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The Role of Clock and Memory Processes in the Timing of Fear Cues by Humans in the Temporal Bisection Task

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ABSTRACT

Recent research on the effects of fear on timing has focused on two accounts proposed by Scalar Expectancy Theory for why the durations of fear stimuli are overestimated in comparison to the durations of neutral stimuli. One possibility is that fear serves as an arouser that increases the speed of a hypothetical internal clock. The other possibility is that fear increases attention to time, which results in organisms' beginning to time fear-evoking stimuli sooner than they do neutral stimuli. In Experiment 1, we asked which of these two possibilities was the underlying mechanism of temporal overestimation of fear cues by presenting emotion-evoking pictures (fear-evoking vs. neutral) across multiple duration ranges in the temporal bisection task. Larger effects of fear were observed at the longest duration range in comparison to the shortest duration range, supporting the arousal hypothesis. Penney et al. 1998 and Penney et al., 2000 memory-mixing hypothesis proposes that overestimation is only possible in preparations that allow for recalled reference memories for stimulus durations to be mixed across conditions. Therefore, in Experiment 2, we manipulated whether or not fear and neutral cues were presented within the same session, a condition that may be necessary for memory mixing to occur. Fear cues were overestimated relative to neutral cues within the session in which fear and neutral cues were both presented, but no effect of emotion was observed between the two sessions in which fear and neutral cues were presented separately.

An active area of research has been the role of emotion in time perception (for a review see Droit-Volet & Gil, 2009 and Droit-Volet & Meck, 2007). Manipulations of stimuli that are both negative in valence and highly arousing (e.g., fear-evoking stimuli) have been used extensively in these studies owing to their consistent effects on time perception (e.g., Anderson et al., 2007; Watts & Sharrock, 1984). Specifically, subjects judge the presentation durations of these stimuli as longer than those of neutral stimuli. For example, Tipples (2008) asked participants to judge the presentation duration of pictures of people making angry facial expressions and pictures of people with neutral expressions in a within-subject preparation using the temporal bisection task (Allan and Gibbon, 1991; Stubbs, 1968; Wearden, 1991). The physical durations of the pictures ranged from 400-1600 ms, and they were presented an equal number of times in both the angry and neutral face conditions. The task of the participants was to classify each picture presentation as being closer to a short or long standard duration that was learned in a training phase. Tipples found that the mean bisection point (BP; the duration that corresponds to 50% "long" responses) associated with the angry faces was smaller than the BP associated with the neutral faces, a pattern of effect indicative of angry facial expressions being overestimated relative to neutral facial expressions.

Scalar Expectancy Theory (SET; Church, 1984; Gibbon, 1977; Gibbon et al., 1984) has been influential in modern studies related to time perception. Fig. 1 is a diagram of SET as it relates to the temporal bisection task. The three main structural components of the model include a clock, memory, and decision stage. The clock stage consists of a pacemaker that transfers pulses to an accumulator during the timed event. Between the pacemaker and the accumulator, there is a switch that is assumed to be under stimulus control. Pulses are gated from the pacemaker to the accumulator in the presence of timing cues. The pulse count is then transferred to working memory where it is compared, by a decision mechanism that controls response output, to previously stored values in reference memory.

There are at least two plausible accounts of how the presentation durations of stimuli may be overestimated during, say, fear conditions relative to neutral conditions within the clock stage of SET (Burle & Casini, 2001). First, arousal could increase the *speed* of emission of pulses of observed time in the pacemaker; that is, clock speed may

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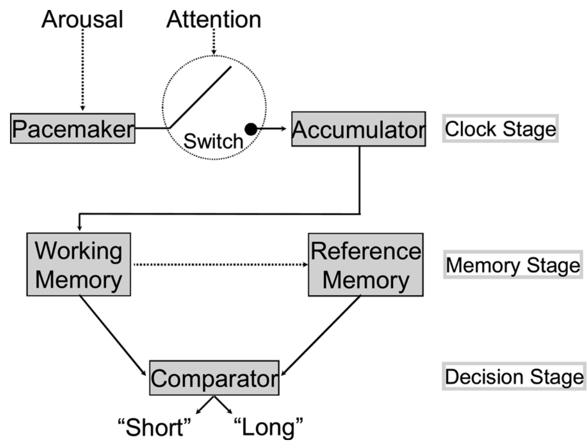

Fig. 1. Temporal Information Processing Version of Scalar Expectancy Theory as applied to the temporal bisection task (Adapted from Gibbon et al., 1984).

increase, resulting in a greater accumulation of clock pulses during the timed interval. Alternatively, fear-evoking stimuli could decrease the switch closure *latency* when attention is directed toward time (e.g., participants may start timing fear cues earlier than neutral stimuli) or increase the opening time when attention is directed away from time (e.g., participants may stop timing fear cues later than neutral stimuli).

The distinction between the two plausible accounts (clock speed vs. switch latency) requires the use of at least two different duration ranges in the temporal-bisection task. In the former (clock speed) case, the magnitude of the overestimation of the fear condition relative to the neutral condition will be greater for longer duration ranges than shorter duration ranges, as the absolute effect of an increase in percentage of clock speed increases with stimulus duration; that is, clock speed effects should vary multiplicatively. In contrast, for the latter (switch latency) mechanism, the magnitude of the overestimation of the fear condition relative to the neutral condition should be constant across duration ranges, as latency to begin or end timing is independent of the duration of the stimulus being timed; that is, switch latency effects should be additive.

Several studies that have used the temporal bisection task to explore the effect of emotional state on temporal perception have included methodology required to dissociate the clock speed account from the switch latency account. Results have been inconsistent, with some data supporting the clock speed hypothesis (Droit-Volet et al., 2011; Droit-Volet et al., 2010; Fayolle et al., 2015), others supporting the switch latency hypothesis (Gil et al., 2007; Grommet et al., 2011), and one observing effects that were not consistent with either hypothesis (Smith et al., 2011). The methodologies of these studies differed in terms of how emotion was induced, i.e., static images (Gil et al.; Grommet et al.; Smith et al.), films (Droit-Volet et al., 2011), sounds (Droit-Volet et al., 2010), or electric shock (Fayolle et al.). They also differed in terms of whether the experimental condition consisted of timing emotion-evoking stimuli (Gil et al.; Grommet et al.; Smith et al.), timing innocuous stimuli while anticipating emotion-evoking stimuli (Droit-Volet et al., 2010; Fayolle et al.), or timing innocuous stimuli after emotion-evoking stimuli had been presented (Droit-Volet et al., 2011). Furthermore, they differed in terms of duration ranges employed: 100-300 ms and 400-1600 ms (Smith et al.), 200-800 ms and 400-1600 ms (Droit-Volet et al., 2011), 250-1000 ms and 400-1600 ms (Grommet et al.), 400-800 ms and 800-1600 ms (Droit-Volet et al., 2010), 400-1600 ms and 600-2400 ms (Gil et al.), and 200-800 ms, 400-1600 ms, 1200-4800 ms, and 2000-8000 ms (Fayolle et al.).

One possible interpretation of the conflicting findings is that some of the aforementioned methodological differences correspond to situations that increase arousal (clock speed) under fear conditions, whereas others correspond to situations that increase attention to the passage of time (switch latency). An alternative explanation is that all of the aforementioned manipulations resulted in clock speed effects, albeit some larger than others. In this view, Gil et al. (2007), Grommet et al. (2011), and Smith et al. (2011) failed to observe larger effects of emotion on BP as duration range increased because their measurement procedures lacked sufficient sensitivity to observe the effects of their relatively modest manipulations of emotion, not because, for example, static images of emotion-evoking stimuli do not increase clock speed.

Effects of manipulations that impact pacemaker speed are multiplicative in nature; therefore, differences between duration judgments of emotion-evoking and control conditions should increase as the spacing between duration range increases. The aim of Experiment 1 in the current investigation was to evaluate whether or not the differences between the spacing of duration ranges could have been a source of the discrepant findings in previous research, by using three duration ranges: 250-1000, 400-1600, and 550-2200 ms. It was hypothesized that, while an effect of emotion (fear vs. neutral) would be seen at all duration ranges, an emotion x duration range effect would only be observed with the shortest (250-1000 ms) and longest duration ranges (550-2200 ms). This outcome was predicted because the differences between 250-1000 ms versus 400-1600 ms and 400-1600 ms versus 550-2200 ms are equal to the difference between the duration ranges used in Grommet et al. (2011), with a difference between arithmetic means of duration ranges of 375 ms, whereas the difference between 250-1000 ms versus 550-2200 ms is substantially larger (750 ms).

An interpretation that is common to all studies that have used the temporal bisection task to explore the effect of emotional state on temporal perception is that the source of temporal overestimation of emotion-evoking cues relative to neutral cues stems from the clock stage of SET. This proposal, however, cannot explain the overestimation by itself, because increased pacemaker speed or decreased switch closure latency in the emotion-evoking condition would not result in overestimation if participants used emotion-specific reference memories, e.g., fear reference memories on fear trials and neutral reference memories on neutral trials. In order for the effects of emotional state on temporal perception to be attributable to changes that occurred in the clock stage, at least one of the following possibilities must be true on a given trial: (a) accumulator contents in emotion-evoking trials are compared to reference memory contents from neutral trials, (b) accumulator contents in neutral trials are compared to reference memory contents from fear trials, or (c) accumulator contents in fear and neutral trials are compared to reference memory values that fall somewhere between those associated with previous fear and neutral trials.

