THE ROLE OF CLOCK AND MEMORY PROCESSES IN THE TIMING OF FEAR CUES IN HUMANS

by

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Abstract

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Advisor: Professor Bruce L. Brown

Recent research on the effects of fear on timing has focused on two accounts proposed by Scalar Expectancy Theory (Church, 1984; Gibbon, 1977) 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. In this account, greater temporal overestimation of fear relative to neutral stimuli is predicted for longer stimulus durations relative to shorter stimulus durations. The other account is that fear increases attention to time, which results in organisms beginning to time fear-evoking stimuli sooner than they do neutral stimuli. In this possibility, the effect of fear does not interact with stimulus duration. Experiment 1 asked which of these two possibilities was the underlying mechanism of temporal overestimation of fear cues by manipulating 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. A related area that has been left relatively unexplored is the role that reference memory may play in the temporal overestimation of fear-evoking stimuli. Penney, Gibbon, and Meck's (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 the second experiment, 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.

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Introduction

An active area of research has been the effect of emotions on time perception (for a review see Droit-Volet & Gil, 2009 and Droit-Volet & Meck, 2007). In particular, the experimental manipulation of stimuli that are both negatively valenced and highly arousing (e.g., fear-evoking stimuli) has been studied extensively due to the consistent effects on time perception that have been associated with it (e.g., Anderson, Reis-Costa, Misanin, 2007; Watts & Sharrock, 1984). Specifically, subjects judge the presentation durations of negatively valenced/highly arousing 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 & 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”) 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.

The scalar expectancy model of timing (SET; Church, 1984; Gibbon, 1977) has been influential in modern studies related to time perception. Figure 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 only in the presence of timing cues. The pulse count is transferred to working memory where it is compared, by a decision mechanism, to previously stored values in reference memory. The decision mechanism in turn controls response output.

There are at least two plausible accounts of how negatively valenced/highly arousing cues may be overestimated relative to neutral cues within the clock stage of SET. First, arousal could increase the speed of emission of pulses of observed time in the pacemaker; that is, clock speed may increase, resulting in a greater accumulation of clock pulses during the timed interval. Alternatively, negatively valenced/highly arousing cues could decrease the closure latency (or decrease the opening latency) of the switch (e.g., participants may start timing fear cues earlier than neutral cues), thus allowing more pulses to accumulate during a fear condition than in a neutral condition.

The distinction between the two plausible accounts (speed *vs*. latency) requires the use of at least two different duration ranges when using the temporal-bisection task. In the former (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, the effect should be multiplicative. In contrast, for the latter (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, latency effects should be additive.

Grommet et al. (2011) asked whether the underlying cause of the overestimation observed in studies like Tipples (2008) was in line with a pacemaker (multiplicative) or switch (additive) effects. Participants were exposed to two successive sessions, corresponding to each of two duration ranges (250-1000 ms and 400-1600 ms), in a counterbalanced fashion. Images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) that participants rated on three scales (valence, arousal, and fear) were presented as temporal stimuli. Three images that were rated as highly fear evoking and three rated low served as fear cues and neutral control images, respectively. Fear images were temporally overestimated relative to neutral images at both duration ranges, but the magnitude of the effect did not differ between ranges. Thus, the fear effects appeared to have been mediated by the switch rather than the pacemaker.

In a similar study, Gil, Niedenthal, and Droit-Volet (2007) randomly assigned participants to one of two duration-range groups (400-1600 ms or 600-2400 ms) in a temporal bisection task. All participants timed the duration of images of faces with angry expressions and neutral expressions. Angry facial expressions were overestimated relative to neutral facial expressions at both duration ranges, but, as in Grommet et al. (2011), the magnitude of the effect did not differ between ranges.

Interestingly, one article (Droit-Volet, Mermillod, Cocenas-Silva, and Gil, 2010) has reported results that are at odds with the switch-mediated interpretation of the fear-overestimation effect given by Grommet et al. (2011) and Gil et al. (2007). Droit-Volet et al.'s participants, who were assigned to one of two duration-range groups (400-800 ms or 800-1600 ms), judged the duration of blue circles that were presented via computer monitor. In one condition, the circles were followed by 50 ms of 95 dB white noise that had been used as a fear cue in previous research (Hillman, Hsiao-Weckslerb, & Rosengren, 2005) and had been rated by Droit-Volet et al.'s participants to be fear evoking. In another condition, the circles were followed by a 50 ms of a 50 dB beep that the participants had judged to be neutral and mildly happiness evoking. Both conditions were randomly presented across trials in a within-subjects fashion and were differentially signaled by a sign that was shown to the participants prior to the start of each trial. In agreement with the results of Grommet et al. and Gil et al., Droit-Volet et al. found that participants overestimated the duration of the timed stimuli on fear trials relative to neutral trials. In apparent conflict with Grommet et al. and Gil et al., Droit-Volet et al. also observed that the overestimation was greater in the longer duration range in comparison to the shorter duration range, thus, supporting the pacemaker rather than the switch hypothesis.

