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Fear and time: Fear speeds up the internal clock

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Abstract

We tested time perception in a bisection task featuring a wide range of durations (from 0.2 to about 8.0 s) and highly arousing stimuli (delivery of an electric shock). In addition, self-report questionnaire responses and skin conductance responses were assessed to measure emotional reactivity. Results clearly demonstrated emotion-related time distortion, as stimulus durations were judged to be longer in the trials with an electric shock than in those without one. In addition, this lengthening effect increased with the length of durations. These findings are consistent with the hypothesis of an arousal-induced speeding up of the internal clock system.

1. Introduction

When we compare episodes of our everyday lives that we experienced in different emotion states, we have the strange impression that time is either speeded up or slowed down. While time seems like an eternity when we are waiting for a loved one, it suddenly seems to fly by once that person has arrived (Droit-Volet, 2014). Time no longer exists! The judgment of time therefore seems to change pace with our emotional states. The past decade has seen an explosion in the number of laboratory studies yielding empirical data on the effects of emotion on time perception (for a review, see Droit-Volet et al., 2013), but the mechanisms underlying these effects remain the subject of debate. One reason why the debate is proving difficult to settle is that the effects of emotion on time perception in humans have mainly been tested with paradigms involving the temporal processing of emotional stimuli, forcing researchers to use short durations in the hundreds of milliseconds, because the emotional state induced by the perception of emotional stimuli are extremely transient. The aim of the present study was thus to examine the effect of one particular emotion on time perception with a wider range of durations, from hundreds of milliseconds to several seconds, using highly arousing stimuli (electric-shock procedure) to induce a fearful state in participants.

Studies of the effects of emotion on the perception of short durations have used a variety of stimuli, including emotional faces (e.g., Bar-Haim et al., 2010; Doi and Shinohara, 2009; Droit-Volet et al., 2004; Gil and Droit-Volet, 2011; Tipples, 2008, 2011), emotional scenes (e.g., Angrilli et al., 1997; Buetti and Lleras, 2012; Gil and Droit-Volet, 2012; Grommet et al.,

2011; Smith et al., 2011), and sounds (e.g., Mella et al., 2011; Noulhiane et al., 2007). Despite the diversity of these emotional stimuli, they have generally found that high-arousal emotional stimuli are judged to last longer than either low-arousal emotional stimuli or neutral stimuli, consistent with a lengthening effect. However, researchers have yet to explain the mechanisms underlying this emotion-related effect on time perception.

According to the models derived from the most popular theory of timing, namely scalar expectancy theory (SET; Gibbon, 1977; Gibbon et al., 1984), the internal clock is composed of a pacemaker, a switch and an accumulator. At the onset of the stimulus to be timed, the attention-controlled switch closes and the pulses emitted by the pacemaker enter the accumulator. At the stimulus offset, the switch re-opens, thus interrupting the pulse transfer. The judgment of a stimulus duration therefore depends on the number of pulses that have been accumulated: the more pulses, the longer the duration is judged to be. There is thus a linear relationship between subjective duration and actual stimulus duration, in that the longer the stimulus duration, the greater the number of pulses that are accumulated.

According to SET, an emotion-related lengthening effect can be obtained via two main mechanisms: (1) an attention-switch mechanism and (2) an arousal mechanism that speeds up the pacemaker system. The distinction between the two is quite clear (see Burle and Casini, 2001). According to the attention-switch hypothesis, the emotion effect is added to the duration effect. More specifically, the attentional switch closes earlier, under the effect of emotion, and a constant number of pulses is added to the number of pulses accumulated during the processing of the stimulus duration. As the number of these early additional pulses is the same for all stimulus durations, irrespective of their length, the combined effect of emotion and stimulus duration is equal to the sum of their separate effects (i.e., additive effect). According to the clock-speed hypothesis, the pacemaker rate increases with arousal and so the emotion effect multiplies the duration effect, such that the number of additional pulses increases with the length of the stimulus duration. In other words, there is a multiplicative interaction between the effects of emotion and stimulus duration (i.e., multiplicative effect). In short, if we wish to test these two hypotheses concerning the mechanisms behind the effects of emotion on time perception, we have to examine several duration ranges (Droit-Volet and Meck, 2007).

