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The role of physiological arousal in time perception: Psychophysiological evidence from an emotion regulation paradigm

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ABSTRACT

Time perception, crucial for adaptive behavior, has been shown to be altered by emotion. An arousal-dependent mechanism is proposed to account for such an effect. Yet, physiological measure of arousal related with emotional timing is still lacking. We addressed this question using skin conductance response (SCR) in an emotion regulation paradigm. Nineteen participants estimated durations of neutral and negative sounds by comparing them to a previously memorized duration. Instructions were given to attend either to temporal or to emotional stimulus features. Attending to emotion with negative sounds generated longer subjective duration and greater physiological arousal than attending to time. However, a shared-attention condition showed discrepancy between behavioral and physiological results. Supporting the idea of a link between autonomic arousal and subjective duration, our results however suggest that this relation is not as direct as was expected. Results are discussed within recent model linking time perception, emotion and awareness.

1. Introduction

Time perception is crucial in numerous everyday life activities and, more generally, in the generation of adaptive responses to the environment. Various studies have shown that humans and other animals are able to estimate time accurately in the millisecond to minutes range. This ability is however highly context dependent and recent studies have pointed out the influence of an emotional context on time judgment (Angrilli, Cherubini, Pavese, & Manfredini, 1997; Droit-Volet, Brunot, & Niedenthal, 2004; Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007; Tipples, 2008). More specifically, emotional events are consistently reported to last longer than neutral ones. Such distortion of time is thought to be linked to fluctuations of the physiological arousal level (Droit-Volet et al., 2004; Droit-Volet & Meck, 2007; Noulhiane et al., 2007). Yet, no study directly tested this assumption. The present study aimed at exploring the relation between physiological arousal and the emotional effect on time judgment by (1) introducing a measure of autonomic arousal and (2) modulating arousal by cognitive control of emotion.

Dominant models of time perception assume that our ability to perceive time relies upon a pacemaker–accumulator clock, where an oscillator – or pacemaker – produces a series of pulses – i.e. temporal units – and the number of pulses recorded over a given timespan represents experienced duration (e.g. Triesman, Faulkner, Naish, & Brogan, 1990). According to such models, two mechanisms can affect the functioning of the timer: attention and arousal. A large number of studies using dual tasks or distracting paradigms have shown that when attention was distracted from the processing of time, duration was perceived as shorter (Brown, 1997; Macar, Grondin, & Casini, 1994). Attentional theories of time perception predict that less attention to time will result in fewer accumulated pulses (e.g. Zakay, 2005). By contrast, arousal is thought to increase the speed of the pacemaker, resulting in a longer perceived duration (e.g. Burle & Casini, 2001).

Only a few studies have focused on the question of how arousal induced by emotion influences the processing of time. Using a temporal bisection task, Droit-Volet and collaborators (2004) showed that the perceived duration of faces expressing emotion was longer than for those with a neutral expression. Replicating this finding, Tipples (2008) showed that this was particularly true of faces expressing anger. In a study using standardized emotional material, we manipulated positive and negative sounds lasting 2–6 s assessed in terms of arousal, in a reproduction and a verbal estimation task (Noulhiane et al., 2007). Results showed that emotional sounds were perceived as longer than neutral ones. Interestingly, the emotional effect was greater with negative stimuli (Noulhiane et al., 2007), which are thought to induce stronger physiological and cognitive responses than neutral or positive stimuli (Caccioppo & Gardner, 1999). Overall these studies thus

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support activation-based models of time perception postulating that a higher level of arousal generates longer subjective durations.

However, while physiological activation is assumed to be responsible for the lengthening of experienced duration, none of these studies used physiological measures able to assess changes in activation level. Electrodermal activity is an indirect measure of the sympathetic autonomic activity frequently used to index modulations in global physiological arousal level (e.g. Boucsein, 1992). More specifically, skin conductance response (SCR) is widely used in the study of emotion and is thought to vary with the level of arousal induced by emotional stimuli (Kreibig, 2010). This measure thus seems to be a valid, non invasive method, to account for the assumed role of physiological arousal in the lengthening effect of emotion on time perception.

