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Time perception, emotions and mood disorders

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ABSTRACT

In this review, we describe recent internal clock models accounting for time perception and look at how they try to explain the time distortions produced by emotion. We then discuss the results of studies of patients suffering from affective disorders (depression) who experience the feeling of time slowing down. A distinction is thus made between time perception and explicit awareness of the passage of time. We conclude that the feeling that time is passing slowly is not systematically associated with a disruption in the basic mechanisms underlying time perception.

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Contents

1. Introduction
2. Internal clock models
3. Emotion and time perception
   3.1. The effect of fearful state on time perception
   3.2. The processing of emotional stimuli
   3.3. The effect of disgust, shame, and sadness
4. Affective disorders and time perception
   4.1. The feeling that time has slowed down experienced by individuals with depression
   4.2. Time perception in individuals with depression
5. Conclusion
6. Acknowledgments
References

1. Introduction

For more than 50 years, researchers have tirelessly amassed data demonstrating that humans, like other animals, are able to accurately estimate durations in the hundreds of milliseconds-to-minutes range, and that their time estimation conforms to Weber’s law. Time estimates are on average accurate (mean accuracy) and the variability in estimates increases linearly with the length of the intervals being timed (scalar property). This has led researchers to conclude that humans and animals share a primitive sense of time, together with its hallmark characteristic: the scalar property. They have thus sought to develop models of the internal mechanism that is presumably responsible for time measurement - the so-called internal clock - and pinpoint its location in the brain. Paradoxically, despite this putative internal clock mechanism, humans sometimes have strange impressions of time (Droit-Volet and Gil, 2009). Time seems to speed up, slow down, or even stop. When individuals become depressed, for example, they experience a slowing down of time, such that “a day feels like a year” (Ratcliff, 2012). Similarly, in everyday life, our experience of time fluctuates according to our emotional states. Time seems to fly when we are happy and to drag when we are bored. The difficulty for researchers is thus to explain these distortions of time on the basis of models designed to account for accurate time measurement. In this review, we begin by describing current models of the internal clock. We then discuss how these models explain the results of studies on the effects of emotion on time perception. We end with

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a description of research findings on time judgments in affective disorders that allow us to make a clear distinction between the feeling of time distortion that originates from explicit introspection onto subjective personal experience and the effect of mood on the basic mechanisms involved in time perception.

### 2. Internal clock models

The idea of a biological clock system specializing in the measurement of time is nothing new. In 1927, a student of Henri Piéron – Marcel François – undertook a series of experiments in order to “provide an empirical contribution to a problem that remains unclear despite the many studies it has already prompted” (p. 187).

In his experiments, François attempted to demonstrate that time measurement depends on “physiochemical mechanisms by manipulating these mechanisms. In particular, he ran high-frequency electric currents through people’s bodies in order to raise their body temperature (a technique known as diathermy) and test the latter’s effect on time perception. His results confirmed that an increase in body temperature lengthens time estimates (i.e., the number of taps per second in a tapping task), as though it had speeded up a clock-like mechanism (François, 1927). A few years latter, Hoagland (1933) replicated these results with experiments run on his own wife when she caught influenza. Since then, numerous studies involving keeping participants in overheated rooms or immersing them in baths of cold water have produced evidence in favor of a relationship between body temperature and the rate of subjective time (for a review, see Wearden and Penton-Voak, 1995). Consequently, almost from the very outset, time perception has been regarded as being dependent upon an internal mechanism that provides a sort of timebase, whose rate can be modified. Researchers have thus proposed a variety of models based on this putative internal clock mechanism (Gibbon, 1977; Gibbon et al., 1984; Treisman, 1963).

The most popular internal clock model (Gibbon et al., 1984) is based on the scalar expectancy theory (SET) proposed by Gibbon (1977) (see Church, 2003). According to this model, the raw material for the representation of time comes from an internal clock composed of a pacemaker, a switch and an accumulator. The switch, connecting the pacemaker to the accumulator, is controlled by attention. When attention is directed toward a stimulus to be timed, it closes, thus allowing the pulses emitted by the pacemaker to flow into the accumulator. At the offset of the stimulus, the switch reopens and stops the flow of pulses. Time estimates thus depend on the number of pulses accumulated during the interval that has elapsed: the more pulses that have accumulated, the longer the duration is judged to be.

