unexpected events [11]. Additionally, optogenetics provide causal evidence for the involvement of the STN in reactive inhibition after unexpected events. In rodents, unexpected events interrupt ongoing licking bouts, mimicking the inhibitory motor effects of surprise in humans. When the STN is optogenetically inactivated, this effect disappears [12].

Together, these recent findings provide converging evidence for reactive motor inhibition after unexpected events. This suggests that the brain has evolved to process such events by reactively inhibiting ongoing motor activity, even when stopping is not anticipated or explicitly necessitated by the task [7,9,12]. Therefore, surprise is ideally suited to study the purely reactive motor inhibition found in many real-world scenarios.

Concluding Remarks
Studying surprise allows investigating reactive motor inhibition in the absence of proactive inhibition. Therefore, it provides a key addition to stopping research and complements classic EICP, which always involve some degree of proactive inhibition. Studying surprise can help investigate unique contributions of reactive and proactive inhibition to action stopping in the laboratory and simulate action stopping in everyday scenarios that do not involve proactive motor inhibition.

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Forum
Finding Consistency in Boredom by Appreciating its Instability
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Boredom has recently piqued cognitive neuroscientific interest, but remains a challenge to scientific investigation in this field. We propose that to advance this research, we should (i) seek greater consistency of operation alization and measurement across studies and participants; and (ii) appreciate the temporal instability of boredom and its ensuing dynamics.

Boredom – a ubiquitous experience in everyday life [1,2] – has recently captured the interest of cognitive neuroscientists, who have begun attempts to understand its neural correlates. While boredom has recently been theoretically defined as ‘the aversive experience of wanting, but being unable, to engage in satisfying activity’ ([1], see p. 482), its experimental operationalizations – especially those that so far have been used within cognitive neuroscience – are not always in concert with this conceptual definition. Furthermore, ways of measuring boredom across studies have varied substantially, raising the question of whether different neuroscientific studies are capturing the same phenomenon. How can we advance current approaches in the cognitive neuroscience of boredom to improve the correspondence between experimental measures and the theoretical concept of boredom, while at the same time capturing its enormous complexity?

Emerging fMRI research on the neural correlates of boredom highlights the diversity of existing experimental approaches. Two of three studies published so far used a ‘boring task’: a video of people hanging clothes [3] and a task requiring participants to decide whether a frame around a picture was blurred [4]. The third study employed a video game and measured periods of activity and inactivity as well as affect before and after play [5]. In this study, boredom was assumed to occur during periods of inactivity that were accompanied by either a reduction in positive affect or an increase in negative affect across an fMRI session.

The fMRI findings reported by these three studies seem as diverse as their approaches: while the prefrontal cortex...
(PFC) was activated in all studies, each study identified a different prefrontal sub-region, including the rostromedial PFC [3], the dorsolateral and ventrolateral PFC [4], and the ventromedial PFC [5]. The insula and the precuneus were implicated as well by two of the three studies. However, in one case the precuneus was deactivated during conditions assumed to reflect boredom [5], whereas in another case the precuneus was part of a functionally coactivated network of regions that overlapped with the default network (DN) and were activated during the boring task [3], leading the authors to suggest that the DN may be involved in the experience of boredom. In the same study, the insula was anticorrelated with the precuneus and the other parts of the DN during the boring task [3], but it was activated during the boring task in another study [4]. What can account for this diversity of findings, and is there a benefit in seeking greater convergence in experimental approaches to boredom? Here we highlight two ways in which the cognitive neuroscience of boredom can be advanced. We suggest that the field should: (i) seek greater consistency of operationalization and measurement across studies and participants; and (ii) appreciate the instability of the experience of boredom and its ensuing temporal dynamics.

A Boring Task Does Not Guarantee a Bored Participant

It might seem plausible to assume that a boring task would induce boredom, but this assumption overlooks the possibility that attending to one’s own thoughts – which are always available – may be a means to escape boredom. If boredom requires ‘wanting, but being unable, to engage in satisfying activity’ [1], for a boring task to reliably elicit boredom participants should not find engaging with their thoughts to be a ‘satisfying activity’.

Do people find thinking about their own thoughts to be a ‘satisfying activity’? Whereas some people find their thoughts boring, others find them to be highly entertaining and enjoyable [6,7] (Figure 1). In a dataset of 190 participants who were left alone in a room with just their thoughts (i.e., no task) [7], over half found their thoughts to be least somewhat enjoyable and entertaining (see re-analysis from [6]). Therefore, for a sizable proportion of participants, their own thoughts may be an effective escape from boredom – something that may itself fluctuate throughout the day. Since people appear to differ in their experience of their own thoughts along continua of satisfaction and boredom, they are also likely to differ along a continuum when it comes how effective a ‘boring task’ is in producing the experience of boredom in each person. Other factors, too, are likely to influence one’s current experience of boredom, such as self-control, perceptions of constraint and agency, and the ability to make meaning out of the task at hand [1,8].