Penney et al. 1998 and Penney et al. 2000conducted a series of experiments aimed at examining a phenomenon similar to the emotion-based overestimation described above. They observed overestimation of auditory cues relative to visual cues in the temporal bisection task when both cue modalities were manipulated within the same duration range and session, but they did not observe this effect when the modalities were manipulated in a between-subjects fashion. Penney et al. (1998, 2000) theorized that these effects occurred because subjects used the same reference memory for both modalities in the within-session manipulation, but that this was not possible in the between-subjects manipulation. Although Penney et al.'s (1998, 2000) effects were achieved with a modality manipulation, their hypothesis should apply to any stimulus feature that operates on the clock stage. Thus, the presentation of emotion-evoking and neutral trials in the same session may be expected to promote storage and retrieval of remembered durations from a common memory (memory mixing), and temporal overestimation of emotion-evoking cues, relative to neutral cues, should be observed. Alternatively, when emotion-evoking and neutral cues are presented in a manner that does not promote memory mixing, subjects may store and retrieve emotion-specific memories of duration on emotion-evoking and neutral trials. If this is the case, no temporal overestimation should be observed in relation to emotion-evoking versus neutral stimuli.

No studies that have used the temporal bisection task to explore the effect of emotional state on temporal perception have directly tested Penney et al.'s (1998, 2000) prediction, as all have manipulated how emotion cues were presented in a manner that would be expected to promote memory mixing; that is, emotion-evoking and neutral stimuli were always presented to all participants in the same session. Therefore, the aim of Experiment 2 was to directly test Penney et al.'s (1998, 2000) memory-mixing hypothesis by varying whether emotion (fear vs. neutral cues) was manipulated within or between sessions.

1. Experiment 1

As pacemaker effects are multiplicative, the differences between duration judgments of fear and neutral stimuli should increase as the spacing between duration range increases. In this view, fear's effects on timing are multiplicative, but Gil et al. (2007), Grommet et al. (2011), and Smith et al. (2011)'s preparations were not sensitive enough to detect them. Therefore, the primary aim of Experiment 1 was to reconcile the inconsistent findings of studies that have used the temporal bisection task to explore the effect of emotional state on temporal perception by manipulating the temporal spacing of the duration ranges. The effect of emotion was compared across three duration-range conditions: 250-1000 ms vs. 400-1600 ms vs. 550-2200 ms. If the difference between studies that have observed an effect of emotion on BP that increased with duration range, and those that have not, was due to the difference in sensitivity between the duration ranges used, then an emotion x duration range interaction for bisection point would be observed between the 250-1000 ms versus 550-2200 ms ranges, but not between the other ranges.

1.1. Method

1.1.1. Participants

Forty-eight Queens College, City University of New York (CUNY), introductory psychology students (35 female and 13 male) served as participants. They received credit toward the research requirements of their course in exchange for their participation. All participants were required to be at least 18 years old at the start of the semester in which they participated, as per the Queens College Psychology Department's Subject Pool regulations, but the specific ages of participants were not documented. This experiment was approved by CUNY's Human Research Protection Program (HRPP).

1.1.2. Setting

The experiment took place in a 142 cm x 295 cm room in Queens College, CUNY. The room contained a table, a chair, and a desktop computer with a keyboard (all keys except "S" and "L" were removed), mouse, and monitor.

1.1.3. Materials

Stimuli consisted of six pictures from the International Affective Picture System (IAPS; Lang et al., 2008), 23.5 cm x 17.5 cm. Three pictures had the highest normative arousal ratings out of the pictures that evoked the single emotion category of fear, as per the criteria used in Mikels et al. (2005) (snake, bear, and shark; IAPS numbers 1052, 1321, and 1931 respectively). The three other pictures had normative ratings that indicated neutrality, i.e., low arousal ratings and valence ratings near the midpoint between positive and negative (basket-7010, fan-7020, and lamp-7175). During the training phase, a 3 cm x 3 cm presumably innocuous green square was presented.

All pictures and instructions were presented via a 15-in. square flat panel liquid crystal display monitor (Planar L2-17) connected to a desktop computer (Dell Optiplex GX270).

1.1.4. Experimental Design

A 6 (sequence group) x 3 (duration range) x 7 (duration) x 2 (emotion) experimental design was used. Sequence groups were determined by randomly assigning participants to one of the six possible sequences of duration range (short: 250-1000 ms; medium: 400-1600 ms; long: 550-2200 ms), with the constraint that eight participants were assigned to each sequence. Stimuli differing in duration (7 linearly-spaced durations within each duration range) and emotion (fear-evoking vs. neutral pictures) were presented to each participant in a random order across trials, with each picture presented four times at each duration in each testing-phase of a given session. A different random order was generated on each session for each participant.

1.2. Procedure

1.2.1. General

Each participant was exposed to three sessions that were duration-range specific; that is, each session corresponded to the short, medium, or long duration range. A session began and ended with a rating phase (i.e., pretest and posttest – which functioned as a manipulation check for the effect of emotion throughout each session). Between the two rating phases, there was a training phase followed by a testing phase. That is, the order of phases in each session was: rating, training, testing, and rating. There was a minimum interval of 24 hr between the start times of each session for each participant.

1.2.2. Rating phase

Participants were exposed to all six IAPS pictures (three fear-evoking and three neutral). Prior to each picture presentation, a fixation point was presented for 800 ms. Each picture was shown for 1225 ms (the midpoint between the smallest value in the short duration range and the largest value in the long duration range) and the presentation sequence of the pictures was randomized independently for each participant and rating phase. Following the presentation of each picture, participants used the Self-Assessment Manikin (SAM; Lang et al., 2008) to rate the picture in regard to valence and arousal, after which the participants also rated each picture for fear using Mikels et al.'s (2005) 1-7 scale. All three scales were presented on a sheet of letter-sized paper and participants made their ratings using a pen. After participants made all three ratings for a given picture, they pressed the left button on the computer's mouse, and another trial began. This process continued until all six pictures had been rated.

1.2.3. Training phase

The purpose of the training phase was to ensure that participants could make accurate discriminations between the shortest and longest durations (the anchor durations) of the duration range that was to be used in the ensuing testing phase. Participants were exposed to green squares that were presented in the center of the screen for either the short or long anchor duration of the duration range that participants were exposed to in the ensuing testing phase of the session. Prior to each square presentation, a fixation point was presented for 800 ms. The task of the participants was to press the "S" or the "L" key on the computer keyboard following the presentation of each square to indicate whether the square was presented for the short or long duration, respectively. Following each response, feedback (i.e., "correct" or "not correct") was presented for 2000 ms. Blocks of eight green squares (four short and four long, in random order) continued to be presented until the participant completed a block with no errors.

1.2.4. Testing phase

Participants were exposed to 2 blocks of 84 trials, for a total of 168 trials per session. Each block contained 12 picture presentations at of each of the seven durations that were comprised of the two anchor durations used in the training phase and five linearly-spaced intermediate probe durations. Each of the six IAPS pictures was presented twice at each duration in each block, and the presentation sequence of these picture-duration combinations was random within each block.

Prior to each picture presentation, a fixation point was presented for 1300-3300 ms (randomly determined). The task of the participants was to press the “S” or the “L” key on the computer keyboard following each picture presentation to indicate whether the picture was presented for a short or long duration, respectively. No feedback was given in this phase, and it ended following the response to the last picture presentation.

1.3. Data Analysis

1.3.1. General

An α level of .05 was used for all statistical tests. The ANOVAs described below were also conducted with sequence group and sex as variables, but as these variables never interacted with emotion (the primary variable of interest), they were removed from the reported analyses. All analyses were conducted with SAS University Edition 3.71.

1.3.2. Rating phase

A 3 (session number: 1-3) x 2 (test: pretest vs. posttest) x 2 (emotion: fear-evoking vs. neutral pictures) and 3 (duration range: short vs. medium vs. long) x 2 (test) x 2 (emotion) repeated-measures ANOVA were conducted on the data from all 3 rating scales (valence, arousal, and fear). As the ANOVAs involving duration range never yielded effects of duration range nor any interactions involving duration range, the results of these analyses were not reported.

1.3.3. Training phase

One-way repeated-measures ANOVAs with session number and duration range as the independent variables were conducted on the number of trial blocks that participants took to meet the training criterion.