The fact that Grommet et al. (2011) and Gil et al.'s (2007) participants timed emotion-evoking cues and Droit-Volet et al.'s (2010) participants timed stimuli that preceded emotion-evoking cues may be one important difference between these studies. Grommet et al. and Gil et al.'s participants may have habituated to the emotional qualities of the pictures within individual trials; that is, picture onset may have been associated with a level of fear and arousal that decreased within trial as a result of continued exposure to the emotion-evoking picture. Droit-Volet et al.'s participants would not be likely to exhibit this same trend as the one speculated for Grommet et al. and Gil et al., as the probability that the aversive sound would be presented in Droit-Volet et al.'s procedure increased as time passed, thus likely resulting in sustained or increasing fear and arousal in aversive-sound trials. These possible differences in how the fear effect was manifested may have resulted in Droit-Volet et al. observing an emotion x duration range interaction and Grommet et al. and Gil et al. only observing an effect of emotion. If Grommet et al. and Gil et al.'s participants exhibited within-trial habituation to the fear-evoking stimuli and Droit-Volet et al.'s participants did not, there may have been a period of time in each trial in which Grommet et al. and Gil et al.'s participants were no longer afraid or aroused. If this were the case, then increases in pacemaker speed would go undetected (no emotion x duration range interaction) in Grommet et al. and Gil et al., as the increases would last for the same amount of time regardless of stimulus duration, whereas Droit-Volet et al.'s participants would have maintained high fear and arousal throughout each trial.

Another methodological difference that may have contributed to the difference in findings between the studies is that Grommet et al.'s participants rated the fear-evoking pictures as less arousing (mean arousal = 3.82 of 9) than Droit-Volet et al.'s participants rated the aversive sounds (mean arousal = 7.25 of 9). Gil et al.'s participants did not rate the pictures that they were presented, so it is not possible to compare this study with the others on this factor. It is possible that either there is some threshold for subjective arousal, after which the pacemaker becomes involved in overestimation, or that the extent to which stimuli in the emotion-evoking condition are overestimated in comparison to stimuli in the control condition increases as arousal increases. If the first possibility (arousal threshold for pacemaker increases) is correct, a possible explanation for Grommet el al.'s failure and Droit-Volet et al.'s success in observing an emotion x duration interaction is that Grommet et al.'s pictures did not elicit enough arousal to exceed the threshold necessary for pacemaker increases, whereas Droit-Volet et al.'s sounds did. If the second possibility (overestimation increases with arousal) is correct then the emotion x duration range interaction observed by Droit-Volet et al. is due to Droit-Volet et al.'s emotion-evoking condition being associated with a faster pacemaker than Grommet et al.'s emotion-evoking condition. If more subjective arousal is associated with a faster pacemaker than that of less subjective arousal, then an emotion x duration range interaction would have been present in both Grommet et al. and Droit-Volet et al., but Droit-Volet et al.'s preparation was more sensitive due to their use of more highly arousing stimuli. The multiplicative relationship between pacemaker rate and stimulus duration should result in higher arousal, relative to lower arousal, being associated with larger subjective timing differences between the differences of the emotion-evoking and control conditions at the longer duration range in comparison to the shorter duration range.

A final methodological difference that should be considered is that Grommet et al. (2011) and Gil et al. (2007) used duration ranges that were more closely spaced together (difference between the arithmetic means of the duration ranges was 375 and 500 ms, respectively) than the duration ranges used by Droit-Volet et al. (mean difference = 600 ms). This is a likely reason for Droit-Volet et al. observing an emotion x duration range interaction, because, as pacemaker effects are multiplicative, the differences between duration judgments of emotion-evoking and control stimuli should increase as the spacing between duration range increases. In this view, the effects of emotion on timing were multiplicative in Grommet et al., Gil et al., and Droit-Volet et al., but the emotion x duration range interaction was only observed in Droit-Volet et al. because Grommet et al.'s and Gil et al.'s preparations were not sensitive enough to detect the interaction.

