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Recent advances in understanding emotion-driven temporal distortions

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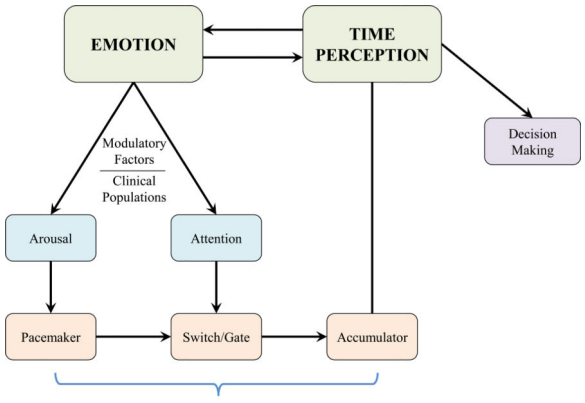
Abstract

Emotions are powerful drivers of distortions in time perception. Recent work continues to support arousal and attentional mechanisms of emotion-driven temporal distortions. A possible memory-related mechanism and various modulatory factors, such as age, gender, and psychopathology, have also been implicated in such distortions. Beyond the rich behavioral literature on this topic, neurobiological substrates associated with emotion-driven temporal distortions have begun to be identified and represent an important next step for research within this domain. The study of emotion-driven temporal distortions holds great promise for advancing our understanding of this perceptual phenomenon and how it may play a functional role in mediating changes in cognition, behavior, and emotion.

Graphical Abstract



PACEMAKER ACCUMULATOR MODEL

Introduction

Emotions are dynamic, unfolding over time. Despite this temporal dependence, it is well known that the way in which we perceive time during emotional experiences does not always conform to reality. Over the past two decades, increased interest in this perceptual phenomenon has greatly advanced an understanding of how emotions distort time perception

and the various factors that modulate these distortions. In more recent years, research within this domain has extended in several exciting new directions. This review will summarize the current state of the literature on emotion-driven temporal distortions in humans, highlighting the psychological and neural mechanisms associated with emotional influences on time perception, the factors that modulate these influences, the translation of emotional timing paradigms into the clinical domain, and the available evidence that emotion-driven temporal distortions shape decision-making and possibly emotion itself (see Figure 1). Throughout the review, promising directions for future research will be emphasized.

Psychological Mechanisms

Across investigations of emotion-driven temporal distortions, a general picture has emerged of the predominant mechanisms underlying such distortions, supported by pacemaker-accumulator models of time perception [1,2]. Specifically, emotions appear to alter time perception via changes in arousal and attention. According to pacemaker-accumulator models, arousal speeds the rate of an internal timekeeping pacemaker, such that an individual perceives more time to have elapsed than the objective duration of the emotional event, resulting in the overestimation of duration. However, in many initial studies of emotion-driven temporal distortions, effects of arousal may have been confounded by factors such as the complexity of visual stimuli [3]. Recent investigations have more clearly linked arousal to duration overestimation by demonstrating a positive relationship between overestimations and arousal ratings [4,5] and by using conditioned stimuli [6,7]. The advantage of using conditioned stimuli is that these stimuli can be simple, as their emotionality is derived from their association with an emotional event, thus deconfounding visual stimulus properties from the effects of arousal.

In addition to evidence for arousal-mediated effects of emotion on time perception, emotion-driven changes in attention have also been shown to modulate time perception. Changes in attention are conceptualized as affecting the activity of a switch or gate that influences the number of pulses emitted from the pacemaker and subsequently collected in an accumulator, representing the perceived duration of the stimulus being timed [2,8]. If attention is directed away from timing, such as in the case of attentional capture by emotion-laden stimuli [9,10], the functionality of the switch/gate changes, resulting in fewer pulses being passed to the accumulator and the underestimation of duration. Such effects have been found by experimentally manipulating emotion, via emotional pictures [11], faces [12], drug-induced euphoria [13], and conditioned stimuli [14].

In addition to the empirical support for the mechanistic roles of arousal and attention in emotion-driven temporal distortions, a recent investigation suggests that the impact of emotion on memory could influence time perception by changing the internal reference to which an interval is compared. Grondin and colleagues [15] showed participants pictures of mutilation and neutral and disgusted faces. Participants were asked to decide if each presented image matched previously learned ‘short’ or ‘long’ target durations. Mutilation images were more frequently overestimated in duration than neutral and disgusted faces. However, the relative overestimation of mutilation images appeared to be driven by a bias to respond ‘short’ more frequently for the neutral/disgusted faces, rather than a bias to respond

'long' more frequently for mutilation images. The authors suggested that this bias might be the result of an effect of emotion on memory, such that the durations of emotional images were given more weight in forming a representation of the durations to which the presented stimuli were compared. Further work can help to establish the relative contributions of memory representations for durations versus pacemaker and switch/gate mechanisms to emotion-driven temporal distortions.