With the aim to manipulate variation of arousal, we chose to study time perception in the framework of emotion regulation. Some studies have pointed out the key role of arousal – and not valence – in the conscious regulation of negative emotion (e.g. Dillon & LaBar, 2005). Such proposal leads to the idea that the cognitive control of emotion might constitute a good way to observe variation of physiological arousal and its related effect on timing. Several means of investigating emotion regulation exist and the most commonly used consists in asking participants to voluntary enhance or decrease emotion generated by a stimulus (e.g. Beauregard, Levesque, & Bourgouin, 2001; Kim & Hamann, 2007; Ochsner & Gross, 2005; Ochsner et al., 2004; Ohira et al., 2006). Another way to study emotion regulation is to manipulate attention to *versus* away from emotion. According to Gross and collaborators (Gross, 1998b; Gross & Thomson, 2007), this strategy, termed 'attentional deployment', have an impact early in the emotion-generative process. In that, it should ensure a good manipulation of top-down control of arousal induced by emotion and its related effect on time perception.

This hypothesis was tested in a duration comparison task, including neutral and negative sounds of varying emotional intensity. The choice of using negative stimuli was guided by the fact that negative events are thought to generate stronger physiological responses than positive events do (e.g. Cacciopo & Gardner, 1999). In a previous experiment, we showed that the effect of emotion on time judgment was maximal with short duration stimuli and progressively declined with the stimulus duration (Noulhiane et al., 2007). Therefore, we chose to focus on short duration processing – i.e. 2 s – in order to maximize the emotional effect on time perception. Attentional deployment was manipulated by prior instructions to attend either to time or to emotion or to both dimensions. These instructions may be linked to the three traditional conditions used in emotion regulation paradigms, i.e. increasing, decreasing and maintaining emotion. Attending to emotion is expected to enhance emotion, while attending to time is expected to down-regulate emotion. Attending to both dimensions may reflect an intermediate condition, which could be assimilated to the 'maintaining emotion' condition. We expected to replicate the relative overestimation of emotional compared to neutral sounds when participants directed their attention toward emotional intensity or divided their attention between time and emotion, but not when they had to focus their attention on time and ignore emotional features. Furthermore, we expected that longer time estimates will be associated to higher levels of SCR.

2. Material and method

2.1. Participants

Nineteen participants aged from 21 to 28 years (9 males, mean age: 26 ± 2.45, 90% postgraduates) gave their informed consent for the experiment. None reported a history of neurological or psychiatric disorders. None of them reported taking any medication. The experiment was approved by the local ethical committee and performed in accordance with the ethical standards laid down in the 1964 declaration of Helsinki.

2.2. Material and design

The experiment was conducted in a small dimly lit room. A specifically designed laboratory program (Stimulat) controlled both the presentation of standard durations and the recording of subjects' responses with an accuracy of ±0.5 ms. Auditory stimuli were presented binaurally via headphones at 70 decibels Sound Pressure Level (dB SPL). Participants' judgments were given with a three-button device held in their dominant hand.

The experiment was composed of two phases – a training phase and a test phase. During the training phase, participants had to memorize the standard duration (2 s). Training was conducted with a pure beep-like tone of 2 s duration which was first presented 10 times, followed by 30 trials in which the duration could either be slightly shorter (1800 ms), equal (2000 ms), or slightly longer (2200 ms). These durations occurred randomly and their probability of occurrence was equivalent. The inter trial interval varied between 1450 and 1550 ms. For each trial, participants decided whether the presented sound was shorter, equal or longer than the standard, using their index finger, middle finger or ring finger respectively to indicate their responses on the three-button panel. Three seconds after the end of the sound, feedback was provided on the screen: the three possible answers were presented, i.e. 'shorter', 'equal' and 'longer', with the correct response illuminated. The standard duration was considered to be correctly memorized when at least 80% of correct responses were reached. The training phase was repeated once if necessary.

In the test phase, 12 neutral sounds (mean arousal 4.39), six low negative sounds (mean arousal 5.71) and six high negative sounds (mean arousal 7.58) taken from the International Affective Digitalized Sounds System (Bradley & Lang, 1999) were used. Three levels of emotional intensity, based on the norms published by Bradley and Lang (1999), were thus manipulated. A list of the selected sounds is presented in the appendix. 80% of these sounds were of the same duration as the standard (2 s), 10% were shorter (1 s) and 10% longer (4 s). Instructions were given as follows:

"You will now hear different sounds. Your task will be twofold: first, you will have to judge for the duration of the sound and say whether it was shorter, equal or longer than the duration of the sound you have just learnt. Second, you will have to determine whether the sound was of low, medium or high emotional intensity. Prior to each sound, you will be asked to attend either to emotional intensity, or to time, or to both dimensions. If you see the letter "T" on the screen, you will have to focus attention on time and ignore emotion. If you see the letter "I", you will have to focus on emotional intensity. If you see the letters "ti", then you will have to attend equally to both dimensions."

