

1 **Modulation of tactile duration judgments by emotional pictures**

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20 **Running title:**

21 Crossmodal emotional modulation of tactile duration

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23

24 **Abstract**

25 Judging the duration of emotional stimuli is known to be influenced by their valence and  
26 arousal values. However, whether and how perceiving emotion in one modality affects time  
27 perception in another modality is still unclear. To investigate this, we compared the influence  
28 of different types of emotional pictures – a picture of threat, disgust, or a neutral picture  
29 presented at the start of a trial – on temporal bisection judgments of the duration of a  
30 subsequently presented vibrotactile stimulus. We found an overestimation of tactile duration  
31 following exposure to pictures of threat, but not pictures of disgust (even though these scored  
32 equally high on arousal), in a short-range temporal bisection task (range 300/900 ms).  
33 Follow-up experiments revealed that this duration lengthening effect was abolished when the  
34 range to be bisected was increased (1000/1900 ms). However, duration overestimation was  
35 maintained in the short-range bisection task regardless of whether the interval between the  
36 visual and tactile events was short or long. This pattern is inconsistent with a general arousal  
37 interpretation of duration distortion and suggests that crossmodal linkages in the processing  
38 of emotions and emotional regulation are two main factors underlying the manifestation of  
39 crossmodal duration modulation.

40

41 *Keywords:* duration estimation; emotion; threat; visual-tactile interaction; embodiment

42

43 **Introduction**

44 Judgments of time intervals are often distorted by the emotional state a person is in. For  
45 instance, when involved in an accident, such as car crash, people often report that they felt  
46 the world slow down. Although the phenomenon has been known for long, it has only been  
47 sparsely examined (Hare, 1963; Lang, Wapner, & Werner, 1961), with more systematic  
48 studies published only in recent years (Angrilli, Cherubini, Pavese, & Mantredini, 1997;  
49 Droit-Volet & Gil, 2009; Droit-Volet, Brunot, & Niedenthal, 2004).

50 The most simple and classical explanation of interval timing is provided by the internal clock  
51 model (Gibbon, Church, & Meck, 1984; Treisman, 1963; Zakay & Block, 1996). This model  
52 assumes an internal pacemaker that emits pulses at regular intervals, and a switch that starts  
53 and stops the counting of pulses. The pulses recorded by an accumulator represent the  
54 subjective time. Studies on emotion and time have shown that emotion can influence the  
55 internal pacemaker and/or the switch, and strongly distort perceived duration (see review  
56 Droit-Volet et al., 2004). For example, Angrilli and colleagues examined duration estimation  
57 for emotional pictures (taken from the International Affective Picture System; Lang et al.,  
58 2008) presented for 2, 4, or 6 s. They found that both emotional valence and arousal were  
59 important factors in duration judgments. For high-arousal stimuli, negative pictures (e.g.,

60 mutilated bodies) were perceived as longer in duration compared to positive pictures (e.g.,  
61 erotic scenes). In contrast, for low-arousal stimuli, duration of negative pictures was judged  
62 shorter than that of positive pictures (Angrilli et al., 1997). Angrilli et al. argued that two  
63 different mechanisms, one attentional and the other emotional, play important roles in time  
64 judgment. Negative events themselves engage more attentional resources (as also indicated  
65 by lowered heart rates). As a result, less attention is devoted to time processing and the  
66 negative events' durations tend to be underestimated. For high-arousal stimuli, so they argued,  
67 the effect of attention is minimized, and an emotional mechanism triggered by the pictures  
68 dominates the time estimation. Since high-arousal negative pictures evoke a defense response  
69 (Bradley, Codispoti, Cuthbert, & Lang, 2001), the duration of negative pictures is  
70 overestimated. By contrast, positive pictures evoke an approach response and thus their  
71 durations are underestimated. Similarly, other studies have shown that angry faces were  
72 judged as longer than neutral faces (Droit-Volet & Meck, 2007; Droit-Volet et al., 2004). It  
73 has been argued that both anger and fear are arousing emotions (Phelps & LeDoux, 2005),  
74 which increase the internal pacemaker rates, leading to temporal overestimation. Besides the  
75 visual modality, emotional modulation of time perception has also been found in the auditory  
76 modality (Noulhiane et al., 2007). Emotional sounds (e.g., a woman crying) were often  
77 judged as longer than neutral ones; and negative sounds were perceived as longer than  
78 positive ones (e.g., laughs).