Few studies of emotion and timing in humans have included the different ranges of stimulus duration needed to examine SET's hypotheses and identify the mechanisms behind the effects of emotion on time perception. In addition, where different duration ranges have been used, they have often been shorter than 2 s, that is, in a narrow temporal window restricting the detection of emotional effects. In the hundreds of milliseconds duration range, results appear to be inconsistent, with some data supporting a multiplicative effect (clock speed; e.g., Droit-Volet et al., 2004; Mella et al., 2011) and others an additive effect (attention; e.g., Grommet et al., 2011; Lui et al., 2011). Some results even support both, depending on the durations that are tested (Gil and Droit-Volet, 2012; Smith et al., 2011). Each researcher nevertheless finds justification for his/her findings in the literature on emotion, insofar as threatening stimuli have been shown to increase arousal, but also capture attention (Anderson and Phelps, 2001; Scherer, 2013). The few studies to have used several duration ranges, including durations of more than 2 s, have shown that the emotion-related lengthening effect decreases, rather than increases, for these longer durations (Angrilli et al., 1997; Bar-Haim et al., 2010). Although this would appear to undermine the SET hypothesis that arousal speeds up the internal clock, it has been suggested that this decrease in the lengthening effect with long durations nonetheless reflects an arousal-based mechanism, given that the attention effect is assumed to be constant, irrespective of duration length (Bar-Haim et al., 2010). Finally, the major problem with studies up to now is that they have used emotional stimuli (e.g., pictures) that induce only short-lived emotions. In other words, participants' arousal level in response to emotional stimuli quickly decreases. In addition, certain characteristics of these stimuli (picture color, sound rhythm) may interfere with time processing, thus modifying the effect of the induced emotion (Droit-Volet et al., 2013). It has been shown, for example, that colors contribute to the emotional charge of the most widely used emotional pictures (Cano et al., 2009). The color red, for instance, which is often presented in high-arousal emotional scenes, signals danger and dominance (for a review, see Elliot, 2015). By definition, therefore, the processing of emotional stimuli involves both ephemeral and variable effects.

The best way to verify the SET hypotheses of a multiplicative (clock speed) versus additive (attention-switch closure) effect is to examine the effect of emotion per se on temporal judgments of neutral stimuli, using emotions that are sufficiently arousing to affect

the processing of even long durations (>2 s). Droit-Volet et al. (2011) recently tested the effects of different moods on the perception of neutral stimuli by immersing participants in threatening films (e.g., *The Shining*) for 10 min before administering a temporal bisection task. However, in their temporal tasks, they only used stimulus durations shorter than 2 s (0.2–0.8 s, 0.4–1.6 s), in order to avoid a decrease in mood level during the temporal processing. When Droit-Volet et al. (2010) used an aversive sound (50-ms burst of 95-dB white noise), judged to be highly arousing, in a temporal bisection task, they observed a multiplicative effect between emotion and duration, consistent with the clock-speed hypothesis. Once again, however, the durations they tested lasted less than 2 s. Two early studies (Falk and Bindra, 1954; Hare, 1963) tested longer intervals (>5 s) using electric shocks, which are currently employed in studies of the fear emotion (e.g., LaBar et al., 1998; Phelps et al., 2004). Obviously, the intensity level of the electric shocks was adjusted to make them bearable for participants. These early authors found that participants overestimated the length of durations in the electric shock condition, compared with the no electric shock condition. However, Falk and Bindra (1954) only tested one duration (15 s) in their temporal production task, and Hare (1963) only tested two (5 s and 20 s). Consequently, their experimental procedure did not allow them to test the SET hypotheses about the mechanisms behind the effect of emotion on time perception.

The aim of the present study was to systematically test the effect of fear, induced by an electric shock delivered during the stimulus, in a temporal bisection task featuring four duration ranges (durations longer and shorter than 2 s), all with the same ratio of short (*S*) to long (*L*) anchors (1:4): 0.2–0.8, 0.4–1.6, 1.2–4.8, and 2.0–8.0 s. In this investigation, we included both self-report (i.e., Self-Assessment Manikin (SAM) scale; Bradley and Lang, 1994) and physiological (i.e., electrodermal activity, EDA) indices of arousal (for a review, see Kreibig, 2010). We hypothesized that if fear speeds up the internal clock, then the difference in lengthening effect between trials with and without electric shocks should increase linearly across the duration ranges.

