Emotion
2007, Vol. 7, No. 4, 697–704

1528-3542/07/$12.00 DOI: 10.1037/1528-3542.7.4.697

How Emotional Auditory Stimuli Modulate Time Perception

Marion Noulhiane
Laboratoire de Neurosciences Cognitives et d'Imagerie Cérébrale and Université Charles de Gaulle Lille 3

Nathalie Mella
Laboratoire de Neurosciences Cognitives et d'Imagerie Cérébrale

S. Samson
Université Charles de Gaulle Lille 3

R. Ragot and V. Pouthas
Laboratoire de Neurosciences Cognitives et d'Imagerie Cérébrale

Emotional and neutral sounds rated for valence and arousal were used to investigate the influence of emotions on timing in reproduction and verbal estimation tasks with durations from 2 s to 6 s. Results revealed an effect of emotion on temporal judgment, with emotional stimuli judged to be longer than neutral ones for a similar arousal level. Within scalar expectancy theory (J. Gibbon, R. Church, & W. Meck, 1984), this suggests that emotion-induced activation generates an increase in pacemaker rate, leading to a longer perceived duration. A further exploration of self-assessed emotional dimensions showed an effect of valence and arousal. Negative sounds were judged to be longer than positive ones, indicating that negative stimuli generate a greater increase of activation. High-arousing stimuli were perceived to be shorter than low-arousing ones. Consistent with attentional models of timing, this seems to reflect a decrease of attention devoted to time, leading to a shorter perceived duration. These effects, robust across the 2 tasks, are limited to short intervals and overall suggest that both activation and attentional processes modulate the timing of emotional events.

Keywords: time perception, emotion, arousal, valence, auditory modality

Temporal information processing plays a fundamental role in human life for the representation of the external environment. In parallel, human beings are continually engaged in emotionally driven behavior in everyday life. Although an increasing number of studies have examined the effect of emotions on cognitive activity, only a few investigations have analyzed the relationship between time estimation and emotional states.

Research in the field of time perception is mostly guided by internal clock models that postulate the existence of an internal source of temporal information (Gibbon et al., 1984; Treisman, 1963). A temporal processor, also called a timer, relies on four interrelated devices: a clock, a working memory store, a reference memory store, and a comparator. The clock consists of a pacemaker producing pulses at a given rate and a switch, driven by external stimuli with some latency, that controls the access to an accumulator summing the pulses. According to Treisman (1963), the activation level of the pacemaker may vary under the influence of external inputs. As its activation level increases, so too will the pulse emission rate. The comparator contrasts the values stored in reference memory from past trials with the current duration value. The temporal response is then determined on the basis of this comparison.

Data from experiments on time perception have often shown that the subjective duration of a stimulus can be influenced by various factors in addition to its actual physical length. In this study, we examined the effects of emotions on time perception. It is important to characterize emotions for a precise understanding of mechanisms acting on the process of time. Schachter and Singer (1962, p. 380) defined emotion as "a state of physiological arousal and of cognition appropriate to this state of arousal." This definition distinguishes between physiological arousal, which can be termed *activation,* and mental arousal, characterized by the subjective experienced intensity of emotions. A similar dissociation is made by Oatley and Jenkins (1996, p. 96), who stated that "the core of an emotion is readiness to act and the prompting of plans." They added that "an emotion is usually caused by a person consciously or unconsciously evaluating an event as relevant to a concern (a goal) that is important." These authors thus described both the physiological arousal induced by emotion, linked to

---

Marion Noulhiane, Laboratoire de Neurosciences Cognitives et d'Imagerie Cérébrale, Centre National de la Recherche Scientifique, Paris, France, and Neuropsychologie et Cognition Auditive, Université Charles de Gaulle Lille 3, Villeneuve d'Ascq, France; Nathalie Mella, Laboratoire de Neurosciences Cognitives et d'Imagerie Cérébrale, Centre National de la Recherche Scientifique; S. Samson, Neuropsychologie et Cognition Auditive, Université Charles de Gaulle Lille 3; R. Ragot and V. Pouthas, Laboratoire de Neurosciences Cognitives et d'Imagerie Cérébrale, Centre National de la Recherche Scientifique.

We are grateful to Laurent Hugueville for his help on protocol design. This study was supported by Grant 022399 from the ACI "Neurosciences Intégratives et Computationnelles" of the French Ministry of Research. Marion Noulhiane was funded both by a doctoral fellowship from the Regional Council of Nord-Pas-de-Calais (France) and by the French League Against Epilepsy (Novartis), and Nathalie Mella was funded by a doctoral fellowship from the DGA (French Ministry of Defense).

Correspondence concerning this article should be addressed to Marion Noulhiane or Nathalie Mella, LENA CNRS UPR 640, Hôpital de la Salpêtrière, 47 Boulevard de l'Hôpital, 75651 Paris Cedex 13, France. E-mail: marion.noulhiane@chups.jussieu.fr or nathalie.mella@chups.jussieu.fr

readiness for action, and the cognitive arousal, linked to self-assessed appraisal. According to the two-arousal hypothesis of Routtenberg (1968), two arousal systems would be sustained by distinct neural underpinnings: A first one, related to the reticular activating system, would maintain the physiological arousal of the organism, which is not specific to the emotion, and would provide the organization for responses, whereas a second arousal system, related to the limbic system, would provide control of responses through incentive-related stimuli. This dissociation is useful because it separates arousal processes involved in behavioral response preparation from those associated with cognitive processes. The first arousal system, in line with action tendency models (e.g., Bradley, Codispoti, Cuthbert, & Lang, 2001; Lang, Bradley, & Cuthbert, 1997), is thought to be linked to motivational systems of survival, such as appetitive and defensive systems, that have evolved to mediate transactions in the environment and either promote or threaten physical survival (Lang et al., 1997). The second arousal system, a more subjective arousal linked to cognitive processes, would reflect enhanced attention to the detection of self-relevant emotional events. In this article, *activation* refers to physiological arousal, which we distinguish from subjective arousal of emotion.