The test phase was composed of three sequences of 24 trials with sounds lasting 2 s, counterbalancing the emotion and the attention conditions. Six trials with shorter and longer durations, considered as fillers, were added to each sequence and were excluded from the analyses. The inter-stimulus interval varied from 5500 to 6500 ms. Participants gave their responses by using their index finger, middle finger or ring finger on a three-button panel. Prior to the test phase, they were given some practice trials.

2.3. Physiological data collection and reduction

Skin conductance response (SCR) was recorded using an MP-150 psychophysiological monitoring system (Biopac Systems, Santa Barbara, CA).

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SCR was measured using two Ag–AgCl electrodes filled with isotonic NaCl unibase electrolyte that were attached to the palmar surface of the middle phalanges of the third and fourth fingers of the non-dominant hand. Before the electrodes were attached, the skin was cleaned with abrasive gel and alcohol. Raw SCR signals were recorded at a sampling rate of 2 kHz, amplified and band-pass filtered online at 0.05–10 Hz. Signals were sampled off-line at 2 Hz and a log(microsiemens + 1) transformation was performed. Trials containing artifacts, noisy baseline (1 s before the sound onset) or too early SCR (beginning before 1 s following the stimulus appearance) were rejected. Observation of our data showed that maximum amplitudes of SCR were reached within 5 s following sound onset. Therefore, the amplitude of SCR was determined by the maximum change from the baseline level occurring between 1 and 5 s after the sound onset. Maximum SCRs were then averaged for each experimental condition and subjected to statistical analyses.

2.4. Data analyses

For behavioral data, mean indexes of time judgments (Mt) and emotional intensity judgments (Mi) were computed as follows: Mt = (number of longer − number of shorter responses)/total number of responses; Mi = (number of high intensity responses − number of low intensity responses)/total number of responses. Those indexes varied from −1 to 1: a positive value corresponded to an overestimation of objective duration (or a high rating of emotional intensity) and a negative value to an underestimation of objective duration (or a low rating of emotional intensity). Effects of emotional intensity and attention allocation on emotional intensity judgments, time judgments and SCR were tested in a two-way repeated-measures ANOVAs carried out with Instruction (attend to time/attend to emotional intensity/divide attention between time and emotional intensity) and emotional intensity' (neutral/low arousing negative/high arousing negative). When necessary, Fisher LSD test was used to test *post hoc* comparisons.

3. Results

3.1. Behavioral results

3.1.1. Emotional intensity judgments

The ANOVA conducted on mean emotional intensity judgments revealed a main effect of 'emotional intensity' [$F_{(2;34)} = 510.52$, $\eta_p^2 = .97$; $p < .05$], indicating that sounds were rated according to IADS ratings (Bradley & Lang, 1999): neutral sounds were judged to be of the lowest emotional intensity (mean = −0.64), low arousing negative sounds were judged to be of average emotional intensity (mean = 0.09), and high arousing negative sounds were judged to be of high emotional intensity (mean = 0.68).

3.1.2. Duration judgments

Fig. 1 shows mean temporal judgment of 2 s sounds as a function of 'emotional intensity' and 'instruction'. The ANOVA performed on this index showed a main effect of 'emotional intensity' [$F_{(2;34)} = 24.45$, $\eta_p^2 = .59$, $p < .05$], indicating that high arousing negative sounds were judged as longer than low arousing negative and neutral sounds. More interestingly, results showed a significant 'emotional intensity' × 'instruction' interaction [$F_{(4;68)} = 4.24$, $\eta_p^2 = .20$, $p < .05$]. *Post hoc* analyses revealed that, while there was no effect of attentional instruction for neutral and for negative stimuli of low intensity (all $ps > .05$), subjective duration of high arousing sounds was longer when participants attended to emotional intensity than when they attended to time ($p < .05$) or when they shared their attention between time and emotional intensity ($p < .05$). No significant difference was observed between the 'attend to time' condition and the 'shared-attention' condition ($p > .05$). Furthermore, when participants attended to emotional intensity, high arousing sounds were judged as longer than low arousing negative ($p < .05$) and neutral sounds ($p < .05$). This difference was also significant in the 'shared-attention' condition (all $ps < .05$). However, it was not significant when participants attended to time (all $ps > .05$).