The dopaminergic system and the structures of the basal ganglia, namely the striatum (i.e., caudate and putamen) and the substantia nigra pars compacta (SNc), were initially regarded as the neural substrates of the pacemaker-accumulator system (for a review, see Meck et al., 2008). The function of the pacemaker was attributed to the SNc, which was assumed to send dopaminergic outputs to the striatal structures. As explained by Warren Meck in 1996 (p. 232), “rats with SN lesions possess severe impairments in their ability to generate the pulses (timekeeping) required to quantify the temporal dimension of stimulus events, and rats with caudate-putamen lesions possess severe impairments in the ability to accumulate (gating) those pulses”. Evidence was found in patients with Parkinson’s disease, a pathology characterized by the degeneration of dopaminergic projections in the basal ganglia, who exhibit impaired timing in both motor and perceptual temporal tasks (e.g., Harrington et al., 2010; Malapani et al., 1998; Pastor et al., 1992; Rammayer and Classen, 1997). Pharmacological studies also showed that the administration of drugs (e.g., methamphetamine) that increase the level of dopamine in the brain lengthens subjective time, as though the rate of the pacemaker had increased (multiplicative clock speed effect) (Buhusi and Meck, 2002; Maricq et al., 1981; Meck, 1983; Rammayer, 1993; Rammayer and Stahl, 2006; Rammayer and Vogel, 1992; Williamson et al., 2008).

However, although the behavioral predictions of SET theory have been widely validated, the idea of a simple pacemaker-accumulator system for timing has since been abandoned on account of its lack of neurobiological plausibility. A consensus has now emerged according to which the processing of time does not involve one simple brain structure, but instead relies on a large and distributed network of neural areas, its precise configuration depending on the nature of the task demand. Matell and Meck (2000, 2004) have proposed a model in which a cortico-striatal circuit underlies the processing of time, called the striatal beat frequency (SBF) model. This model is currently considered to be the most plausible biological model of the internal clock (Coull et al., 2011). However, it is important to bear in mind that not all scientists agree with this model. Some of them hold that there is no such thing as a specific time-processing mechanism, arguing that time measurement emerges from the dynamic activity of a population of neurons that are intrinsically capable of coding time (for a discussion, see Iyry and Schierf, 2008). Fig. 1 presents the SBF model.

In this model, the representation of time arises not from impulses produced by the SNc, but instead from the synchronized oscillatory activity of a large area of the cortex. In the SBF model, the dopaminergic system simply signals the onset of a stimulus to be timed by sending a burst of dopamine (DA) to the striatum (phasic DA) or modifying cortical oscillation frequencies (tonic DA) (Meck et al., 2008). The role of the spiny neurons in the striatum, which receive inputs from cortical neurons, is to detect coincident activity between a large number of oscillators beating at different frequencies. In the SBF model, the striatum is thus the main structure involved in the detection of cortical oscillatory patterns associated with signal duration. Neuroimaging studies using different techniques (fMRI, PET) have confirmed the critical role played by the striatum in time encoding (e.g., Coull and Nobre, 2008; Harrington et al., 2010; Rao et al., 2001). Time judgment, however, is which is particularly complex, also involves other neural structures (e.g., prefrontal cortex, supplementary motor areas (SMA), cerebellum), whose activation depends both on task nature (motor or perceptual) and on duration (less than or more than 1 s) (for a recent meta-analysis, see Wiener et al., 2010). Whatever the case may be, the exact role of the striatum in timing is still poorly understood, as it is a complex structure that has extensive connections with different regions of the cortex, and subserves different functions. It is nevertheless believed to be the common neural substrate for the learning and encoding of time across different tasks. Harrington et al. (2010) concluded that the striatum works as a core timer integrating cortical oscillatory states over time, as suggested in the SBF model.

Whichever neural structures are involved in the processing of time, internal clock models allow us to account for the linear relation between time estimates and stimulus duration values. In addition, as we will see for emotion, it also allows us to explain a certain number of time distortions in terms of attention or clock speed phenomena, although other mechanisms may also be involved (i.e., decision, conscious awareness of emotional and bodily states).

### 3. Emotion and time perception

#### 3.1. The effect of fearful state on time perception

Of all the primary emotions (fear, anger, happiness, disgust, sadness, surprise, fear) (Ekman, 1999), fear is without doubt the
emotion that has been the most intensively examined in studies of time judgments in humans, as well as in other animals. Fear refers to a subjective feeling associated with a series of behavioral and physiological responses to threatening environmental situations (Ledoux, 2012). These responses serve an adaptive function of defense for survival (Darwin, 1872/1998). For example, in both nonhuman and human primates, the sight of a snake or the angry face of a conspecific has an innate propensity to trigger defense reactions (Öhman and Soares, 1998). Whenever a threat presents itself, the body activates its stress response, a state of alarm that triggers an array of changes in the autonomic (cardiovascular, respiratory) and somatic (facial and bodily motor expression) nervous systems designed to prepare the organism to act as quickly as possible, i.e., fight-or-flight response (Cannon, 1929).

