Time estimation of fear cues in human observers

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A paraître dans / To appear in:


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Abstract

Previous research suggests that time judgments are a function of the affective properties of stimuli that are fear-inducing (e.g., Hare, 1963; Watts and Sharrock, 1984). The goals of the present study were twofold: to replicate the effect of a fear cue on time estimation, and to evaluate the mechanism underlying the effect. Seven stimulus durations in two different duration ranges (short: 250–1000 ms; long: 400–1600 ms) were employed in the bisection procedure. Adult human participants were exposed to two successive sessions, one each with the short and long range. Images from the International Affective Picture System (IAPS; Lang et al., 2008) that were rated on three scales including arousal and fear were presented as temporal stimuli. Three images that were rated high on fear and three rated low served as fear cues and neutral control images, respectively. Results indicated that for both ranges, judgments were longer for fear cues than for neutral images, and that the magnitude of the effect did not differ between ranges as measured by the bisection point. Application of scalar expectancy theory (SET; Gibbon, 1977; Church, 1984) to these results suggests that the fear effects were mediated by switch latency of an internal clock, rather than by clock speed.

Introduction

Time judgments are known to be modulated by emotional factors, including the emotional properties of the cues that are the object of time judgments (e.g., Angrilli et al., 1997; Droit-Volet et al., 2004; Gil et al., 2007; Hare, 1963; Tipples, 2008; Watts and Sharrock, 1984). The aim of the present study was to investigate how fear-evoking cues affect the perception of time in humans. Recently, in a temporal bisection task, Droit-Volet and her collaborators found that photographs of faces expressing anger were overestimated in comparison with neutral expressions (for a review see Droit-Volet and Gil, 2009). They proposed that perception of the other's anger produced fear in the perceiver; however, they were unable to determine whether the perception of angry faces produced fear rather than anger in the participants. Some early studies in human adults have investigated the effect of fear cues on timing, but did not directly assess the emotional properties of the stimuli. For example, Watts and Sharrock presented a live spider for 45s to participants who were or were not spider phobic, and reported longer estimates of the duration of the spider presentation in the phobic group. In that study, not only were diagnostic group differences confounded with fear-evoking properties of the cue, but also time estimates of a non-fear-evoking cue were not provided. In a different design, Hare (1963) asked participants to estimate the elapsed time between two successive clicks on a stopwatch under conditions in which a shock was delivered by finger electrodes at the end of the interval or the electrodes were absent. A sample shock was delivered prior to the first time estimation trial containing shock. Two intervals (5s and 20 s) were each presented twice; one trial with each interval was followed by the previously sampled shock and the other was not. The results showed that the participants judged the interclick interval longer on trials with shock in comparison to trials without shock. Hare interpreted the difference between the shock and no-shock conditions as evidence either of anxiety-provoking effects of a stimulus (including electrodes) that predicts shock or of anticipation of the shock. Hare did not consider the possibility of a confound arising from shock itself exerting retrospective effects on the estimation of the duration of the time cues. A condition with no shock in the presence of the electrodes would be necessary to determine whether this factor indeed played a role in the overestimates in timing.

One goal of the present study was thus to investigate, more systematically, the role of fear-evoking cues on time estimation. Subjects estimated the duration of fear evoking and neutral pictures from the International Affective Pictures System (IAPS; Lang et al., 2008) that have been extensively tested for their emotionality, both for their level of induced arousal and for the type of emotion induced. A well-controlled standard time estimation task, the bisection
procedure, was used. In that procedure, the participant is initially trained to make one response (e.g., keystroke) following a short-duration anchor cue and another response following a long-duration anchor cue. Then, in the test phase, anchor durations are presented as well as five intermediate durations in random order over a series of trials, and the participants must judge whether each duration is more similar to the short or to the long anchor duration. When the proportion of trials with a “long” response \( p(\text{Long}) \) is plotted against stimulus duration, the result is a sigmoidal psychometric function that increases with stimulus duration. In classical psychophysics, the stimulus duration corresponding to \( p(\text{Long}) = .50 \) is the point of subjective equality (PSE) that has been taken as the subjective bisection point between the anchor durations. Consequently, an overestimation of duration produced by fear would be expected to inflate \( p(\text{Long}) \) scores and shorten the bisection point.