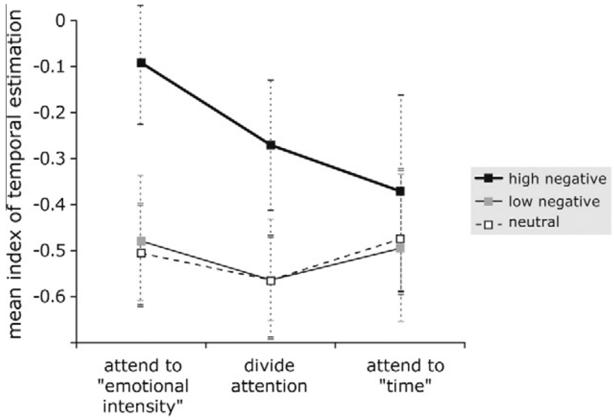

Fig. 1. Mean subjective duration for 2 s sounds indicated by the following ratio: (number of "longer" responses − number of "shorter" responses)/total number of responses, as a function of the attention instruction (T: attend to time, I: attend to emotional intensity, and ti: divide attention between time and emotional intensity), and of the emotional intensity level (low intensity for neutral sounds, medium intensity for low negative sounds and high intensity for high negative sounds). Bars in dotted lines represent the standard error.

3.2. Physiological results

Two participants were excluded from analyses due to bad signals. Physiological analyses were therefore conducted with the data of 17 participants.

SCR results, displayed in Fig. 2, showed a significant 'emotional intensity' × 'instruction' interaction [$F_{(4;64)} = 2.65$, $\eta_p^2 = .14$, $p < .05$]. *Post hoc* analyses revealed that while there was no effect of attentional instruction for neutral and for negative stimuli of low intensity (all $ps > .05$), mean SCR induced by high arousing sounds was higher when participants attended to emotional intensity than when they attended to time ($p < .05$) or when they shared their attention between time and emotional intensity ($p < .05$). No significant difference was observed between the 'attend to time' condition and the 'shared-attention' condition ($p > .05$).

Furthermore, mean SCR induced by high arousing sounds was higher when attending to emotional intensity than when attending to time ($p < .05$) or when sharing attention ($p < .05$). Conversely, no significant differences were observed for less arousing and for neutral sounds (all $ps > .05$).

Main effects of 'emotional intensity' and of 'attentional instruction' were not significant ([$F_{(2;32)} = 1.57$, $\eta_p^2 = .09$, $p > .05$] and [$F_{(2;32)} = 2.2$, $\eta_p^2 = .12$, $p > .05$], respectively).

4. Discussion

Manipulating top-down attention to negative emotion, the present study aimed at assessing the link between autonomic arousal and the lengthening effect of emotion on time perception. Results show that attending or not to emotion modulates both time judgments and physiological arousal. When participants attended to emotion, the duration of highly arousing stimuli was judged to last longer and autonomic arousal was higher than when

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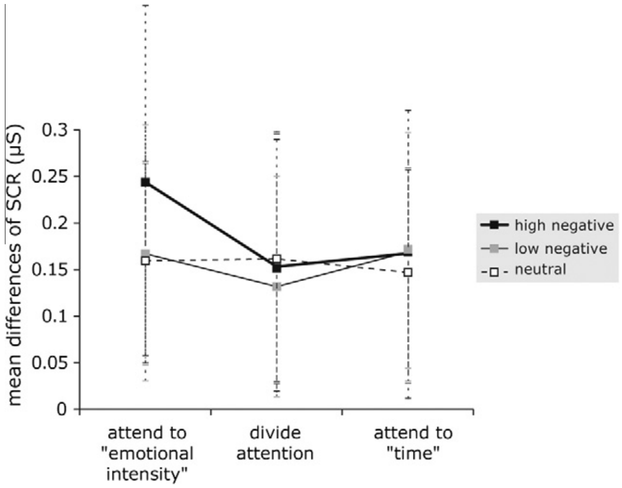

Fig. 2. Mean SCR amplitude (in log $(\mu S + 1)$) as a function of the attention instruction and the emotional intensity level: low intensity for neutral sounds, medium intensity for low negative sounds and high intensity for high negative sounds. Bars in dotted lines represent the standard error.

they attended to time or when they shared their attention between time and emotion. This result supports activation-based models of time perception postulating that a higher level of arousal generates longer subjective durations. However, a shared-attention condition showed discrepancy between behavioral and physiological results, suggesting that the link between autonomic arousal and subjective duration is not as direct as was previously predicted (e.g. Burle & Casini, 2001).