In the framework of internal clock models of timing, those two aspects of emotions, that is, physiological activation and attention, would have opposite effects on time estimation. Physiological activation has been shown to increase the rate of the pacemaker, leading to a longer perceived duration (e.g., Boltz, 1994; Delay & Mathey, 1985; Penton-Voak, Edwards, Percival, & Wearden, 1996; Rai, 1975; Wearden, Pilkington, & Carter, 1999). Whereas levels of physiological arousal have been manipulated by controlling internal sources such as body temperature (e.g., Fox, Bradbury, Hampton, & Legg, 1967) or sensory inputs such as a click train (e.g., Penton-Voak et al., 1996), few studies have investigated activation induced by emotion. By using emotional visual stimuli (of less than 2 s) as standards in a temporal bisection task, Droit-Volet, Brunot, and Niedenthal (2004) showed that pictures of faces expressing emotion were judged to be of longer duration than neutral ones, supporting activation-based models of time perception. Therefore, we assumed that an emotional sound timed with an accelerated clock will seem longer than a neutral sound timed with a slower clock. Conversely, emotion may induce inattention to time, which according to attentional models of timing would lead to a shorter perceived duration. Indeed, in the internal clock perspective, a distraction from time would either delay the closing of the switch (absolute effect) or induce a flickering of the switch while estimating a duration (proportional effect), which in both cases would result in a loss of pulses incremented in the timer and thus in a shorter perceived duration (Lejeune, 1998, 2000; Meck, 1984).

Using a reproduction and an analog-scale estimation method in which participants had to mark on a graduated analog scale (0–10 s in 20-cm length) the perceived duration of the stimulus, Angrilli, Cherubini, Pavese, and Mantredini (1997) conducted a study in which participants were presented slides depicting emotional scenes of 2-, 4-, and 6-s durations crossed for their valence and arousal (International Affective Picture System; Lang, Greenwald, Bradley, & Hamm, 1993). Analyses revealed an interaction between affective valence and arousal on duration judgments. For low-arousing stimuli, the duration of negative slides was judged to be shorter than that of positive ones. For high-arousing stimuli, durations of negative slides were perceived to be longer than those of positive ones. The same results were found for both timing tasks. The authors concluded that both attentional and arousal mechanisms accounted for their findings. However, in their experiment, no clear comparison with neutral stimuli, which were used as fillers, was performed.

The purpose of our study was to extend to the auditory modality results previously obtained in the visual modality (Angrilli et al., 1997; Droit-Volet et al., 2004). As did Angrilli et al. (1997), we used a reproduction (Experiment 1) and a verbal estimation (Experiment 2) task in which standard durations from 2 s to 6 s were presented. Sounds from the International Affective Digitalized Sounds System (IADS; Bradley & Lang, 1999) were selected. Such a battery allows a comparison between temporal judgments of neutral and emotional stimuli of the same subjective arousal to address the question of the effect of activation on temporal judgments, that is, physiological arousal induced by emotion. Furthermore, it makes it possible to complete and characterize the emotional effect by manipulating self-assessed dimensions of valence and arousal. The dimensional approach enables a precise control of emotional variables and thus a better understanding of how emotions can affect temporal processing. Considering the previously described effect of activation level on the internal clock, we hypothesized that temporal judgments would be longer with emotional than with neutral stimuli. Subsequently, we investigated to what extent the perceived duration could be affected by the manipulation of self-assessed emotional dimensions of valence (positive or negative) and arousal (high level or low level).

Experiment 1: Reproduction of Durations

Method

Participants. Twenty-four right-handed participants (12 women, ages 26 ± 3.96 years, and 12 men, ages 25 ± 3.64 years) were recruited for this experiment. None had a history of neurological or psychiatric disorders. Informed consent was obtained from all participants.

Materials. The experiment was conducted using a computer with a sound card for the presentation of the auditory stimuli. A specifically designed laboratory program controlled both the presentation of standard durations and the recording of participants' responses (reproduced durations) with an accuracy of ±0.5 ms. Auditory stimuli were presented binaurally via headphones at 70 dB SPL.

Design and stimuli. Thirty-six sounds were selected from the IADS. They consisted of four groups of 6 sounds corresponding to (a) pleasant high-arousal sounds (e.g., erotic sounds), (b) pleasant low-arousal sounds (e.g., laughs), (c) unpleasant low-arousal sounds (e.g., sobs), and (d) unpleasant high-arousal sounds (e.g., woman crying), as well as one group of 12 neutral low-arousal sounds (e.g., street noises). The selected sounds are reported in the Appendix.

The duration reproduction task involved three standard durations of 2, 4, and 6 s. Three series of 36 different sounds were created in which each sound appeared once with a randomly defined duration presentation (2, 4, or 6 s). Each series was thus composed of two stimuli for each emotional category and of four neutral sounds per standard duration.