1.3.4. Testing phase

BP and a measure of temporal sensitivity (gamma) were estimated from the bisection function for each participant using the pseudo-logistic 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 (a measure of temporal sensitivity) is proportional to the Weber ratio (difference limen/BP) for time and decreases as the slope of the bisection function in the vicinity of the BP increases. BP and gamma were estimated for each participant with GraphPad Prism 7.0d software for the Macintosh operating system using Equation 1 (Allan, 2002, Eq. 5), which treats nonscalar sources of variance as negligible.

$$P(R_L) = \left[1 + \exp\left(\frac{T_{1/2} - t}{\frac{\sqrt{3}}{\pi}\gamma t}\right)\right]^{-1} \quad (1)$$

The median proportion of variance accounted for (R^2) by the fit to 288 functions (48 participants x 3 duration ranges x 2 emotions) was .98 (range: .56-1). A 3 (duration range) x 2 (emotion) repeated-measures ANOVA was conducted on the BP and gamma scores, and partial eta-squared (η_p^2) was reported as a measure of effect size for all effects involving emotion.

2. Results

2.1. Rating Phase

2.1.1. Valence.

The top panel of Fig. 2 shows valence ratings of the fear-evoking and neutral pictures plotted as a function of pretests and posttests across sessions. Fear-evoking pictures were rated as more negative than the neutral pictures. This was verified by a significant effect of emotion in the primary analysis of fear ratings (see Table 1).

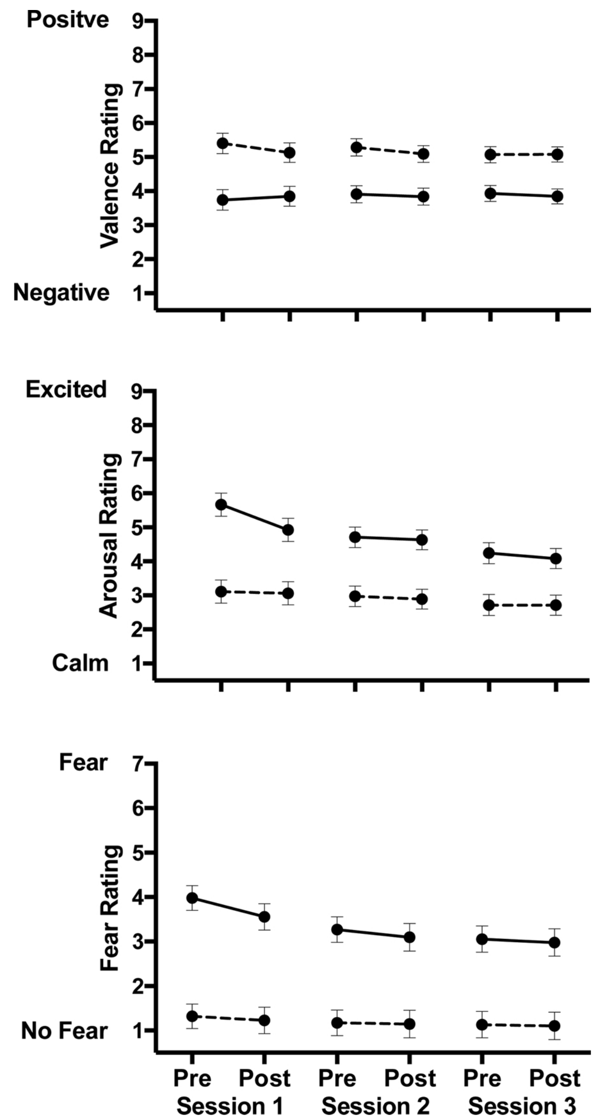

Fig. 2. Mean valence, arousal, and fear ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures in Experiment 1. Fear-evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines. Error bars display 95% within-subjects confidence intervals, as per Loftus and Masson (1994), for the emotion variable at each of the 6 rating phases.

2.1.2. Arousal

The middle panel of Fig. 2 shows arousal ratings of the fear-evoking and neutral pictures plotted as a function of pretests and posttests across sessions. Fear-evoking pictures were rated as more arousing than the neutral pictures. This was verified by the primary analysis of arousal ratings (see Table 1) yielding not only effects of session number, test, and emotion, but also session number x emotion, test x emotion and session number x test x emotion interactions. The source of these interactions was a decrease in reported arousal that occurred over sessions and tests in response to the fear-evoking pictures, but not to the neutral pictures. This was supported by a 3 (session number) x 2 (test) ANOVA restricted to the fear pictures that yielded significant effects of session number, $F(2, 94) = 13.74$, $p < .001$ (Tukey’s HSD indicated that all sessions differed from each other), test, $F(1, 47) = 10.16$, $p = .003$, and a session number x test interaction, $F(2, 94) = 6.73$, $p = .002$. It was further supported by an 3 (session number) x 2 (test) ANOVA restricted to the neutral pictures in which no effects were observed. The session number x test interaction in the fear condition was due to the pretest-posttest effect being restricted to session 1. This was

Table 1
Analysis of Variance for Fear, Arousal, and Valence in Rating Phase of Experiment 1.

Source	df	SS	MS	F
Valence				
Emotion	1	756.05	756.05	32.54**
Error	47	1092.15	23.24	
Session Number	2	0.97	0.49	0.16
Error	94	281.97	3.00	
Test	1	3.08	3.08	1.74
Error	47	83.11	1.77	
Session Number x Emotion	2	6.00	3.00	1.93
Error	94	146.39	1.56	
Test x Emotion	1	2.01	2.01	1.97
Error	47	47.96	1.02	
Session Number x Test	2	0.63	0.32	0.27
Error	94	109.42	1.16	
Session Number x Test x Emotion	2	3.90	1.95	2.84
Error	94	64.71	0.69	
Arousal				
Emotion	1	1397.52	1397.52	45.70**
Error	47	1437.2	30.58	
Session Number	2	162.83	81.42	10.91**
Error	94	701.39	7.46	
Test	1	14.81	14.81	8.21**
Error	47	84.80	1.80	
Session Number x Emotion	2	42.39	21.19	5.59**
Error	94	356.06	3.79	
Emotion x Test	1	8.61	8.61	5.32**
Error	47	76.11	1.62	
Session Number x Test	2	9.58	4.79	2.60
Error	94	173.3	1.84	
Session Number x Test x Emotion	2	9.67	4.83	4.13*
Error	94	110.11	1.17	
Fear				
Emotion	1	1976.33	1976.33	62.28**
Error	47	1491.39	31.73	
Session Number	2	64.89	32.44	14.11**
Error	94	216.11	2.30	
Test	1	8.06	8.06	14.89**
Error	47	25.44	0.54	
Session Number x Emotion	2	28.22	14.11	7.40**
Error	94	179.23	1.91	
Test x Emotion	1	3.34	3.34	5.10*
Error	47	30.82	0.66	
Session Number x Test	2	3.30	1.65	4.26*
Error	94	36.37	0.39	
Session Number x Test x Emotion	2	1.51	0.75	1.56
Error	94	45.49	0.48	

Note. p-values ≤ .05 are marked by an * after the F-value. $p \leq .01$ are marked with an **. $N = 48$.

verified by a correlated-samples t-test of test restricted to session 1 of the fear condition that resulted in a significant effect, $t(47) = 2.84$, $p = .007$, and a 2 (session number) x 2 (test) ANOVA of the fear condition restricted to sessions 2 and 3 that did not result in an effect of test, $F(1, 47) = 1.03$, *ns*, or a session number x test interaction, $F(1, 47) = 0.26$, *ns*.

2.1.3. Fear

The bottom panel of Fig. 2 shows fear ratings of the fear-evoking and neutral pictures plotted as a function of pretests and posttests across sessions. Fear-evoking pictures were rated as more fear evoking than the neutral pictures, and fear ratings to fear-evoking pictures decreased with repeated ratings. This was verified by the primary analysis of fear ratings (see Table 1) yielding not only effects of session number, test, and emotion, but also a session number x test interaction, a session number x emotion interaction, and a test x emotion interaction. The source of the interactions involving emotion was a decrease in reported fear that occurred over sessions and tests in response to the fear-evoking pictures, but not to the neutral pictures. This was supported by a 3 (session number) x 2 (test) ANOVA restricted to one emotion condition at a time. No effects were observed in the neutral picture analysis, but significant effects of session number, $F(2, 94) = 12.68$, $p < .001$, and test, $F(1, 47) = 11.28$, $p = .002$, were observed in the fear picture analysis. A parsing of the session number effect in the fear condition by Tukey's HSD indicated that session 1 was associated with higher fear ratings than sessions 2 and 3. The session number x test interaction in the initial ANOVA was due to a larger decrease in reported fear from pretest to posttest isolated to session 1 in comparison to sessions 2 and 3. This was supported by a correlated-samples t-test of test restricted to session 1 that yielded a significant effect, $t(47) = 3.75$, $p < .001$, and a 2 (session number) x 2 (test) ANOVA restricted to sessions 2 and 3 that yielded a significant effect of test, $F(1, 47) = 5.72$, $p = .02$, but no session number x test interaction $F(1, 47) = 0.49$, *ns*.

2.1.4. Training Phase

Participants took an average of 1.33 training blocks (8 trials per block) to pass the training phase in a given session and took longer to pass session 1 ($M = 1.56$ training blocks) than session 2 ($M = 1.17$ training blocks) or 3 ($M = 1.27$ training blocks). A one-way ANOVA confirmed the main effect of session number, $F(2, 94) = 9.21$, $p < .001$, and Tukey's HSD, confirmed that session 1 required more training blocks than sessions 2 or 3. No difference was observed between sessions 2 and 3. A one-way repeated-measures ANOVA with duration range as the independent variable did not yield an effect, $F(2, 94) = 1.31$, *ns*.

