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EFFORT AND BOREDOM SHAPE OUR EXPERIENCE OF TIME

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ABSTRACT

Situations change over time, and so does our experience of them. For example, a task may initially feel engaging but can, over time, become monotonous and boring. Similarly, as processing demands increase or one's momentary capabilities decline, the same task can feel more or less effortful. The dynamics of these task-induced sensations matter because boredom and perceived effort shape behavior by driving optimization of resource utilization. A fundamental resource people do not want to waste is time. Here, we propose that the sensations of boredom and effort influence how the passing of time is experienced. Specifically, both states are linked to changes in interoception—the perception of internal bodily signals—which is known to play a key role in time perception. This proposal offers a framework for understanding how fundamental regulatory sensations, such as boredom and effort, shape temporal experience through interoceptive mechanisms. We highlight the insular cortex as a potential hub mediating the effects of interoceptive signals on time perception, integrating feelings of boredom and effort, and their influence on the experience of time.

Keywords: boredom, time, time estimation, time perception, time awareness, insula, monotony, effort, interoception

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Situations change over time. Novel tasks or situations can be loaded with processing demands and require significant effort. With increasing exposure and repetition they can feel void of meaningful events, generating the feeling of boredom [1]. Crucially, both sensations—effort and boredom—are understood to be powerful modulators of human behavior [1–6]. Generally speaking, effort is thought to signal action costs, whereas boredom signals that one's current engagement with the internal and/or external world is not sufficiently rewarding. Reward-based choice models of human behavior posit that both sensations are taken into account when people try to orient their behavior in an attempt to preserve limited resources [1,7–9]. One fundamental resource we do not want to waste is time [10–12]. More specifically, we do not want to spend our time doing *too much* or *too little* of whatever we are doing. Whenever we feel that we are not getting much out of the time we spend doing something, we feel that time is dragging on. This can, for example, be the case if an activity is exceedingly hard or excessively boring. Here, we suggest that the perception of effort and boredom dynamically affect how the passing of time is experienced. More specifically, we draw from research on time perception, effort, and boredom to make the case that effort and boredom increase awareness of bodily states, which in turn makes time seem to pass more slowly.

Imagine yourself sitting in front of your computer. You are tasked with rapidly categorizing words according to the color they are presented in. Sometimes the presented color and the meaning are congruent (the word green written in green color) and sometimes they are incongruent (the word green written in red color; i.e., the classic Stroop task) [13]. You know you will do this task for one hour with a small break every 5-minutes. In the beginning the task demands all your attention: Successive words seem to blur into each other, creating a seemingly constant stream of information and you have your hands full to correctly categorize the color of the words. The attentional demands of the task feel a bit overwhelming, and you wonder why it takes so long until the first break relieves you from the task. This was hard, you feel mentally drained, and although you know it was only five minutes, it felt much longer. In the next block, the task begins to feel easier, and the words do not seem to appear so rapidly after one another, making categorization a bit easier. You are absorbed by the task, and you are surprised that the second five minutes pass so quickly. After 50 minutes, it feels as if the duration the words are presented in has been shortened even further, and as if the empty time between successive presentations has been extended. Your attention starts to shift—you start to notice that the chair you are sitting on is slightly too low and you notice that your thoughts are drifting elsewhere. You also notice that you have started to commit more errors when categorizing the presented words. In your mind, you begin to explore other thoughts, sensations, observations. The last five minutes seem to drag on forever and you feel bored to death.

As this thought experiment illustrates, the very same sensory input—and rules on how to act upon this input—can create strikingly different feelings: As a function of one's familiarity with the input, perceptions of high effort and/or perceptions of high boredom might arise. Interestingly, the same sensory input can also feel as if it lasted longer or shorter. In the beginning, when processing the presented words required the most effort, stimulus duration felt longer and the 'empty time' [14] between successive presentations felt short. Conversely, when the person becomes bored, the stimulus presentation felt short and the empty time felt long. Importantly, in both scenarios the total duration of each five-minute block felt longer than in the middle of the task. This begs the question, why does subjective duration dynamically change, and how do effort and boredom affect the subjective shrinking or expansion of time?