Procedure. Each trial started with the presentation of a randomly selected standard interval. During the presentation phase, participants were instructed to pay attention to the sound duration to reproduce it and were advised to avoid chronometric counting strategies. After the stimulus disappeared, a pure tone of 500 Hz was presented. Participants were asked to press the button when they considered that the duration they had previously been presented had elapsed. The reproduced interval duration was recorded. This design allowed us to draw inferences on changes in the pacemaker rate during initial presentation of emotional as compared with nonemotional sounds. Therefore, if the clock runs faster with emotional sounds, the participant will respond later than with nonemotional ones, that is, he or she should reproduce longer durations. A variable 2- to 3-s delay was introduced between the presentation and the reproduction phases and in the intertrial interval to avoid implicit evaluation of a fixed delay. Such an evaluation could have interfered with the encoding and the reproduction of the standard durations. Before starting the experiment, the participants received five training trials with neutral sounds to familiarize themselves with the task.

Results

Effect of emotion on time reproduction. Temporal performance was examined by computing a *T*-corrected score with the following formula: [T corrected = (T estimated − T standard)/T standard] (Brown, 1985; McConchie & Rutschmann, 1970; Treisman, 1963). This transformation provided information about both the extent and direction of the error of temporal estimation, with negative values indicating that the stimulus was reproduced shorter than the standard duration and positive values indicating that the stimulus was reproduced longer than the standard duration. Precision of temporal performance was examined by computing the coefficient of variation (CV) with the following formula: standard deviation of mean reproduction time divided by mean reproduction time.

The first analysis focused on the effect of emotion on time reproduction. The self-assessed arousal variable being controlled, we compared neutral low-arousal sounds with low-arousal positive and negative sounds. The analysis of variance (ANOVA) carried out on *T*-corrected scores showed a main effect of duration, $F(2, 44) = 77.60$, $p < .001$, and a main effect of emotion, $F(2, 44) = 37.92$, $p < .001$. The Duration × Emotion interaction was significant, $F(4, 88) = 11.84$, $p < .001$. Post hoc tests (Newman–Keuls) revealed that neutral sounds were reproduced shorter than low-arousal positive and low-arousal negative sounds for the 2- and 4-s standard durations (ps $< .001$). For the 6-s standard duration, no significant differences were observed, either between neutral and low-arousal positive emotional sounds or between neutral and low-arousal negative emotional sounds (see Figure 1). No effect of sex, $F(1, 22) = 0.12$, $p = .72$, and no interaction between sex and any other variables were observed.

The ANOVA carried out on CV of time judgments for the same stimuli (neutral vs. low-arousal emotional sounds; see Table 1) revealed a main effect of duration, $F(2, 44) = 20.92$, $p < .001$. There was no significant effect of emotion, $F(1, 22) = 1.06$, $p = .35$, although a significant Duration × Emotion interaction, $F(2, 44) = 6.99$, $p < .001$, was found. Post hoc tests (Newman–Keuls) revealed that for the 2-s standard duration, the mean CV for the reproduction of low-arousal positive and low-arousal negative sounds was greater than that of neutral ones ($p < .05$). For 4- and 6-s standard durations, no significant differences were observed, either between neutral and low-arousal positive sounds or between neutral and low-arousal negative sounds. No effect of sex, $F(1, 22) = 0.008$, $p = .92$, and no interaction between sex and any other variables were found.

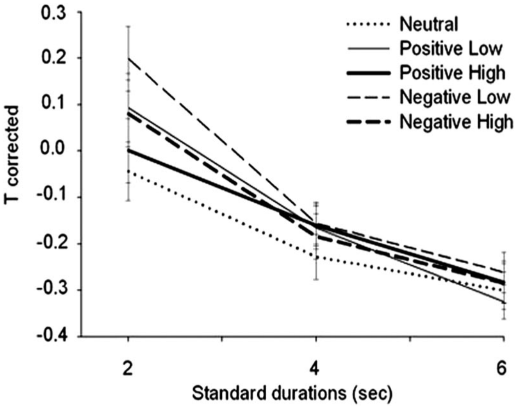

Figure 1. Reproduction task: *T*-corrected values (*M* ± *SD*) for each standard duration (2, 4, and 6 s) as a function of emotional content (neutral, positive–low, positive–high, negative–low, and negative–high).

Effect of emotional dimensions (valence and arousal) on time reproduction. The second ANOVA, excluding neutral sounds, examined the effect of emotional dimensions, namely, self-assessed valence (positive and negative) and arousal (high and low) on time reproduction. The ANOVA carried out on *T*-corrected scores demonstrated a main effect of duration, $F(2, 46) = 80.57$, $p < .001$; a main effect of valence, $F(1, 23) = 11.03$, $p < .01$; and a main effect of arousal, $F(1, 23) = 16.45$, $p < .001$. A significant Duration × Valence interaction, $F(2, 46) = 8.99$, $p < .001$, was found. Post hoc tests (Newman–Keuls) revealed that for the 2-s standard duration, reproduction of positive stimuli was shorter than that of negative ones ($p < .001$). No significant effect of valence was observed either for the 4-s or for the 6-s standard duration (see Figure 1). The results also showed a significant Duration × Arousal interaction, $F(2, 46) = 13.16$, $p < .001$. Post hoc tests (Newman–Keuls) revealed that reproduction of high-arousing stimuli was shorter than that of low-arousing ones ($p < .001$) for a 2-s standard duration, whereas no significant effect was observed with 4- and 6-s durations (see Figure 1). Interactions between valence and arousal, $F(2, 23) = 3.13$, $p = .08$, and between duration, valence, and arousal, $F(2, 46) = 0.28$, $p = .75$, were not significant. The results revealed no effect of sex, $F(1, 23) = 0.22$, $p = .64$, and no interaction of sex with any other variables.