As expected, attending to emotion increased its effect on time judgments: highly arousing sounds were judged to last longer than in the shared-attention and in the "attend to time" conditions. This enhancement of the emotional impact on timing was associated to an increased physiological arousal level, assessed by higher SCR amplitudes. Our finding supports the assumption that increasing physiological arousal would be responsible for the lengthening of subjective duration in a negative emotional context. In accordance with previous observations concerning body temperature (François, 1927; Hoagland, 1933, 1935) or dopaminergic activity (Meck, 1996), it provides a physiological link between autonomic arousal and modulation of time judgments. This result is also consistent with previous studies showing that durations of emotional events or faces, and especially that of high arousing ones – e.g. faces expressing anger – are judged longer than neutral ones (Droit-Volet et al., 2004; Effron, Niedenthal, Gil, & Droit-Volet, 2006; Noulhiane et al., 2007; Tipples, 2008).

Conversely, when participants attended to time, duration estimates and physiological arousal were similar whatever the emotional intensity of the stimuli. Attentional control was therefore effective in modulating the emotion-induced arousal effect on perceived time. Previous physiological studies of emotion regulation have shown that instruction to enhance or reduce emotion altered physiological responses of emotion (Jackson, Malmstadt, Larson, & Davidson, 2000). Investigating autonomic responses associated with down-regulation of emotion, Gross (1998a) observed that suppressing emotional expression led to increase sympathetic arousal, whereas reappraisal of the scenes did not, suggesting that reappraisal is more effective and less costly for the organism. Although we did not have a direct measure of emotional experience to assess that emotion regulation has occurred, our results showed that attending away to emotion reduced associated physiological arousal. According to Gross (1998b), attentional deployment is an *antecedent-focused* strategy of emotion regulation, which suggests that attending away to emotion prevents the speeding up of the inner time before the interval to be timed begins. This opens up possible directions for future research into the efficiency of different strategies of emotion regulation acting on various moments of the emotion-generative process. For example, is it possible to prevent the emotional effect on timing once the emotion is initiated?

Interestingly, when sharing attention between time and emotion, highly emotional sounds were judged to last longer than sounds of less emotional intensity, while autonomic arousal levels were similar, whichever the emotional intensity. The discrepancy between physiological and behavioral results suggests that the relation between heightened arousal and acceleration of the sense of time is not as direct as initially proposed by internal clock theories. The link between emotion and time perception seems stronger than the relation between autonomic arousal and time perception. This unexpected observation is interesting regarding a recent proposition by Craig (2007, 2009a, 2009b) that time perception is intrinsically linked to our emotional state, because they share a common underlying neural system, namely the anterior insular cortex (AI) and the interoceptive system. According to Craig, the AI – considered as the basis for subjective awareness across time – integrates the salience of the environment via representation of the body condition, and then motivational, hedonic and social conditions represented in other interconnected parts of the brain. This hierarchical integration of the salience leads to a unified representation of a "global emotional moment" at the immediate moment of time—'now'. Accordingly, the succession of "global emotional moments" would be used for subjective time estimation. Craig's model predicts that high emotional salience will accelerate the succession of these "global emotional moments", enhancing self-awareness, thus producing the sensation that time stands still. Accordingly, timing would be a self-referential process inextricable from our emotional state. In this line, recent empirical evidence support the assumption that time perception is a self-referential process in which the insular cortex has a key role (Wittmann, Leland, & Paulus, 2007; Wittmann & Paulus, 2008; Wittmann, van Wassenhove, Craig, & Paulus, 2010).