2.2. Testing Phase

2.2.1. p(Long)

Fig. 3 shows group mean probability of a "long" response, p(Long), plotted against stimulus duration under each emotion condition (fear vs. neutral cue) at each duration range. The figure suggests that p(Long) was greater under the fear condition than under the neutral condition and that the difference between fear and neutral increased with duration range.

2.3. PLM

BP. The trends observed in the visual inspection of Fig. 3 were confirmed by a quantitative inspection of the mean BP values. Fig. 4 shows the BP (calculated using the PLM) plotted as a function of duration range for the fear and neutral emotion conditions. The fear condition was associated with a lower mean BP in comparison to the neutral condition, consistent with overestimation of duration of fear cues relative to neutral cues. More importantly, the extent to which fear-evoking pictures were overestimated relative to neutral pictures

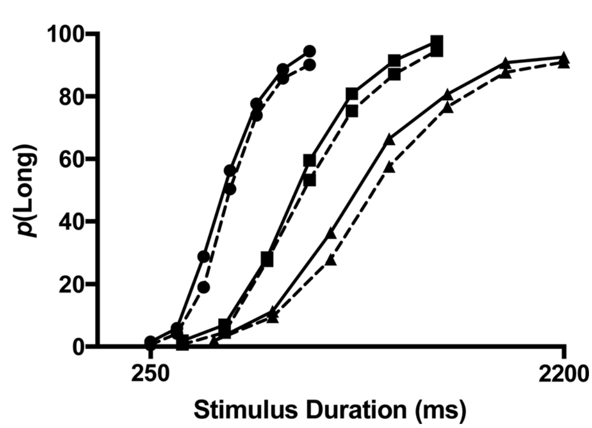

Fig. 3. Mean percent "long" presented as a function of stimulus duration (ms) across duration ranges in Experiment 1. The solid lines are the fear plots, and the dashed lines are the neutral plots. The circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

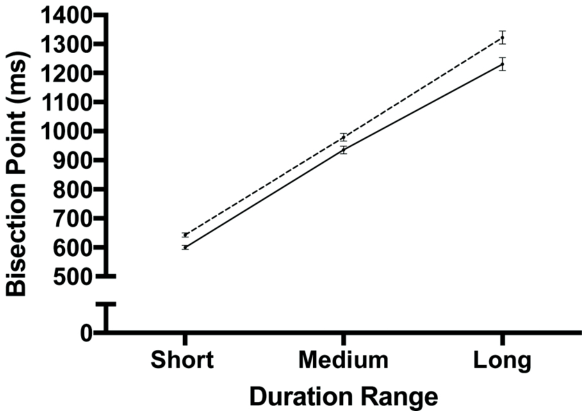

Fig. 4. BP (ms), calculated using the PLM, as a function of duration range for the fear and neutral conditions in Experiment 1. The solid line represents the fear condition, and the dashed line represents the neutral condition. Error bars display 95% within-subjects confidence intervals, as per Loftus and Masson (1994), for the emotion variable at each duration range.

was greater at the long duration range than at the short duration range on the measure of BP. This evaluation was supported by a 3 (duration range) x 2 (emotion) ANOVA of BP that yielded not only effects of duration range, $F(2, 94) = 182.28$, $p < .001$, and emotion, $F(1, 47) = 39.63$, $p < .001$, $\eta_p^2 = .46$, but also a duration range x emotion interaction, $F(2, 94) = 3.41$, $p = .04$, $\eta_p^2 = .07$.

Subsequent ANOVAs in which one duration range at a time was systematically removed from each analysis revealed that the interaction was the result of the difference in BP values associated with fear and neutral cues being greater at the long duration range than at the short duration range and that the effect of emotion was present in all duration ranges. No duration range x emotion interaction was observed when only the short and medium duration ranges were included in the analysis, $F(1, 47) = 0.01$, *ns*, $\eta_p^2 < .01$, but there were still significant effects of duration range, $F(1, 47) = 232.87$, $p < .001$, and emotion, $F(1, 47) = 30.12$, $p < .001$, $\eta_p^2 = .39$. Likewise, no duration range x emotion interaction was observed when only the medium and long duration ranges were included in the analysis, $F(1, 47) = 3.72$, *ns*, $\eta_p^2 = .07$, but there were still significant effects of duration range, $F(1, 47) = 69.47$, $p < .001$, and emotion, $F(1, 47) = 25.02$, $p < .001$, $\eta_p^2 = .35$. The duration range x emotion interaction was, however, observed when only the short and long duration ranges were included in the ANOVA, $F(1, 47) = 4.25$, $p = .04$, $\eta_p^2 = .08$. Significant effects of duration range, $F(1, 47) = 271.39$, $p < .001$, and emotion, $F(1, 47) = 33.14$, $p < .001$, $\eta_p^2 = .41$, were also observed in this analysis, as was the effect of emotion when correlated-samples *t*-tests were conducted on emotion at the short, $t(47) = 5.94$, $p < .001$, $\eta_p^2 = .43$, and long, $t(47) = 4.09$, $p < .001$, $\eta_p^2 = .26$, duration ranges. Means for BP are presented in Table 2.

In line with the aforementioned duration range x emotion interaction on BP, linear regression analysis indicated that the neutral condition depicted in Fig. 4 exhibited a steeper slope ($M = .91$ ms/ms) in comparison to the fear condition ($M = .84$ ms/ms). In order to confirm

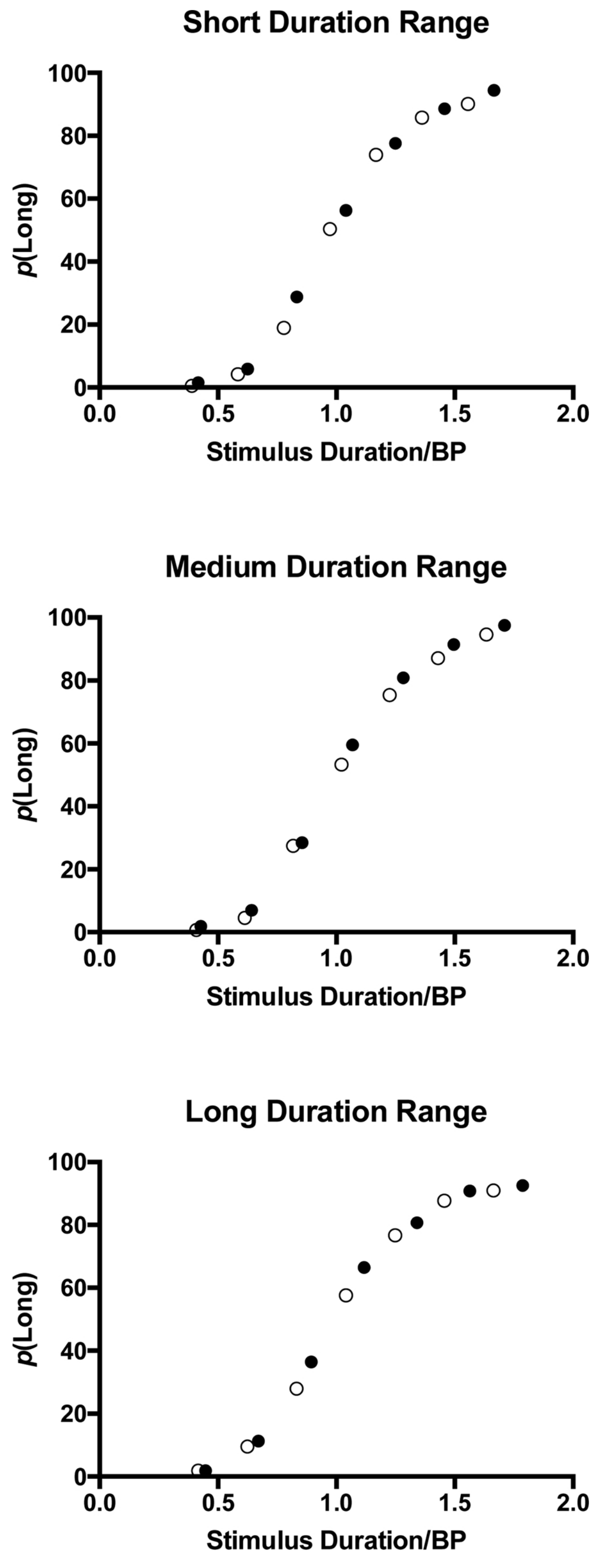

Fig. 5. Group mean percent "long" as a function of stimulus duration/BP in Experiment 1. The solid symbols are the fear plots, and open symbols are the neutral plots. Data are shown separately for short, medium, and long duration ranges in the top, middle, and bottom panels, respectively.

this effect, slope and y-axis intercept were calculated for each participant at each emotion, with duration range (i.e., the midpoint of each range: 625, 1000, and 1375 ms) as the x-axis and BP as the y-axis. Correlated-samples *t*-tests yielded an effect of emotion on slope, $t(47) = 2.06$, $p = .04$, $\eta_p^2 = .08$, but not on intercept, $t(47) = 0.56$, *ns,*

Table 2
Mean Bisection Point and Gamma under each emotion condition and duration range in Experiment 1.