The ANOVA carried out on the CV revealed a main effect of duration, $F(1, 23) = 20.88$, $p < .001$, but no significant effects of valence, $F(1, 23) = 0.91$, $p = .34$, or of arousal, $F(1, 23) = 0.06$, $p = .81$. However, the results revealed a significant Duration × Valence interaction, $F(2, 46) = 11.07$, $p < .001$. Post hoc tests indicated that the mean CV for negative stimuli was more important than that of positive ones ($p < .001$) for a 2-s standard duration, whereas no significant differences were found with 4-

Table 1
Reproduction Task: Mean Coefficient of Variation for Female (F) and Male (M) Participants for Each Standard Duration and Condition

Duration (in seconds)	Mean coefficient of variation									
	Neutral		Positive low arousal		Positive high arousal		Negative low arousal		Negative high arousal	
	F	M	F	M	F	M	F	M	F	M
2	0.23	0.26	0.24	0.22	0.24	0.23	0.30	0.32	0.27	0.28
4	0.23	0.23	0.23	0.21	0.25	0.20	0.18	0.20	0.21	0.23
6	0.21	0.21	0.19	0.18	0.21	0.17	0.17	0.18	0.17	0.17

and 6-s standard durations. No other interaction was found. The results showed no effect of sex, $F(1, 23) = 0.13$, $p = .71$, and no interaction with any other variables.

Discussion

The aim of Experiment 1 was to investigate the influence of emotional auditory stimuli on time reproduction. As expected, emotional sounds were perceived as being longer than neutral ones, at least for short durations. Using a similar paradigm in the visual modality, Angrilli et al. (1997) observed that neutral stimuli were "somewhat more underestimated than the mean of the emotional conditions" (p. 976), although no clear comparison was made between emotional and neutral durations, the latter having been used as fillers. In agreement with our results, Droit-Volet et al. (2004) and recently Gil, Niedenthal, and Droit-Volet (2007) showed that the emotional faces were judged longer than neutral ones, thus supporting activation-based theories of time perception (Burle & Casini, 2001; Droit-Volet et al., 2004). Indeed, a higher level of physiological activation elicited by emotional stimuli (Izard, 1990; Oatley & Jenkins, 1996; Routtenberg, 1968; Schachter & Singer, 1962) would lead, in the framework of internal clock models, to a longer perceived duration. The observed variability in the reproduction of 2-s emotional sounds is also consistent with the hypotheses of the internal clock model elaborated by Treisman (1963). According to Treisman, activation affecting the rate of the pacemaker would generate little variation during the course of any one trial, but its value would vary from trial to trial. In analogy with Treisman's proposal, emotional sounds were probably not equally activating. Hence, an increased variability is associated with a change in the speed of the pacemaker rate. Furthermore, negative stimuli were judged to be longer and with more variability than positive ones for a 2-s standard duration. This suggests that the influence of activation on the pacemaker rate is modulated by the valence of the stimuli. Negative sounds would generate a greater increase of this rate than would positive sounds, leading to a relatively longer subjective duration. As mentioned in the introduction, it is more important to escape from a danger than to pursue an opportunity. An avoidance or defensive behavior would be more activating than an appetitive reaction, leading negative stimuli to be perceived as being longer than positive ones. Negative affect produces physiological, cognitive, and social responses that are stronger than those produced by neutral or positive affects (e.g., Cacioppo & Gardner, 1999; Taylor, 1991). Because of this negativity bias, people may be especially sensitive to negative affect when estimating time. In agreement with this proposition, Thayer and Schiff (1975) found that the duration of threatening faces was perceived as longer than that of pleasant ones. Similar findings have been obtained using other bipolar affective states, such as danger and safety (Langer, Wapner, & Werner, 1961).

Our results also revealed a self-assessed arousal effect on time perception for a 2-s standard duration: Reproduction of high-arousing stimuli was shorter than that of low-arousing stimuli. This effect could be related to the proposed dissociation between arousal processes involved in behavioral response preparation from those associated with cognitive processes (Oatley & Jenkins, 1996; Routtenberg, 1968). The latter is linked to the evaluation of an event as relevant to an important concern (Oatley & Jenkins, 1996). Attention should be highly involved in such appraisal processes. Therefore, in the reproduction of an emotional sound duration, attention would be shared between timing and emotion processing. Attentional models of time perception assume that the less attention allocated to time, the shorter the subjective duration will be, with the switch either closing later or opening and closing more frequently, leading to a loss of pulses (Lejeune, 1998, 2000; Meck, 1984). In a high-arousing emotional context, attention would be particularly captured by emotional characteristics, and thus distracted from temporal ones, resulting in a shorter perceived duration than in a low-arousing context.

Overall, our results suggest that activation and attentional processes play a role in the timing of emotional events. However, the effects appear limited to duration processing of relatively short intervals. Owing to the lack of steps within the range we used, our design did not allow us to determine whether the decline of emotional effect is gradual or not. Besides the reproduction phase requiring memory retrieval, we cannot rule out the possibility that the observed decrease of the emotional effect could reflect a decline of the long duration mnemonic trace, which would not be specific to emotional sounds. Indeed, longer neutral sound durations were also relatively more underestimated than shorter ones. To address these questions, we conducted a second experiment with the same material but with additional durations (2, 3, 4, 5, and 6 s). We did not use shorter durations because recognition of contextual sounds of less than 2 s was rather poor. We also used another task: a verbal estimation task, which does not involve retrieval in memory after a delay, therefore reducing the impact of memory trace decline on emotion. Yet, it also allows testing of the robustness of our results across temporal paradigms.