Before we address these questions, we will briefly define key terms from research on time, explain how we use them in the present paper, and cover how they relate to boredom and effort. We will then describe pacemaker-accumulator models as a general cognitive framework for studying the perception of time and highlight how boredom and effort can affect time perception according to this model. We next turn to the putative mechanisms that explain how boredom and effort relate to time perception. To conclude, we will draw from neuroscientific research on boredom, effort, time perception and interoception, to suggest the insular cortex as a key junction that links boredom, effort and the perception of time.

Temporal dynamics of 'empty time' and 'loaded time'

Time perception refers to the degree of agreement between objective and subjective time [15]. For example, how accurately one can guess the minutes one has waited in a room [16,17] or how long one was cycling on an ergometer [18–20]. In turn, time perception can be more or less accurate, and people integrate various bits of information or situational knowledge to assess this. For example, I *know*, writing this paragraph cannot have exceeded one hour, because I have started writing about an hour before lunch break, and so far, no one has knocked to let me know it is lunch time. Time awareness on the other hand refers to 'the subjective impression of time passing quickly or slowly' [15]. So, in contrast to time perception, time awareness does not focus on how long something actually took, but how long it felt. For example, I *think* writing this paragraph took me almost one hour, but this hour *felt* like it took forever. In turn, time awareness is inherently about the subjective experience of the passage of time. While the distinction between time perception and time awareness highlights different aspects of temporal experience [21], we will use the term time perception throughout this paper for simplicity, unless a statement specifically pertains to time awareness [a].

With respect to the perception of time, we will focus on what can be referred to as 'empty time' [22] and 'filled' or 'loaded time' [23]: In the introductory Stroop example, the person was presented with stimuli that appeared with a short interval in between. In this example, the stimulus presentation would refer to loaded time and the inter-stimulus interval to empty time. In general, tasks can often be divided in empty and loaded parts. In the context of a typical experimental task, this distinction is straightforwardly reflected in the stimulus presentation time and the inter-stimulus interval. However, in everyday life, even though the distinction might not be so

[a] Interestingly, under certain conditions people might slightly overestimate the amount of time something took (time perception) but report that time was passing very slowly (time awareness). So, while they are often correlated, the mapping between both concepts is not one-to-one [16].

clear-cut, most experiences contain both loaded and empty time. Periods of intense cognitive or physical work, are akin to loaded time, while moments of waiting or transition represent empty time.

As the Stroop example illustrated, the perception of how fast or slow loaded time and empty time are passing is a dynamic process. This perception can shrink and expand over the total duration of a task (see Figure 1 for a conceptual illustration). Simply put, if the duration of each stimulus (loaded time) feels shorter after repeated presentations, then the intervals between these stimuli (empty time) are likely to feel longer. This is because the objective duration of stimulus presentation and the interval between presentations is constant, but the time it takes a person to process the stimuli is dynamic. In our proposal, loaded time is associated with high processing demands, while empty time is linked to low processing demands. Consequently, loaded time relates to effort, and empty time to boredom. Research supports the notion that the duration of a repeatedly presented stimulus feels shorter [24–26]. This dynamic of shrinking and expanding loaded and empty time raises the question of how time perception is understood to function in general.

Time perception is generally understood through the lens of pacemaker-accumulator models which offer a cognitive framework for how time perception might function in general. To understand why the subjective duration of events changes with repetition, we refer to Eaglemann and Pariyadath [25]. They describe time perception of individual stimuli in terms of the neural effort required to process them and focus on the timing mechanisms of 'automatic' sensations in the sub-second range. As many things in everyday life whose duration we judge are in the supra-second range, we will also refer to Wittmann's [27] embodied time account. The embodied time account conceptualizes time perception via the integration of interoceptive signals processed in the insula, combining affective and cognitive processes. As our proposal is focused on how effort and boredom, as cognitive-affective phenomena, relate to time perception, we will restrict our review of the neuroscience of time perception on this body of literature. We will demonstrate that all three perspectives support the idea that effort and boredom can alter time perception.