79 Although there is now ample evidence of how emotion distorts duration perception, most of  
80 the studies have focused on unisensory modulation only. Given this, to date, there is still only  
81 scant understanding of how emotion induced from one sensory modality influences time  
82 judgments in another modality. The likely reason is that emotional effects are generally (and  
83 tacitly) assumed to be amodal in nature, that is: emotional arousal or anxiety exerts a general  
84 influence, not restricted to one sensory modality. This implicit assumption can be clearly seen  
85 in early crossmodal duration studies. For example, Hare attempted to examine how electrical  
86 shock influences auditory interval judgments (Hare, 1963). Auditory intervals were defined  
87 by two successive clicks. In the shock condition, a moderately painful (tactile) shock was  
88 delivered to participants' fingers at the second click, to induce general anxiety. Hare found  
89 that anxiety did indeed lead to a greater overestimation of auditory intervals compared to the  
90 baseline condition. However, recent crossmodal studies have provided evidence that each  
91 sensory system may possess its own clock (Buhusi & Meck, 2009), and time processing is  
92 distributed across brain regions (Matell & Meck, 2004). The sensory-specific clock model is  
93 supported by behavioral evidence, such as for modality-specific pacemaker rates (Droit-Volet,  
94 Meck, & Penney, 2007; Penney, Gibbon, & Meck, 2000; Wearden, Edwards, Fakhri, &  
95 Percival, 1998), as well as by neurophysiological evidence, for example, for separate brain  
96 regions underlying visual and auditory duration processing (Buetti, 2011; Buetti, Bahrami, &  
97 Walsh, 2008; Ghose & Maunsell, 2002). Studies on non-emotional crossmodal duration  
98 judgments have revealed rather complex, and inconclusive results (K.-M. Chen & Yeh, 2009;  
99 L. Chen, Shi, & Müller, 2010, 2011; Shi, Chen, & Müller, 2010; Walker & Scott, 1981; van  
100 Wassenhove, Buonomano, Shimojo, & Shams, 2008). For example, van Wassenhove et al.  
101 (2008) examined influences of visual (and, respectively, auditory) inputs on duration  
102 judgments of auditory (visual) events using looming and receding stimuli. They found the

103 duration of auditory events was lengthened or shortened by the presence of conflicting visual  
104 information, while the perceived duration of visual events was unaffected by auditory stimuli.  
105 However, other studies using static stimuli or implicit measures have reported the opposite  
106 effect, that is, perceived visual duration was affected by auditory duration (K.-M. Chen &  
107 Yeh, 2009; Shi et al., 2010). Interestingly, in order to explain the crossmodal duration  
108 interaction by looming stimuli, van Wassenhove et al. (2008) suggested that salient, looming  
109 stimuli might be treated as “threat” signals (i.e., as having a negative emotional valence),  
110 causing duration dilation within and across modalities. Again, as concerns emotion, the  
111 influence of emotion on duration judgments was implicitly assumed to reflect a  
112 sense-independent arousal effect.

113 However, as suggested by recent discrete emotion theory (Izard & Ackerman, 2000; Mikels  
114 et al., 2005), the arousal and valence dimensions may not provide a complete description of  
115 emotions. It is also conceivable that different types of emotion link to different behavioral  
116 functions and sensory modalities. For example, although both threat and disgust are  
117 categorized as high-arousal negative-valence emotions, they activate different processes.  
118 Threat activates our defensive system and biases motor responses (Bradley, Codispoti,  
119 Cuthbert, & Lang, 2001). Given that a threatening or dangerous event is most likely directed  
120 towards our body (e.g., the sight of a snake attacking), an association between what we see  
121 and what we feel in our body can be quickly established (Poliakoff, Miles, Li, & Blanchette,  
122 2007). This, in turn, may increase the tactile pacemaker speed and/or shorten the latency of  
123 the switch. Disgust, by contrast, is more related to avoiding something detrimental to our  
124 health or something tasting bad (Droit-Volet & Gil, 2009; Rozin & Fallon, 1987). Given this,  
125 the linkage between the visual and the tactile system by disgust events might not be as strong  
126 as that by threat events. Consequently, visual disgust signals may have only a relatively weak,  
127 if any, influence on the internal clock of the tactile system.

128 Moreover, duration judgments may also be influenced by the strength of perception-action  
129 associations. Research on duration estimation of emotional faces has shown that angry or  
130 fearful faces are often perceived as longer than neutral faces (Droit-Volet et al., 2004; Efron,  
131 Niedenthal, Gil, & Droit-Volet, 2006). However, when participants in such a study held a pen  
132 in their mouth to inhibit imitation of emotional faces, the duration lengthening was abolished  
133 (Efron et al., 2006). This finding suggests that perception-action associations are one of the  
134 critical factors causing changes of the internal clock system. Crossmodal associations induced  
135 by emotional stimuli might have a similar impact on time judgments.

136 To examine whether crossmodal emotional modulation of perceived duration is a general  
137 arousal effect or an emotion-specific effect, we compared modulations induced by three types  
138 of emotional pictures (threat, disgust, and neutral) on subsequent judgments of vibrotactile  
139 duration (Experiment 1). We chose threat and disgust since both are categorized as  
140 high-arousal negative emotions. If crossmodal emotional modulation reflected a general  
141 arousal effect, both types of emotional picture would engender similar distortions of tactile  
142 duration judgments. On the other hand, images depicting threat or fear may have particularly  
143 strong associations with the defensive system, compared to disgusting images. As supported  
144 by studies on affective modulation of the human startle blink (Balaban & Taussig, 1994;

145 Stanley & Knight, 2004), blink magnitude was significantly larger during the presentation of  
146 frightening pictures compared to disgusting pictures. Thus, an alternative prediction is that  
147 threatening pictures would influence perceived duration by related sensory systems, such as  
148 touch, more than disgusting pictures would.

149 To further investigate the mechanisms underlying crossmodal emotional modulation of the  
150 internal clock system, we explored effects of emotions by comparing their modulatory  
151 influences between short and long tactile durations (Experiment 2) as well as short and long  
152 inter-stimulus intervals (ISIs) between the emotional picture and the vibrotactile stimulus  
153 (Experiment 3). Analogous to unimodal studies, the rationale was to examine whether the  
154 internal pacemaker rate or/and the switch latency in the tactile modality are changed by  
155 emotional events from visual modality. If the tactile pacemaker rate is impacted, one would  
156 expect a slope effect (multiplicative effect) on short and long duration judgments (Wearden,  
157 1992, 2006), that is, the crossmodal emotional influence should be greater for long than for  
158 short durations. By contrast, if emotion influences only the switch latency, one would expect  
159 duration overestimation for both short and long duration conditions. However, if processes of  
160 emotional regulation supersede processes of activation during a late stage of processing, one  
161 might fail to observe duration overestimation in the long duration condition. Experiments 2  
162 and 3 were designed to examine for these effect patterns.