Studies of time perception have thus logically assumed that the perception of a threatening signal speeds up the internal clock system, as this system is sensitive to arousal effects (e.g., Treisman, 1963; Treisman et al., 1990), thus producing a time-lengthening effect. According to SET theory, when the rate of the internal clock increases, more pulses are accumulated and the signal is perceived to last longer. Clear evidence of this fear-related lengthening effect did. More recently, Buetti and Lleras (2012) replicated these results in spider-fearful individuals with high-arousal images of spiders. They also showed that the magnitude of this temporal overestimation increased with the degree of individual fear. Using a temporal bisection task with different duration ranges, Droit-Volet et al. (2010a,b) successfully demonstrated that fear produces a lengthening effect characteristic of a speeding-up of the internal clock, but without disrupting time discrimination ability. In their study,
participants were initially presented with short and long standard durations in the form of a simple circle (400 vs. 800 ms, or 800 vs. 1600 ms). They were then presented with the same stimulus, but with different durations that were either equal to the standard durations or of intermediate values. The participants’ task was to judge whether these comparison durations were closer to the short or the long standard durations. In addition, before each trial, a specific signal warned them that, at the end of each comparison duration, they would hear (through their headphones) either an aversive stimulus, a nonaversive stimulus or nothing. The aversive stimulus was a 50-ms burst of 95-dB white noise with instantaneous rise time, which hurts ears and produces a defensive startle reflex. The nonaversive stimulus was a simple 50-ms beep. Fig. 2 sets out the psychophysical functions obtained in this temporal bisection task, with the proportion of “long” responses (comparison durations judged to be more similar to the long standard duration) plotted against the stimulus duration. This figure clearly shows a leftward shift of the psychophysical function for the aversive stimulus compared with the other stimuli. This leftward shift indicated that the stimulus durations were judged to be longer when the participants expected a threatening stimulus. In addition, its magnitude was greater for the long duration range than for the short one, consistent with the multiplicative clock speed effect (for a discussion, see Marticq et al., 1981). The lengthening effect produced by the fear emotion was therefore not constant across durations (additive effect), as it would be in the case of earlier switch closure due to heightened attention. When the switch closes earlier, the stimulus is also judged to be longer, as more pulses are accumulated, but the number of pulses accumulated at stimulus onset remains the same whatever the duration. The results of Droit-Volet et al. (2010a,b)’s study also showed that time distortions in a threatening situation do not disrupt time discrimination. In fearful conditions, psychophysical functions remained intact, with the proportion of “long” responses increasing with stimulus duration and, more importantly, no decrease in sensitivity to time. Therefore, the Weber ratio, which constitutes an index of time sensitivity, remained unchanged in a threat situation. Droit-Volet et al. (2011) replicated these results by showing participants 10-min excerpts of horror films (Scream, Shining) in order to alter their mood during a subsequent temporal task. In addition, when Gil et al. (2007) exposed children to facial expressions of anger, which are known to activate the amygdala, the key neural structure of fear (Whalen et al., 2001; Stein et al., 2002), they observed that children as young as 3 years reacted just as the adults did in a temporal discrimination task. The children overestimated the duration of exposure to angry faces compared with neutral ones, without any developmental differences (Droit-Volet and Meck, 2007; Gil et al., 2007; Droit-Volet, 2011a). Consequently, time distortions in fearful conditions may be based on automatic processes that emerge at an early age. They thus represent a sort of implicit measure of the normal reaction to fear. Consistent with this idea, some recent studies have suggested that the magnitude of temporal distortion provides a means of diagnosing abnormal fearful reactions in the case of anxiety disorders (Bar-Haim et al., 2010; Tippé, 2011), as highly anxious individuals overestimate the presentation duration of fearful stimuli (faces) more than less anxious individuals do. In sum, without disrupting time discrimination, the internal clock automatically runs faster in a threatening situation, thus producing a lengthening effect associated with a constant state of alertness, mobility and readiness to act.

3.2. The processing of emotional stimuli

This past decade has seen a veritable explosion in studies on emotion and time perception. However, most of them have focused on time judgments for emotional stimuli rather than on the effect of emotion per se on time perception with neutral stimuli, as reported above. In these studies, participants are required to judge the duration of exposure to emotional stimuli such as (1) faces expressing an emotion (e.g., Bar-Haim et al., 2010; Doi and Shinohara, 2009; Droit-Volet et al., 2004; Gil and Droit-Volet, 2011a,b; Thayer and Schiff, 1975; Tippé, 2008, 2011), (2) pictures taken from the International Affective Picture System (IAPS) (e.g., Angrilli et al., 1997; Gil and Droit-Volet, 2012; Grommet et al., 2010; Lambrechts et al., 2011; Smith et al., 2011; Yamada and Kawabe, 2011) or (3) music and sounds from the International Affective Digital Sounds (IADS) system (Droit-Volet et al., 2010a,b; Mella et al., 2010; Noulihane et al., 2007).