A second goal of the present study was to evaluate the mechanism underlying a fear effect on the perception of time in the bisection task. In the structural instantiation of scalar expectancy theory (SET; Gibbon, 1977; Church, 1984), there are three main stages in prospective timing: clock, memory, and decision-making. The source of overestimation may be located in the clock stage, consisting of a pacemaker that gates pulses through a switch to an accumulator, the contents of which represent subjective elapsed time. The switch is assumed to be under stimulus control such that the onset of a timing cue closes the switch with a given latency, permitting pacemaker-emitted pulses to flow to the accumulator until the switch is opened, with a given latency, at the termination of the cue. Fear-driven overestimation may be the result of one or more of these clock subcomponents: a higher pacemaker emission rate, a shorter switch closure latency, or longer switch-opening latency. A distinction between these pacemaker- or switch-based mechanisms can be achieved with a manipulation of timing-cue duration, as clock speed and switch latency effects are multiplicative and additive, respectively (Maricq et al., 1981; Meck, 1983). That is, if overestimation of the fear-cue duration results from a faster clock, then the difference between fear- vs. neutral-cue time estimates should be greater for a longer duration cue than for a shorter duration cue. In contrast, no difference in magnitude of fear effects between duration ranges is expected if overestimation is based in switch latency.

In the present study, fear and neutral cues in the form of the IAPS pictures were presented under the bisection task within two different duration ranges for which anchor durations were 250 vs. 1000 ms or 400 vs. 1600 ms. The mechanism underlying the expected fear effect was evaluated by comparing time judgments for fear vs. neutral cues at each duration range.

**METHOD**

**PARTICIPANTS**

Forty introductory psychology students (24 female and 16 male; mean age = 19 years, range = 18–35) participated in order to fulfill a course requirement. There were no other inclusion criteria.

**MATERIALS**

The experiment took place in a room located in a laboratory in Queens College, CUNY. Participants sat at a desk in front a personal computer monitor (Sony VGN-FS742/W). In the testing phase, six 23.5cm × 17.5cm pictures from the IAPS (Lang et al., 2008) were presented in the center of the computer monitor; 3 pictures that evoked isolated fear and that had the highest reported normative ratings for arousal (pictures 1052,1321, and 1931 depicting a snake, bear, and shark respectively) (see Lang et al., 2008; Mikels et al., 2005), and three other pictures (7010-basket, 7020-fan, and 7175-lamp) that were rated as both neutral in valence and low arousing (Lang et al., 2008) were used in the bisection task. Five additional IAPS pictures (1110-snake, 1113-snake, 1301-dog, 1302-dog, and 1930-snake) were also used during rating phases.

During the training phase, a 3 cm × 3 cm green square was presented in the center of a computer monitor.
PROCEDURE

A crossover design in which emotional pictures, duration range, and stimulus duration were manipulated within subjects was used. Participants were thus given two bisection sessions, one with the short (250–1000 ms) and the other with the long (400–1600 ms) duration range. Half of the participants were exposed to the short duration range in session 1 followed by the long range in session 2 (S-L), and the others were exposed to the opposite order (L-S). In the short duration range, the anchor durations were 250 and 1000 ms and the probe durations were 375, 500, 625, 750, and 875 ms, and in the long duration range, the anchor durations were 400 and 1600 ms and the probe durations were 600, 800, 1000, 1200, and 1400 ms. Each bisection session was composed of a training and a testing phase. During the training phase, participants were exposed to the green square for each of the two anchor durations. There was a series of blocks of eight trials that consisted of four presentations of each of the two anchor durations in random order. Training terminated when the participant made no errors on a trial block. On each trial, the participant had to press one key on the computer keyboard for the short and another key for the long anchor duration. Visual feedback on the computer monitor indicated if the key press was “correct” or “not correct.” After the feedback, the participants pressed the Enter key to initiate another trial. In the testing phase, participants were given 168 trials, i.e., the 6 pictures (3 fear and 3 neutral) presented 4 times each across the 7 durations (2 anchors and 5 probe). All picture and duration combinations were randomly presented twice in each of 2 blocks of 84 trials in each session. Participants reported their responses in the same way as in the training phase, but feedback was not given.

