate successful engagement with the interesting movie. An opposite pattern was observed during the boring condition and sustained attention tasks, revealing bilateral anticorrelation between the anterior insula and the DMN. Finally, a third pattern was seen for the rest condition scans: there was no correlation (or anticorrelation) between the anterior insula and DMN. Thus, despite all three tasks (resting state, sustained attention, and boring condition) having similar subjective ratings of state-boredom, the differences in correlations with the insula may reveal different pathways to boredom. Specifically, the authors suggest the differences might be attributed to the fact that the anterior insula acts as part of the salience network, representing important information in the environment: While the resting state scans provided no meaningful information in the environment to engage in (no correlation between anterior insula and DMN), the boring video and sustained attention tasks may represent a failure to engage (anticorrelation between insula and DMN). Nevertheless, both situations (either failure to engage or nothing to engage with) resulted in the same end results, elevated levels of state-boredom.

The three published neuroimaging studies converge in demonstrating a link between boredom and the DMN, especially the MTL and mPFC. One reason for such activation in the DMN might be that participants are directing their attention internally as a way of coping with boredom; the MTL and the vmPFC have been linked to spontaneously arising thoughts (Ellamil et al. 2016). Therefore, a potential explanation of these fMRI results is that when the aversive experience of boredom occurs, attention is directed toward a new internal source of stimulation, which may be presented by spontaneously arising thoughts.

A complimentary explanation is that the vmPFC is active during boredom, in part, due its involvement with appraisals—some of which may be more likely during a boring task (e.g., appraisals of spontaneous thought content and the self). Indeed, different PFC subregions have recently been proposed to underlie specific appraisal functions (Dixon et al. in press). Two of these regions are particularly relevant, given the results of the fMRI studies reviewed here: Appraisals of internally generated events (either episodic or imaginative in nature) are associated with medial orbitofrontal cortex activation, while appraisals of one's self-image (including subjective feelings and autobiographical narratives) are associated with rostromedial prefrontal cortex activation. These two appraisal dimensions are consistent with the type of internally generated content expected to occur during an episode of boredom: When one is unable to engage in external activities, one may cope by focusing on self-referential thoughts or internally generated mental simulations (including spontaneous thoughts), and their continuous valuation. This is also consistent with the idea that daydreaming helps to cope with boredom (Eastwood et al. 2012; Smith 1981; Tushup and Zuckerman 1977).

There were significant differences, however, in how boredom was operationalized across the three studies, and in the brain areas that were observed to be recruited (e.g., hippocampus and insula). For example, while Danckert and Merrifield (2016) induced boredom with a video, Mathiak et al. (2013) observed boredom, as operationalized by negative affect and inactivity in a video game. Furthermore, the three studies differ in terms of the observed involvement of the MTL during boredom: Ulrich et al. (2014) implicating an active hippocampus, Mathiak et al. (2013) suggesting the opposite (deactivation), and Danckert and Merrifield (2016) reporting no evidence of its involvement either way (no mention).

Neural oscillations

One of the major challenges in studying boredom is that it is an inherently internal experience, making it difficult to experimentally determine when boredom begins and ends. This makes it challenging to use high temporal resolution technologies, such as electroencephalography (EEG), to study boredom. Nevertheless, a link between neural oscillations and the experience of boredom has been reported. Oswald (1962) was among the first to suggest that boredom has neuropsychological markers, hypothesizing that increased alpha waves may be linked to both visual inattention and boredom. This hypothesis is consistent with Gevins and Schaffer's (1979) notion of an inverse relationship between the magnitude of alpha waves and the level of task-related cortical recruitment: alpha waves typically occur during wakeful relaxation and mental inactivity (Klimesch 1999).

Since increased whole-brain alpha power is proposed to be a positive correlate of boredom, we might expect to see the opposite pattern for beta waves since they have been consistently associated with sustained attention (Okogbaa et al. 1994; Tinguely et al. 2006). A decrease of beta power during boredom would be consistent with the idea that boredom is linked to attentional failure (the opposite of sustained attention; Eastwood et al. 2012). Indeed, a recent study by Tabatabaie et al. (2014) found that the power of beta-2 waves (i.e., 16.5–20 Hz) over the dorso-lateral prefrontal cortex (DLPFC) was significantly lower when subjects listened to self-reported boring music compared to self-reported arousing music.

It is also worth mentioning that engagement indexes can be calculated using EEG, which might help us infer what EEG frequencies are likely not related to boredom. According to Pope, Bogart, & Bartolome (1995), a common calculation for engagement is the ratio of (beta power/ alpha power) or [beta power/ (alpha power + theta power)]. These indexes highlight the fact that engagement is reflected by increases in beta power, while a decrease in engagement is reflected by alpha and theta. Consistent with this, Tabatabaie et al. (2014) found lower beta power during boring music. Indeed, given the recent advances in identifying cognitive load and engagement from EEG indices (Berka et al. 2004; Mills et al. in press), future work may reveal that boredom can be reliably detected as well.