The underlying hypothesis of these studies is that the perception of these emotional stimuli, chosen for their affective valence (positive or negative) and arousal level, induces particular emotional reactions in the perceiver. However, the problem of these studies is that time processing is highly context-dependent. Consequently, the characteristics of the emotional stimuli (e.g., color, complexity) may also affect the processing of time independently of their emotional effects. For instance, concerning emotional sounds, the emotion induced by sounds is strictly related to their tempo, the tempo of a negative high arousal sound being faster than that of a low-arousal sound. Numerous studies of time perception have shown that time estimates lengthen when the rate of a simple series of clicks is increased (e.g., Droit-Volet and Wearden, 2002; Treisman et al., 1990; Wearden et al., 1999). In unpublished data, in our laboratory, we showed that emotional music has exactly the same effect on time judgments as a series of clicks matched with its tempo. In this case, the temporal effect of the emotion and the characteristics of the stimuli are confounded. Another problem is the difficulty of inducing a sufficiently strong emotion level through the perception of emotional pictures to affect the perception of time whatever the experimental conditions. Gil and Droit-Volet (2011b) recently tested the effect on time perception of angry faces versus neutral faces, and found that the lengthening effect was easier to obtain in some tasks (a time comparison task where participants had to categorize stimuli as short or long, a verbal estimation or temporal production task) than in others (a temporal generalization or temporal reproduction tasks). In addition, the emotional effects triggered by the perception of emotional pictures are rapid and transient, and therefore difficult to maintain over time. This makes it difficult not only to test the generalization of emotional effects to different durations ranging from a few milliseconds to several seconds, but also to test the clock-speed hypothesis whereby there is a greater lengthening effect for long durations than for short ones.

Nevertheless, with different temporal tasks, most of these studies have found that negative high-arousal pictures (faces, IAPS) are perceived of as lasting longer than neutral low-arousal ones. This is thus a relatively robust effect. However, the nature of the mechanism underlying the lengthening effect of these emotional stimuli is still unclear. Using a temporal bisection task sometimes produces a slope effect consistent with the clock-speed hypothesis (Droit-Volet et al., 2004; Gil and Droit-Volet, 2012), sometimes an intercept effect (additive effect) consistent with the attention hypothesis whereby the attentional switch closes earlier (Grommet et al., 2010). Furthermore, the effects of emotion on time judgments often change, if not disappear, with long presentations of emotional stimuli (approx. >2 s) (e.g., Angrilli et al., 1997; Bar-Haim et al., 2010). There is therefore a debate in the literature as to the causes of the lengthening effect in time judgments of emotional stimuli, two possible explanations being an increase in the level of arousal and/or in the degree of attention aroused by the emotional stimuli.

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Most researchers logically suggest that this lengthening effect is due to an arousal effect, as testified by the participants’ responses on the self-report arousal scale, and heart rate and electrodermal measures (e.g., Angrilli et al., 1997; Gil and Droit-Volet, 2012; Mel-la et al., 2010). In addition, as some researchers have argued, the disappearance of the emotional effect for long durations speaks in favor of an arousal-related effect (Bar-Haim et al., 2010; Nather et al., 2011). The biological process of physiological activation triggered by the perception of an emotional picture is short-lived and rapidly returns to its baseline state, whereas an attentional effect is maintained for longer durations. Consistent with this idea, Bar-Haim et al. (2010) showed that the overestimation of the duration of fearful faces observed for 2 s did not occur for longer exposures of 4 and 8 s. In the same way, Angrilli et al. (1997) observed that negative high-arousal pictures were overestimated at 2 s, but underestimated at 6 s. As these authors explained, arousal mechanisms may thus give way to other mechanisms (attention- or decision-based) over time. Finally, time perception is difficult to investigate because emotion is a dynamic process that changes over time, with a cascade of different systems. The emotional reaction and its underlying mechanisms therefore change over time, as do their effects on time judgments. Accordingly, it is difficult to identify the different mechanisms underlying the effects of emotion at different stages in temporal information processing. In a temporal bisection task featuring IAPS pictures, Smith et al. (2011) recently replicated the lengthening effect for durations of 400-1600 ms, but not for shorter durations of 100-300 ms. For the latter, they found a shortening, not a lengthening effect. They ascribed this shortening effect to a rapid activation of the amygdala during the initial perceptual stage (first 300 ms), before the influence of attentional processing in the extrastriate cortex “kicks in” via its connections with the amygdala. Meck and Macdonald (2007) underscored the critical role of the amygdala in the selective attention paid to temporal information under emotional conditions. When rats have to simultaneously time a 50-s visual stimulus and a 10-s auditory stimulus accompanied by a footshock, they are unable to divide their attention and time both signals simultaneously. By contrast, rats with amygdala lesions, which block this fear-related impediment, are able to time the two signals simultaneously. Consistent with these results, Lui et al. (2011) found that when individuals were shown an emotional picture just before a comparison duration, it captured their attention, to the detriment of the timing of the subsequent signal. We can therefore postulate that the presentation of negative high-arousal pictures that attract attention may trigger earlier closure of the attentional switch. However, beyond this very early effect of emotion at the onset of stimulus processing, we would expect a stimulus that captured attentional resources to shorten, rather than lengthen, time estimates, as suggested by research on attention and time perception (see Coull et al., 2004).