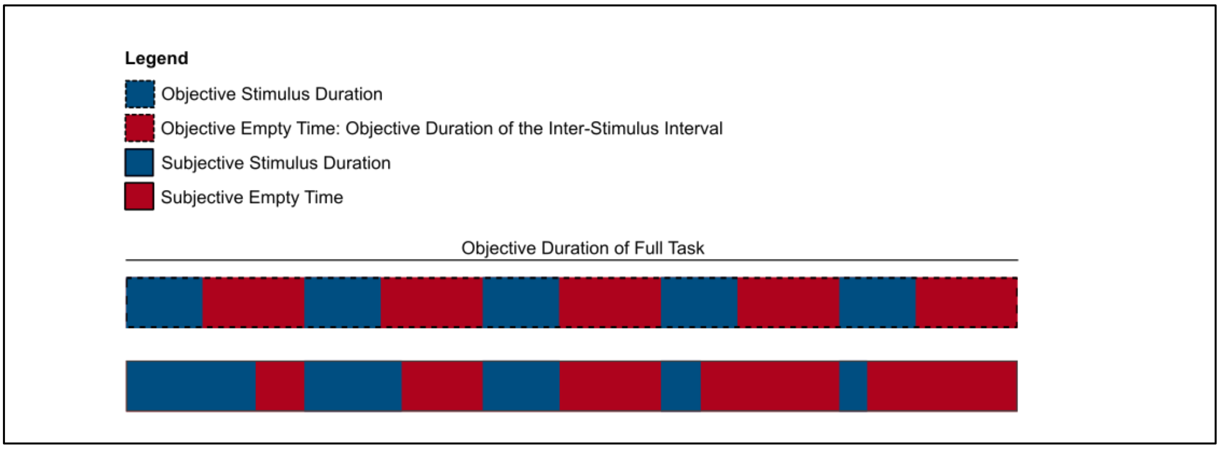

Figure 1. Schematic visualization of how the duration of the same sensory input, and the space between successive inputs, can feel different when the input is presented repeatedly. More specifically, repeated exposure increases

processing efficiency of the presented stimuli, thereby causing loaded time to shrink. At the same time, the subjective experience of the interval between successive stimuli expands, thereby causing empty time to expand. These depicted dynamics relate to the processing demands of the same sensory input over time and the resulting shift in the empty time–loaded time relationship. Importantly, this depiction is agnostic of a potential change in attentional demands during the sequence of events. For example, attentional demands might increase, and performance deteriorate when empty time grows, as boredom sets in, and the person resists the impulse to engage in another activity. However, while not directly within the scope of the present paper, such attention and performance effects would be consistent with the present proposal, as increased processing efficiency is not necessarily linked to improved performance [28]. In addition, with respect to the changing of loaded time, the depiction does not consider effects, such as the accumulation of fatigue but focuses exclusively on the processing demands of a stimulus/target. If a person were to become fatigued (i.e., processing capacity is reduced), then the same processing demands would require relatively more effort for them, causing loaded time to once more, increase. This implies that the actual dynamics of perceived loaded time would depend on the ratio of how fast processing efficiency increases in relation to how fast fatigue accumulates.

Pacemaker-accumulator models of time: boredom and effort increase the accumulator's count rate

The pacemaker-accumulator models of time perception [22,29,30], suggest that a pacemaker emits regular pulses that are then counted by an accumulator. Crucially, the accumulator is thought to only track these pulses when one is actively attending to time [30]. A prototypical illustration of this is a person sitting in a waiting room, bored. With no distractions, the person's attention is drawn to the passage of time, allowing the accumulator to count more pulses. As a result, time may feel like it is dragging on, leading the person to overestimate how long they have been waiting. Indeed, a number of waiting room studies have found support for the claim that time drags on when waiting [16,17]. Supporting boredom's role in this, we found a strong positive correlation between boredom and the perceived slowing of time in a recent waiting room study [16]. Interestingly, the correlation was substantially larger if participants explicitly referred to time awareness and not more generally to time perception. That is, boredom was strongly linked to how slow the passing of time felt, but less so to the estimation of *how much* time had elapsed. Further, a recent study found that participants who had to silently spend time in a boring environment, such as a seminar room, were more aware of time and felt it passed more slowly compared to when they spent time in a less boring environment, like nature [31]. This finding is consistent with the idea that being bored while waiting increases one's awareness of time, causing the pacemaker to track more pulses in a given timeframe.