163

## 164 **Material and Methods**

### 165 **Participants**

166 14 (6 female; mean age 28), 15 (10 female; mean age 25), and 16 volunteers (10 female;  
167 mean age 25) took part in Experiments 1, 2, and 3, respectively. All participants had normal  
168 or corrected-to-normal vision, and none reported any somatosensory disorder. Written  
169 informed consent was obtained before the experiments.

### 170 **Materials**

171 The experiments took place in a sound-isolated cabin, which was dimly lit with an ambient  
172 luminance of  $0.76 \text{ cd/m}^2$ . Visual stimuli were presented on a 21-inch Sony CRT monitor with  
173 a refresh rate of 100 Hz. The viewing distance was kept constant at 57 cm using a chin-rest.  
174 Tactile vibration (250 Hz) was produced by an *AEC TACTAID VBW32* vibrator  
175 (Audiological Engineering Corp.; Vibrating surface  $1.6 \times 2.4 \text{ cm}$ ), which was fixed to the  
176 index finger of the participant's right hand. The participant was asked to place her/his right  
177 hand, behind a short black curtain, on the table in front of her/him; the curtain ensured that  
178 the participant could not see her/his hand, while she/he had a free view of the display screen.  
179 Visual and tactile stimuli presentation was controlled by a Matlab program using the  
180 Psychophysics Toolbox (Brainard, 1997).

181

182 Three types of pictures were selected from the International Affective Picture System (IAPS)  
183 (Lang, Bradley, & Cuthbert, 2005): threatening pictures evoking high arousal (such as a  
184 snake, shark, etc.); disgusting pictures also classed as high on arousal (such as a burn victim,  
185 mutilation); and neutral pictures rated ‘neutral’ in both valence and arousal. For Experiment 1,  
186 we used 5 pictures of disgust (mean valence 1.69; mean arousal 6.90), 5 pictures of threat  
187 (mean valence 3.28; mean arousal 6.73), and 10 neutral pictures (mean valence 4.82; mean  
188 arousal 2.47). For Experiments 2 and 3, we selected 10 threatening and 20 neutral pictures.  
189 Pictures were then evenly divided into two groups, each containing 5 attacking (mean valence  
190 3.3; mean arousal 6.7) and 10 neutral pictures (mean valence 4.9; mean arousal 2.7); these  
191 were assigned randomly to one or the other of two test sessions (see details in Procedure  
192 section). Descriptions and IAPS numbers of the pictures are given in Appendix 1.

### 193 **Procedure**

194 We used a temporal bisection task in all experiments. Participants were first trained with two  
195 anchor tactile durations: a short vibration (S) and a long vibration (L). Then, in the  
196 subsequent test sessions, several probe durations between S and L were presented to  
197 participants, who had to indicate whether the probe duration was closer to S or to L. In  
198 Experiments 1 and 3, S and L durations were 300 and 900 ms and the probe durations were  
199 400, 500, 600, 700, and 800 ms, respectively. In Experiment 2, there were two different  
200 ranges of temporal bisection tasks: 300/900 ms and 1000/1900 ms. For the range of 300/900  
201 ms, S, L, and probe durations were the same as in Experiment 1. For the range of 1000/1900  
202 ms, S and L durations were 1000 and 1900 ms and the probe durations were 1150, 1300,  
203 1450, 1600, and 1750 ms, respectively.

204 In the training session, an experimenter sat beside the participant to make sure that her/his  
205 anchor discrimination performance reached perfect level. Then, the experimenter left the  
206 cabin and the test session started. In the test session, a trial started with a ‘go’ display which  
207 contained a central blue fixation dot (subtending 0.3° of visual angle) and the blue word  
208 “Ready!” just above fixation on a gray background. After the participant pressed a button, the  
209 ‘go’ display disappeared and a blank display was shown randomly for 300 to 800 ms. Then a  
210 picture, randomly chosen from selected pictures, was presented for 1 second. In Experiments  
211 1 and 2, after a short, random inter-stimulus interval (ISI) of 400 to 600 ms, a vibration was  
212 delivered to the participant’s index finger for a given probe duration (see above). In  
213 Experiment 3, the ISIs between picture and vibration were fixed to be either short (500 ms) or  
214 long (1500 ms). When the vibration had terminated, a question mark was displayed on the  
215 screen prompting the participant for a response: she/he had to judge, as accurately as possible,  
216 whether the duration of the vibration was closer to S or to L and indicate the choice by  
217 pressing keys labeled ‘short’ and ‘long’ on the keyboard. The inter-trial interval (ITI) was set  
218 to 4 to 6 seconds, in order to avoid potential inter-trial interference. There were 4 blocks,  
219 each of 25 trials. At the beginning of each block, both the S and L anchor durations were  
220 presented 5 times each, for refreshing the participant’s memory of two anchors. Participants  
221 took rests of about 1 minute between blocks.

222 After the test session, the participant was asked to rate the valence and arousal of the pictures  
223 using a sheet of paper with 9-point scales Self-Assessment-Manikin (SAM) (Bradley & Lang,  
224 1994).