In addition, before and after each bisection session, the participants rated 11 pictures from the IAPS (the 6 pictures used in the bisection task and 5 additional fear pictures; see Section 2.2 for the list of stimuli used). The additional pictures were used to evaluate possible habituation of emotion as a function of prior exposure (repeated vs. non-repeated stimulus presentation). The pictures were presented for 812 ms in a random order; a press on the left mouse key resulted in the presentation of the next picture after a 500 ms delay. Participants rated each picture using the 9-point paper-and-pencil scale employed by Lang et al. (2008) for affective valence and arousal, and the 7-point scale employed by Mikels et al. (2005) for fear emotion.

DATA ANALYSIS

The bisection point and a measure of temporal sensitivity (gamma) were estimated from the bisection function for each participant with the use of the pseudologistic model (PLM; Killeen et al., 1997), which has provided very good fits to bisection data from both human and animal studies (e.g., Allan, 2002; Callu et al., 2009). In the model, gamma is proportional to the Weber fraction (difference limen/PSE) for time, and decreases as the slope of the bisection function in the vicinity of the bisection point increases. The bisection point and gamma were estimated from the data with a nonlinear regression algorithm using Prism software. The median proportion of variance accounted for by the fit to 160 functions (40 participants x 2 emotions x 2 duration ranges) was .99 (range: .73–1.00). The results obtained with PLM yielded the same conclusions as when PSE and sensitivity (Weber fraction) were evaluated with the linear regression analysis procedure described by Church and Deluty (1977).

An $\alpha$ level of .05 was employed in all statistical analyses of results.

RESULTS

RATINGS

Fig. 1 shows group mean ratings of the pictures used in the testing phase as a function of emotion condition (fear vs. neutral). Participants indicated that they were more unhappy, excited, and afraid in the presence of the fear-evoking pictures than in the presence of the neutral pictures. A condition x session analysis of variance (ANOVA) of each of the rating scores yielded a significant main effect of condition for valence, $F(1,39) = 50.19$, arousal, $F(1,39) = 59.82$, and fear,
F(1,39)=63.57. There was no significant main effect of session nor a condition x session interaction; therefore, ratings showed no evidence of habituation across the 2 sessions of the present study.

Figure 1. Group mean picture ratings as a function of emotion condition. Error bars represent standard error of the mean.

PERCENT LONG

Fig. 2 shows p(Long) plotted against stimulus duration under each emotion condition (fear vs. neutral cue) at each duration range. For both ranges, the fear condition was associated with a higher percentage of long judgments in comparison to the neutral condition. A mixed ANOVA was conducted on p(Long) with 4 factors (levels): emotion (2), duration range (2), stimulus duration (7), and session order (2). The ANOVA yielded not only significant main effects of emotion, F(1,38) = 41.10, and stimulus duration, F(6, 228) = 675.07, but also a significant emotion x stimulus duration interaction, F(6, 228) = 4.60. When the ANOVA was confined to the three middle durations, the condition x stimulus duration interaction was not significant, F(2,76) = 1.98, indicating that the interaction obtained with all 7 durations was attributable to the convergence of the functions for fear and neutral cues at the extreme short and long stimulus durations. Overall, these results suggested that the participants judged probe durations to be longer for fear cues in comparison with neutral cues.
Figure 2. Percent “long” as a function of stimulus duration. Data under the fear-cue (solid line) and neutral-cue (dashed line) conditions are shown separately for the short (filled circles) and long (open circles) duration ranges.

Other significant effects in the ANOVA were main effects of session order, $F(1,38)= 7.12$, and duration range, $F(1, 38)=46.46$, duration range $\times$ stimulus duration and session order $\times$ stimulus duration interactions, $F(6,228) = 16.94$ and $3.27$, respectively, and a duration range $\times$ session order $\times$ stimulus duration interaction, $F(6, 228) = 6.49$. These effects are apparent in Fig. 3, which plots $p(\text{Long})$ as a function of stimulus duration separately for each duration range and session order. $p(\text{Long})$ was generally higher for the long than for the short-duration range. When analyses were confined to the two longest and shortest stimulus durations the ordering of $p(\text{Long})$ values among duration-range and session-order combinations differed. The duration range $\times$ session order interaction was not significant at intermediate durations (durations 4 and 5). None of the foregoing effects interacted with emotion.

A more interesting aspect of the data in Fig. 3 is that there was no apparent effect of duration range on session 1, but the effect emerged on session 2. A duration range $\times$ duration ANOVA of $p(\text{Long})$ yielded only a significant main effect of duration on session 1, $F(6,228) = 572.71$, but on session 2 yielded a duration effect $F(6, 228) = 363.70$, a range effect, $F(1,38) = 21.79$, and a range $\times$ duration interaction, $F(6, 228) = 12.37$. Prior exposure to a short duration range led subjects to produce more frequent “Long” judgments on the subsequently presented long range, while prior exposure to a long range produced fewer “Long” judgments on the short range. Again, none of these effects interacted with emotion.