Importantly, this example does not only hold for empty time like sitting in a waiting room but also for loaded time in a high effort scenario. For example, during a cycling ergometer task that gets progressively harder over time, an athlete's attentional focus might be primarily concerned with the seconds ticking down until they can finally stop the exhausting task. Again, time will feel like it is dragging, and the athlete is likely to overestimate how long they actually cycled. Supporting effort's role in time perception, research from sport science has shown that during very hard physical efforts people estimate that more time has passed than actually has [18,32]. With respect to cognitive effort, research shows that people overestimate how long a task took when it had required cognitive effort [33] [b].

This implies that empty time and highly loaded time can feel long because attention is either explicitly directed to the temporal aspects of the situation or the situation produces a high number of pulses that can be tracked. Indeed, pacemaker-accumulator models further posit that the pacemakers' pulse frequency increases as a function of arousal [27]. Thus, in high arousal states, such as the ergometer ride, more pulses should be emitted and tracked by the accumulator, again creating the feeling that more time has passed. A similar mechanism may explain boredom, although the relationship between boredom and arousal is more complex. Research suggest that boredom can occur in both high- and low-arousal states, which could lead to differing outcomes for pulses emitted by a pacemaker. However, arousal may not be the sole aspect influencing the perception of time—it may be sufficient that attention is directed toward time, increasing the pulses counted by the accumulator.

How boredom and effort affect the functional processing of time

In this perspective, we have suggested that effort and boredom shape our experience of time. This should increase the number of pulses that are tracked in a given timeframe, which is expected to lead to an expansion of loaded (in high effort) and empty time (boredom) alike. However, although pacemaker-accumulator models offer a useful framework to describe the perception of time, a specific modality that represents a physical counterpart to the metaphorical pacemaker and accumulator has not yet been identified. Here, we turn to two promising accounts that attempt to explain the functional processing of time and whose propositions are consistent with our proposal that effort and boredom affect time perception.

Focusing on events in the millisecond range, Eagleman and Pariyadath, propose that subjective duration is determined by the amount of effort it took to process a stimulus [25]. This neural energy hypothesis is consistent with our introductory Stroop example: The same stimulus starts to feel progressively shorter when it is presented repeatedly [36] with subjective shortening accompanied by diminished cortical firing rates in response to repeated stimulus presentation [37]. More generally, this implies that after repeated or prolonged presentation of any stimulus, the environment becomes more predictable, processing becomes more efficient and therefore less effortful, which in turn makes the stimulus feel shorter. The proposed increase in processing efficiency is consistent with the large body of research on habituation, finding reduced sensory, neuronal, and behavioral responsiveness when stimuli are repeatedly presented [38–40]. This model offers a mechanistic explanation for why we experience a shift in perceived stimulus duration over time: If a stimulus is processed more efficiently and therefore feels shorter, this should shrink the loaded time and increase the empty time between successive stimulus presentations (for a tentative explanation of how these changes to time perception on the stimulus level could translate to changes in overall time perception of blocks/activities that consist of separate

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[b] Although people seem to treat cognitive and physical effort differently [34], similar theoretical frameworks have been used to explain the processes by which effort signals are integrated and processed by the brain [35]. In turn our proposal is not specific to either form of effort.

stimuli, see Box 1).