Short: 250-1000 ms		Medium: 400-1600 ms		Long: 550-2200 ms	
Fear	Neutral	Fear	Neutral	Fear	Neutral
		Bisection Point			
600.35	642.81	935.57	979.20	1230.84	1322.06
		Gamma			
.25	.25	.23	.26	.27	.28

Note. N = 48; values are in ms.

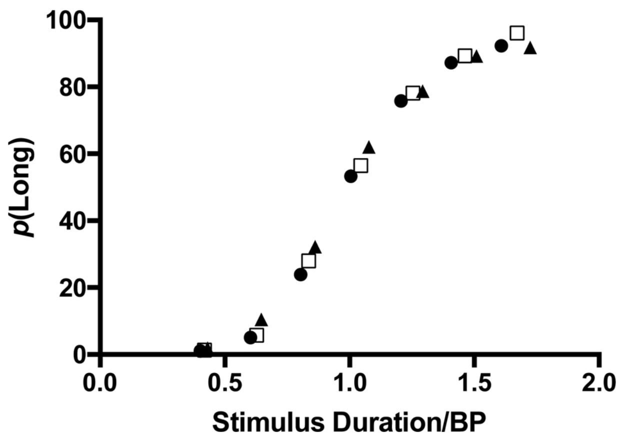

Fig. 6. Mean percent "long" as a function of stimulus duration/BP at each duration range in Experiment 1. The circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

η_p^2 = .01. The median proportion of variance accounted for (r^2) by the fit of the linear function to the 96 functions (48 participants x 2 emotions) was .98 (range: .03-1).

Gamma. A duration range x emotion ANOVA of gamma did not yield any significant effects. Means for gamma are presented on Table 2.

2.3.1. Superposition of duration range and emotion

The time axis for the group mean *p*(Long) functions were rescaled by dividing the value for each stimulus duration by the BP for each of the 6 emotion x duration range combinations. Fig. 5 shows *p*(Long) plots of fear and neutral cue data with normalized axes (stimulus duration/BP), separately for each duration range. Visual inspection indicated that the normalized plots exhibited superposition of fear and neutral values at all duration ranges, consistent with a scalar effect of emotion on temporal perception.

Stimulus duration/BP normalized duration range functions (short, medium, and long collapsed across emotion) were also plotted on a single graph to examine whether superposition was exhibited across duration ranges. Fig. 6 shows normalized *p*(Long) plots for each duration range. Visual inspection indicated that the normalized plots exhibited superposition across all duration ranges, consistent with a scalar effect of duration range on temporal perception.

3. Discussion

Fear pictures were judged to be longer in duration than neutral pictures, and the extent to which fear-evoking pictures were overestimated was greater at the long duration range than at the short duration range. This outcome provides evidence for a non-additive mechanism underlying the difference in temporal judgments occasioned by fear versus neutral cues.

Within the context of SET, larger differences in BP between conditions at longer duration ranges relative to shorter duration ranges have often been interpreted as evidence for the pacemaker's role in overestimation of fear cues relative to neutral cues (e.g., Droit-Volet & Meck, 2007); that is, non-additive effects have been interpreted as evidence for an increase in the pacemaker's pulse emission rate under emotion-evoking conditions relative to neutral conditions.

Although the larger effect of emotion at the long duration range relative to the short duration range offers good support for the role of the pacemaker in fear overestimation, it does not preclude the possibility that switch latency is also affected by emotion; that is, larger differences in BP between conditions at longer duration ranges relative to shorter duration ranges could result from (a) an increase in pacemaker rate or (b) an increase in pacemaker rate and an increase or decrease in switch latency. In the current experiment, these two possibilities were dissociated by comparing the fear and neutral conditions on the measures of slope and y-intercept, derived from functions relating BP to duration-range. As increased pacemaker speed is assumed to result in proportional increases in the effect of emotion across duration ranges, and changes in switch latency are assumed to result in the same absolute increase or decrease at all duration ranges, differences in slope between conditions suggest pacemaker involvement and differences in y-intercept suggest switch latency involvement. Consistent with the non-additive results of the BP analyses, the neutral condition was associated with a steeper slope than the fear condition, but no effect was observed on the measure of y-intercept. This outcome suggests that only the pacemaker was involved in the observed fear overestimation. Further support for an effect consistent with pacemaker-specific involvement was provided by the generally strong fits obtained by the linear functions used to derive the slopes and intercepts; that is, the linear increase in slope from the fear to neutral conditions and absence of evidence of y-intercept differences displayed in Fig. 4 suggest that the non-additive shift in bisection points across duration ranges is multiplicative in nature.

No effects on gamma were observed, suggesting that temporal sensitivity did not differ across duration ranges or emotion conditions. Additional support for this assertion can be found in the superposition of functions across emotion and duration range conditions, as superposition of stimulus duration/BP normalized functions are only observed when changes in the difference limen are proportional to changes in the BP across conditions.

When the BP analysis for the present experiment was restricted to the short and the medium duration ranges or the medium and long duration ranges, the results were consistent with those of Gil et al. (2007) and Grommet et al. (2011). Both of these studies used static images to induce emotion and duration-range spacing that was similar to the spacing between the short versus medium and medium versus long spacing currently employed. As the present experiment, however, included three duration ranges, an additional and more sensitive measure of the emotion x duration range interaction on BP was permitted (i.e., the comparison of the difference in effect of emotion at the short duration range to the difference in effect at the long duration range). Consistent with SET, this larger spacing between duration ranges resulted in observable differences in the effect of emotion. As pacemaker rate is assumed to be constant within each emotion condition, but the stimulus duration values that pacemaker rate is multiplied with increases with duration range, the difference in magnitude of effect of emotion between duration ranges becomes larger and, therefore, more readily detectable as the spacing between duration ranges is increased.

4. Experiment 2

In the SET clock model, a comparison is presumed to be made between the contents in the accumulator and reference memory on each trial. Penney et al. (1998, 2000) argued that when a given duration is presented in the context of differing nontemporal stimulus dimensions (e.g., auditory versus visual stimuli) across trials within a session, accumulator values for that duration may be stored in memory irrespective of modality of the nontemporal dimension. If clock rate differs in the presence of the nontemporal stimulus dimensions, a mixed reference memory bank will be created, consisting of accumulator values associated with differing clock rates. This model was proposed to account for their observation that overestimation of the duration of auditory stimuli relative to visual stimuli occurred only when all test durations were paired equally often with auditory and visual stimuli within an individual session, in a within-subjects fashion. The model predicts that if reference memory is stored in separate memory banks on, say, high-clock-rate (auditory) and low-clock-rate (visual) trials, then no clock rate effect should be observed, as the duration of each cue will be evaluated with respect to only its distribution of values.

Alternatively, if high-rate and low-rate duration representations are stored in the same memory bank (i.e., mixed), then comparison of an accumulated duration under high-rate conditions with a sample drawn from the mixed memory bank will tend to yield a "long" judgment, while comparison of an accumulated duration under low-rate conditions will tend to be judged as "short."

In the current experiment, only fear-evoking pictures were presented in one session type. In another, only neutral pictures were presented, and in a third, both fear-evoking and neutral pictures were presented in a mixed fashion (random order across trials), as was the case in previous studies that have observed the effect of emotion on time perception in the temporal bisection task (e.g., Grommet et al., 2011). If fear overestimation is attributable to memory mixing, and assuming that no memory mixing occurs between sessions, temporal overestimation of fear-evoking relative to neutral pictures should be observed in the comparison between fear-evoking and neutral pictures in the mixed session, but not in the comparison between fear-evoking and neutral pictures in the unmixed sessions. If, instead, fear overestimation were to be observed in both the comparison between fear-evoking and neutral pictures in the mixed session and the comparison between fear-evoking and neutral pictures in the unmixed sessions, this would suggest that fear overestimation may not be not due to memory mixing. If this were to be the case, then the origin of fear overestimation must be somewhere other than in the clock stage of SET.

4.1. Method

4.1.1. Participants

Forty-eight Queens College, CUNY, introductory psychology students (36 female and 12 male) served as participants. They were recruited from the Queens College Psychology Department's Subject Pool. None of these students participated in Experiment 1. They received credit toward the research requirements of their course in exchange for their participation. This experiment was approved by CUNY's HRPP.

4.1.2. Setting and Materials

Experiment 2 used the same setting and materials as Experiment 1. The only exception was that IAPS pictures replaced the green square in the training phase. This allowed for better control of the emotional qualities of the stimuli that participants were asked to time in each session.

4.1.3. Experimental Design

Sequence of session type (fear unmixed: only fear-evoking pictures presented; neutral unmixed: only neutral pictures presented; mixed: fear-evoking and neutral pictures presented in a random order across trials) was counterbalanced across participants. Participants were randomly assigned to one of the six possible sequence groups with the constraint that eight participants were assigned to each sequence. Within sessions, the order of the seven linearly-spaced durations (from 550-2200 ms) was random across trials. A different random order was generated on each session for each participant.