Experiment 2: Verbal Estimation of Durations

Method

Participants. Seventeen right-handed participants (12 women, age 21 ± 3 years, and 5 men, age 24 ± 3.88 years) participated in this experiment. None had a history of neurological or psychiatric disorders, and informed consent was obtained from all of them.

Material, design, and stimuli. The apparatus and auditory stimuli were the same as in Experiment 1 and corresponded to the four emotional categories (i.e., pleasant high arousal, pleasant low arousal, unpleasant high arousal, and unpleasant low arousal) and the neutral category. The paradigm consisted of a verbal estimation task for which five standard durations were selected: 2, 3, 4, 5, and 6 s. Three series of 36 different sounds were created in which each sound appeared twice with a randomly attributed duration presentation (2, 3, 4, 5, or 6 s). Each series was thus composed of 72 stimuli.

Procedure. Each trial started with the presentation of a randomly selected standard interval. After the sound was presented, participants were required to write in a small notebook (one page per trial) an estimate of its duration using chronometric units. They were asked to be as precise as possible, and decimals could be used. They were first exposed to the shorter (2-s) and the longer (6-s) durations of a neutral sound to establish a representation of the range used in the experiment. Furthermore, they were given three training trials with neutral sounds to familiarize themselves with the task.

Results

Effect of emotion on time estimation. The ANOVAs were performed on *T*-corrected scores and CV as in the previous experiment. As in Experiment 1, the results showed a main effect of duration, $F(4, 44) = 6.69$, $p < .001$, and a main effect of emotion, $F(2, 22) = 3.94$, $p < .05$, on *T* corrected. The Duration × Emotion interaction was also significant, $F(8, 88) = 3.74$, $p < .001$. Post hoc tests (Newman–Keuls) indicated that neutral sounds were estimated to be shorter (see Figure 2) than low-arousal positive and negative sounds for the 2-s, 3-s, and 4-s standard durations ($ps <$ .05). This difference was not significant for 5- and 6-s durations ($ps > .05$). No effect of sex, $F(1, 22) = 0.66$, $p = .43$, and no significant interaction between sex and any other variables were found.

The ANOVA carried out on the CV (neutral vs. low-arousal emotional sounds; see Table 2) revealed a main effect of emotion, $F(2, 18) = 15.28$, $p < .01$, indicating that the mean CV for low-arousal negative sounds was greater than that of neutral ones, without significant difference between low-arousal positive sounds and neutral ones. A main effect of duration was also found, $F(4, 36) = 6.49$, $p < .01$, indicating that the mean CV for the 2-s standard duration was greater than those of longer durations. However, the Emotion × Duration interaction failed to reach significance, $F(8, 72) = 1.73$, $p = .10$. The results showed no effect of sex, $F(1, 9) = 1.07$, $p = .32$, and no significant interaction with any other variables.

Effect of emotional dimensions (valence and arousal) on time estimation. The ANOVA carried out on *T*-corrected scores revealed a main effect of valence, $F(1, 16) = 5.57$, $p < .05$, indicating that, as in Experiment 1, negative sounds were estimated to be longer than positive ones. A main effect of duration, $F(4, 64) = 6.37$, $p < .001$, was also found. The main effect of arousal was not significant, $F(1, 16) = 2.08$, $p = .17$. Contrary to Experiment 1, the Valence × Duration interaction failed to reach significance, $F(4, 64) = 0.51$, $p = .72$. However, planned comparisons revealed that for the 2-s standard duration, the negative sounds were significantly perceived to be longer than positive ones ($p < .05$); this difference was not significant for longer durations ($ps > 0.05$; see Figure 2). As in Experiment 1, the Arousal × Duration interaction was significant, $F(4, 64) = 3.20$, $p < .05$. Post hoc tests (Newman–Keuls) revealed that for the 2-s standard duration, low-arousal emotional sounds were perceived to be longer than high-arousal emotional ones ($p < .001$). This difference was not significant for longer durations ($ps > .05$). The Valence × Arousal interaction, $F(4, 64) = 0.73$, $p = .41$, and the Duration × Valence × Arousal interaction, $F(4, 64) = 0.95$, $p =$ .44, were not significant. The results demonstrated no effect of sex, $F(1, 16) = 1.04$, $p = .33$, and no significant interaction with any other variables.

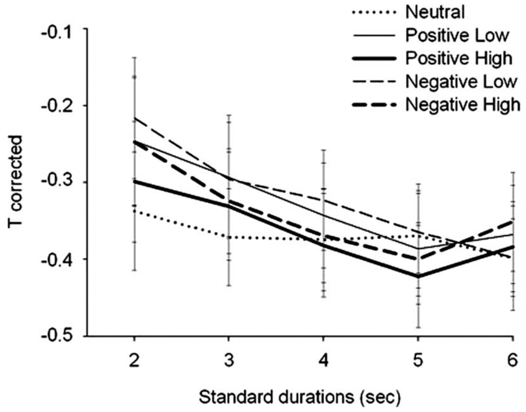

Figure 2. Verbal estimation task: *T*-corrected values (M ± SD) for each standard duration (2, 3, 4, 5, and 6 s) as a function of emotional content (neutral, positive–low, positive–high, negative–low, and negative–high).