While the neural energy hypothesis [25,36] offers an explanation for why high effort situations are likely to be perceived to last longer, how does this relate to boredom? The expansion of empty time is prototypical for boredom (incidentally, the German word for boredom—Langeweile—literally translates to 'long while'). As most readers can attest, when we are repeatedly exposed to the same input, we tend to become bored [41,42]. Expressed more technically, it has been suggested that boredom occurs when the environment does not generate sufficient informational value, which would indicate suboptimal learning rates and reward prediction errors that have been minimized because one's environment has become overly predictable [42–44]. Prototypically this can occur in situations where entropy is low [45]. So, as stimuli are processed more efficiently and feel shorter, empty time expands and one experiences less 'news' from the environment (i.e., minimized reward prediction error, low entropy). But how might boredom now create the feeling of 'long while'?

When bored, people increase their motor and mental activity in search for more rewarding things to engage in [43]. Consistent with this, an emerging body of research shows that bored people display higher rates of non-instrumental movements [46], for example reflected in repeated pressure changes on the chair one is sitting [47] or off-target gaze behavior [43]. This is consistent with research showing that feeling bored is associated with self-reported restlessness [48] [c]. In addition to unspecific motor activity that occurs when bored, boredom is also linked to mind-wandering, with the link to spontaneous mind-wandering being particularly strong [50]. As these findings indicate, boredom appears to increase attention to one's internal (bodily and mental) states, making one notice their own discomfort or that one's thoughts are drifting away. Supporting this claim, recent work has shown that people who are frequently bored report greater attention to interoceptive signals [51]. While boredom likely increases sensitivity to exteroceptive signals as well, here we focus on its link to interoceptive signals and how this relates to time perception. To do so, we turn to Wittmann's interoceptive embodied time account to propose an explanation of how boredom and effort can create the feeling that time is passing slowly [27].

Box 1 – Perceived total subjective duration as the sum of empty and loaded time
Let's briefly return to our initial example of the dynamic changes of perceived duration during a Stroop task: If loaded time and empty time change as a function of processing efficiency and if time passes very slowly during highly loaded or empty timeframes, this begs the question of how total duration of any given timeframe is affected by these changes. Put simply, since any situation consists of a mix of empty and loaded task demands, how is the overall experience of time shaped by this mix? In our initial example, during the first five minutes, time felt 'loaded'

[c] Interestingly, providing people opportunities to engage in fidgeting behavior to reduce boredom does not appear to be effective [49]. One reason for this might be boredom motivates the *search* for rewarding things to engage in and provision of outlets for one's restlessness could potentially defeat this very function of boredom.

because processing and categorizing word stimuli required high amounts of cognitive effort. In the last five minutes, time felt empty because processing and categorizing the stimuli had become almost second nature to the person. So, in the first example, most of the five minutes consisted of loaded time (almost no empty time) and in the second example the empty time/loaded time ratio was reversed. In both cases time seemed to pass slowly. But what is the computational underpinning of this observation? We suggest that the experienced total time is the sum of time perception during empty time and loaded time. While the exact temporal dynamics of how these periods shift with repeated presentations remain an open question, research in related areas, such as habituation, often points towards exponential changes [38] or sigmoidal changes [52]. If similar dynamics apply to empty and loaded time, we might predict that total subjective duration is longest at the extremes—when feelings of either effort or boredom are at their most intense (Figure 2). However, further research is needed to test this prediction and to better understand the temporal dynamics underlying these shifts.