2. Material and methods

2.1. Participants

Participants were 60 (48 women and 12 men) psychology undergraduates (mean age = 19.41 years, SD = 4.8) from Clermont Auvergne University (Clermont-Ferrand, France). They received course credits in exchange for their participation. All the participants provided their written informed consent to taking part in this experiment, which was conducted in accordance with the Declaration of Helsinki. One participant decided to withdraw from the study, and one decided not to participate.

2.2. Apparatus

The participants were tested individually in a quiet laboratory room, where they were seated in front a computer with a 15" square screen. E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA, United States) generated the experimental events and recorded the data. The stimulus to be timed was a blue circle displayed in the center of the computer screen. The participants responded either "short" or "long" by pressing the *S* or *L* key of the computer keyboard with their dominant hand. In addition to recording participants' EDA, two finger electrodes were placed on the index and middle finger of their nondominant hand. These electrodes were connected to the FE116 amplifier (ADInstruments, Colorado Springs, CO, United States), a fully insulated galvanic skin response amplifier with low-voltage 75 Hz AC excitation and automatic zeroing. We chose a common 1–4 s latency window (i.e., between 1 and 4 s following stimulus onset) and a minimum amplitude criterion of 0.05 μ s (Dawson et al., 2007; Levinson and Edelberg, 1985). For the purpose of the analyses, participants' EDA responses were baseline-corrected by their EDA values at stimulus onset. They were then square-root transformed to normalize the response amplitude data (Edelberg, 1972), and averaged for each type of trial. Electric shocks were delivered by an electrode placed with Velcro straps on the middle finger of the dominant hand. This electrode was connected to a device developed by ADInstruments (<http://www.adinstruments.com/products>) to provide noninvasive aversive stimuli (PowerLab 4/25T). The intensity of the electric shocks was individually determined so that it was deemed tolerable for each participant. The participants received an initial shock at the beginning of the experiment. They then increased its intensity until they judged it to be highly unpleasant, but not painful. The shock intensities chosen by the participants ranged from 6.42 to 20 μ A. A second

computer allowed us to generate the electric shocks and record EDA with LABChart software.

2.3. Procedure

2.3.1. Temporal task

Participants were assigned to one of four groups, according to the duration range used in the temporal bisection task: 0.2–0.8, 0.4–1.6, 1.2–4.8, or 2.0–8.0 s. For the 0.2–0.8 s group, where the *S* and *L* standard durations were 0.2 and 0.8 s, respectively, the comparison durations were 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, and 0.8 s. For the 0.4–1.6 s group, *S* and *L* were 0.4 and 1.6 s, and the comparison durations 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6 s. For the 1.2–4.8 s group, *S* and *L* were 1.2 and 4.8 s, and the comparison durations 1.2, 1.8, 2.4, 3.0, 3.6, 4.2 and 4.8 s. For the 2.0–8.0-s group, *S* and *L* were 2.0 and 8.0 s, and the comparison durations 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, and 8.0 s. To prevent the participants from counting, they were instructed not to count because this would bias the scientific data (see Rattat and Droit-Volet, 2012).

In each group, the participants underwent a training phase, followed by a testing phase. In the training phase, they were first introduced to the *S* and *L* durations, represented by the blue circle. They then learned to respond “*S*” and “*L*”, by pressing the corresponding button, in eight training trials (four trials for each standard duration) presented in random order. The intertrial interval was randomly chosen between 500 and 1000 ms, and a fixation point in the form of a cross appeared in the center of the computer screen at the beginning of each trial. After these training trials, the participants were introduced to two symbols: a lightning flash and a barred lightning flash. They were told that the lightning flash symbol would always be followed by a trial with a shock during the stimulus presentation, whereas the barred lightning flash would be followed by a trial without a shock.

The testing phase procedure was similar to the training phase procedure, except for the comparison durations and the electric shocks that were delivered. The participants’ task was to decide whether the comparison duration was more similar to *S* or to *L*. In the test phase, the participants were administered eight blocks of 21 trials: two trials in the shock condition (1) and one in the no-shock condition (2) for each of the seven comparison durations (8 × 3 =

168 trials). The symbols indicating whether the trials would be with or without an electric shock were displayed 200 ms before the to-be-timed stimulus, and remained on the screen for 1 s. In each shock trial, a single electric shock was delivered during the presentation of the temporal stimulus, at a randomly chosen time between 50 ms after stimulus onset and 50 ms before stimulus offset.