The ANOVA carried out on the CV revealed a main effect of duration, $F(4, 64) = 7.54$, $p < .001$, and a significant Duration × Valence interaction, $F(4, 64) = 5.04$, $p < .01$. Post hoc tests (Newman–Keuls) showed that for the 2-s standard duration, the CV of the negative sounds were greater than those of the positive ones ($p < .05$). Contrary to Experiment 1, no Arousal × Duration interaction was found, $F(4, 64) = 0.07$, $p = .99$. The results revealed no effect of sex, $F(1, 16) = 0.89$, $p = .37$, and no interaction with any other variables was found (see Table 2).

Discussion

The data of this second experiment were consistent with those of the first one. First, emotional sounds were perceived to be of longer duration and with higher variability than neutral ones. Second, results showed that negative sounds induced a longer subjective duration than positive ones. Droit-Volet et al. (2004) observed an emotion-induced activation effect on time judgments within a temporal bisection task. We showed such an emotion-induced activation effect on time judgments in a reproduction task (Experiment 1) and in a verbal estimation task (Experiment 2).

Table 2
Verbal Estimation Task: Mean Coefficient of Variation for Female (F) and Male (M) Participants for Each Standard Duration and Condition

	Mean coefficient of variation									
	Neutral		Positive low arousal		Positive high arousal		Negative low arousal		Negative high arousal	
Duration (in seconds)	F	M	F	M	F	M	F	M	F	M
2	0.30	0.44	0.30	0.28	0.33	0.35	0.41	0.32	0.38	0.26
3	0.25	0.38	0.27	0.20	0.32	0.23	0.32	0.25	0.38	0.17
4	0.25	0.35	0.24	0.18	0.29	0.22	0.31	0.23	0.26	0.22
5	0.23	0.29	0.21	0.17	0.25	0.25	0.26	0.23	0.28	0.18
6	0.22	0.27	0.18	0.20	0.27	0.17	0.27	0.18	0.23	0.17

This emphasizes the robustness of emotion-induced activation across temporal judgment paradigms. Moreover, the results of our first experiment suggest that attentional mechanisms are driven by the emotional intensity of the sounds. Experiment 2 indicates a similar effect, with high-arousal emotional sounds perceived as being of shorter duration than low-arousal emotional sounds. The consistency of this effect across both temporal tasks shows its reliability. Owing to the difficulty of creating sounds that can be recognized within less than 2 s, we were not able to assess these emotional effects with shorter durations as was done in the visual modality. For example, the results of Droit-Volet et al., obtained with durations of up to 1,600 ms, only revealed the implication of activation mechanism. Although both experiments displayed differences between time estimates of neutral and emotional sounds for durations up to 4 s, Experiment 2 provides evidence for a gradual decline of the emotional effect (see Figure 2). Because the verbal estimation paradigm does not involve retrieval in memory after a delay, the observed decrease of emotional effect cannot be attributed to mnemonic trace decay.

Experiment 3: Induction of Emotion (Self-Assessment Manikin Ratings)

Method

An additional control experiment was performed to verify that stimuli elicited the emotions under consideration for all the durations used. Ratings of arousal and valence levels were collected in a group of 12 young adults (6 women, age 27 ± 3.43 years, and 6 men, age 27 ± 3.77 years) who did not participate in the main experiments. These participants were asked to rate the Self-Assessment Manikin (Hodes, Cook, & Lang, 1985; Lang, 1980) on two 9-point visual scales representing a cartoon subject ranging from sad to happy (emotional valence) and from calm to excited (arousal). Stimuli were presented for 2, 3, 4, 5, and 6 s in a random order.

Results

Kendall's correlations between IADS and rated scores were computed for the five durations. Correlations between subjective valence scores obtained by our participants and those of the IADS were significant, indicating that subjective valence ratings did match with those of the IADS, whatever the duration (2 s, $r = .78$; 3 s, $r = .77$; 4 s, $r = .78$; 5 s, $r = .78$; and 6 s, $r = .80$; all $ps < .001$). Correlations between subjective arousal scores obtained by our participants and those of the IADS were also significant, indicating that subjective arousal ratings did match with those of the IADS, whatever the duration (2 s, $r = .61$; 3 s, $r = .60$; 4 s, $r = .63$; 5 s, $r = .61$; and 6 s, $r = .61$; all $ps < .001$). ANOVAs performed on subjective valence scores with duration as a factor revealed no significant effects of duration, pleasant–high $F(4, 44) = 0.60$, $p = .66$; pleasant–low $F(4, 44) = 2.40$, $p = .08$; unpleasant–high $F(4, 44) = 2.35$, $p = .07$; unpleasant–low $F(4, 44) = 0.11$, $p = .97$; and neutral $F(4, 44) = 0.41$, $p = .24$. Similar analyses performed on the arousal score also showed no significant effects of duration, pleasant–high $F(4, 44) = 1.06$, $p = .38$; pleasant–low $F(4, 44) = 1.55$, $p = .20$; unpleasant–high $F(4, 44) = 0.56$, $p = .68$; unpleasant–low $F(4, 44) = 0.86$, $p = .48$; and neutral $F(4, 44) = 2.31$, $p = .07$. All these findings suggest that emotional arousal or valence of a sound does not vary as a function of duration.