4.2. Procedure

4.2.1. General

Each participant was exposed to three session types. Session type differed in terms of the number and emotional properties of the pictures to which participants were exposed; that is, each of the three sessions corresponded to either the three fear-evoking pictures presented in an unmixed fashion, the three neutral pictures presented in an unmixed fashion, or the three fear-evoking and three neutral pictures presented in a mixed fashion. Each session began and ended with a rating phase. Between these rating phases, there was a training phase and a testing phase; that is, the order of phases for each participant during each session was: rating, training, testing, and rating. There was a minimum interval of 24 hr between the start times of each session for each participant.

4.2.2. Rating phase

The procedure for the rating phase was the same as in Experiment 1, except that each picture was shown for 1375 ms (the midpoint of the duration range used in the training and testing phases). All six IAPS pictures were presented in each rating phase, regardless of the pictures shown in the intervening training and testing phases.

4.2.3. Training phase.

IAPS pictures were presented for either the shortest (550 ms) or longest (2200 ms) duration to which the participants were exposed in the testing phase. In the fear-unmixed session, each of the three fear-evoking pictures was shown two times at each of the two anchor durations per training block. In the neutral-unmixed session, each of the three neutral pictures was shown two times at each of the two anchor durations per block, and in the mixed session, all six pictures were shown one time at each duration per block. The fixation point procedure, participant task, and feedback procedure were the same as in the training phase of Experiment 1. Blocks of 12 pictures (six short and six long, in random order) continued to be presented until the participant completed a block with no errors.

4.2.4. Testing phase

Participants were exposed to two blocks of 84 trials (168 trials in total) per session. Each block contained 12 presentations of each of the two durations used in the training phase (anchor durations) and of the five linearly-spaced intermediate probe durations that fell between the two training durations. The fixation point procedure and participant task were the same as in the testing phase of Experiment 1.

The difference in treatment between the three session types was as follows: (a) The fear-unmixed session consisted of exposure to only the three fear-evoking pictures, (b) the neutral-unmixed session consisted of exposure to only the three neutral pictures, and (c) the mixed session consisted of exposure to all six pictures (three fear-evoking and three neutral). The presentation sequence of all combinations of pictures and durations was random within each block with the following constraints: each of the three fear pictures was presented four times per block at each of the seven durations in the fear-unmixed session, each of the three neutral pictures was presented four times per block at each of the seven durations in the neutral-unmixed session, and each of the six pictures was presented two times per block at each of the seven durations in the mixed session.

4.3. Data Analysis

4.3.1. General

As in Experiment 1, an α level of .05 was used for all statistical tests, and the ANOVAs described below were conducted with sequence group and sex as variables, but as these variables never interacted with emotion (the primary variable of interest), they were removed from the reported analyses. All analyses were conducted with SAS University Edition 3.71.

4.3.2. Rating phase

A 3 (session number: 1-3) x 2 (test: pretest vs. posttest) x 2 (emotion: fear-evoking vs. neutral pictures) and 3 (session type: fear unmixed vs. neutral unmixed vs. mixed) x 2 (test) x 2 (emotion) repeated-measures ANOVA were conducted on the ratings from all 3 scales (valence, arousal, and fear). As the ANOVAs involving session type never yielded effects of session type nor any interactions involving session type, the results of these analyses were not reported.

4.3.3. Training phase.

One-way repeated-measures ANOVAs with session number and session type as the independent variables were conducted on the number of trial blocks that participants took to meet the training criterion.

4.4. Testing phase

p(Long). A 2 (presentation method: unmixed vs. mixed) x 7 (duration) x 2 (emotion) repeated-measures ANOVA was conducted on the percentage of trials that participants indicated were "long" (*p*(Long)).

BP and gamma. BP and gamma were also calculated for each participant in each presentation method x emotion, using the PLM as in Experiment 1. The median proportion of variance accounted for by the fit to the 192 functions (48 participants x 2 presentation methods x 2 emotions) was .99 (range: .59–1). A 2 (presentation method) x 2 (emotion) repeated-measures ANOVA was conducted on the BP and gamma scores.

Partial eta-squared (η_p^2) was reported as a measure of effect size for all testing phase effects involving emotion.

5. Results

5.1. Rating Phase

5.1.1. Valence

The top panel of Fig. 7 shows valence ratings of the fear-evoking and neutral pictures plotted as a function of tests across sessions. As was the case in Experiment 1, fear-evoking pictures were rated as more negative than the neutral pictures, but unlike Experiment 1, ratings to both picture types (fear-evoking and neutral) increased across sessions. These effects were confirmed by the primary analysis of valence (see Table 3) yielding significant effects of session number and emotion. Tukey's HSD indicated that pictures were rated more positively on session 3 than on session 1.

5.1.2. Arousal

The middle panel of Fig. 7 shows arousal ratings of the fear-evoking and neutral pictures plotted as a function of pretests and posttests across sessions. As was the case in Experiment 1, fear-evoking pictures were rated as more arousing than neutral pictures. Unlike Experiment 1, arousal ratings to both the fear-evoking and neutral pictures decreased with repeated ratings; there was, however, a larger decrease from session 1 to sessions 2 and 3 in arousal for the fear-evoking pictures than for the neutral pictures, and a trend indicated that there was a larger decrease for the fear-evoking pictures than for the neutral pictures from the pretests to the posttests. These effects were verified by the primary analysis of arousal (see Table 3) yielding not only an effect of session number, test, and emotion, but also a session number x emotion interaction and test x emotion interaction. The session number x emotion interaction was parsed by a series of three 2 (session number) x 2 (emotion) ANOVAs that were conducted by removing one session at a time. The analyses that included sessions 1 and 2, $F(1, 47) = 5.28$, $p = .03$, and 1 and 3, $F(1, 47) = 4.77$, $p = .03$, both yielded session number x emotion interactions. The analysis that included sessions 2 and 3 did not yield the interaction, $F(1, 47) = 0.18$, *ns*. The test x emotion interaction could not be successfully parsed.

5.1.3. Fear

The bottom panel of Fig. 7 shows fear ratings of the fear-evoking and neutral pictures plotted as a function of pretests and posttests across sessions. As was the case in Experiment 1, fear-evoking pictures were rated as more fear evoking than neutral pictures, and fear ratings to fear-evoking pictures decreased with repeated ratings. This was verified by the primary analysis of fear (see Table 3) yielding significant effects of session number, test, and emotion, and a session number x emotion interaction. The session number x emotion interaction was parsed by a pair of ANOVAs for session restricted to one emotion at a time. These analyses revealed a significant effect of session number, $F(2, 94) = 39.71$, $p < .001$ (Tukey's HSD indicated that all sessions differed from each other), in the ratings of the fear-evoking pictures, but no effects in the ratings of the neutral pictures. The primary analysis also yielded a session number x test interaction that was due to a larger decrease in fear rating from pretest to posttest in session 1, in comparison to sessions 2 and 3. This was supported by a series of three 2 (session number) x 2 (test) ANOVAs that were conducted by removing one session at a time. The analysis that included sessions 1 and 2, $F(1, 47) = 4.38$, $p = .04$, and the analysis that included sessions 1 and 3, $F(1, 47) = 4.66$, $p = .04$, both yielded a session number x test interaction. The analysis for sessions 2 and 3 did not yield the interaction, $F(1, 47) = 0.01$, *ns*.

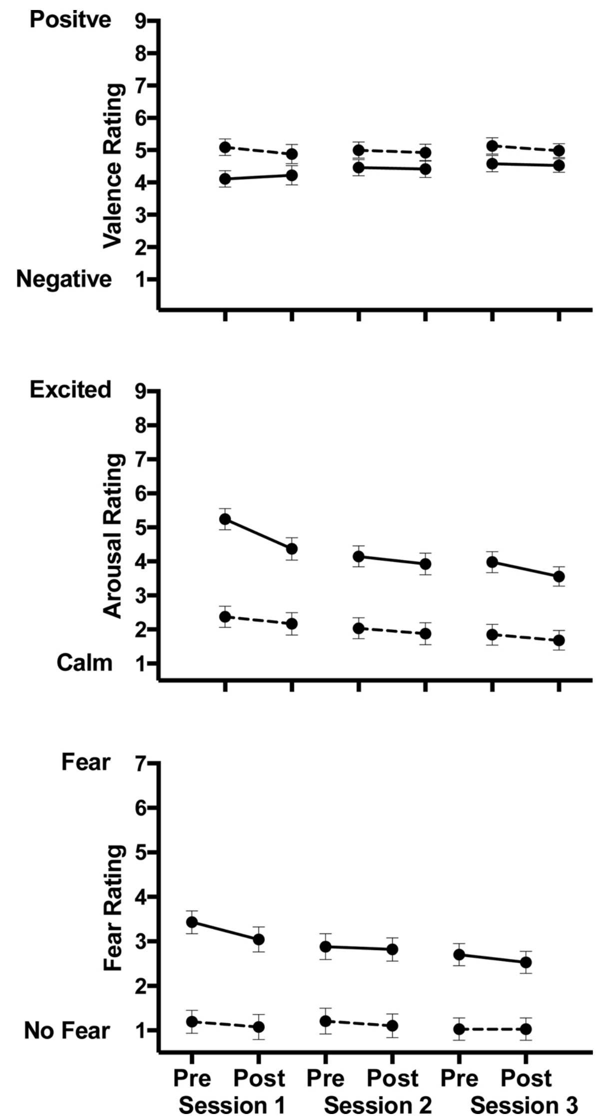

Fig. 7. Mean valence, arousal, and fear ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures in Experiment 2. Fear-evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines. Error bars display 95% within-subjects confidence intervals, as per Loftus and Masson (1994), for the emotion variable at each of the 6 rating phases.