The aim of Experiment 1 in the current study was to evaluate whether or not the last of these possibilities (differences between duration ranges was too small to yield an interaction) could have been the source of the discrepant findings, 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 difference between these two duration ranges was comparable to the difference in duration ranges used by Droit-Volet et al., whereas the differences between 250-1000 ms *vs.* 400-1600 ms and 400-1600 ms *vs.* 550-2200 ms were equal to the difference between the duration ranges used in Grommet et al.

An interpretation that is common to Grommet et al. (2011), Gil et al. (2007), and Droit-Volet et al. (2010) 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 Grommet et al., Gil et al., and Droit-Volet et al.'s effects of emotion to be attributable to changes that occurred in the clock stage, one of the following possibilities must be true on a given trial: (a) accumulator contents in emotion-evoking trials must be compared to reference memory contents from neutral trials, (b) accumulator contents in neutral trials must be compared to reference memory contents from fear trials, or (c) accumulator contents in fear and neutral trials must be compared to reference memory values that fall somewhere in between that associated with previous fear and neutral trials.

Penney, Allan, Meck, and Gibbon (1998) and Penney, Gibbon, and Meck (2000) conducted a series of experiments aimed at examining a similar phenomenon 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 separate sessions or in a between-subjects manner, subjects may store and retrieve separate memories on emotion-evoking and neutral trials, therefore no timing differences should be expressed in relation to the emotion-evoking and neutral stimuli.

Grommet et al. (2011), Gil et al. (2007), and Droit-Volet et al.'s (2010) results are in line with Penney et al.'s (1998; 2000) prediction in that emotion-evoking and neutral cues were presented in random order across trials, and overestimation of emotion-evoking relative to neutral cues was observed. None of these studies, however, directly tested Penney et al.'s prediction, as none manipulated how emotion cues were presented, i.e., 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) was manipulated within or between sessions. In one session type, only fear-evoking pictures were presented. In another session type, only neutral pictures were presented, and in a third session type both fear-evoking and neutral pictures were be presented in random order, as in Grommet et al. resulting in fear-mixed and neutral-mixed conditions. If the fear overestimation effect is attributable to memory mixing, then temporal overestimation of fear-evoking relative to neutral pictures should be observed in the comparison of the fear-mixed to the neutral-mixed conditions, but not when the fear-only and neutral-only conditions were compared to each other.

Experiment 1

An important methodological difference between Grommet et al. (2011), Gil et al. (2007), and Droit-Volet et al. (2010) is that Droit-Volet et al. used duration ranges that were spaced further apart than those used in Grommet et al. and Gil et al. This is a likely reason for Droit-Volet et al. observing an emotion x duration range interaction, because, 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 Grommet et al.'s preparation was not sensitive enough to detect them. Therefore, the primary aim of Experiment 1 was to reconcile the findings of Grommet et al. with those of Droit-Volet et al. 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 in effects between Grommet et al. and Droit-Volet et al. was due to the difference in sensitivity between the duration ranges used then an emotion x duration range interaction for time estimates would be observed between the 250-1000 ms *vs.* 550-2200 ms ranges, but not necessarily between the other ranges.

Method

Participants

Forty-eight Queens College, City University of New York (CUNY), introductory psychology students served as participants. They received credit toward the research requirements of their course in exchange for their participation.

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 computer.

Materials

Stimuli consisted of six photographs (23.5 cm x 17.5 cm) from the International Affective Picture System (IAPS; Lang Bradley, & Cuthbert, 2008). Three photographs were the pictures with 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). Mikels et al. had 60 participants rate 203 emotionally negative pictures from the IAPS on four 7-point scales based on how much the pictures made them feel the following emotions: fear, disgust, sadness, and anger. A rating of 1 indicated *not at all* and a rating of 7 indicated *a great amount*. A 90% confidence interval (CI) was calculated for the mean rating of each picture. A picture was designated to singularly evoke fear if the mean fear rating was higher than all other ratings and if the CI for fear did not overlap with the CIs of any other ratings. The three other photographs were the pictures with normative ratings that indicated that they were neither arousing nor calming and neither positive nor negative (basket-7010, fan-7020, and lamp-7175). During the training phase a 3 cm x 3 cm green square was presented.