One way in which the cognitive neuroscience of boredom can advance is to

![Frequency distribution of boredom, enjoyable, and entertaining ratings](tcs.png)

**Figure 1. People Do Not Necessarily Find Their Own Thoughts Boring.** Ratings of participants’ own thoughts on three dimensions: boredom, enjoyment, and entertaining. Participants were left to think about whatever they wanted for 6–15 min. Data from [7], figure recreated from [6] with permission.
incorporate measures of subjective experience of boredom and its moment-to-moment changes in order to refocus investigations from the current task-based emphasis to a more subjective experience emphasis in line with current theoretical conceptualizations of boredom [1]. Being engaged in a boring task does not guarantee that a person is continuously bored: people may find a task very boring yet be satisfactorily engaged with their own thoughts or even make a game out the task to keep themselves engaged. Periodic sampling of subjective experience throughout an experimental session (i.e., online experience sampling) is likely to prove superior compared with retrospective ratings at the end of a session because it occurs in closer temporal proximity to the actual experience and will allow us to examine the corresponding neural correlates during more specific windows of time preceding subjective reports of boredom (Figure 2A). Indeed, the use of online experience sampling has led to significant advances in other areas of investigation [9,10], yet has not been used in any fMRI studies of boredom to date.

Boredom Is a Dynamic, Not a Stable State

The definition of boredom emphasizes the ‘wanting to’ engage in a satisfying activity. Recent philosophical and psychological accounts propose that the function of such ‘wanting’ during boredom is to trigger a search for a satisfying activity [11] or a new goal [12]. This active search can be seen as a mental or physical locomotion [11] and is likely to produce an inherently unstable mental state. As we make successful or unsuccessful attempts to escape, the experience of boredom is likely to fluctuate dynamically (Figure 2B) with temporally variable behavioral and physiological signatures. Understanding attempts to escape boredom on finer-grained timescales may inform one of the longstanding debates about boredom [2]. Although the current

Figure 2. Example Fluctuations in Boredom across an Experimental Session. (A) Hypothetical examples of three different participants’ levels of boredom across an fMRI scanning session. In this example, all three participants have the same average level of boredom, and they may have similar retrospective ratings of boredom when asked about the entire task (i.e., the currently dominant way of measuring boredom in cognitive neuroscience). By instead probing individuals periodically throughout a task, we can tie concurrent neural measures more closely to ratings in time (e.g., in the windows shown above preceding thought reports), gaining a more precise understanding of the correlates of boredom. This sampling method also affords the opportunity to examine windows between consecutive thought reports that correspond to reductions or increases in boredom across time, which may then be linked to specific physiological signatures. (B) Temporal dynamics in boredom and their possible relationship to attempts to escape it.

Example participants

(A)  

Boredom

Thought probe

Thought probe

Thought probe

Thought probe

Thought probe

(B)  

Attempts to escape boredom

✓ Successful  × Unsuccessful

Boredom

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debate aims to ascertain whether boredom is a high- or low-arousal state, introducing empirical findings about its dynamics may introduce to this debate the possibility that boredom involves both high (e.g., during escape attempts) and low (e.g., giving up or successfully escaping) arousal.

To date, the dynamic signatures of the psychological and physiological variables linked to the experience of boredom remain understudied. Periodic online experience sampling is a well-suited method to help capture these rich fluctuations. Examining windows between two such subjective reports of boredom may reveal more information about the patterns of arousal that accompany boredom: reductions and increments in subjective boredom over time can be linked to other psychologically relevant physiological measures such as heart rate, galvanic skin response, and neuroimaging.

These dynamic-based approaches may also help to reconcile some of the apparent discrepancies in fMRI so far, such as the patterns seen for the insula [3,4]: the insula may effectively ‘shut down’ after repeated failures to escape boredom compared with when there is some successful strategy available to escape it – which may occur at inherently different rates across the tasks employed in the various studies (watching a video vs detecting changes in pictures). In this scenario, a better understanding of boredom would require relating frequent periodic subjective reports to concurrent fMRI measures. Novel measures of dynamic functional connectivity could be particularly effective in linking the fluctuations in key brain networks to dynamically changing states of boredom.

**Concluding Remarks**

We suggest that the cognitive neuroscience of boredom can be advanced by adopting methodologies that increase the consistency of operationalization and measurement, such as periodic online experience sampling. At the same time, tracking the dynamics of boredom across time could increase the precision with which boredom can be observed and understood. Given the complexity of boredom, these suggestions are unlikely to be sufficient in fully capturing its cognitive-affective signature, but may provide an important step in this direction.

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**Forum**

**Striatal Microstructure and Its Relevance for Cognitive Control**

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The relevance of the striatum for cognitive control processes is increasingly appreciated. The striatum is not a homogenous structure but instead is compartmentalized into the ‘matrix’ and ‘striosomes’. Here, we discuss experiments on a model disease of striosomal dys-function and provide evidence for the importance of the striatal microstructure for cognitive control in humans.

In human cognitive neurosciences, sub-cortical structures, including the basal ganglia, have increasingly come into focus in recent years. This is particularly true for studies addressing the neuronal basis of cognitive control. Cognitive control encompasses the multi-faceted set of cognitive functions required to monitor behaviors and attain goals. These functions include processes involved in inhibiting prepotent responses, resolving interference (conflict), adapting behavior, and planning behavior ahead of time. Because the striatum is structurally and functionally connected to the prefrontal cortex, the striatum’s role in cognitive control is of particular interest.

For more than 30 years it has been clear that the striatum is not a homogenous neuroanatomical structure but instead is compartmentalized into the ‘matrix’ and the ‘striosomes’ [1]. However, there is a discrepancy between what we know about the neurobiological and