## 225 **Results**

### 226 **Assessment of Emotions**

227 For Experiment 1, a repeated-measures ANOVA revealed rated valence to differ significantly  
228 among threatening, disgusting, and neutral pictures,  $F(2,26) = 94.08$ ,  $p < 0.01$ . Follow-up  
229 Bonferroni t-tests showed that the average valence was lower for disgusting pictures  
230 compared to both threatening and neutral pictures (both  $p < 0.01$ ), and the mean valence of  
231 threatening pictures was lower than that of neutral pictures,  $p < 0.01$ . A further  
232 repeated-measure ANOVA revealed rated arousal, too, to differ significantly among  
233 conditions,  $F(2,26) = 112.89$ ,  $p < 0.01$ . Follow-up Bonferroni t-tests showed that disgusting  
234 and threatening pictures were higher in arousal ratings than neutral pictures (both  $p < 0.01$ ),  
235 without a difference between the former ( $p > 0.1$ ).

236 The mean valence of threatening pictures was significantly lower than that of neutral pictures,  
237 in both Experiment 2 ( $F(1,14) = 77.79$ ,  $p < 0.01$ ) and Experiment 3 ( $F(1,15) = 116.94$ ,  $p < 0.01$ ).  
238 Furthermore, repeated-measures ANOVAs revealed the mean arousal to be significantly  
239 higher for threatening than for neutral pictures,  $F(1,14) = 86.30$ ,  $p < 0.01$  (Experiment 2) and  
240  $F(1,15) = 125.88$ ,  $p < 0.01$  (Experiment 3).

241 Thus, the results of the subjective ratings were consistent with the rating of valence and  
242 arousal from the IAPS.

### 243 **Temporal Bisection**

244 The proportions of 'long' responses were calculated for the 5 probe durations and fitted by a  
245 logistic function, for each condition and each subject. The temporal bisection points were  
246 then calculated based on the 50% point of the estimated logistic functions (Treutwein &  
247 Strasburger, 1999).

248 Figure 1 shows average psychometric curves for the three emotion (i.e., neutral, disgust, and  
249 threat) conditions in Experiment 1. The mean temporal bisection points ( $\pm$ SE) for the tactile  
250 S/L duration pair 300/900-ms were  $552 \pm 14$ ,  $550 \pm 19$ , and  $529 \pm 15$  ms for the neutral, disgust,  
251 and threat conditions, respectively (Figure 2). A repeated-measures ANOVA showed that the  
252 type of emotion picture significantly influenced the (subsequently performed) judgment of  
253 tactile duration,  $F(2,26) = 4.41$ ,  $p < 0.05$ . Follow-on linear contrast tests revealed tactile  
254 temporal bisection point to be significantly lower in the threatening condition compared to  
255 both the neutral ( $p < 0.01$ ) and disgust ( $p = 0.05$ ) conditions, while there was no difference  
256 between the latter ( $p > 0.1$ ). This pattern indicates that the modulatory influence of emotional  
257 pictures on tactile duration judgments was due mainly to the threatening condition. The lower  
258 temporal bisection point in this condition means that participants tended to overestimate the  
259 physical tactile duration of a vibratory stimulus preceded by a threatening picture.

260 Interestingly, however, the subjective ratings of arousal (mean 7.41) were as high for  
261 disgusting pictures as for threatening pictures (mean 6.86). Given that duration  
262 overestimation only occurred in the threatening condition, arousal level alone cannot explain  
263 the crossmodal emotional modulation of time judgments.

264 \*\* Figure 1 & 2\*\*

265 Experiment 2 was designed to examine how threatening pictures influence performance on  
266 short-range (300/900 ms) and long-range (1000/1900 ms) tactile temporal bisection tasks. In  
267 the short-range task, the mean temporal bisection points ( $\pm$ SE) were  $550\pm 12$  and  $573\pm 12$  ms  
268 for the threat and neutral conditions, respectively; and in the long-range task, the points were  
269  $1399\pm 16$  (threat) and  $1385\pm 18$  ms (neutral), respectively (Figure 3). A two-way  
270 repeated-measures ANOVA with the factors temporal bisection range (300/900 vs.  
271 1000/1900 ms) and emotional picture type (threat vs. neutral) revealed the main effect of  
272 temporal bisection range,  $F(1,14)=2136.55$ ,  $p<0.01$ , and the interaction,  $F(1,14) = 6.18$ ,  
273  $p<0.05$ , to be significant; the main effect of emotional picture type was non-significant,  
274  $F(1,14)=0.14$ ,  $p=0.71$ . Follow-up simple contrast tests showed that the temporal bisection  
275 point was lower with threatening pictures (indicative of a duration overestimation) in the  
276 short-range task,  $F(1,14) = 5.17$ ,  $p<0.05$ , but not in the long-range task,  $F(1,14) = 0.71$ ,  
277  $p=0.42$ . Thus, while the results from the short-range condition are consistent with those of  
278 Experiment 1, there was no evidence of crossmodal duration lengthening in the long-range  
279 condition.

