



# Recent advances in understanding emotion-driven temporal distortions

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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.

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## 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.

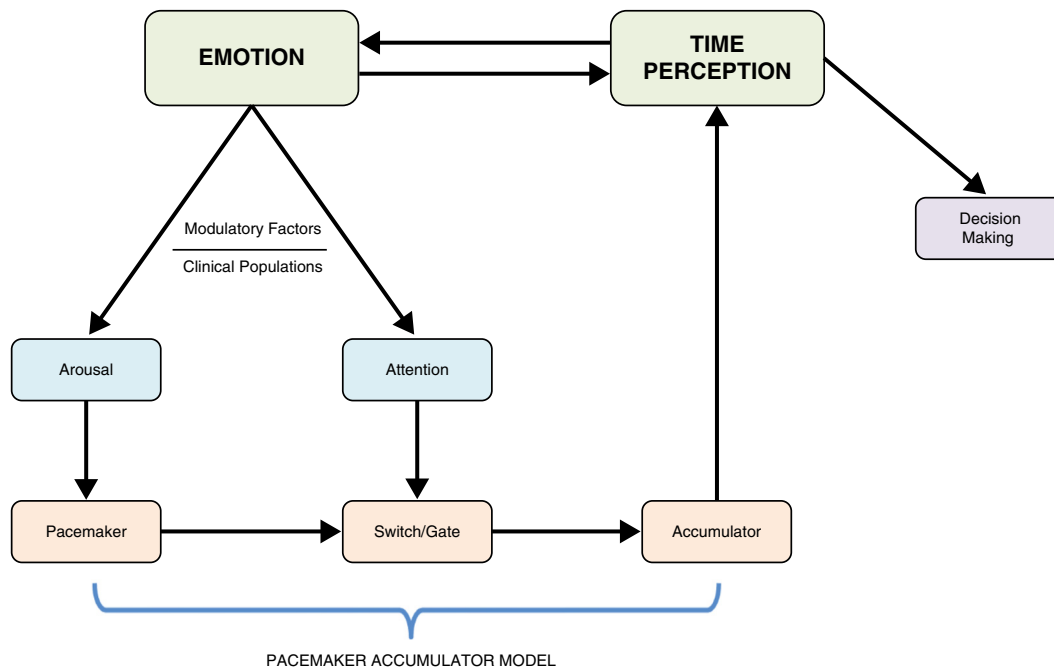
## Psychological mechanisms

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

Figure 1



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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.

of emotion on memory could influence time perception by changing the internal reference to which an interval is compared. Grondin and colleagues [15<sup>\*</sup>] 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<sup>\*</sup>,19<sup>\*</sup>]. 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<sup>\*</sup>] 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<sup>\*\*</sup>] who used drift diffusion modeling for a bisection timing task, wherein spider phobics and healthy controls were tasked with judging whether pictures of spiders 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,

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