In summary, although the existing evidence about the neural correlates of boredom is at present limited, a tentative initial picture is emerging. The DMN appears to be a consistent correlate of boredom (across three studies), while other brain regions, such as the hippocampus and insula, may play a more variable role. In terms of neural oscillations, there is some evidence linking boredom to increased alpha power and decreased beta power, but the literature examining the direct relationship between neural oscillations and boredom is scarce. Both fMRI and EEG are important tools for investigating boredom in the future, as they might help explain the mechanisms behind this phenomenon. More work needs to be done to take advantage of the temporal sensitivity offered by EEG. On the other hand, fMRI results suggest that boredom may share neural correlates with states such as mind-wandering. Future research, however, will need to undertake fine-grained temporal analyses to attempt to distinguish states of mind wandering in the midst of boredom episodes to determine if they are separable.

Mood and fatigue

Two additional factors are worth mentioning: mood and fatigue (we refer to these as probable correlates; see Table 1). Although there is limited empirical evidence linking each to boredom, they may be related to boredom due to their close relationships with failures in attentional allocation. Indeed, such failures in attention are considered to be a hallmark of the boredom experience (Eastwood et al. 2012).

Inducing negative mood has been linked to reduced performance on the attentional blink task (Jefferies et al. 2008), SART (Smallwood et al. 2009), and the Stroop task (Crocker et al. 2012). In contrast, thirty-minute meditation sessions over a two-week period reduced negative affect and increased correct response rate on an attention task (Menezes and Bizarro 2015). Furthermore, an ecologically relevant study in which workers were allowed to play their favorite music whenever they wish displayed improved mood along with improved cognitive performance scores (Lesiuk 2010).

The neural mechanisms by which mood affects attentional allocation are still not well understood. One study provided preliminary insight by investigating the neural correlates of negative affect during an attentional task (Crocker et al. 2012). The study revealed an increase in activation in cognitive control areas (dlPFC and dorsal anterior cingulate cortex), as well as in rostral anterior cingulate cortex and precuneus. Crocker et al. (2012) concluded that high levels of negative mood lead to increased difficulty attending to stimuli related to current goals. Negative mood was also associated with an increased tendency to process the emotional stimuli.

Fatigue, similar to mood, may also be related to boredom. Sleepiness, as well as trait-level boredom proneness, have been found to predict cognitive failures in a sample of military personal and university students (Wallace et al. 2003). There is also evidence that engaging in a non-stimulating activity can induce more boredom depending on the time of day (Mavjee and Home 1994). Specifically, boredom may be more likely to occur during the early afternoon, when individuals experience high levels of sleepiness (Lavie 1986, 1989; Mavjee and Home 1994). It is possible, therefore, that individuals' chronotypes (e.g., their tendency to be morning or night person) may moderate boredom intensity throughout the day.

In sum, both mood and fatigue have the potential to influence one's attentional allocation, and thus may influence levels of boredom. Boredom may be correlated with negative mood and more fatigue, however, empirical research on this is scarce at present. More work is needed before we can consider mood and fatigue to be consistent correlates of boredom.

Conclusion

In this review, we highlighted consistent correlates of boredom as well as inconsistent and unknown (not enough evidence) correlates. Some of the most consistent correlates are lack of agency, under- or over-stimulation, negative affect (valence,) task-unrelated thoughts, and over-estimates in time perception. DMN recruitment appears to be a consistent correlate of boredom, yet there has been far less research on how boredom is associated with brain regions and which frequencies of EEG patterns are most common. In particular, we note that very few fMRI or EEG studies have operationalized boredom the same way. Finally, inconsistencies are currently observed in the following correlates of boredom: arousal, recruitment of the hippocampus and anterior insula, as well as how attributions of attentional failures are related to the experience of boredom.

Looking forward, we suggest two steps that will help resolve the inconsistencies in the literature and refine our understanding of boredom: First, a more standardized operationalization of boredom (and its components) should be adopted, so that various studies are measuring the same construct. Second, additional work should examine whether there are indeed different types of boredom, and what their antecedents might be (e.g., over vs. under-stimulation). Different types of boredom may manifest in different ways, causing some of the inconsistencies in the correlates we have reviewed here (e.g., arousal). Second, if different types of boredom do exist, operational definitions should be formulated more precisely to account for such differences. Currently, the term boredom is used to refer to potentially diverse phenomena, making it difficult to compare across studies. Adopting this approach may provide traction in efforts to understand what boredom is and why we experience it.

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