On another hand, emotional states generated by high salience are generally characterized by increased physiological arousal (e.g. Schacter & Singer, 2000), but in the divided attention condition autonomic arousal was not heightened when exposed to highly arousing sounds. The instruction to equally divide attention between time and emotion may be more demanding in cognitive resources than focusing attention on a single dimension (Posner, 1978). This could prepare participants to exert some form of emotional control, thus limiting autonomic responses to emotion such as physiological arousal. In line with this view, attentional control has been associated with activity in the anterior cingulate cortex (see Medford and Critchley (2010) for a review), a brain region that is also known to regulate SCR (Critchley, 2002; Critchley, Elliott, Mathias, & Dolan, 2000), via amygdala modulation (Sarinopoulos, Dixon, Short, Davidson, & Nitschke, 2006). Conversely to central activity in response to highly arousing stimuli, SCR (and thus its top-down regulation) is a long-latency process elicited between 1 and 3 s (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). This difference of temporality may encounter for the observed discrepancy between physiological and cognitive effects of the exposure to highly arousing stimuli. It can be assumed that the "divided attention" condition induced a cognitive control, less important than the "attend to time" condition, which does not impact the fast neural processes involved in emotional timing. If the lengthening of subjective time in a highly emotional context should normally be associated to an increased physiological arousal because of high salience, heightened physiological arousal does not seem to be at the root of subjective time dilation. Considering Craig's proposition that the global emotional moments – used for time estimation – are

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inextricable from salience and recent findings suggesting that time a self-referential process, one can assume that salience – inducing enhancement of immediate self-awareness – is a key factor of time dilation in an emotional context.

It is interesting to notice that studies of emotional timing mostly report time dilation with highly negative stimuli, which may be important from an evolutionary view. Enhancement of self-awareness – or acceleration of the representation of the self – may allow a sharper representation of the body state while the sensation of time dilation may enable a greater mastering of motor preparation in response to a threatening situation. Our study however presents the limitation of using negative stimuli only. It would be interesting to better explore the contribution of valence and arousal in the effect of emotion on time perception, with the use of physiological measurement. Previous studies suggest that positive stimuli also generate time dilation, however less strongly than negative do (Droit-Volet et al., 2004; Noulhiane et al., 2007; Tipples, 2008). Still, future work should explore the specific role of valence in the perception of time.

Finally, an intriguing point of our results is worth discussion: temporal data showed a global underestimation of time, which makes that the lengthening effect induced by emotion produced a more precise estimation of real duration than when participants attend to time. This interesting result raises the question of a gain of emotion on time judgments. The idea that emotion induces gains for perception and cognitive processes has been advanced by various authors (e.g. Anderson & Phelps, 2001; Fridlund, Ekman, & Oster, 1987; Scherer, 1984). For instance, Anderson and Phelps (2001) provided evidence of a gain of emotion on attention to visual stimuli. More generally, physiological activation induced by emotion is thought to have the essential function of readiness for action by regulating the internal state of the organism, preparing the specific reaction to the stimulation. In the context of time perception, attending to arousing negative stimuli could help to better appraise their exact duration. However, underestimation was not systematic in previous timing studies manipulating emotion. (e.g. Angrilli et al., 1997), Thus, the overall underestimation observed in the present experiment may be task-dependent. In particular, we propose that this underestimation could be due to a general attentional effect. In the present study, participants were trained with a pure beep-like tone and comparison was made with contextual sounds. As processing the context draws attentional resources, less attention may be available to estimate duration. According to theories of time perception, this must result in a loss of temporal information (e.g. Zakay & Block, 2004). Further experiments will then be necessary to study the effect of context processing on timing.

5. Conclusion

Integrating an objective measure of arousal in the study of emotional timing, the present experiment accredits prior assumptions that the modulation of physiological arousal is related to variation of subjective time (e.g. Burle & Casini, 2001). It nonetheless suggests that this relation is not as direct as suggested by initial theories of internal clock (Treisman, 1963). Rather heightened arousal and subjective dilation of time are likely to be concomitant of a same phenomenon. In line with recent findings attempting to link time perception to self-referential processing, we propose that enhancement of self-awareness – induced by high salience – constitutes the basis for time dilation in an emotional context.

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Appendix A

List of the sounds used (by IADS sound number)
Neutral sounds
100, 171, 262, 311, 320, 322, 325, 358, 410, 425, 602, 704, 708, 722
Negative sounds of low intensity
130, 252, 280, 292, 380, 420, 500, 706
Negative sounds of high intensity
106, 116, 276, 277, 278, 279, 711, 712

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