In judgments of temporal exposure to emotional stimuli, it is difficult to distinguish attention from arousal-related processes, as both play a critical role (Gil and Droit-Volet, 2012). As several scientific experts have argued, attention and arousal are two distinct but interrelated processes (Paus, 2000; Robertson and Gara- van, 2004). Numerous studies have showed that performance always improves with the level of arousal—up to a certain degree. As regards threatening situations, the main role of the amygdala is to detect meaningful events (Ledoux, 2007). The perception of significant events for survival thus mobilizes attentional processes (vigilant attention system) (Ledoux, 1996, 2002; Vuilleumier et al., 2003). However, efficient effects occur concomitantly in the autonomic and somatic nervous systems to prepare action readiness. Therefore, the activation of both attentional and arousal circuits in the brain may contribute to the lengthening effect observed for short picture-presentation durations. For longer exposures, however, initial mechanisms may give way to other, higher-order cognitive processes that modulate arousal levels, sustain focused attention, and appraise the emotional stimulus and the experienced emotional state (Scherer, 2009). However, the dearth of studies investigating the effect of emotion on the processing of long durations does not allow us to validate this hypothesis. Nevertheless, whichever mechanisms are involved as a function of duration, within the framework of the SBF model of timing, we suggest that the lengthening effect observed in negative high-arousal conditions may reflect an improvement in the efficiency of the nervous system. In support of this hypothesis, a recent study revealed that long-term recall for stimulus durations is better for ones learned in a stressful condition than for ones learned in a neutral condition (Cocenas-Silva et al., 2012).

Moreover, because the processing of emotional stimuli is so complex, the effect of these stimuli on time judgments cannot be fully explained by clock-speed and/or attentional mechanisms (Droit-Volet, in press; Schirmer, 2011). Humans’ conscious awareness of their emotional and body states may also influence their explicit judgments of time, as suggested in the new theories of grounded time (for further discussion, see Droit-Volet and Gil, 2009; Droit-Volet, in press; Effron et al., 2006). According to Craig (2009), the anterior insula builds a unified metarepresentation of homeostatic feelings which constitutes the experienced self at one moment in time. In a recent fMRI study, Wittmann et al. (2010) observed the activation of the insular cortex in a duration reproduction task. Consequently, explicit temporal judgments may be influenced by individuals’ awareness of experienced emotional and body states. Lamotte et al. (2012) recently showed that individuals’ awareness of time distortions affects their time judgments. In particular, the more aware they are of being subject to time distortions, the more accurate they are in their time judgments. In sum, human time judgments result from an interaction between several different processes whose respective contributions depend on task demands and the affective significance of the stimuli. This is clearly illustrated by observations of emotion in contexts other than threatening high-arousal situations.

3.3. The effect of disgust, shame, and sadness.

The effects on time perception of emotions other than fear illustrate the diversity of the mechanisms involved in processing emotional stimuli. For example, in our laboratory, we tested perceptions of time (between 400 and 1600 ms) for the same emotion – disgust – but with different types of emotional stimuli: disgusted pictures from the IAPS (Gil and Droit-Volet, 2012), facial expressions of disgust (Droit-Volet and Meck, 2007; Gil and Droit-Volet, 2011a), and pictures of disgusting food (Gil et al., 2009). The durations of the IAPS pictures (mutilated bodies, burnt victims) were systematically overestimated compared with those of the other affective pictures. However, for the facial expressions of disgust, which were also categorized as unpleasant and high arousal, no effect of emotion was found on time judgments. It is important to note that the primary aim of facial expressions is to communicate information to one’s counterparts. When a person expresses disgust, he/she is communicating the need to pay attention to a particular food because it is probably bad for one’s health (Darwin, 1872/1998). This is therefore not about warning individuals to act urgently and defend themselves against a potential aggression. On the contrary, the bad food has to be appraised, in order to decide whether or not it can be eaten. Neuroimaging studies have shown that the processing of disgusted faces activates the insula but not the amygdala that is involved in alertness states (Adolphs, 2002). Supporting this idea, Gil et al. (2009) showed that participants in their study underestimated the presentation duration of food pictures compared with nonfood pictures, especially...
when the food looked unpleasant. Viewing bad food therefore distracts attention from time processing. Time underestimations have also been found in the case of secondary social emotions such as shame (facial expressions of shame), which direct participants’ attention towards reflexive thoughts about the sources of this shame (Gil and Droit-Volet, 2011c).