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

Experimental Design

A 3 (duration range) x 7 (duration) x 2 (emotion) within-subjects experimental design was used. Sequence of duration range (short: 250-1000 ms *vs.* medium: 400-1600 ms *vs.* long: 550-2200 ms) was counterbalanced across participants, with participants each being randomly assigned to one of the six possible sequence combinations with the constraint that eight participants were assigned to each sequence (see Table 1). 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 session. A different random order was generated on each session for each participant.

Procedure

General. Each participant was exposed to three sessions. Sessions were duration-range specific; that is, each session corresponded to the 250-1000 ms, 400-1600 ms, or 550-2200 ms duration range. A session began and ended with a rating phase (i.e., pre- and posttest). 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. The script that experimenters followed while interacting with participants can be found in Appendix A.

Rating phase. Participants were exposed to all 6 IAPS pictures (3 fear-evoking and 3 neutral). Each picture was shown for 1225 ms and the presentation sequence of the pictures was randomized independently for each rating phase. Following the presentation of each picture, participants used the Self-Assessment Mannequin (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 (see Appendix B) 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 picture to be rated was presented following a 500 ms delay. This process continued until all 6 pictures had been rated.

Training phase. The purpose of the training phase was to ensure that participants made accurate discriminations between the shortest and longest durations (the anchor durations) of the duration range in the ensuing testing phase. In the training phase, participants were exposed to green squares that were presented in the center of the screen for either the shortest or longest duration of the duration range that the participants were exposed to in the testing phase of the session. 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. Then a fixation point was presented for 1000-3000 ms (randomly determined) before the presentation of the next square. Blocks of eight green squares (4 short and 4 long, in random order) continued to be presented until the participant completed a block with no errors.

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 7 durations comprising the 2 anchor durations used in the training phase and 5 linearly-spaced intermediate probe durations that fell between the 2 training durations. Each of the 6 IAPS pictures were presented twice at each duration in each block. The presentation sequence of these picture-duration combinations was random within each block. 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. Following the "S" or "L" key press, there was a 1000-3000 ms random-duration inter-trial interval (ITI) during which a fixation point was presented. After the termination of the ITI, the next picture was presented. This phase ended following the response to the last picture presentation.

Data Analysis

Testing phase.

p(Long). A 3 (duration range) x 7 (duration) x 2 (emotion) repeated-measures factorial ANOVA was conducted on the percentage of trials in which duration was judged to be "long" (*p*(Long)). Duration was scaled 1-7 for all duration ranges for this analysis.

BP, temporal variability, and temporal sensitivity. The BP and a measure of temporal sensitivity (gamma) were estimated from the bisection function for each participant with the use of the pseudo-logistic model (PLM; Killeen, Fetterman, & Bizo, 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 ratio (difference limen/BP) for time, and decreases as the slope of the bisection function in the vicinity of the BP increases. The BP and gamma were estimated from the data with a nonlinear regression algorithm using the Prism 5.04 software package for the Windows operating system. The median proportion of variance accounted for 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 factorial ANOVA was conducted on the BP and gamma scores. The results obtained with PLM were compared with values for BP, temporal variability (difference limen, half the difference between the stimulus duration associated with 25% "long" and the stimulus duration associated with 75% "long"), and temporal sensitivity (Weber ratio, difference limen divided by BP) obtained from the linear regression analysis procedure described by Church and Deluty (1977).

Superposition of duration range and emotion. SET predicts that group mean *p*(Long) bisection functions obtained from duration ranges with the same ratio between the duration associated with the *short* trained duration and the *long* trained duration (1:4 in the case of the duration ranges in the current experiment) will superimpose if the functions are rescaled by dividing the value for each stimulus duration by the BP (Allan & Gibbon, 1991; Gibbon, 1981; 1986). In the current experiment, Stimulus duration/PLM-BP normalized duration range functions (short, medium, and long collapsed across emotion) were plotted on a single graph in order examine whether superposition was exhibited across duration ranges (e.g., Allan & Gibbon, 1991; Church & Deluty, 1977). Stimulus duration/PLM-BP normalized emotion condition (fear and neutral) functions were also plotted at each duration range in order to test whether this effect was scalar, and would exhibit the superimposition typically associated with duration range manipulations.