280 \*\* Figure 3 \*\*

281 However, it remains unclear from Experiment 2 whether the absence of a crossmodal  
282 duration overestimation following threatening pictures in the long-range temporal bisection  
283 task (1000/1900 ms) is due to the modulatory effect of emotion passively dissipating over  
284 time. Experiment 3 was designed to examine this question by comparing the effects of short  
285 (500 ms) and long (1500 ms) ISIs between the emotional picture and the tactile stimulus  
286 using the short-range temporal bisection task (300/900 ms). The intervals from the onset of  
287 the emotional picture to the offset of the tactile stimulus in the long ISI condition were then  
288 similar to that in the long-range condition (Experiment 2). Figure 4 depicts the mean tactile  
289 temporal bisection points for the neutral and threat picture conditions for short and long  
290 visual-tactile ISIs, respectively. The average temporal bisection points ( $\pm$ SE) were  $532\pm 12$   
291 and  $549\pm 11$  for threatening and neutral pictures in the short-ISI condition, and  $527\pm 12$   
292 (threatening) and  $549\pm 10$  ms (neutral) in the long-ISI condition. A two-way  
293 repeated-measures ANOVA with main terms of ISI and emotional picture type revealed the  
294 bisection points to be significantly lower in the threatening compared to the neutral condition,  
295 for both short and long visual-tactile ISIs. There were no effects involving ISI (main effect,  
296  $F(1,15)=0.26$ ,  $p=0.62$ ; interaction,  $F(1,15)= 0.11$ ,  $p=0.74$ ). This indicates that the  
297 modulatory effect of threatening picture in the short-range condition did not simply lessen  
298 over time, that is, as a function of merely lengthening the ISI between the emotional picture  
299 and the tactile stimulus.

300

\*\* Figure 4 \*\*

301

302 **Discussion**

303 The present study was designed to investigate the effect of viewing visual emotional stimuli  
304 on the subsequent estimation of the duration of non-emotional tactile events. We compared  
305 the effects of viewing three types of emotional pictures (neutral, threat, and disgust) in a  
306 short-range (300/900 ms) tactile temporal bisection task in Experiment 1. The results  
307 revealed the processing of threatening pictures to lengthen, relative to the neutral baseline,  
308 the subsequent judgments of tactile duration, as evidenced by a lowered mean temporal  
309 bisection point in the threat compared to the neutral condition. Interestingly, the lengthening  
310 effect was not simply due to the high arousal induced by the threatening pictures: both threat  
311 and disgust pictures were rated as high in arousal negative in valence in the subjective ratings  
312 (using SAM sheets) of the participants in the present study as well as in the IAPS norms. Yet,  
313 no lengthening effect was evident in the disgust condition. This is clearly inconsistent with  
314 the predictions deriving from the assumption of a general arousal effect.

315 Previous studies of judged durations of emotional events themselves have shown that arousal  
316 and valences are two main factors for duration distortions (Angrilli et al., 1997; Droit-Volet  
317 et al., 2004; Grommet et al., 2011; Noulhiane et al., 2007). Using IAPS pictures, Angrilli and  
318 colleagues observed that the durations of high-arousal negative-valence pictures were  
319 overestimated (Angrilli et al., 1997). A similar effect has been reported for the auditory  
320 modality, with high-arousal negative sounds being judged as longer in duration than positive  
321 ones (Noulhiane et al., 2007). Moreover, a recent study suggests that negative high-arousal  
322 activation, such as produced by a frightening movie, can also influence the subsequent time  
323 judgment of a neutral visual event (Droit-Volet, Fayolle, & Gil, 2011). However, it is not  
324 clear from those studies whether arousal activation from one modality can influence time  
325 perception in another modality. In contrast to these earlier studies on the temporal perception  
326 of emotional events themselves, in the present study, we focused on duration distortions  
327 induced by crossmodal emotional linkages. We found that viewing a rather threatening (e.g.,  
328 a snake attacking), but not a disgusting (e.g., a mutilated body), picture expanded the  
329 subsequent tactile duration, although both threat and disgust emotions induced high arousal.  
330 Our findings suggest that the crossmodal modulatory effect of emotion depends on the type  
331 of emotional stimuli. This is consistent with the ‘discrete emotion’ theory (Izard & Ackerman,  
332 2000; Mikels et al., 2005), which posits that different core emotions (such as disgust, fear,  
333 anger, etc.) link different behavioral functions. Studies of the affective modulation of the  
334 startle blink reflex (Balaban & Taussig, 1994; Stanley & Knight, 2004) and duration  
335 estimation of emotional faces (Droit-Volet & Gil, 2009; Droit-Volet et al., 2007) suggest that  
336 the emotion of disgust has less salience than that of threat. A threatening picture often  
337 portrays an attack signal, which invokes the anticipation (or fear) of potential damage to  
338 perceiver’s body. Thus, the perceiver is put in a state in which she/he needs to react as  
339 quickly as possible to the threatening signal (e.g., fight or flight). Indeed, it has been found

340 that automatic defense systems come into operation within an ‘eye blink’ for biologically  
341 relevant threat events (e.g., snakes, spiders), with their activation being based mainly on  
342 preattentive coding mechanisms (Öhman, 1997; Öhman & Mineka, 2001). The threatening  
343 event also establishes a strong association between the visual and tactile modalities, as  
344 suggested by several neuro-imaging studies (Dong, Chudler, Sugiyama, Roberts, & Hayashi,  
345 1994; Gray & Tan, 2002; Keysers et al., 2004; Lloyd, Morrison, & Roberts, 2006). For  
346 example, posterior parietal cortex has been shown to play an important role in the early  
347 integration of visual information with somatosensory, proprioceptive signals. Lloyd and  
348 colleagues found an increase in posterior parietal cortex activity in response to observing a  
349 sharp (painful) stimulus, versus a non-painful stimulus, touching a rubber hand in peripheral  
350 space, in the absence of any direct tactile stimulation (Lloyd et al., 2006). Consistent with  
351 reports such as these, our findings provide further behavioral evidence of visual-tactile  
352 associations elicited by threat-type emotional pictures.