General Discussion and Conclusion

Overall, the present findings support the idea that activation induced by emotional stimuli affects the processing of durations in the range of seconds, up to 4 s in our experiment, making time appear longer for emotional than for neutral stimuli. In line with activation-based models of time perception (Treisman, 1963), emotions probably generate an increase in the pacemaker rate, leading to a longer perceived duration than in nonemotional situations. Activation seems to be a predominant aspect of the influence of emotions on time perception, as all emotional stimuli, regardless of their self-assessed valence and arousal, are perceived as being longer than neutral ones. Furthermore, and consistent with action tendency models, the observed relative overestimation of negative stimuli compared with positive stimuli suggests that negative stimuli induce greater physiological activation than positive ones. The perception of duration of emotional events appears to involve not only activation but also attentional processes. Such attentional mechanisms would be driven by the level of self-assessed arousal, a high-arousing context distracting attention from temporal characteristics leading to a shorter perceived duration than in a low-arousing context.

Our results differ from those of Angrilli et al. (1997) with emotional pictures in the visual modality. Indeed, we found significant effects on both valence and arousal on duration judgments. Whereas Angrilli et al. failed to demonstrate any main effect of these variables, they obtained a significant interaction between them. The question is then to determine why effects that seem to be independent in the auditory modality should interact in the visual one. The discrepancy between our results and those of Angrilli et al. may come from modality differences in the processing of emotion. Several studies have addressed the modality effect in timing, with literature reporting that auditory signals are judged as longer and with greater precision than visual ones (e.g., Penney, Gibbon, & Meck, 2000; Wearden, Edwards, Fakhri, & Percival, 1998, Wearden, Todd, & Jones, 2006). These studies, however, have not addressed the issue of modality effect in the context of emotions, and it seems difficult to draw yet firm conclusions on this issue.

The results of both of our experiments suggest that emotion only affects the processing of short durations (up to around 3–4 s). This finding was consistent with that of Angrilli et al. (1997), who observed a significant arousal effect for 2 s. The presently observed absence of emotional effect for long durations cannot be explained by a different subjective perception of valence or arousal as function of duration because participants rated sounds equally whatever the duration (control Experiment 3). Moreover, this lack of difference for the long durations could not be explained by the use of counting. The large values observed for the CVs in the two tasks suggest that participants did not use chronometric counting (Wearden, 1991). This lowering of emotion-induced activation with time appears inconsistent with the literature on activation and timing. Indeed, studies usually report a greater overestimation with an increase of standard duration, this effect being multiplicative (e.g., Burle & Casini, 2001). The activation effect is greater for longer times than for shorter ones. In both our experiments, the interaction between emotion and duration showed the reverse pattern. Nevertheless, studies in which activation has been manipulated mostly tested the influence of activation on timing with short durations. Droit-Volet et al. (2004) used ranges from 400 to 1,600 ms, Wearden et al. (1998, 1999) used ranges from either 700 to 1,183 ms or 200 to 800 ms, and Burle and Casini (2001) examined a duration of 1,100 ms. All these studies thus tested the influence of activation on the processing of durations shorter than 2 s, which corresponds to the inferior limit of the range we used in both our experiments.

A simple and logical hypothesis is that the pacemaker rate would be increased by activation within the duration of the emotional effect and would then gradually return to its baseline. High-arousing stimuli should also have accelerated the pacemaker rate; therefore, it is somewhat surprising that they were underestimated compared with low-arousing stimuli. This could be a result of a confounding of the arousal with an attentional effect (for a similar argument, see Effron, Niedenthal, Gil, & Droit-Volet, 2006, p. 7, footnote 6). As discussed above, attention would be particularly captured by emotional characteristics in a high-arousing emotional context, resulting in an important loss of pulses. As duration was increased, so probably was attention to emotional sounds. This could entail more and more frequent openings and closures of the switch, that is, flickering (Buhusi & Meck, 2006; Fortin, 2003). Following this line of reasoning, we propose that the apparent restricted duration of emotional effect may stem from the interplay between a transitory acceleration of the pacemaker rate and increased attentional role with time. Thus, emotional stimuli would temporarily increase the pacemaker rate, and attentional sharing between timing and emotion processing would increase progressively with duration. This sharing would produce a loss of the number of pulses, cancelling the difference between estimated duration of emotional versus nonemotional stimuli, especially for the longest durations.

In conclusion, the present results support that both activation and attentional processes modulate the timing of emotional events and that such effects appear to be limited to the processing of short intervals.

References

Angrilli, A., Cherubini, P., Pavese, A., & Mantredini, S. (1997). The influence of affective factors on time perception. *Perception and Psychophysics, 59,* 972–982.

Boltz, M. G. (1994). Changes in internal tempo and effects on the learning and remembering of event duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1154–1171.

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion, 1,* 276–298.

Bradley, M. M., & Lang, P. J. (1999). *International affective digitized sounds (IADS): Stimuli, instruction manual and affective ratings* (Tech. Rep. No. B-2). Gainesville, FL: University of Florida, Center for Research in Psychophysiology.

Brown, S. W. (1985). Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception and Psychophysics, 38,* 115–124.

Buhusi, C. V., & Meck, W. H. (2006). Interval timing with gaps and distracters: Evaluation of the ambiguity, switch, and time-sharing hypotheses. *Journal of Experimental Psychology: Animal Behavior Processes, 32,* 329–338.

Burle, B., & Casini, L. (2001). Dissociation between activation and attention effects in time estimation: Implications for internal clock models. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 195–205.

Cacioppo, J. T., & Gardner, W. L. (1999). Emotion. *Annual Review of Psychology, 50,* 191–214.

Delay, E. R., & Mathey, M. E. (1985). Effects of ambient noise on time estimation by humans. *Perceptual and Motor Skills, 61,* 415–419.

Droit-Volet, S., Brunot, S., & Niedenthal, P. M. (2004). Perception of the duration of emotional events. *Cognition and Emotion, 18,* 849–856.