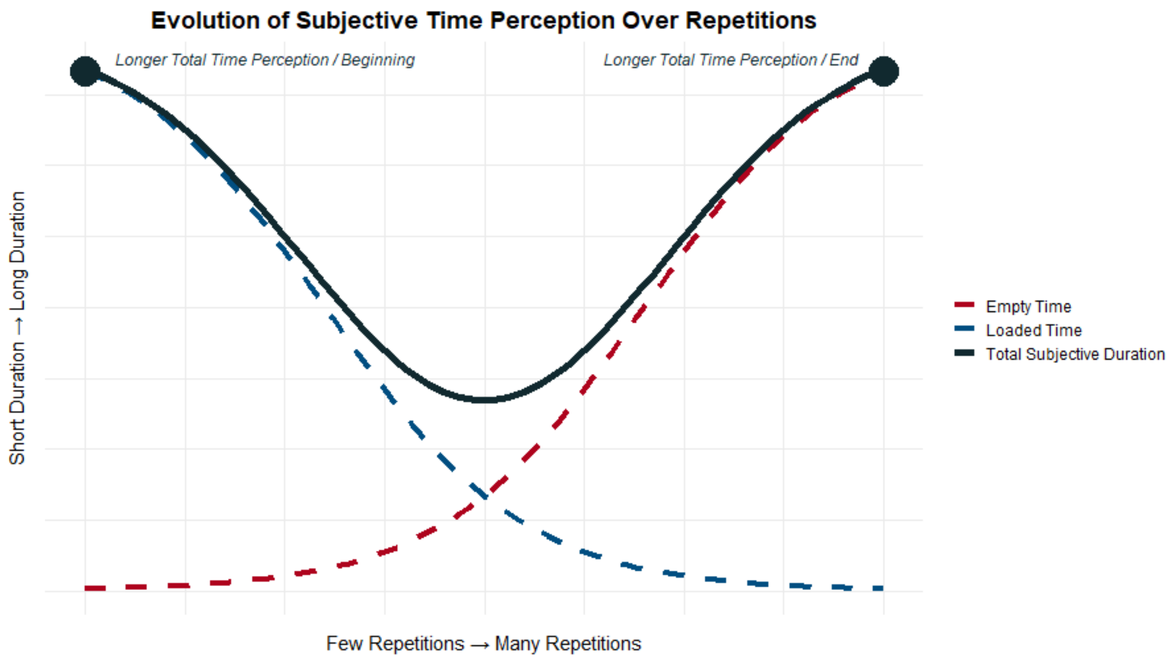

Figure 2. Conceptual representation of how the total subjective duration of an activity might be affected by the dynamic changes in empty time and loaded time for processing the chunks that make up the activity. More specifically, it visualizes how the perceived total duration of an activity might change as a function of the frequency with which chunks that make up the activity must be processed. At the beginning of an engaging activity, the novelty requires more effort, making time seem to pass more slowly (see loaded time, blue curve). As the task becomes more familiar through repetition, the required effort decreases, and time seems to shorten. However, with further repetition and the onset of boredom, time starts to stretch again (see empty time, red curve). Total subjective duration of an activity or an experimental block (see black curve) combines both the loaded and the empty time.

Note. The conceptual model visualizes these dynamics as a sigmoidal function for empty time and loaded time. We have chosen this function over an exponential function as this does not force empty time and loaded time be infinitively high at the extremes.

According to Wittmann, the number of interoceptive signals that an agent attends to indicates how much time has elapsed. Through the lens of pacemaker-accumulator accounts this implies that various interoceptive bodily signals contribute to our perception of time. As no specific sensory organ for tracking time appears to exist in the human body, this embodied account—where multiple interoceptive signals collectively shape the experience of time—provides an elegant explanation for human time perception. This approach is especially compelling because sensory experiences inherently possess a temporal quality. To illustrate, one might feel a moderate degree of discomfort while sitting on a chair (signaled by nociceptor activity) for a certain amount of time.

But how does the embodied time account relate to boredom and boredom's effect on how we perceive the passage of time? When loaded time shrinks and empty time expands (e.g., as one becomes more proficient at processing environmental inputs [25]), boredom is likely to occur. Boredom is associated with increased interoceptive awareness—such that bodily signals are more assiduously attended to—and with a drive to seek additional sensory input, thus generating more interoceptive signals. In addition, boring situations are prototypically characterized by a lack of relevant/rewarding exteroceptive signals (e.g., interesting things to hear, see, or taste), further tilting the balance towards heightened interoceptive awareness. Boredom should therefore impact time perception in two ways: first, because pulses (interoceptive signals) are tracked at a higher rate when one is bored, and second, because additional pulses are generated due to heightened interoceptive awareness.