353 The asymmetrical crossmodal modulation of duration judgments by pictures of threat versus  
354 those of disgust would also argue in favor of multiple-clock models (Buetti, 2011; Buhusi &  
355 Meck, 2005; Ivry & Richardson, 2002). On this notion, time processing is “distributed” to  
356 different sensory-specific brain regions, with each of the multiple clocks operating separately.  
357 Within this framework, our results complement, rather than being in conflict with, previous,  
358 unimodal studies of emotional modulations of duration judgments. These studies have shown  
359 that the durations of emotional pictures themselves are overestimated, likely due to the  
360 “visual” clock being modulated by the pictures’ arousal and valence signals. Our results go  
361 beyond this by showing that emotions induced via the visual modality may influence the  
362 “tactile” clock, depending on the strength of the emotional association induced between the  
363 visual and tactile modalities.

364 How does visual threat influence the tactile clock? Does exposure to threatening pictures  
365 subsequently speed up the tactile pacemaker or/and shorten the switch latency? Using a short-  
366 and a long-range temporal bisection task in Experiment 2, we observed a crossmodal duration  
367 lengthening by the threatening pictures in the short-range temporal bisection task (300/900  
368 ms), replicating the finding of Experiment 1; by contrast, no such lengthening was observed  
369 in in the long-range task (1000/1900 ms). The lacking crossmodal modulation in the  
370 long-range condition suggests that the tactile pacemaker is unlikely to be speeded up by  
371 preceding high-arousal visual stimuli. Otherwise, one would have expected to see a general  
372 slope effect, that is, a larger duration expansion in the long-range condition. A recent study  
373 (Grommet et al., 2011) of the time estimation of visual fear cues using two different duration  
374 ranges (250/1000 ms, 400/1600 ms) concluded that the fear effects were mediated mainly by  
375 the switch latency, rather than the speeding up of the internal pacemaker. In the study of  
376 Grommet et al., the duration expansion of the fear cue itself was of a similar magnitude in  
377 both the short- and the long-range condition.

378 If the tactile switch latency is shortened by the presentation of threatening images in the  
379 present study, then why did we fail to observe a duration lengthening in the long-range  
380 condition? We suggest that the absence of such an effect is due to a dynamic shifting of  
381 attention from emotional activation to emotional regulation mechanisms (Casini & Macar,

1997; Fortin, 2003; Macar, Grondin, & Casini, 1994; Zakay, 1989). Emotional activation is often followed by emotional regulation, in line with the existence of two emotional pathways, one subcortical and one cortical (LeDoux, 1995). The former is rapidly activated by potentially dangerous or survival-relevant stimuli – even though the stimuli are not fully processed, facilitating the preparation of (physiologically autonomous) response programs for avoidance (flight) or fight. The cortical pathway, by contrast, processes information more precisely, though this takes more time. Precise cortical stimulus analysis in turn can help to inhibit or correct ‘erroneous’ early responses elicited by the subcortical pathway, thus readjusting the subsequent behavior. When participants in the present study are exposed to threatening pictures, attentional resources may first be rapidly directed to the defensive system, including the somatosensory system, for preparing a reaction. Possibly, the strong visual-tactile linkage reduces the latency of the tactile switch at the beginning. Consistent with this, tactile duration was overestimated in the short-range temporal bisection tasks of the present Experiments 1 and 2. While the same would apply to the long-range condition, participants (in this condition) would eventually realize that the tactile vibration is not a threat event. Accordingly, attentional resources would be increasingly redirected to processes of emotional regulation. As a consequence, some pulses may be lost in the time accumulation, leading to an underestimation of the tactile duration. The absence of an (overt) emotional modulation in the long-range condition may then arise from the overestimation brought about by the shortened switch latency being nulled by an underestimation owing to the emotional regulation.

However, one alternative explanation: general emotional attenuation, could also account for the absence of duration lengthening in the long-range condition. As reported in previous unimodal studies (Angrilli et al., 1997; Noulhiane et al., 2007), the duration lengthening induced by emotional stimuli disappeared for the judgment of long durations (usually above 4 seconds). The absence of an emotion effect in these studies has been attributed to dynamic pacemaker changes by emotional attenuation: The pacemaker rate would be increased by the onset of the emotion event and would then gradually return to baseline when emotion attenuates over time. Note, however, that the emotional attenuation could also be the result of emotional regulation – which are the two faces of one and the same coin.

One interesting question, though, is at what point in time emotional regulation takes over. The results of the present Experiment 3 suggest that emotional regulation is unlikely to occur prior to the subsequent (tactile) event. Recall that in the long-ISI condition of Experiment 3, the time interval from the onset of the emotional picture to the offset of the tactile vibration was the same as that in the long-duration condition of Experiment 2. If emotional regulation (or emotional attenuation) took place immediately after the onset of the emotional event, one would predict both conditions to yield the same crossmodal emotional modulation of duration judgments. However, on the opposite (and unlike the nulling effect in the long-duration condition), the tactile duration lengthening effect evoked by threatening pictures was almost as large in the long-ISI as in the short-ISI condition. This suggests that the crossmodal linkage activated by threatening events was not attenuated before the subsequent event, at least within the time range of our study (3 s). The defensive system appears to be still highly activated and dominant for reacting to the external world after the threatening events. Only

425 when the subsequent event is identified to be non-threatening (as under the long-duration  
426 condition of Experiment 2) does emotional regulation become dominant and the  
427 emotion-induced defensive bias dissipates gradually.