Figure 3. Percent “long” as a function of normalized stimulus duration for duration range and session order (S-L = short range first, L-S = long range first).
**Bisection Point and Gamma**

Fig. 2 shows that there were leftward shifts in the functions for fear cues (solid lines) in comparison to those for neutral cues (dashed lines). This impression was supported by the statistical analysis of mean bisection point (see Table 1 for means and standard deviations). A 2 (session order) × 2 (duration range) × 2 (emotion) mixed ANOVA was performed on the bisection point. This ANOVA yielded a significant effect of emotion, $F(1, 38) = 22.9$, indicating that the bisection point value was lower with the fear cues than with the neutral cues. There was also a significant main effect of duration range, $F(1, 38) = 161.32$, but no emotion × duration range interaction. No other effects were significant. Thus, the bisection point value was higher for neutral than for fear cues under both ranges, but the magnitude of the difference was not greater for the long ($M=38$ ms) than for the short duration ($M=42$ ms) range. A session order × duration range × emotion ANOVA of gamma values (see Table 1) yielded no significant main effects or interactions.

### Table 1 - Group mean (M) and standard deviation (SD) bisection point and gamma

<table>
<thead>
<tr>
<th>Group</th>
<th>Short range</th>
<th></th>
<th>Long range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fear</td>
<td>Neutral</td>
<td>Fear</td>
<td>Neutral</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Bisection point</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-long</td>
<td>576.95</td>
<td>73.03</td>
<td>611.65</td>
<td>95.55</td>
</tr>
<tr>
<td>Long-short</td>
<td>612.57</td>
<td>123.21</td>
<td>681.05</td>
<td>142.03</td>
</tr>
<tr>
<td>Gamma</td>
<td>.19</td>
<td>.08</td>
<td>.20</td>
<td>.07</td>
</tr>
<tr>
<td>Short-long</td>
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<td>.16</td>
<td>.29</td>
<td>.18</td>
</tr>
<tr>
<td>Long-short</td>
<td>.24</td>
<td>.14</td>
<td>.24</td>
<td>.20</td>
</tr>
</tbody>
</table>

$a$ $n=20$

**Discussion**

Results with both $p$(Long) and bisection point measures indicated that fear cues were associated with overestimation of duration compared with neutral cues, while fear cues did not affect gamma, an index of temporal sensitivity. For neither measure of estimated duration did condition (fear vs. neutral cues) interact with duration range, nor was there a trend indicating a greater difference in bisection point between conditions in the long duration range compared to the short range. The latter results suggest that the mechanism underlying the difference in temporal judgments occasioned by fear vs. neutral cues was additive rather than multiplicative.

In the clock model (Church, 1984; Gibbon and Church, 1990), an additive effect may imply mediation by the switch mechanism as opposed to the pacemaker. That is, presentation of the fear cues could have resulted in shorter switch closure latency at the start of a trial and/or longer switch opening latency at the end of the trial than did presentation of neutral cues.

Owing to the presentation of two different kinds of stimuli within the same session, the memory mixing model of Penney et al. (2000) may also be applicable in the present study. In that model, an elaboration of SET, stimuli that control different clock rates are predicted to produce different bisection functions only when experimental conditions favor mixing of reference memories of each type of stimulus. Mixing is assumed to occur when durations of the stimuli types are the same and when they are presented in the same session, but not when they belong to nonoverlapping duration ranges or are presented in separate sessions in a within-subject design. Penney et al. applied the model to data from human subjects who timed both auditory and visual signals, where clock rate appeared faster for the auditory stimuli. Aspects of the present data are consistent with a clock rate/memory mix account, as bisection points...
were greater for neutral than for fear cues for both duration ranges. Moreover, if both the bisection point and difference limen increased in a proportional manner under a slower clock, the Weber fraction would remain constant, consistent with the absence of a significant difference in gamma between emotion conditions in the present study. However, the model would also predict a larger difference in bisection points between neutral and fear cues under the long-range condition than under the short-range condition, a finding that appeared to apply to the data of Penney et al. (2000, Exp. 2, Table 3). Thus, while aspects of the present findings are consistent with a clock rate effect, strong support for that mechanism was not obtained.