Finally, the standard classification of emotional stimuli according to their level of arousal does not systematically allow us to obtain effects on time perception. For example, when Gil and Droit-Volet (2012) matched IAPS pictures inducing different emotions (disgust, fear, sadness) on the basis of their arousal level, they failed to find the same degree of temporal overestimation for each emotion. In particular, the pictures of disgust were judged to last longer than the fearful pictures. It seems reasonable to assume that extreme, disgust-inducing pictures representing mutilated bodies have a greater effect on time perception than fear-inducing stimuli representing attacking animals (shark or bear). Similarly, although the pictures that evoked sadness were as highly arousing as the disgust or fear pictures, they led to relatively moderate time distortions. Studies using other emotional stimuli of sadness (faces, film clips) have also found few effects of sadness on time perception (Droit-Volet et al., 2004; 2011; Gil and Droit-Volet, 2011a). As we discuss below, sadness is associated with a loss of energy. In all probability therefore, it is harder to obtain an effect on time perception via a slowing down of the internal clock than via the speeding up of the internal clock. Nevertheless, in contrast to fear, sadness is a poorly understood emotion – an “obscure emotion” as Lazarus (1991) wrote. Its function is not clearly identified, since it often coexists with other emotions such as guilt and anger. In addition, it seems that no specific neuroanatomical structures are involved in sadness, although the induction of a sad mood seems to involve the anterior cingulate cortex (Barrett, 2006; Freed and Mann, 2007). This probably explains the results for sadness. However, it also allows us to assert that the feeling of time slowing down in the state of sadness is not systematically linked to a problem of time perception, as will we see for affective disorders. In sum, for the same emotion or the same level of arousal, the effects of emotion on time perception will vary according to the significance of each emotional stimulus (Frijda, 2007; Scherer, 2009).

This considerably complicates the investigation of the relationships between emotion and time, but also demonstrates that psychological time may be a good implicit indicator of the functions of emotions.

4. Affective disorders and time perception

4.1. The feeling that time has slowed down experienced by individuals with depression

Depression is a mood disorder that alters the subjective experience of time (for recent reviews, see Gallagher, 2012; Msetfi et al., 2012; Ratcliffe, 2012). Depressed individuals often report that time seems to pass more slowly than usual or even stops. To describe this particular time feeling, Minkowski (1968/1988) distinguished between “self-time” (Ich-Zeit) and “world-time” (Welt-Zeit) (Strauss, 1947). As he explained, self-time sometimes seems to go faster than world-time, giving the impression of fast-flowing time. By contrast, at other times, it seems to lag behind world-time: “Time drags on, we become morose and are overtaken by boredom” (p. 278). The contrast between these two kinds of time is particularly salient in depressive states. Depressed individuals feel a kind of desynchronisation between their own time and others’ time (Fuchs, 2001). As one patient expressed it: “world-time rushes past me” (Minkowski, 1968/1988). Several studies have used questionnaires to investigate this explicit feeling of slowed-down time in depressive disorders (e.g., Bech, 1975; Blewett, 1992; Hoffer and Osmond, 1962; Kitamura and Kumar, 1982; Mezey and Cohen, 1961; Wyrick and Wyrick, 1977). For example, Hoffer and Osmond (1962) asked patients to indicate how far they agreed with a series of six statements printed on cards, such as “The days seem to go by very slowly” or “The world has become timeless for me”. They found that most depressed patients and some anxious patients felt that time passed more slowly than usually. Individuals with schizophrenia and patients in toxic confused states were more inconsistent in their responses. Blewett (1992) also administered five forced-choice questions to patients suffering from moderate to severe depression, asking them if time seemed to go by at a different rate since the onset of their illness, and whether it passed more slowly, more quickly or fluctuated from hour to hour, in relation to normal experience. Similarly, Wyrick and Wyrick (1977) used a perception of time passage questionnaire (PTPQ) featuring five self-report questions on respondents’ feelings and their beliefs about other people’s feelings regarding the passage of time (“Other people/I feel that time is passing slowly”). Taken together, these different studies systematically demonstrate that individuals suffering from depression experience a slowing down of time compared with normal people: “Time seems to drag. A day feels like a year” (Ratcliffe, 2012).

Depression therefore changes the experience of the passage of time. The question is, does this time experience in individuals with depression correspond to genuine changes in the basic mechanisms of time perception? As previously suggested, this feeling probably has nothing to do with time perception, but is a simple inference resulting from a consciousness that something has gone wrong in their lives. This feeling about the slow flow of time may be the verbal expression of their boredom, and their lack of interest and pleasure in everyday life. As Heidegger explained (1927), when nothing significant happens to absorb one’s attention, one becomes increasingly aware of the passage of time. Zimbardo and Boyd (2008) constructed a personality questionnaire on individuals’ ability to project themselves into the future: the Zimbardo Time Perspective Inventory (ZTPI). On the basis of participants’ responses, they concluded that people for whom time passes too slowly are likely to be suffering from depression. More interestingly, depressed patients’ responses to this type of questionnaire reveal that they are preoccupied by the past (past-oriented) and, to some degree, by the present, but not by the future (e.g., Ghaemi, 2007; Wyrick and Wyrick, 1977). They have a sense of hopelessness about future, in other words, they cannot see any future openings. This is mainly linked to the fact that they are continuously engaged in rumination, focusing on their negative emotions and the symptoms of their distress (“I feel so lousy”) or the causes of their illness (Koster et al., 2011; Nolen-Hoeksema, 2000). This lack of a future-oriented perspective may be the key to depression (Abramson et al., 1989; Beck, 1967). As Ratcliffe (2012) described, it is as though there were absolutely nothing between the present moment and death, except for the fruitless unfolding of time. Martens and Schmeichel (2011) recently revealed, for example, that the more often people think about death, the more a given time interval is retrospectively judged to be long (12-s or 21-s interval). Consequently, depressive patients’ feeling of time slowing down may derive from their introspections about life changes, in short, from their awareness of their illness and its consequences on their life, rather than from changes in temporal mechanisms. It is therefore important to distinguish between the explicit awareness of time and the direct perception of time. A disturbance in the former does not systematically imply a disturbance in the latter. That said, time awareness may sometimes affect time judgments to a certain extent. As indicated earlier, Lamotte et al. (2012) showed that participants who were more aware of their tendency to produce distorted time estimates when their attention was distracted,
produced more accurate time judgments in a dual-task paradigm.