2.3.2. Mood assessment

After the temporal bisection task, participants were administered additional trials to measure both their physiological reactions (EDA) and their subjective emotional assessments, in terms of valence and arousal, of the emotion they felt while awaiting the electric shocks. For the EDA recordings, participants performed 12 trials, six with and six without an electric shock. These trials were exactly the same as those used in the temporal bisection task, except for the intertrial interval (20 s), and the comparison durations, which were randomly chosen (without replacement) from the seven comparison durations. For the subjective emotional assessment, participants performed two trials, one with and one without a shock. After each trial, they rated the valence (from *very unpleasant* to *very pleasant*) and the arousal level (from *very calm* to *very aroused*) of the emotion they felt during the trial on the 9-point Self-Assessment Manikin (SAM) scale (Bradley and Lang, 1994).

3. Results

3.1. Subjective emotional assessment

An analysis of variance (ANOVA) was performed on both the mean arousal and mean valence ratings of the emotion felt in the trials with and without an electric shock. The felt emotion was judged to have a higher level of arousal and be less pleasant in the trials with an electric shock (Arousal: shock, $M = 5.15$, $SD = 2.07$; no-shock, $M = 3.83$, $SD = 2.04$, $F(1, 56) = 11.87$, $p = .001$, $\eta_p^2 = .18$; Valence: shock, $M = 4.87$, $SD = 1.76$; no-shock, $M = 5.65$, $SD = 1.61$), $F(1, 56) = 7.59$, $p = 0.008$, $\eta_p^2 = .12$. The main effect of duration range and the duration \times shock interaction were not significant ($p > .05$).

3.2. EDA

An ANOVA¹ was conducted on the amplitude of the EDA response, with trial type (shock vs. no-shock) as the within- participants factor. This analysis revealed a significant main effect of shock, $F(1, 32) = 6.43$, $p = .01$, $\eta_p^2 = .17$, indicating that EDA amplitude was greater for trials with an electric shock ($M = 1.38$, $SD = .66$) than for those without one ($M = 1.06$, $SD = .44$). This physiological index of arousal therefore confirmed that arousal was greater for trials with an electric shock.

3.3. Temporal bisection

3.3.1. Effect of electric shocks on the bisection point and the Weber ratio

Fig. 1 shows the proportion of long responses ($p(\text{long})$), plotted against the comparison durations in the shock and no-shock trials for each duration group. Inspection of the psychophysical functions for each duration group revealed that $p(\text{long})$ systematically increased with comparison duration, even for trials with an electric shock, indicating that the shock condition did not disrupt time judgment in bisection. Furthermore, in all duration groups, psychophysical functions shifted toward the left for the shock trials compared with the no-shock trials, suggesting that the stimulus durations were judged to be longer in the trials with an electric shock. This was confirmed by analyses of the bisection point (BP). BP is the stimulus duration that elicits $p(\text{long}) = .50$, and was derived from the fit of each individual function to the pseudologistic function (Killeen et al., 1997). There was a good fit between the two (mean $R^2 = .92$, $SD = .089$, $p < .05$) (see **Table 1**).

The ANOVA run on BP, with duration group as the between participants factor and shock as the within-participants factor, showed a significant main effect of duration range, $F(3, 56) = 95.09$, $p = 0.001$, $\eta_p^2 = .84$, indicating that the BP value increased with duration

The correct measurement of EDA was only possible for 33 participants (55% of the sample). A variety of artefacts prevented us from properly recording or measuring the other participants' EDA responses.¹

range. More interestingly, there was a significant main effect of shock, $F(1, 56) = 68.04$, $p = 0.0001$, $\eta_p^2 = .55$, indicating that the BP value was lower for the shock trials than for the no-shock trials, consistent with a lengthening effect. In addition, electric shock significantly interacted with duration range, $F(3, 56) = 13.65$, $p = 0.0001$, $\eta_p^2 = .42$. As illustrated in **Fig. 2**, this interaction revealed that the magnitude of the difference in BP between the shock and no-shock trials increased with duration range. The follow-up linear contrast test revealed a significant effect of linearity for the interaction between emotion and duration range, $F(3, 56) = 13.65$, $p = 0.0001$, $\eta_p^2 = .42$. There was a significant linear regression between the duration range and the magnitude of the difference between the shock and no-shock trials, $R = .52$, $p = .0001$. As discussed below, this linear effect clearly showed a multiplicative effect of emotion on time perception, consistent with the clock-speed hypothesis.