Effron, D. A., Niedenthal, P. M., Gil, S., & Droit-Volet, S. (2006). Embodied temporal perception of emotion. *Emotion, 6,* 1–9.

Fortin, C. (2003). Attentional time-sharing in interval timing. In W. H. Meck (Ed.), *Functional and neural mechanisms of interval timing* (pp. 235–259). Boca Raton, FL: CRC Press.

Fox, R. H., Bradbury, P. A., Hampton, I. F., & Legg, C. F. (1967). Time judgment and body temperature. *Journal of Experimental Psychology, 75,* 88–96.

Gibbon, J., Church, R., & Meck, W. (1984). Scalar timing in memory. *Annals of the New York Academy of Sciences, 423,* 52–77.

Gil, S., Niedenthal, P., & Droit-Volet, S. (2007). Anger and temporal perception in children. *Emotion, 7,* 219–225.

Hodes, R. L., Cook, E. W., 3rd, & Lang, P. J. (1985). Individual differences in autonomic response: Conditioned association or conditioned fear? *Psychophysiology, 22,* 545–560.

Izard, C. E. (1990). Facial expressions and the regulation of emotions. *Journal of Personality and Social Psychology, 58,* 487–498.

Lang, P. J. (1980). Behavioral treatment and bio-behavioral assessment: Computer applications. In J. B. Sidowski, J. H. Johnson, & T. A.

Williams (Eds.), *Technology in mental health care delivery systems* (pp. 119–137). Norwood, NJ: Ablex.

Lang, P. J., Bradley, M. M., & Cuthbert, M. M. (1997). Motivated attention: Affect, activation, and action. In P. J. Lang, R. F. Simons, & M. T. Balaban (Eds.) *Attention and orienting: Sensory and motivational processes* (pp. 97–135). Hillsdale, NJ: Erlbaum.

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology, 30,* 261–273.

Langer, J., Wapner, S., & Werner, H. (1961). The effect of danger upon the experience of time. *American Journal of Psychology, 74,* 94–97.

Lejeune, H. (1998). Switching or gating? The attentional challenge in cognitive models of psychological time. *Behavioural Processes, 44,* 127–145.

Lejeune, H. (2000). Prospective timing, attention and the switch. A response to "Gating or switching? Gating is a better model of prospective timing" by Zakay. *Behavioural Processes, 52,* 71–76.

McConchie, R. D., & Rutschmann, J. (1970). Reliability of time estimation: Effect of preceding reproduction series on the reliability of subsequent verbal estimates of the same standard stimuli. *Perceptual and Motor Skills, 31,* 51–55.

Meck, W. H. (1984). Attentional bias between modalities: Effect on the internal clock, memory, and decision stages used in animal time discrimination. *Annals of the New York Academy of Sciences, 423,* 528–541.

Oatley, K., & Jenkins, J. M. (1996). *Understanding emotions.* Oxford, England: Blackwell.

Penney, T. B., Gibbon, J., & Meck, W. H. (2000). Differential effects of auditory and visual signals on clock speed and temporal memory. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1770–1787.

Penton-Voak, I. S., Edwards, H., Percival, A., & Wearden, J. H. (1996). Speeding up an internal clock in humans? Effects of click trains on subjective duration. *Journal of Experimental Psychology: Animal Behavior Processes, 22,* 307–320.

Rai, S. N. (1975). Effects of environmental noises on estimation of duration. *Perceptual and Motor Skills, 40,* 338.

Routtenberg, A. (1968). The two-arousal hypothesis: Reticular formation and limbic system. *Psychological Review, 75,* 51–80.

Schachter, S., & Singer, J. E. (1962). Cognitive, social, and physiological determinants of emotional state. *Psychological Review, 69,* 379–399.

Taylor, S. E. (1991). Asymmetrical effects of positive and negative events: The mobilization–minimization hypothesis. *Psychological Bulletin, 110,* 67–85.

Thayer, S., & Schiff, W. (1975). Eye-contact, facial expression, and the experience of time. *Journal of Social Psychology, 95*(First Half), 117–124.

Treisman, M. (1963). Temporal discrimination and the indifference interval. Implications for a model of the "internal clock." *Psychological Monographs, 77,* 1–31.

Wearden, J. H. (1991). Do humans possess an internal clock with scalar timing properties? *Learning and Motivation, 22,* 59–83.

Wearden, J. H., Edwards, H., Fakhri, M., & Percival, A. (1998). Why "sounds are judged longer than lights": Application of a model of the internal clock in humans. *The Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology, 51*(2), 97–120.

Wearden, J. H., Pilkington, R., & Carter, E. (1999). Subjective lengthening during repeated of the simple temporal discrimination. *Behavioural Processes, 46*(1), 25–38.

Wearden, J. H., Todd, N. P., & Jones, L. A. (2006). When do auditory/visual differences in duration judgements occur? *Quarterly Journal of Experimental Psychology, 59,* 1709–1724.

Appendix

List of the Sounds (by International Affective Digitalized Sounds System Number)

Neutral sounds: 100, 171, 251, 262, 311, 320, 322, 358, 425, 602, 708, and 726.

Pleasant low arousal sounds: 206, 221, 230, 721, 811, and 820.

Pleasant high arousal sounds: 200, 201, 202, 352, 810, and 815.

Unpleasant low arousal sounds: 130, 280, 380, 420, 500, and 706.

Unpleasant high arousal sounds: 106, 115, 276, 277, 279, and 711.

Received September 6, 2006
Revision received May 14, 2007
Accepted May 23, 2007 ■