Neural Mechanisms

Only in the past few years have human studies begun to address the neural regions associated with emotion-driven temporal distortions. Theories have focused on the anterior insula as a key potential region involved in the subjective experience of time and the integration of emotional experiences into an internal representation of time [16,17]. Functional MRI investigations of emotion-driven temporal distortions have provided support for the engagement of regions implicated in timing networks, including the anterior insula, as well as the right inferior frontal gyrus (rIFG) and supplementary motor area (SMA), and emotionally relevant regions, such as the amygdala [4,18,19]. A particularly compelling finding was that a rIFG region, defined by a timing localizer task, showed greater activation for emotional versus neutral images during an emotional timing task [19] and the magnitude of this contrast correlated with an emotion-driven overestimation bias.

A promising novel approach to investigating emotion-driven temporal distortions was taken by Tipples [20] who used drift diffusion modeling for a bisection timing task, wherein spider phobics and healthy controls were tasked with judging whether pictures of spider and birds were presented for a duration that more closely matched a previously learned 'short' or 'long' duration. The findings supported an increase in temporal accumulation in spider phobics for images of spiders versus birds, resulting in changes in the rate at which a decision threshold was met, with this decision threshold representing the time point at which a presented image switches from being judged as closer in duration to the 'short' duration to being judged as closer in duration to the 'long' duration. This finding dovetails with the results of a recent fMRI investigation [18] in which a bisection timing task was used to demonstrate that activation in a rIFG/anterior insula cluster and the SMA were modulated by emotion at the stimulus duration associated with the slowest response times, indicative of maximal temporal discrimination difficulty, and thus, the duration nearest the decision threshold. These findings suggest a role for the rIFG/anterior insula and SMA in the affective modulation of temporal decision-making.

Neuroimaging studies have begun to identify regions that may plausibly be implicated in emotion-driven temporal distortions, with encouraging consistency in reported regions across investigations. Nevertheless, the specific mechanistic contributions of these regions to distortions in time perception remain unclear. Investigating functional connectivity measures will be an important avenue for future research to understand the likely communication between emotion detection regions, such as the amygdala, and regions implicated in timing networks, such as the rIFG, insula, and SMA.

Modulatory Factors

Beyond attempts to clarify mechanisms, much of the work on emotion-driven temporal distortions has focused on identifying factors that modulate these distortions. Findings for valence-related modulations have varied [21–25] and a better understanding of these discrepancies across studies is necessary. Recent evidence has shown that declarative knowledge—what information people were told about the expected direction of emotional biases on time perception—enhanced existing biases if the information was accurate and decreased existing biases if the information was inaccurate [26]. Participant gender [27] and age [28], perceived control over emotional events [29,30], as well as trait measures of fearfulness [29,31] and anxiety [32] have all been shown to modulate the magnitude of emotion-driven temporal distortions. These findings point to the ability of various factors to impact the magnitude of temporal distortions. At the same time, Van Volkinburg and Balsam [25] demonstrated that contextual factors may modulate not just the magnitude of an emotion-driven temporal distortions, but also the underlying mechanisms of distortion. In a temporal reproduction task, these researchers found that emotion-driven temporal distortions were consistent with an enhanced arousal effect when emotional stimuli were presented during duration encoding, but were more consistent with an attentional distraction effect when an emotional stimulus was presented during the reproduction of a temporal duration. The growing number of factors reported to modulate emotion-driven temporal distortions are a testament to the flexibility of time perception.

Clinical Populations

The field of emotion-driven temporal distortions has seen a recent increase in translation into the clinical domain [33–35]. Whereas baseline time perception appears to be intact in emotion-related disorders [36,37], exaggerations of emotion-driven temporal distortions have been observed, particularly in individuals with anxiety and specific phobias [20,38,39]. Manic, but not euthymic, bipolar patients also demonstrate altered emotion-driven temporal distortions, suggesting that such distortions are state, rather than trait, dependent features of this disorder [33]. Intriguingly, individuals with autism spectrum disorders, known to have problems with face processing and social interaction, do not differ from healthy controls in demonstrating the canonical overestimation of emotional relative to neutral faces [35], suggesting that implicit emotional processing may be intact in these individuals. The translation of emotion-driven temporal distortion paradigms for use in clinical populations seems a particularly fruitful area for further research to better understand how timing during emotional experiences can go awry and what that might tell us about the nature of timing as well as the perceptual experiences and behaviors of clinical populations [40].