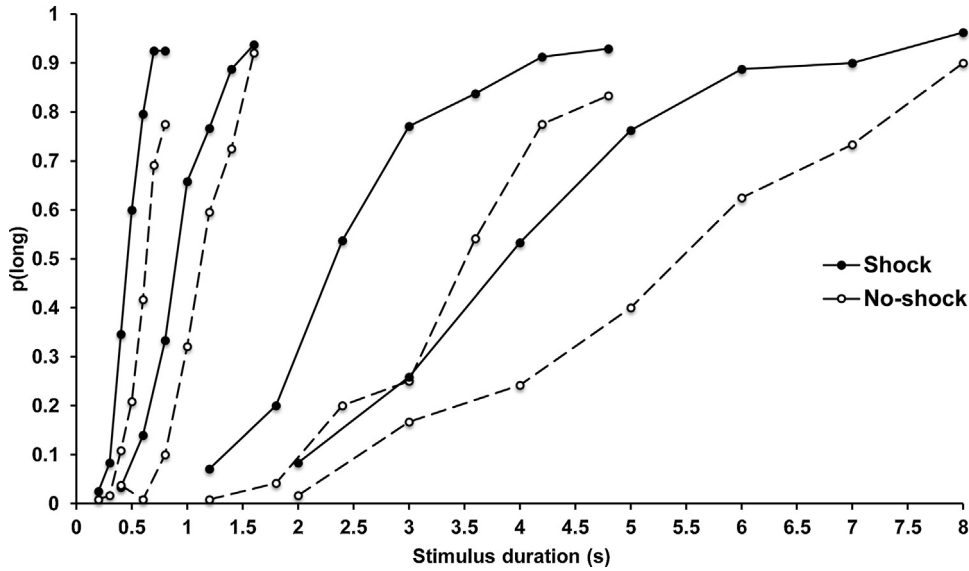


Fig. 1. Proportion of long responses ($p(\text{long})$) plotted against comparison durations (s) for the trials with and without an electric shock in the 0.2–0.8, 0.4–1.6, 1.2–4.8 and 2.0–8.0-s duration ranges.

Table 1

Mean (*M*) and standard deviation (SD) of the Bisection point and the Weber ratio for the trials with and without shock in the 0.2–0.80, 0.4–1.6, 1.2–4.8 and 2.0–8.0-s duration groups.

	No-shock		Shock	
	<i>M</i>	SD	<i>M</i>	SD
Bisection point 0.2–0.8	0.61	0.09	0.46	0.06
0.4–1.6	1.15	0.17	0.90	0.12
1.2–4.8	3.48	0.61	2.31	0.42
2.0–8.0	5.48	2.07	3.86	0.87
Weber ratio 0.2–0.8	.20	.12	.21	.11
0.4–1.6	.16	.08	.23	.09
1.2–4.8	.21	.11	.25	.13
2.0–8.0	.27	.26	.21	.06

An ANOVA was also performed on the Weber ratio (WR), with the same factorial design as that used for the BP (see **Table 1**). WR is an index of temporal sensitivity. It is calculated by dividing the difference limen [$(p(\text{long}) = .75 - p(\text{long}) = .25)/2$] by BP. The greater the WR, the lesser the time sensitivity. As with BP, WR was derived from the fit of each individual function to the pseudo logistic function. This ANOVA did not reveal any significant effect: emotion, $F(1, 56) = 0.36$, $p = 0.55$; duration range, $F(3, 56) = 0.51$, $p = 0.68$; emotion duration range, $F(3, 56) = 1.71$, $p = 0.18$. This lack of effect concerning the duration factor supported the existence of the scalar property of timing observed in previous research. In addition, the lack of an effect of emotion suggested that the expectation of a threatening stimulus did not affect time sensitivity, whatever the duration range.