5.1.4. Training Phase

Participants took an average of 1.18 training blocks (12 trials per block) to pass the training phase in a given session and took longer to pass session 1 (M = 1.38 training blocks) in comparison to session 2 (M = 1.08 training blocks) or 3 (M = 1.08 training blocks). This effect was

Table 3
Analysis of Variance of Fear, Arousal, and Valence values in Rating Phase of Experiment 2.

Source	df	SS	MS	F
Valence				
Emotion	1	163.79	163.79	7.64**
Error	47	1007.55	21.44	
Session Number	2	15.38	7.69	4.20*
Error	94	172.23	1.83	
Test	1	2.08	2.08	2.31
Error	47	42.47	0.90	
Session Number x Emotion	2	8.99	4.50	2.64
Error	94	160.17	1.70	
Test x Emotion	1	2.37	2.37	2.64
Error	47	42.19	0.90	
Session x Test	2	0.22	0.11	0.09
Error	94	112.73	1.20	
Session Number x Test x Emotion	2	1.64	0.82	0.74
Error	94	104.64	1.11	
Arousal				
Emotion	1	2102.34	2102.34	71.63**
Error	47	1379.44	29.35	
Session Number	2	181.38	90.69	13.28*
Error	94	641.90	6.83	
Test	1	50.70	50.70	23.76**
Error	47	100.30	2.13	
Session Number x Emotion	2	23.76	11.88	3.79*
Error	94	294.63	3.13	
Test x Emotion	1	11.67	11.67	5.89*
Error	47	93.11	1.98	
Session Number x Test	2	9.34	4.67	2.69
Error	94	163.49	1.74	
Session Number x Test x Emotion	2	6.85	3.42	1.83
Error	94	175.54	1.87	
Fear				
Emotion	1	1390.34	1390.34	56.40**
Error	47	1158.66	24.65	
Session Number	2	38.28	19.14	18.05**
Error	94	99.66	1.06	
Test	1	8.61	8.61	17.39**
Error	47	23.28	0.50	
Session Number x Emotion	2	21.15	10.58	6.67**
Error	94	149.01	1.59	
Test x Emotion	1	1.95	1.95	1.35
Error	47	67.94	1.45	
Session Number x Test	2	2.72	1.36	3.85
Error	94	33.22	0.35	
Session Number x Test x Emotion	2	1.84	0.92	1.90
Error	94	45.44	0.48	

Note. *p*-values ≤ .05 are marked by an * after the *F*-value. *p* ≤ .01 are marked with an **. *N* = 48.

verified by a one-way repeated-measures ANOVA of session number that revealed an effect, $F(2, 94) = 9.18$, $p < .001$, and Tukey's HSD, which confirmed that session 1 required more training blocks than sessions 2 or 3. No difference was observed between sessions 2 and 3. A one-way repeated-measures ANOVA with session type coded as the independent variable did not yield a significant effect on training blocks, $F(2, 94) = .16$, *ns*.

5.2. Testing Phase

5.2.1. p(Long)

Fig. 8 presents *p*(Long) as a function of stimulus duration. The left panel represents responding to the fear-evoking versus neutral pictures in the unmixed sessions, and the right panel represents responding to the fear-evoking versus neutral pictures in the mixed session. *p*(Long) increased as a function of stimulus duration in both the mixed session and the unmixed sessions, regardless of picture type (fear-evoking and neutral). This was confirmed by a 2 (presentation method) x 7 (duration) x 2 (emotion) ANOVA that yielded only a significant effect of duration, $F(6,282) = 562.15$, $p < .001$, and Tukey's HSD, which indicated that *p*(Long) differed at all stimulus durations. There was no evidence of an effect of presentation method $F(1,47) = 0.24$, or emotion $F(1,47) = 1.05$, *ns*, $\eta_p^2 = .02$, and there were also no interactions involving either of these variables.

A tendency for fear overestimation to be confined to the mixed presentation method can be seen on close inspection of Fig. 8. The right panel shows that *p*(Long) for the fear stimuli is above or equal to the neutral stimuli at every stimulus duration in the mixed session; whereas, relative *p*(Long) for fear versus neutral stimuli varies nonsystematically with stimulus durations for the unmixed presentation method (left panel). Fear overestimation in the mixed session, but not between the unmixed sessions, can be seen more clearly in Fig. 9 in which mean *p*(Long) is presented at each condition (fear unmixed, neutral unmixed, fear mixed, and neutral mixed), collapsed across stimulus duration. This effect was confirmed by a planned comparison in which separate correlated-samples *t*-tests with emotion as the factor were conducted on the data from the mixed session and unmixed sessions. The analysis of the mixed session data yielded a significant effect of emotion, $t(47) = 3.03$, $p = .004$, $\eta_p^2 = .16$, whereas the unmixed session comparison did not, $t(47) = 0.14$, *ns*, $\eta_p^2 < .01$.

As the comparison of fear versus neutral conditions from the unmixed sessions did not yield an effect of emotion, these conditions were pooled and compared to fear versus neutral from the mixed session in a one-way repeated-measures ANOVA with fear mixed versus neutral mixed versus combined unmixed as levels, which did not yield a significant effect, $F(2, 94) = 0.36$, *ns*, $\eta_p^2 = .01$.

In order to keep the total number of pictures the same in each session, participants were exposed to twice as many fear-evoking and neutral pictures in the unmixed fear and neutral sessions as in the mixed session. To examine the possibility that failure to observe differences between fear versus neutral in the unmixed sessions was due to more exposure to the timed pictures, a 2 (presentation method) x 2 (trial block: 1st 84 trials in a session vs. 2nd 84 trials) x 7 (duration) x 2 (emotion) ANOVA was conducted. This analysis yielded only one effect involving trial block, a trial block x duration interaction, $F(6, 282) = 5.05$, $p < .001$. A series of seven correlated-samples *t*-tests were conducted in which the trial blocks were compared to each other on the measure of *p*(Long) at each stimulus duration. Block 2 was associated with a more "long" responses than block 1 at 825 ms, $t(47) = 2.21$, $p = .03$, and block 1 was associated with more "long" responses at 1925 ms, $t(47) = 3.21$, $p = .002$, and 2200 ms, $t(47) = 2.48$, $p = .02$. No differences were observed at between trial blocks at any of the other durations. More importantly, trial block did not interact with presentation method or emotion, lending no support to the possibility that the absence of an effect of emotion between the unmixed sessions was due to more exposure to the pictures than in the mixed session.

5.2.2. BP and gamma.

Although the pattern for the group BP means was consistent with the fear overestimation restricted to the mixed session that was observed in the *p*(Long) data (mixed fear BP lower than mixed neutral BP), a presentation method x emotion repeated-measures ANOVA yielded no significant effects for BP or gamma. Correlated-samples *t*-tests on the effect of emotion on BP were also conducted on the unmixed sessions, $t(47) = .02$, *ns*, $\eta_p^2 < .01$, and in the mixed session, $t(47) = 1.42$, *ns*, $\eta_p^2 = .04$, as planned comparisons, but neither achieved significance.

6. Discussion

Fear pictures were judged to be longer than neutral pictures on the measure of *p*(Long) in the mixed session, but not when the unmixed sessions were compared to each other. This effect was not confirmed by the BP analyses, but trends in the BP data were consistent with this effect; that is, the difference between the mean BP values for fear and neutral cues in the unmixed sessions was smaller than in the mixed session.

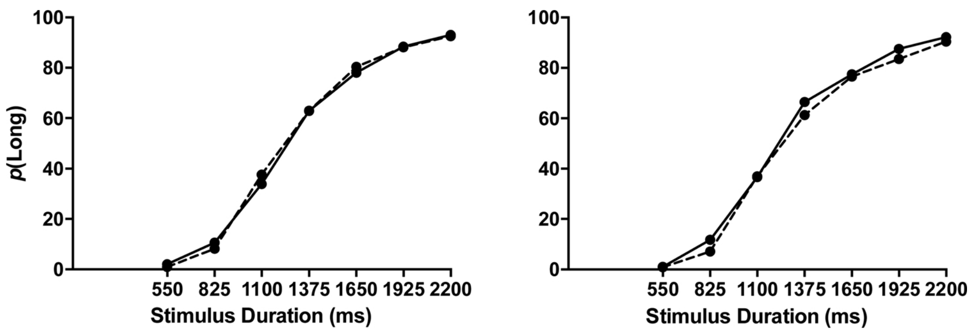

Fig. 8. Mean percent "long" presented as a function of stimulus duration (ms) in Experiment 2. The solid lines are fear plots, and the dashed lines are neutral plots. The left panel represents unmixed sessions and right panel represents mixed session.