Consequences for Cognition, Behavior, and Emotion

The relationship between emotion and time begs the question of whether emotion-driven temporal distortions are merely a byproduct of emotional processing or instead, play a functional role. Although little research has attempted to address this question directly, available evidence suggests that temporal distortions may mediate certain consequences of emotion. For example, time perception has been implicated in decision-making processes

and, as emotions contribute to time perception, the emotional modulation of time perception may have important consequences for such processes. One decision-making domain that might be particularly sensitive to emotion-driven temporal distortions is the phenomenon of temporal discounting [41–46]. Temporal discounting is defined as the devaluation of future rewards in favor of more imminent rewards and follows a hyperbolic response distribution, such that the subjective value of future rewards decreases with the duration of the delay. The steepness of this function is sensitive to individual difference factors, such as impulsivity; more impulsive individuals demonstrate greater discounting of future rewards in favor of temporally proximal rewards [47–50]. Theoretical work suggests that biases in time perception may mediate the relationship between impulsivity and temporal discounting [44]. A tendency to overestimate the duration of time between a decision and its anticipated outcome may explain the greater tendency to favor more imminent rewards. In support of such theories, empirical studies have supported a relationship between impulsivity and temporal biases [51,52] and between time perception and temporal discounting [42,43,46,53].

Given the available evidence pointing to the role of time perception in influencing temporal discounting, emotions may have a considerable impact on the role of time perception in temporal discounting [44]. If decision-making occurs during or after an emotionally arousing event, an arousal-driven temporal overestimation bias may increase the steepness of the hyperbolic temporal discounting curve, resulting in an increased bias towards imminent versus delayed rewards. Such an influence would be similar to that of impulsivity. This premise is consistent with recent evidence that emotional priming with negative images, relative to priming with neutral or positive images, induces greater temporal discounting in favor of smaller but more temporally proximal rewards [54]. Furthermore, this temporal discounting effect was correlated with time perception during a temporal reproduction task, such that greater temporal discounting after negative priming was associated with greater temporal overestimation of negative versus neutral images. This is just one example of how time perception may mediate the effects of emotion on cognition and behavior. Other aspects of decision-making, such as when decisions are made under time pressure, might also be affected by emotion-driven temporal distortion.

Although it is clear that emotion influences the perception of time, preliminary evidence suggests that the relationship between emotion and time perception may be bidirectional. In a study of pain, Pomares and colleagues [55] delivered painful thermal stimulation while participants viewed a clock that indicated the duration of the painful stimulation. In one condition, the clock indicated that the duration of the painful stimulation was shorter than the duration of stimulation in the other condition, but the actual durations of painful stimulation were identical in both conditions. Participants generally rated the stimulation as less painful during the condition in which they were led to believe that the duration of stimulation was shorter, suggesting that perceived time influenced affective responses irrespective of the actual duration of painful stimulation. Given the positive relationship between arousal and temporal overestimation, it is possible that perceived time may serve as a proxy for emotional intensity. It would be fruitful to consider if such an effect generalizes to highly arousing emotions, such as fear or excitement. If time perception serves a feedback function, it could have important implications in understanding exaggerated emotional

responses, such as in individuals with heightened fear and anxiety who tend to show exacerbated temporal biases during emotionally arousing events [29,31,32]. These exaggerated overestimation biases could increase the perceived intensity of an emotionally arousing event, perpetuating fearful and anxious responding. Additionally, individuals with anxiety often generalize fear to nonthreatening cues [56–58]. It could be worthwhile to assess whether such generalizations are mediated by distortions in time perception that are interpreted as evidence of threat. Preliminary evidence has supported a possible relationship between threat discrimination and time perception [14].

Conclusions

Investigations of emotional influences on time perception have made considerable progress in furthering our understanding of the psychological mechanisms underlying the plasticity of our sense of time and the factors that modulate emotion-driven temporal distortions (Figure 1). Investigations into the neural correlates of this perceptual phenomenon are still in their infancy, but further consideration of neural mechanisms holds great promise for advancing an understanding of emotion-driven temporal distortions, particularly given criticisms of the biological plausibility of pacemaker-accumulator models typically relied on for interpreting emotional timing data [59, 60]. The recent translation of emotional timing paradigms into the clinical domain may have important consequences for understanding the perceptual experiences of individuals with emotion-related disorders. At the same time, investigating how emotion-driven time perception may mediate emotional effects on cognition and behavior, and even feedback to influence emotion itself is an especially attractive area for further research. If these distortions do play a functional role, future work should consider how the malleability of time perception could be leveraged to affect behavioral, cognitive, and emotional changes. There is great promise that the study of emotion-driven temporal distortions can tell us more about how time perception shapes how we experience the world [61].