The embodied time account is also consistent with research showing that high effort activities tend to feel longer than low effort activities [18,32]: When time is loaded with processing demands, interoceptive signals are generated at a higher rate. For instance, as an exercise session intensifies, an exerciser's heart will beat more frequently, increasing interoceptive signaling. Likewise, in the first block of a demanding Stroop task, an overwhelmed participant will focus on multiple unfamiliar stimulus features, again allowing for more interoceptive signals to be accumulated by the pacemaker. In both cases, the high processing load should generate more pulses that can be tracked by the pacemaker, creating the feeling that more time has passed than actually has [d]. Notably, interoceptive sense data have relatively low spatial specificity making their experience more diffuse (compared to vision, for example) [53], and an effort-applying person is likely to causally attribute the most notable interoceptive changes to the effort they are exerting. In contrast, the interoceptive changes that are associated with being bored will likely evade such a causal interpretation by the bored person. The relative amorphousness of feeling bored is also reflected in the heterogenous findings linking boredom to low, mixed or even high arousal. Irrespective if the experiencing agent causally attributes interoceptive signals to heightened effortful processing demands or experiences them as an unspecific corollary of

[d] Please note, that this might also be described as a speeding up subjective time, as the person estimates to have performed an activity for more seconds than they actually have. So, relative to chronological time, subjective time has sped up. At least one of the authors can attest to the agony of this experience when – during a high intensity cycling effort – one thinks the three minute effort block should be almost finished by now, only to find that one is only halfway through it.

boredom, both scenarios are expected to change the perception of time in the same direction.

Taken together, the neural energy hypothesis provides a mechanistic explanation for why the same sensory input can feel longer or shorter. It illustrates how situations can shift from high effort to boredom as the neural energy required for processing changes dynamically. Building on this, the embodied time account explains how effort and boredom influence interoceptive signaling and awareness of bodily signals. Thereby offering a functional explanation for why effort and boredom can make time feel as though it is dragging on.

How the neuroscience of time perception aligns with effort and boredom research

So far, we have discussed how boredom and effort influence the subjective experience of time. First, we have examined this conceptually through the psychological pacemaker-accumulator model of time perception. Second, we have turned to the neural energy hypothesis [25] and the embodied time account [27,54] to highlight putative mechanisms through which boredom and effort affect the functional processing of time. Building on this, we will now review neuroscientific research on insula activity that might offer insights into the mechanistic underpinnings of the link between boredom, effort and time perception.

The insula has been identified as a key structure for processing bodily, affective, and cognitive states, and it plays a regulatory role in decision-making by integrating internal and external information [55]. More specifically, and relevant for this perspective, the insula has been implicated in interoception [56–59], time perception [21,56,60], boredom [61–63], and effort [55,64,65]: The human insula consists of various subregions that differ in lamination and cytoarchitecture [53,66,67]. In the context of this paper, we will only broadly differentiate between functions along the posterior-anterior axis. The processing from high-dimensional representation into more low-dimensional multimodally integrated representations appears to progress along a dorsal-posterior to ventral-anterior gradient [53]. Posterior parts of the insula seem to be the key structure for receiving and integrating various interoceptive signals. These are then passed on to the anterior insula to be processed for higher order representations [59,66]. Simply speaking, posterior parts of the insula appear to be more relevant for processing raw signals, whereas anterior parts seem to be more involved for processing these into more abstract cognitive-affective signals/states.

The accumulation of interoceptive signals as a meter of elapsed time has been associated with activity in the posterior insula [68]. A neural mechanism called *climbing neural activation* where neural activity gradually increases or decreases during a timed interval, peaking at its end, has been proposed to underly the tracking of time in the posterior insula [30]. Consistent with the dorsal-posterior to ventral-anterior gradient of increasing complexity, anterior insula activity has been associated with reproduction of time intervals [68] or the accuracy of duration discrimination [69]. These findings are consistent with the view that time perception is embodied and influenced by internal bodily states [21,54]. In turn, feelings that can affect the magnitude of and sensitivity to such bodily states, such as boredom and effort, could be expected to dynamically affect time awareness through their effect on insula activity.

