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Review article

Emotional modulation of interval timing and time perception

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ABSTRACT

Like other senses, our perception of time is not veridical, but rather, is modulated by changes in environmental context. Anecdotal experiences suggest that emotions can be powerful modulators of time perception; nevertheless, the functional and neural mechanisms underlying emotion-induced temporal distortions remain unclear. Widely accepted pacemaker-accumulator models of time perception suggest that changes in arousal and attention have unique influences on temporal judgments and contribute to emotional distortions of time perception. However, such models conflict with current views of arousal and attention suggesting that current models of time perception do not adequately explain the variability in emotion-induced temporal distortions. Instead, findings provide support for a new perspective of emotion-induced temporal distortions that emphasizes both the unique and interactive influences of arousal and attention on time perception over time. Using this framework, we discuss plausible functional and neural mechanisms of emotion-induced temporal distortions and how these temporal distortions may have important implications for our understanding of how emotions modulate our perceptual experiences in service of adaptive responding to biologically relevant stimuli.

Contents

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1. Introduction

The ability to accurately perceive time is critical for adaptively navigating through our everyday lives. We utilize timing processes to gage whether we have enough time to cross the street before an approaching car arrives at the intersection, to maintain a regular rate of conversation flow when speaking with a friend, and when we determine a website is not loading properly and click "refresh" (e.g., Allman et al., 2014; Buhusi and Meck, 2005; Matthews and Meck, 2014). Given the ubiquity of actions and decisions that rely on timing processes, it is noteworthy that our perception of time is often distorted rather than perceived veridically. The cognitive processes that support time perception appear to be flexibly modulated by components of our ongoing experiences. Such temporal distortions may allow us to adaptively respond to stimuli in our environment (e.g., Harrington et al., 2011; Lewis and Meck, 2012; Matthews and Meck, 2014; Meck, 2003).

Perhaps the strongest and most salient manipulations of time perception come from experiences of emotion (Agostino et al., 2008; Lake, 2016). Common expressions such as "time flies when you're having fun" or "time seemed to move in slow motion" illustrate the pervasiveness of emotional distortions in our perception of time. In line with anecdotal experiences, early human studies suggested that emotionally arousing experiences led to the overestimation of temporal durations – participants believed that more time had passed during an emotional event than actually had (e.g., Hare, 1963; Langer et al., 1961; Thayer and Schiff, 1975, but see Falk and Bindra, 1954). For example, when asked to estimate an interval of time while moving toward a precipice, participants overestimated how much time had passed relative to when they were moving away from the precipice toward safety (Langer et al., 1961). Despite fairly consistent reports of temporal overestimation in response to emotional events, these studies suffered from methodological limitations. For example, appropriate comparisons between emotional and non-emotional control conditions were not performed. Instead, temporal estimates were either compared to physical durations of time (Hare, 1963; Langer et al., 1961), or to estimates of empty temporal intervals (Thayer and Schiff, 1975), rather than to estimates of a neutral stimulus. Without a neutral baseline condition, it is difficult to conclude that the overestimation biases observed were specifically due to the emotional content of the stimuli rather than to other properties of the emotional event. These studies also only used a single emotion-related stimulus, relied on a limited number of trials, and did not compare temporal estimates across multiple durations or levels of arousal. These issues limit a comprehensive understanding of the relationship between emotion and time perception, as well as the underlying mechanisms that support it.

Only recently has empirical research begun to consider the mechanisms underlying emotional distortions in the subjective experience of time more systematically (Lake, 2016; Lake et al., 2016; Schirmer, 2016; Schirmer et al., 2016). Researchers have improved upon earlier study limitations by utilizing standardized tasks that allow for distortions to be compared across multiple durations and standardized emotional stimuli that allow for more mechanistic interpretations of resultant temporal distortions. Such studies have frequently interpreted findings within the context of pacemaker-accumulator (PA) models of time perception (Gibbon et al., 1984; Treisman, 1963, 2013; van Rijn et al., 2014). However, a review of the existing literature suggests that such interpretations have been limited by a variety of factors.

We begin by reviewing the basic tenets of PA models and describe the mechanisms of temporal distortions within this model framework that are most relevant to the study of emotional distortions of time perception. Next, we will argue that using PA models to interpret the extant literature on emotional effects on time perception is limiting due to different interpretations of such models and different operational definitions of arousal and attention as plausible temporal distortion mechanisms across timing and affective/cognitive science fields. After a review of the current literature, we propose a new model of emotional influences on time perception that may provide a better framework for understanding underlying mechanisms. We will consider how these proposed mechanisms might be instantiated in the brain based on the neurobiologically plausible striatal beat frequency (SBF) model of interval timing in conjunction with existing time perception and affective/cognitive neuroscientific evidence. Finally, we address possible implications of the described effects of emotion on time perception and suggest avenues for further exploration of such interactions.

2. Pacemaker-accumulator models of timing: arousal, attention, and working memory

Pacemaker-accumulator (PA) models of time perception (Fig. 1 Gibbon et al., 1984; Treisman, 1963; Zakay and Block, 1997) posit that there are three main levels in making a temporally based judgment involving clock, memory, and decision-making stages. During the clock stage, a pacemaker emits pulses that are subsequently collected by an accumulator. The number of pulses collected by the accumulator represents the duration of time that has elapsed during the timing of a particular interval. A switch controls the transfer of pulses from the pacemaker to the accumulator (LeDoux, 2012; Meck, 1984). When the switch closes, pulses pass into the accumulator; pulses are blocked when the switch is open. In the memory stage, the duration of the interval being timed (represented by the number of pulses collected in the accumulator) can be transferred from working memory to long-term memory. Lastly, in the decision-making stage, the temporal interval being timed is compared to duration representations stored in long-term memory to determine if the current interval is of an equivalent duration. If, for example, an individual is required to perform an action after a specific time interval has elapsed, that individual will compare the current interval being timed with previous representations of this interval stored in memory and will effect the appropriate behavior when these two representations are judged to be equivalent. Scalar timing theory states that the variability in temporal estimates is

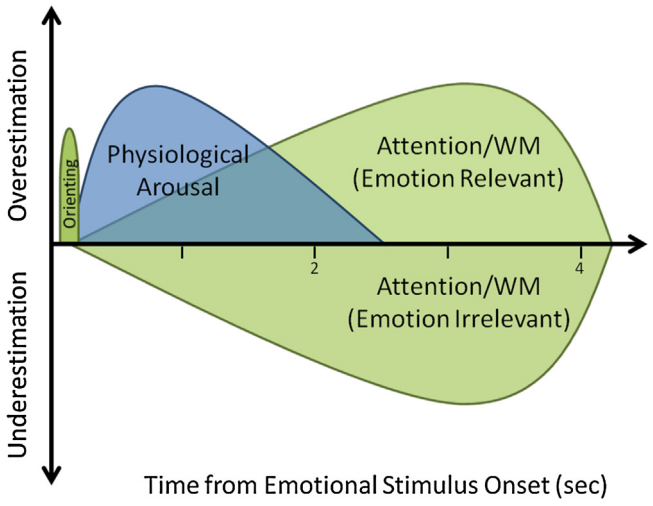

Fig. 1. Proposed theoretical model of emotion-induced temporal distortions. This model illustrates the temporal dynamics underlying temporal distortions after the presentation of an emotional stimulus, the proposed relationship between arousal (blue) and attention (green) components during this evolving perceptual experience, and the importance of the way in which attention is directed in determining the influence of the attention components.