Similarly, Sackett et al. (2010) showed that individuals who agreed with the statement that “Time flies when you’re having fun” reported faster time progression for a 10-min task and rated it as more enjoyable.

4.2. Time perception in individuals with depression

Until now, few empirical data have been collected on the perception of time per se in mood disorders. In addition, experimental evidence for the disturbance of time perception in depression is sparse and somewhat contradictory (Msetfi et al., 2012). This may be due in part to the heterogeneity of the samples. Some studies have recruited clinical patients suffering from major depression, whereas others have used students with depression as assessed on the Beck Depression Inventory (BDI; Beck and Beamesderfer, 1974). Nevertheless, numerous studies have failed to find any evidence of disturbance in duration judgments by participants with different levels of depression (Bech, 1975; Hawkins et al., 1988; Kitamura and Kumar, 1984; Mezey and Cohen, 1961; Prabhoo et al., 1969; Wyrick and Wyrick, 1977). Wyrick and Wyrick (1977) noted that the clinically depressed participants in their study overestimated durations longer than 2 min compared with controls, but they attributed these results to a lack of motivation to perform the task for such a long period, rather than to a specific timing problem. By contrast, other studies have suggested that affective disorders alter the perception of time intervals (Bsch et al., 2004; Gil and Droit-Volet, 2009; Grinker et al., 1973; Kitamura and Kumar, 1984; Kuhs et al., 1991; Msetfi et al., 2012; Rammssayer, 1990; Sévigny et al., 2003; Tysk, 1984). In particular, some studies using discrimination tasks have found that students with or without depression exhibit a similar degree of sensitivity to subsecond durations (Gil and Droit-Volet, 2009; Msetfi et al., 2012; Sévigny et al., 2003). Conversely, they display less sensitivity to suprasecond durations (Msetfi et al., 2012; Sévigny et al., 2003).

For patients with major depression and melancholia, Rammssayer (1990) also found poorer time discrimination with very short durations in the millisecond range.

The question raised here is, why does depressive mood alter the processing of durations in the supra-second but not the subsecond range? There is now cumulative evidence to show that the processing of sub- and suprasecond durations relies on different mechanisms (Lewis and Miall, 2003, 2006). The processing of short durations appears to be automatic, whereas that of long durations seems to require more attentional resources. In the case of long durations, participants must not only hold temporal information in working memory, but must also continue focusing their attention on the passage of time until the end of the stimulus being timed. The impairment of both sustained and selective attention in patients with depression is now well documented (e.g., Gualtieri et al., 2006). Consistent with these results, neuroimaging studies in depressive patients have revealed both structural anomalies and dysfunctions in areas of the prefrontal network such as the dorso-lateral prefrontal cortex (DLPFC), which is involved in attentional control (Holmes and Pizzagalli, 2008; for reviews, see Rogers et al., 2004; Price and Drevets, 2010). The difficulty experienced by depressed individuals in controlling attention may thus account for their reduced sensitivity to long durations. In addition, deficits in attentional control are a risk factor for the intrusion of negative cognitions (ruminations) in working memory, and depression is characterized by ineffective inhibition of negative thought (Koster et al., 2011). Patients with major depressive disorder have abnormalities in the limbic structures (i.e., the rostral anterior cingulate cortex (ACC)) involved in emotional behavior, as well as reduced connectivity between the DLPFC and the rostral ACC involved in the regulation of affective responses to emotional stimuli (Siegle et al., 2007). Depressed individuals therefore often find themselves engaged in negative rumination that they are unable to stop, with rumination being negatively correlated with attentional control (Davis and Nolen-Hoeksema, 2000). In sum, we can postulate that negative cognitions are often activated in working memory in depressed people during temporal tasks, especially in the case of long durations, thus disrupting time processing. According to the models of the internal clock, an attention switch allows time units produced by the pacemaker to be transferred to the accumulator. Within this framework, we can theorize that the attentional switch system flickers or oscillates during stimulus timing more often in depressives than in controls, with greater intertrial variability. The deterioration in temporal performance with mood disorders may thus be due to deficits in the attention and the executive function needed for time processing.