428 In summary, the present results indicate that the crossmodal subjective-duration lengthening  
429 effect is emotion-specific: tactile duration is overestimated following exposure to pictures of  
430 threat, but not to pictures of disgust of the same high-arousal potential. However, the duration  
431 lengthening disappears for long-range durations. This pattern may be best explained by the  
432 latency of the tactile (clock's) switch being shortened by crossmodal emotional activation,  
433 while emotional regulation takes over after the subsequent (tactile) event is identified as a  
434 non-threatening signal.

435

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572 **Appendix**573 **Table 1. IAPS stimuli used in the current study**

<b>Category of pictures</b>	<b>IAPS number</b>	<b>Picture description</b>
<b>Mutilation pictures</b>	3030	Mutilation
	3053	Burn Victim
	3060	Mutilation
	3071	Mutilation
	3120	Dead body
<b>Animal or human attacking pictures</b>	1052	Snake
	1120	Snake
	1201	Spider
	1300	Pit Bull
	1321	Bear
	1930	Shark
	6250	Aimed Gun
	6260	Aimed Gun
	6300	Knife
	6510	Attack
<b>Neutral Pictures</b>	2840	Chess
	5500	Mush room
	7000	Rolling Pin
	7009	Mug
	7035	Mug
	7041	Baskets
	7050	Hair Driver
	7059	Key ring
	7090	Book
	7140	Bus
	7150	Umbrella
	7161	Pole
	7185	Abstract Art
	7224	File Cabinets
	7233	Plate
	7235	Chair
	7490	Window
7700	Office	
7705	Cabinet	

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577 **Figure Captions**

578 Figure 1. Mean proportions of “Long” responses plotted against probe durations and fitted  
579 psychometric functions for three emotion conditions (neutral, threat, and disgust). The dotted  
580 curve and crosses represent the neutral condition, the dash-dotted curve and pluses the disgust  
581 condition, and the solid curve and diamonds the threat condition.

582 Figure 2 Mean temporal bisection points (and associated standard errors) for three emotional  
583 conditions (n=14).

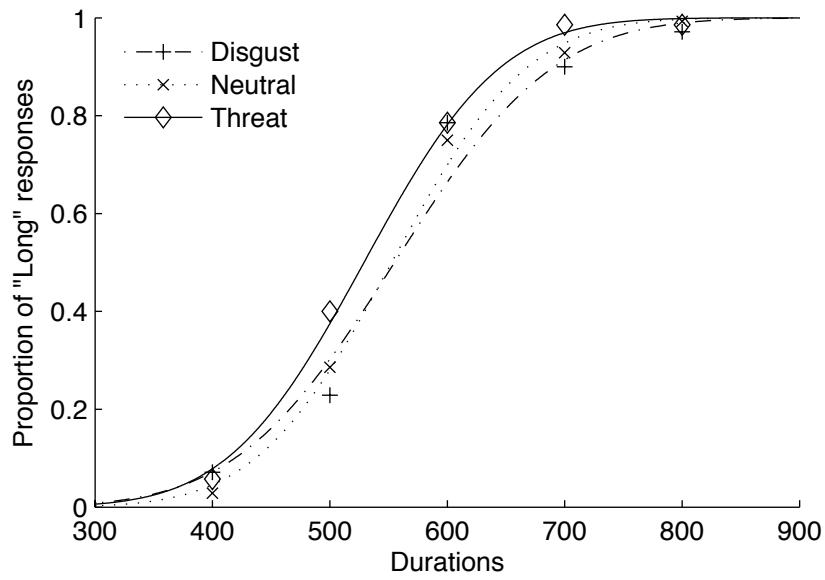
584 Figure 3. Mean temporal bisection points (and associated standard errors) plotted against  
585 threat and neutral picture conditions, for the short-range (300/900 ms) and the long-range  
586 (1000/1900 ms) sessions (n=15).

587 Figure 4. Mean temporal bisection points (and associated standard errors) plotted against  
588 threat and neutral picture conditions, for the short-ISI (500-ms) and the long-ISI (1000-ms)  
589 session (n=16).