Response latency. A 3 (duration range) x 2 (emotion) repeated-measures factorial ANOVA was conducted on the latency to respond (ms) from picture offset in the testing phase of the temporal bisection task.

Training phase. One-way repeated-measures ANOVAs of session and duration range were conducted on the number of training blocks that participants took to complete the training phase.

Rating phase. A 3 (session) x 2 (emotion) x 2 (test: pretest *vs.* posttest) repeated-measures factorial ANOVA was conducted on the data from all 3 rating scales (arousal, valence, and fear).

Rating and BP correlations. Pearson's *r* was calculated for the BP values and picture ratings of fear, arousal, and valence at each of the two conditions (fear and neutral).

Additionally, the difference in BP from the neutral to fear condition was calculated for each participant, as was the difference in fear, arousal, and valence ratings. Then Pearson's *r* was calculated to determine the correlation between the difference in BP with the difference in fear, arousal, and valence.

The foregoing analyses were conducted on the data collapsed across duration range and at each duration range separately.

α level and additional analyses. An α level of .05 was used for all statistical tests. The foregoing tests were also conducted with sequence group as a variable, but as this variable never interacted with emotion (the primary variable of interest) it was removed for the reported analyses. Additional analyses were conducted, as needed, to parse effects that were observed in the primary analyses.

Results

Testing Phase

***p*(Long).** Figure 2 shows group mean *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. Figure 3 presents the data replotted with a common time axis (durations scaled as 1-7), consistent with the duration range x duration x emotion ANOVA used for the primary analysis of *p*(Long) values. Results for this ANOVA can be found in Table 2. The fear condition was associated with a higher percentage of long judgments in comparison to the neutral condition, but this effect was most pronounced at the middle stimulus durations in each duration range. This was evidenced by the primary *p*(Long) ANOVA yielding not only significant main effects of emotion and duration, but also a significant emotion x duration interaction. When the ANOVA was confined to the three middle durations, there was still an effect of emotion, $F(1, 47) = 40.37$, $p < .0001$, but the emotion x duration interaction was not significant, $F(2, 94) = 1.07$, *ns*, suggesting 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.

There was also a duration range x duration interaction. Figure 4 indicates that all three duration ranges exhibited an ascending sigmoidal function in which *p*(Long) increased with duration. The one exception to this was flattening in the *p*(Long) function that occurred between durations 6 and 7 in the long (550-2200 ms) duration range. Indeed, when the ANOVA was confined to all but the longest stimulus duration, the duration range x duration interaction was not significant, $F(10, 470) = 1.36$, *ns*, suggesting that the interaction obtained with all 7 durations was attributable to the aforementioned flattening of the long duration range plot.

It should be noted that there was no evidence of an emotion x duration range interaction in the primary analysis. This is consistent with an effect of emotion on *p*(Long) that is multiplicative with duration range, as data for this analysis were plotted on a normalized (1-7) time axis.

BP, temporal variability, and temporal sensitivity.

PLM.

BP. Figure 2 shows that there were leftward shifts in the functions for fear cues (solid lines) in comparison to those for neutral cues (dashed lines) and that the difference between the fear and neutral plots increases with duration range. This impression was confirmed quantitatively by inspection of the mean BP values. Figure 5 shows the BP (calculated using the PLM) plotted as a function of duration range for the fear and neutral emotion conditions (left panel) and the difference in BP between the neutral and fear conditions as a function of duration range (right panel). 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 was greater at the long duration range than at the short duration range on the measure of BP. These effects were supported by a 3 (duration range) x 2 (emotion) repeated-measures factorial ANOVA of BP, yielding not only significant effects of emotion and duration range, but also an emotion x duration range interaction. Subsequent ANOVAs in which each duration range was systematically removed (one at a time) from each analysis revealed that the interaction was the result of the difference in BP values between fear and neutral cues being greater at the long duration range than at the short duration range; no emotion x duration range interaction was observed when the middle duration range was analyzed with the short, $F(1, 47) = .01$, *ns*, or long, $F(1, 47) = 3.72$, *ns*, duration range, but the interaction was present when only the short and long duration ranges were included in the ANOVA, $F(1, 47) = 4.25$, $p = .04$. Results for the primary analysis of BP can be found in Table 3. Means and standard errors of the mean (*SEM*) for BP are presented on Table 4.