So far, only few studies have investigated the neuroscience of boredom (for an overview, please see [63]) with the anterior insula regularly implicated in research that has investigated the bored brain. Being bored has been linked to reduced activity in the anterior insula [38]. However, when people tried to reduce their boredom, increases in anterior insula activity was reported [39]. Similarly, another study observed less activity in the anterior insula during boredom (when compared to states of flow or overload), but relatively stronger functional connectivity between anterior insula and the ventral striatum [70]. One can speculate that boring situations characterized by an initial lack of relevant things to engage in, are then met by attempts to address this state by increasing the number of things the person tries to attend to or engage with. The former state is then expected to be characterized by reduced anterior insula activity, whereas the latter would correlate with increased anterior insula activity and/or heightened connectivity with regions that allow for the exploration of viable things to engage in. To the best of our knowledge, boredom has not been linked to altered activity in the posterior insula. A speculative interpretation is that boredom's effect on time perception may stem less from increasing the number of pulses accumulated by the pacemaker and more from directing attention to these pulses in the absence of relevant exteroceptive information. During periods of empty time, the anterior insula may become more sensitive to internal bodily states, as boredom is associated with increased interoceptive sensitivity [51]. Since time perception is influenced by how much attention is paid to its passage, boredom may make available more attention to focus on internal sensations, such as heart rate, breathing, and posture. This hyperawareness of bodily states may amplify the feeling that time is moving slowly. In states of boredom, when prediction errors are low (i.e., there are no unexpected events or new stimuli) the anterior insula becomes more focused on internal states, further enhancing time awareness. Conversely, when prediction errors are high (due to surprises or rewards), external stimuli capture attention, reducing boredom and making time seem to pass more quickly. Indirect evidence for such a relationship comes from research showing that people with heightened interoception overestimated time, whereas those with heightened exteroception underestimated time [71].

The posterior and anterior insula have also been associated with effort in neuroscientific research [65,72]. Consistent with its function as a key hub for interoception, posterior insula activity has been related to sensations such as pain [73] or tachycardia [74], and the sensing of aversive states in general [75], all of which contribute to feelings of effort. Further, effort demanding tasks are related to increased activity in anterior and posterior insula and activity profiles in the posterior insula have been linked to feelings of fatigue, a consequence of prolonged effort exertion [65,76]. Again, in keeping with the dorsal-posterior to ventral-anterior gradient, anterior insula activity has been found to play a role in decisions to invest or withhold effort [77,78] or feelings of fatigue as a more generalized cumulative consequence of exerting effort [65]. The evidence linking effort and insula activity aligns with the idea that effort demanding situations alter the number and intensity of interoceptive signals that are processed by the insula, thereby potentially directly affecting how we perceive the passage of time.

Taken together, effort and boredom have been conceptually and empirically associated with heightened interoceptive signaling or interoceptive awareness, and insula activity has been observed to increase in response to a wide range of interoceptive signals [59], which may account for its engagement during both effort and boredom. The extant neuroscientific evidence is therefore largely consistent with the proposal we have outlined in this paper. Namely, that boredom and effort increase awareness to internal bodily states, thereby altering the number of pules the 'internal clock' tracks.

Conclusion

In this perspective, we propose a tentative explanation for why events of the same objective duration can feel as if they pass faster or slower, focusing on the roles of effort and boredom in shaping time awareness. We suggest that increasing exposure to a task improves the efficiency of processing external and internal sensations, thereby altering how 'empty' or 'loaded' a timeframe feels. While effortful situations are characterized by a higher share of loaded time, boredom is characterized by more empty time. Importantly, both sensations contribute to the feeling that time is dragging. Mechanistically, boredom and effort might influence time perception by increasing attention to internal bodily states. In line with this argument, both effort and boredom have been linked to heightened interoceptive signaling and sensitivity, processes that appear central to time perception through the integration of interoceptive signals. At the neural level, the insular cortex emerges as a promising candidate region for understanding this relationship, as it serves as a key hub for boredom, effort, interoception, and time perception. We have written this perspective through the lens that effort and boredom alter the perception of time. However, one might also make the case that the relationship between effort, boredom and time perception we outline here is in the reverse. Disentangling the causal dynamics among these processes will be critical to advance our understanding of the subjective experience of time.

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