However attention abilities are closely related to information processing speed. An increase in information processing speed allows individuals to perform a whole series of tasks more automatically and fluently (Salthouse, 1996). Droit-Volet and Zelanti recently measured processing speed in children of different ages using two subtests of the WISC-IV: Coding and Digit Symbol (see Droit-Volet, 2012). As illustrated in Fig. 3, there was a significant correlation between sensitivity to time and information processing speed: the faster the processing, the greater the time sensitivity. In

![Fig. 3. Significant correlation between the Weber Ratio (WR) in time bisection and processing speed index in the 4.0/8.0-s and the 0.5/1.0-s anchor duration condition (from Droit-Volet, 2012).](http://dx.doi.org/10.1016/j.jphysparis.2013.03.005)
other words, time resolution improves as information processing speed increases. More specifically, information processing speed may be an indicator of internal clock speed.

In the internal clock model described previously, the raw material for the representation of time consisted of cortical oscillatory activity detected by the striatum. A low rate of cortical oscillation and/or a low level of synchrony between cortical oscillators may thus be a source of variability in timing. One important symptom of depression reported in the DSM-IV is a loss of energy in motor and cognitive activities. Depression is characterized by poor scores on the neuropsychological tests assessing psychomotor speed and information processing speed (VanHooft et al., 1998; Tsourtos et al., 2002). One may thus assume that the slow information processing speed observed in depressed individuals is associated with a slow internal clock. Consequently, as argued by Rammsayer (1990), their impaired time discrimination is partly due to the slowing down of the clock rate. This slowing down may be induced by a dysfunction in the dopaminergic activity of the frontal-striatal loops subtending duration processing. Finally, depressed individuals’ feelings of time slowing down may result in part from awareness of their motor and cognitive slowing. However, this cannot account for the lack of difference in temporal performance between depressives and controls observed for sub-second durations, despite the fact that the clock-speed effect is relatively greater with long durations.

Added to this temporal imprecision, some studies have also observed distortions in time estimates by people suffering from depression. Bschor et al. (2004) found that, compared with non-depressive patients, depressive patients tended to underestimate durations in temporal production (35 and 90 s) and verbal estimation tasks (109 s). Tysk (1984) also observed that severely depressed patients with melancholia or bipolar depression underestimated elapsed durations (7–27 s), while patients with manic disorders overestimated them and healthy participants judged them accurately. In Kuhs et al. (1991)’s study, the depressed patient underestimated a 30-s interval but the control overestimated it. Finally, Grinker et al. (1973) established a significant correlation between individual depression scores and time estimates in a discrimination task: the more depressive the participants were, the shorter they estimated the standard 1- and 3-s durations to be. Therefore, when a time distortion is observed in depressed individuals, it often seems to take the form of a shortening effect. Further evidence for this shortening effect is nevertheless required. In addition, one major problem is that the mechanisms underlying this time distortion in depression have yet to be fully understood. One hypothesis is that this temporal bias is related to the smaller amount of attentional resources available for processing time in depressive patients, as suggested previously. A second hypothesis is that it is due to a gradual decrease in arousal, such that tiredness increases as the experiment progresses causing a decrease in the clock rate. By administering boring temporal tasks with experimental trials at 10-s intervals, Wearden (2008) showed that the decrease in arousal over the experimental sessions, assessed on a self-rated arousal scale, produced a shortening effect in temporal generalization and verbal estimation tasks. A third and final hypothesis is linked to the idea of a general slowing down of the internal clock in depressed people, associated with a loss of energy and a slowdown in motor and cognitive activity. It is, however, theoretically difficult to demonstrate the effect on time perception of an internal clock that continuously runs slowly, because there is a recalibration of this clock over time. The effects on time estimates of the acceleration or deceleration of the clock’s speed are mainly observed in within-participants conditions, when different clock rates can be compared. Nevertheless, transient intrusions of negative thoughts in the course of a temporal task may well produce transient episodes of sadness. In a bisection task, Gil and Droit-Volet (2009) found a positive correlation between the shortening effect and current sad mood, as assessed by the Brief Mood Introspection Scale (BMIS; Mayer and Gaschke, 1988): the higher the sadness scores were, the shorter the durations were judged to be (Fig. 4). However, more research is now required to test these different hypotheses.

5. Conclusion

Mystery continues to surround the mechanisms by which mood disorders influence time perception. However, the studies conducted this far allow us to clearly distinguish explicit time-awareness (subjective feelings about the passage of time) from time perception, as the feeling of time slowing down is not systematically associated with a specific problem of time perception.

6. Unicted references

Krishnan et al. (1993) and Vogeley and Kupke (2007).

References


Correlation between mean p(long) responses and the sadness scores assessed by the Brief Mood Inventory Scale (from Gil and Droit-Volet, 2009).

Fig. 4. Correlation between mean p(long) responses and the sadness scores assessed by the Brief Mood Inventory Scale (from Gil and Droit-Volet, 2009).


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