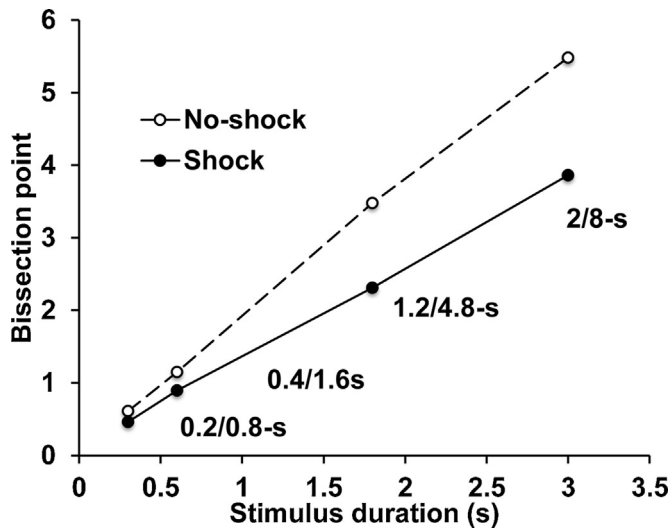


Fig. 2. Mean bisection points for the trials with and without an electric shock in the 0.2–0.8, 0.4–1.6, 1.2–4.8 and 2.0–8.0-s duration ranges.

3.3.2. Additional analysis of the effect of electric shock as a function of delivery time

Complementary analyses were performed to examine whether the time at which the electric shock was actually delivered during the stimulus influenced temporal responses. As the electric shock was randomly administered during each trial, we calculated a shock-time index: the difference between the stimulus duration and the shock time, divided by the stimulus duration. The higher the index value, the earlier the electric shock occurred during the stimulus. This complementary analysis was performed using the GLIMMIX procedure (logistic mixed models) in SAS 9.4 statistical software (SAS Institute Inc., Cary, NC, USA). Our model included duration range, shock time and their interaction as fixed effects, and participants as a random intercept. As the number of observations varied, we applied the Satterthwaite correction. These statistical analyses revealed that both duration range and shock time predicted “long” responses, $F(3, 7160) = 8.43, p < .001$, and $F(1, 7160) = 284.00, p < .001$. The duration range shock time interaction was not significant, $F(3, 7160) = 2.27, p = .08$. The effect of duration range indicated that the longer the duration range, the more frequently the participants responded “long”. More interesting for our purpose, the effect of shock time also indicated that the earlier the electric shock was delivered, the more individuals responded “long”.

4. Discussion

This study showed that the administration of an electric shock during a stimulus duration does not disturb temporal *sensitivity*, as indicated by the constant value of WR whatever the experimental condition. In other words, fear induced by the perception of a threat does not impair fundamental time discrimination abilities. However, as clearly demonstrated by our results, it did produce a distortion in the perception of time, such that time passed more quickly and the stimulus duration was therefore judged to have lasted longer. In our study, the bisection curves were systematically shifted leftward, with a significant lowering of BP for the trials with an electric shock, compared with those without one. In addition, participants' ratings on the SAM scale indicated that the shock trials were less pleasant and more arousing than the no-shock trials. Consistent with their subjective self-reports, the magnitude of their EDA increased for the shock trials compared with the no-shock trials, revealing a physiological response to threat that is characteristic of an increased level of arousal (Kreibitz, 2010). Overall, these results allow us to conclude that an electric shock inducing a state of fear increased participants' level of arousal. This, in turn, produced a lengthening of perceived time.

As reported in the Introduction, a lengthening effect observed with the emotion of fear may be induced either by an attention-related switch mechanism (additive effect) or by an arousal-related clock mechanism (multiplicative effect). However, SET allowed us to dissociate these two mechanisms. The originality of our study lay in the use of stimulus durations ranging from a couple of hundred milliseconds (0.2 s) to several seconds (8 s). First, our results showed that the lengthening of perceived time in a threatening context is not only observed with short durations of just a few hundred milliseconds, as tested on numerous occasions, but also with longer durations of 2 s or more. The time distortion habitually observed in threatening situations for short durations (<2 s) can thus be generalized to other duration lengths. This is consistent with studies that have found a lengthening effect in temporal judgments of long events, such as the estimation of a 3-min video clip of the September 11th terrorist attack (Anderson et al., 2007), the duration of novice skydivers' first jump (Campbell and Bryant, 2007), or the amount of time (12 and 36 s) spent in front an angry person (Thayer and Schiff, 1975). It is also consistent with individuals' reports of time distortions experienced during a traumatic event when they were victims of aggression or an

accident (e.g., Loftus et al., 1987). Distortions of time in threatening contexts thus represent a robust phenomenon that is observed for different ranges of durations. However, other mechanisms related to memory processes may interfere with time judgments of long durations (i.e., several minutes). Further experiments are thus required to understand the emotional distortions involved in the judgment of durations of several minutes.