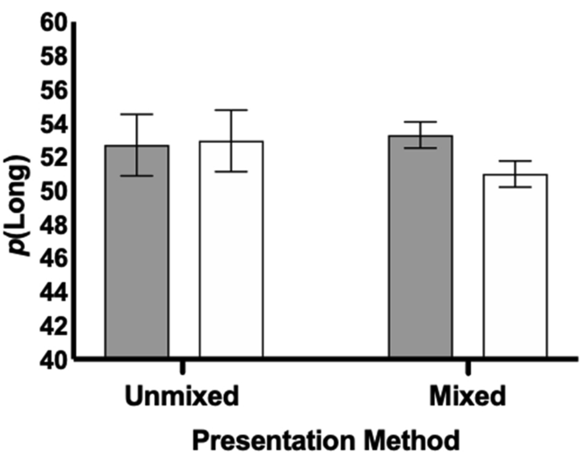

Fig. 9. Mean percent "long" as a function of presentation method collapsed across stimulus duration in Experiment 2. The gray bars represent fear conditions, and the white bars represent neutral conditions. Error bars display 95% within-subjects confidence intervals, as per Loftus and Masson (1994), for the emotion variable at each presentation method. The y-axis has been truncated so that the lowest point on the axis is 40% and the highest is 60%.

The effects on *p*(Long) were consistent with Penney et al.'s (1998, 2000) memory-mixing model that asserts that differences in temporal estimation caused by manipulations that affect the clock stage of SET can only be expressed if there is a single memory store to which timed values from two or more conditions (fear-evoking and neutral images in the present study) associated with the clock-stage manipulation are compared. Overestimation was not predicted to be observed between fear and neutral in the unmixed sessions, assuming that new reference memories are formed during the training phase of each session. Under this assumption, only one emotion should contribute to the stored values for a given stimulus duration in these sessions. For example, if fear-evoking pictures are associated with a faster pacemaker than neutral pictures, but the only reference memories available are timed durations of fear-evoking pictures, then overestimation would not be expressed in the testing phase. Alternatively, as the mixed session included both fear-evoking and neutral pictures, timed values could have been formed in the fear, neutral, or fear and neutral conditions; therefore, stored and recalled reference memories may be fear-based, neutral-based, or a combination of fear and neutral values.

Unlike Penney et al. (1998, 2000), who determined that temporal overestimation of auditory relative to visual stimuli was due to auditory memory bias, the current experiment was unable to determine whether the source of the observed memory-mixing effect (fear overestimation confined to the mixed session) was due to a fear-exclusive, neutral-exclusive, or intermediate value reference memory; that is, no differences in *p*(long) were observed between the fear-mixed or neutral-mixed condition and the combined data from the unmixed sessions.

7. General Discussion

Experiment 1 demonstrated that emotion-based overestimation of duration increased as duration range increased, but only when duration ranges were spaced more widely apart than in previous studies that had employed static images to evoke emotion (Gil et al.; Grommet al.; Smith et al.). Furthermore, the slope and y-intercept analyses of the duration range by BP plots indicated that the differences in BP between emotions were proportional across duration ranges. When considered through the lens of the clock stage of SET, these results support a pacemaker-rate account of the fear-overestimation effect.

Experiment 2 demonstrated that the fear-overestimation effect occurred when fear-evoking and neutral pictures were both presented within the same session, but not when picture type was manipulated across sessions. This is consistent with Penney et al.'s (1998, 2000) memory-mixing hypothesis, which asserts that the manipulation of stimulus features that operate on the clock stage (in this case, the features that control emotion) may be expected to promote storage and retrieval of remembered durations from a common memory store under conditions that favor memory mixing (e.g., manipulation of emotion within session).

An effect of emotion was not observed in any of the Experiment 2 BP analyses. This was surprising given that an a priori power analysis based on the effect of emotion in the long duration range of Experiment 1 indicated that Experiment 2 was run at $>.98$ power. The relatively small effect size of emotion on BP associated with the mixed session in Experiment 2 in comparison to that of Experiment 1 suggests that the methodological differences between the experiments interacted with the emotion manipulation. In Experiment 2, session type (a variable associated with how emotion was manipulated) was varied across sessions. This differed from Experiment 1 in which both fear-evoking and neutral pictures were presented in all sessions. The mechanism by which the session type manipulation could suppress the effect of emotion is difficult to speculate on at present.

Gamma values did not vary across duration ranges and duration/BP normalized functions superimposed across duration range. This is consistent with scalar timing (Gibbon, 1991; Gallistel & Gibbon, 2000) and previous findings in temporal bisection with human (e.g., Allan, 2002) and animal (e.g., Church, 1984) observers. Gamma was also invariant when there was an effect of emotion on BP and duration/BP normalized functions superimposed across emotion. This is consistent with an effect of emotion that is the product of pacemaker-based effects; that is, when emotion-evoking stimuli are presented in a mixed fashion, larger fear trial values in working memory should draw larger values from reference memory, which will be more variable (from trial to trial) than the smaller values drawn on neutral trials in the mixed session. This interpretation, however, should be tempered, as faster clocks have higher resolution than slower clocks, increased pacemaker speed may be associated with increased sensitivity (Gibbon, 1977; Wearden et al., 1998). If true, this would result in decreases in gamma, therefore, obscuring whether or not gamma should be expected to remain invariant across emotion conditions.

While it is possible that the observed effects on timing behavior were due to differences in picture attributes instead of differences in the emotions that they evoked (e.g., differences in color and complexity between the pictures from the fear-evoking and neutral conditions), support for the assertion that the observed differences in timing were due to emotion can be found in the differences between emotion condition ratings. Participants in both experiments rated the emotion-evoking pictures as more negative in valence, higher in arousal, and more fear evoking than the neutral pictures. The general finding across both experiments was that participants rated the fear-evoking pictures a progressively less arousing and fear evoking with subsequent ratings, but their valence ratings did not change. This dissociation has implications for what may be learned during habituation to fear-evoking stimuli, as it suggests that the appraisal of a stimulus as negative may be fixed, whereas the arousal associated with that appraisal is more malleable and prone to decrease with repeated presentations.

Multiplicative effects of emotion on BP across duration ranges have often been interpreted as evidence for pacemaker rate increases in the fear condition (e.g., Droit-Volet e al., 2010). There have been instances, however, in which the pacemaker has not been invoked in cases of multiplicative effects on time estimation. For example, in their interpretation of an effect in which children diagnosed with autism spectrum disorder multiplicatively overestimated the duration of stimuli in comparison to neurologically typical children, Allman et al. 2011offer an alternative explanation for multiplicative effects. They suggested that perhaps emotion-evoking stimuli do not increase pacemaker speed, and instead, they shorten reference memories. Experiment 2, however, allows for the dissociation of these two possibilities. If fear conditions are associated with shorter stored memories than neutral conditions, then fear overestimation should have not only been observed in the mixed session, but also in the unmixed session; that is, a smaller multiplier would result in fear overestimation regardless of presentation method (mixed vs. unmixed), whereas increases in pacemaker rate require conditions that favor memory mixing (e.g., within-session manipulation of emotion) in order for overestimation to be expressed.

Other non-pacemaker-based possibilities that could be used to explain fear overestimation are (a) the “flickering switch” (for a review see Lejeune, 1998) and that (b) fear-evoking and neutral stimuli may differ in terms of decisional bias (P. D. Balsam, personal communication, April 18, 2013). In the flickering switch account, attention to time vacillates throughout the presentation of timed stimuli, but the fear-evoking stimuli are associated with relatively more attention to time than the neutral stimuli. In this account, the percentage of time that the switch remains in the closed position (thus allowing pacemaker generated pulses to pass to the accumulator) is the same across duration ranges within a given emotion condition. This results in a larger absolute difference between the fear and neutral conditions on the measure of BP in longer duration ranges relative to shorter duration ranges, and therefore, makes it impossible to dissociate between the clock speed account and the flickering switch account using timing behavior as a measure (e.g., both accounts predict a duration range x emotion interaction). In the decisional bias account, subjects exhibit a response bias toward calling stimulus durations “short” versus “long;” e.g., there is a bias to more likely call stimuli “long” in the fear condition than in the neutral condition. For this account to explain the duration range x emotion interaction observed in Experiment 1, the “short” versus “long” criterion for one emotion condition, say neutral, would have to shift progressively farther from the criterion of the other emotion condition as duration range increased. Furthermore, in order for this account to explain the memory mixing results of Experiment 2, an additional stipulation would need to be added in which the criterion shift would occur when fear-evoking and neutral stimuli are manipulated within session, but not between sessions. As these possibilities are difficult to rule out, the dissociation between pacemaker and decision-based effects within SET remains an empirical and theoretical challenge.

8. Author Note

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