590

591 **Figures**

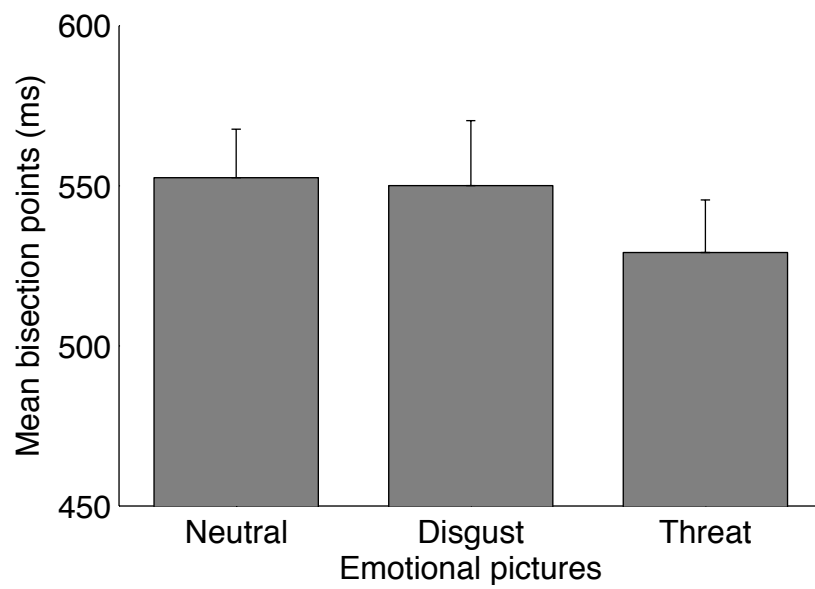
592 Figure 1



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594

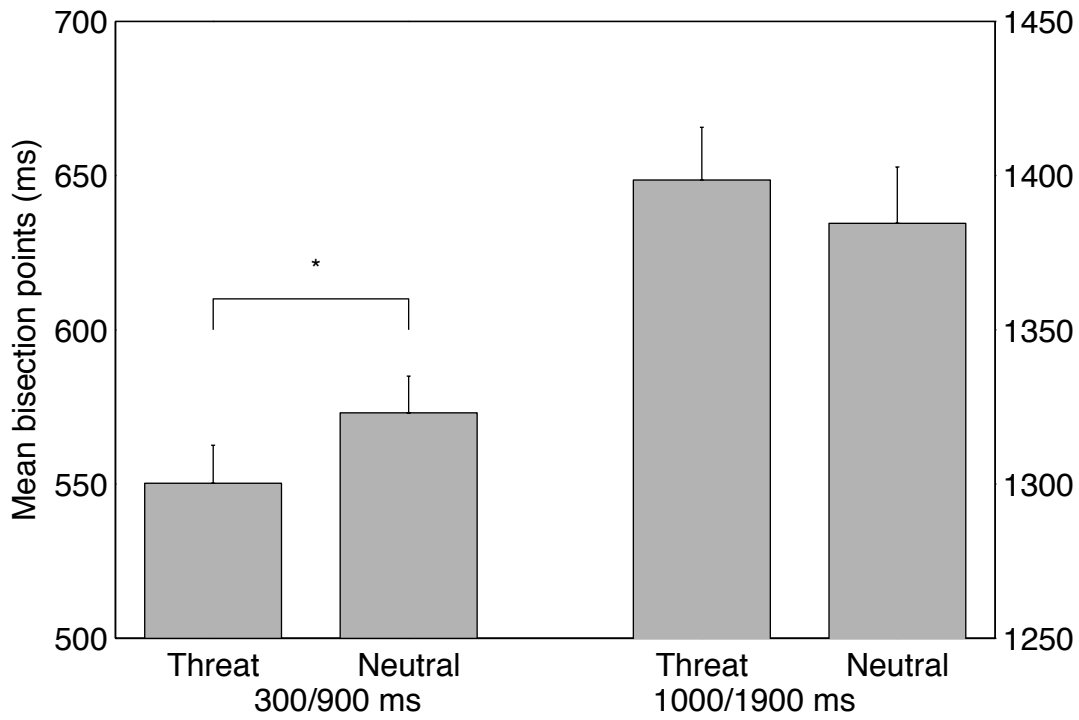
595 Figure 2



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597

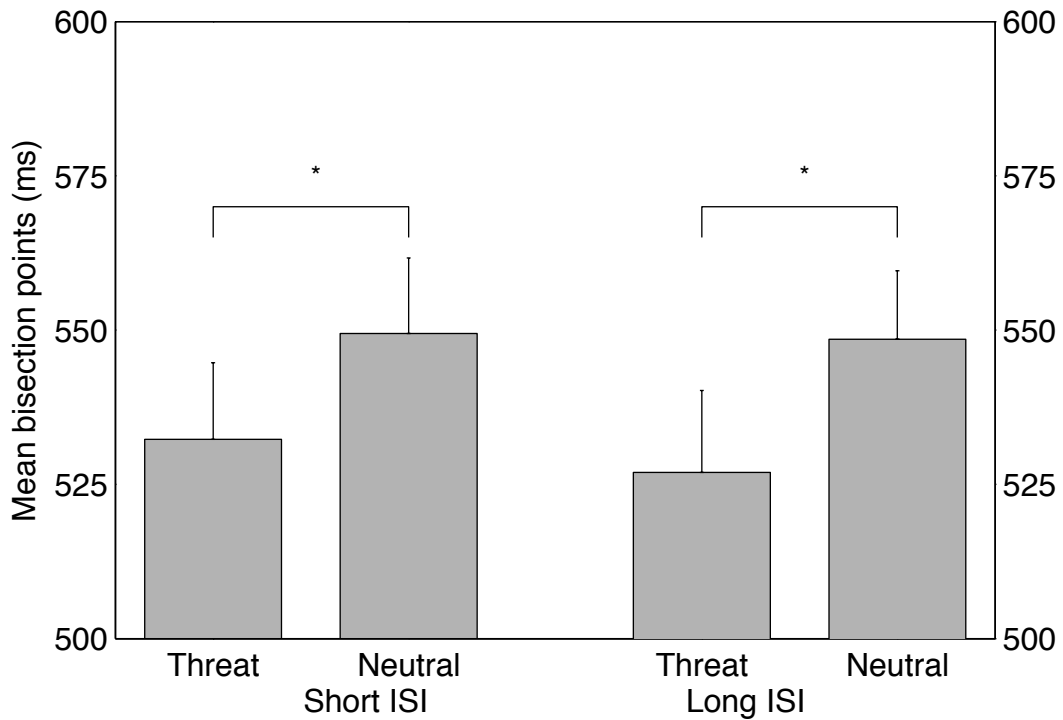
598 Figure 3



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601 Figure 4



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