The conclusion that the present findings were mediated by the clock switch, as opposed to the pacemaker, is at variance with prior results on the influence of emotional factors on time judgment. For example, in a bisection task with emotionally expressive and neutral faces, Droit-Volet et al. (2004) and Gil et al. (2007) reported that p(Long) was greater and the bisection point lower for angry faces than for neutral faces, and that these differences increased with stimulus duration. As the angry faces were rated as high arousing, the authors interpreted the overestimation of angry faces as an arousal effect that influences clock speed.

Other findings may also anticipate arousal activation effects. Data reported by Hare (1963) suggested a larger effect of aversive cues on time estimates at a longer duration than at a shorter duration, but no statistical test of the interaction was provided. More recently, Droit-Volet et al. (in press) reported overestimation of the duration of a cue signaling an aversive stimulus (sound) compared to a nonaversive cue in a bisection task, and that temporal overestimation was greater for a longer duration range (800–1600ms) than for a shorter range (400–800ms). Angrilli et al. (1997) reported that IAPS stimuli normatively rated as high arousal-negative valence were overestimated by a constant proportion relative to high-arousal-positive valence stimuli at each of three durations (2, 4, 6 s), implying that the absolute degree of overestimation of high-arousal-negative valence images increased with stimulus duration. While the normative arousal (Lang et al., 2008) and fear (Mikels et al., 2005) levels for the negative images used in the present study were comparable to those of Angrilli et al., it is possible that the subjective emotional effects of the stimuli differed between these studies. In the present study, mean subject-reported arousal and fear ratings were lower than the standard values; however, subjective ratings were not reported by Angrilli et al. Therefore, it is possible in the present study, given the relatively low reported arousal level, that the emotional effect of the pictures may not have been sufficient to produce a significant difference in the temporal judgment at different duration values.

The difference between the present results and those of other studies is also possibly attributable to the brief durations for which pictures were presented in the present study. Plausibly, an arousal mechanism that induces an increase in effective clock speed may require a threshold of activation that was not exceeded by the images viewed under conditions of the present study. It would be of interest to assess timing of the fear cues in the present study at longer durations. However, the problem in studying the effect of emotion on time perception is complicated by the temporal dynamics of emotional processes. That is, the emotion effect decreases when the pictures are presented for an extended period of time (Droit-Volet and Meck, 2007).

An effect of order of exposure to the short vs. long duration range was observed, suggesting that judgments were influenced by exposure to the prior duration range. While this effect was independent of the fear effect, it precluded assessment in individual subjects of superposition of p(Long) functions for the two duration ranges by plotting the data on time-normalized axes (e.g., Church and Deluty, 1977). However, timescale invariance was observed at the level of groups on session 1 (Fig. 3), and gamma values did not vary across duration range, in line with scalar timing (Gibbon, 1991; Gallistel and Gibbon, 2000), and consistent with previous findings in temporal bisection with animal (Church, 1984) and human (Allan, 2002) observers.

The present findings implicating modification in switch closure latency under the fear condition may be understood in terms of emotional processing of a threatening stimulus. There is now a large body of research showing the critical role of the amygdala in the establishment of fear conditioning and in the processing of fear cues such as faces expressing fear (e.g., Adolphs, 2002; Adolphs et al., 1994; LeDoux, 1996; Meck and MacDonald, 2007). This subcortical structure can
allow organisms to rapidly process dangerous stimuli (Droit-Volet et al., in press; Krolak-Salmon et al., 2004; LeDoux, 1996; Phelps et al., 2001; Pourtois et al., 2010), possibly promoting shorter switch closure latency in the processing of fear stimuli. However, while there is good evidence for dissociation of clock components at the behavioral level, neural mechanisms underlying temporal control, including emotional control of a gating mechanism, remain to be determined (Buhusi and Meck, 2005; Gibbon et al., 1997).

In summary, the present findings establish an effect on timing of fear-evoking stimuli. Inasmuch as fear cues occasioned overestimation of duration, the results are in line with previous findings on the role of emotion in timing. In contrast to some of those findings, the data support an interpretation based on clock switch latency as opposed to arousal-mediated effects on functional clock speed, although the generality of that inference at higher arousal levels and longer stimulus durations remains to be determined.

REFERENCES