Second, and more interesting for the purpose of our study, our results clearly demonstrate that the magnitude of emotion-related time distortion in humans increases with the length of the duration. There was a significant linear relation between the length of the durations we tested and the magnitude of the difference between time judgment in the trials with and without an electric shock. This linear increase in the magnitude of time distortion with duration value validates our hypothesis that the administration of an electric shock during a stimulus duration increases the level of arousal, thus automatically speeding up the internal clock system. In addition, analyses of the effect of the time at which the electric shock was delivered suggested that the time distortion observed in our study was due to the aversive stimulus we used, rather than to its anticipation per se. Had the latter been the case, the lengthening effect would have been greater for trials where the electric shock occurred late than for trials where it occurred earlier. The anticipation of the shock is theoretically maintained until the electric shock occurs, after which it disappears. However, our analyses revealed a greater lengthening effect when the electric shock came earlier. Consequently, as suggested in the literature on fear induced with electric shocks (Phelps, 2006; Phelps and LeDoux, 2005), we can assume that this aversive stimulus automatically activated a series of physiological responses associated with fear, including the acceleration of the internal clock.

The idea that the temporal distortions observed in threatening situations are produced by the perception of a threat that automatically speeds up the internal clock is entirely consistent with the literature on fear using electric shocks (Phelps, 2006; Phelps and LeDoux, 2005). This literature explains that an aversive stimulus automatically activates a variety of physiological responses associated with the emotion of fear (increased heart rate, dilated pupils, contracted muscles), so that the whole body is prepared to act for its survival (i.e., to avoid an imminent danger). In other words, when it is threatened in some way, the whole

body is mobilized to respond rapidly (fight or flight). This explanation is supported by the role of the dopaminergic system, both in temporal and emotional processes. Neuropharmacological studies have shown that an increase in the dopamine level in the brain produces temporal overestimation (e.g., Maricq et al., 1981; Rammsayer, 1990, 2009). Furthermore, the influence of dopamine on amygdala functioning is well established, the amygdala being a central structure in emotion processing (e.g., Adolphs, 2002; Adolphs et al., 1994; LeDoux, 2000). In sum, the speeding up of the internal clock can be regarded as an automatic consequence of general physiological activation in threatening situations (Droit-Volet, 2014).

Most previous studies had tested the effect of highly arousing negative stimuli (pictures of emotional faces or scenes) on time perception in humans, rather than the effect of aversive stimuli. Some of these studies found an interaction (multiplicative effect) between emotion and duration for short durations of less than 1s (Droit-Volet et al., 2010; Gil et al., 2007), but others did not (Grommet et al., 2011; Lui et al., 2011). A number of studies also observed that the effect of emotion on time perception decreases rather than increases beyond a 2-s duration (Angrilli et al., 1997; Bar-Haim et al., 2010). Angrilli et al. (1997) therefore assumed the presence of an arousal-based effect for short durations and an attention-based effect for longer ones. However, when the emotional context raises participants' arousal level sufficiently, as it did in our study featuring electric shocks, the time distortion is not only maintained for long durations (>2 s), but actually increases, consistent with the clock-speed hypothesis. Consequently, our results allow us to assume that the inconsistent results of previous studies and the lack of an effect for long durations were due to the use of emotional stimuli (pictures) that were not sufficiently arousing to produce a lasting increase in arousal level. The emotions induced by the perception of emotional pictures are too short-lived, and thus too variable. This also makes it difficult to test SET's predictions about the mechanisms underlying the effect of emotion on time judgments. In other words, to further examine the mechanisms involved in the effects of emotion on the perception of all durations, including long durations, emotional stimuli other than emotional pictures must be used.

In conclusion, the procedure used in our study allowed us to test the SET-based hypothesis of an interaction between emotion and duration (i.e., an increase in arousal level accelerates

the internal clock rate) with several duration ranges, including one of more than 5 s. Our results validated this hypothesis, thus demonstrating that highly arousing stimuli (i.e., electric shocks) automatically produce an acceleration of the internal clock system underlying the representation of time, such that stimulus durations are judged to be longer.

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