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Highlights

- Emotions influence timing via changes in arousal, attention, and possibly memory.
- Emotion-driven time distortions are modulated by trait and state dependent factors.
- Evidence implicates the insula, rIFG, SMA, and amygdala in these distortions.
- Emotion effects on timing may impact cognition, behavior, and emotion itself.

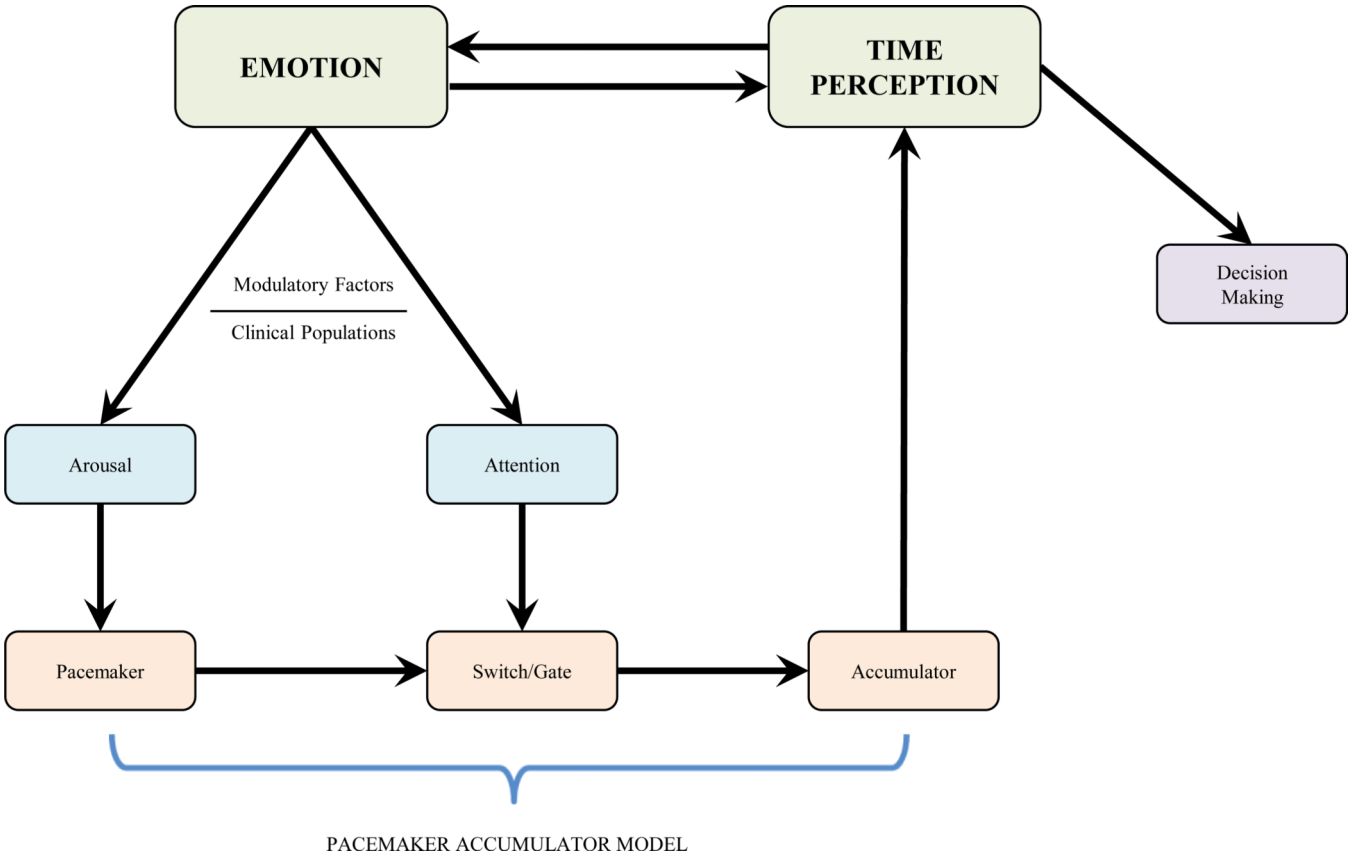

Figure 1. The relationship between emotion and time perception

Extension of (a part of) the pacemaker-accumulator model of time perception [1,2,8] to include the mechanisms of emotion-driven temporal distortions and the processes influenced by emotion-driven manipulations of perceived duration.