In line with the aforementioned emotion x duration range interaction on BP, the neutral condition in the left panel of Figure 5 exhibits a steeper slope ($M = .91$ ms/ms, $SEM = .06$ ms/ms) in comparison to the fear condition ($M = .84$ ms/ms, $SEM = .04$ ms/ms). In order to confirm this effect, slope and y-axis intercept were calculated for each participant at each emotion with duration range (numbered as 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, $t(47) = 2.06$, $p = .05$, but not on intercept, $t(47) = .56$, *ns*.

Gamma. A duration range x emotion repeated-measures factorial ANOVA of gamma did not yield any significant effects. Results for this analysis can be found in Table 3. Means and *SEMs* for gamma are presented on Table 4.

Church and Deluty.

In order to assess the generality of the analysis with the PLM, the linear regression analysis procedure described by Church and Deluty (1977) that yields BP, difference limen, and Weber ratio was calculated for each participant at each duration range and emotion condition combination.

BP. Figure 6 shows BP calculated as per Church and Deluty (1977) plotted as a function of duration range for the fear and neutral emotion conditions (left panel) and the difference in BP between the neutral and fear conditions as a function of duration range (right panel). The function is similar to that in Figure 5, showing an apparent graded effect of duration range on the difference in BP between fear and neutral cues. As was the case with the BP values obtained from the PLM, the fear condition was associated with lower BP values in comparison to the neutral condition and the extent to which fear-evoking pictures were overestimated relative to neutral pictures was greater at the long duration range than at the short duration range.

A 3 (duration range) x 2 (emotion) repeated-measures factorial ANOVA corroborated the significant effects of emotion and duration range that were present in the data obtained with the PLM, but in contrast with the PLM analysis no emotion x duration range interaction was observed. Planned comparisons in which each duration range was systematically removed (one at a time) from each analysis revealed that the underlying pattern of effects responsible for the emotion x duration range interaction in the data from the PLM analysis was also present in the Church and Deluty (1977) analysis; that is, no emotion x duration range interaction was observed when the middle duration range was analyzed with the short, $F(1, 47) = .81$, *ns*, or long, $F(1, 47) = 1.53$, *ns*, duration range, but the emotion x duration range interaction was present when only the short and long duration ranges were included in the ANOVA , $F(1, 47) = 4.58$, $p = .04$. Results for the primary analysis of BP can be found in Table 5. Means and *SEMs* for BP are presented on Table 6.

As was the case with PLM derived mean BPs, the neutral condition in the left panel of Figure 6 exhibits a steeper slope ($M = .92$ ms/ms, $SEM = .05$ ms/ms) in comparison to the fear condition ($M = .86$ ms/ms, $SEM = .04$ ms/ms). In order to confirm this effect, slope and y-axis intercept were calculated using the same method as for the PLM BP data. Correlated-samples *t*-

tests yielded an effect of emotion on slope, $t(47) = 2.14$, $p = .04$, but not on intercept, $t(47) = .57$, *ns*. No other effects were observed.

Difference limen. Means and *SEMs* for difference limen are presented on Table 6. Consistent with a scalar effect of duration range, difference limen increased as a function of duration range. This was confirmed by a 3 (duration range) x 2 (emotion) repeated-measures factorial ANOVA in which only a significant effect of duration range was observed and Tukey's HSD, which indicated all three duration ranges differed from each other on this measure. Results for the primary analysis of difference limen can be found in Table 5.

Weber ratio. Table 6 displays means and *SEMs* for the Weber ratios. Unlike the analysis of gamma (which yielded no effects), the mean Weber ratio was larger (indicative of lower sensitivity) in the fear condition relative to the neutral condition, and increased as a function of duration range. This was confirmed by a 3 (duration range) x 2 (emotion) repeated-measures factorial ANOVA in which significant effects of emotion and duration range were observed. Tukey's HSD indicated that the Weber ratios of the short and long duration ranges differed, but that the medium duration range did not differ from either the other duration ranges. Results for the primary analysis of Weber ratio can be found in Table 5.

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 PLM obtained BP for each of the six emotion x duration range combinations. Figure 7 shows *p*(Long) plots of fear and neutral cue data with normalized axes (stimulus duration/BP), separately for each duration range. Normalized plots exhibited superposition of fear and neutral values at all duration ranges, consistent with a multiplicative effect of emotion on time estimation in the bisection protocol.

Stimulus duration/PLM-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. Figure 8 shows normalized *p*(Long) plots for each duration range. Normalized plots exhibited superposition across all duration ranges. The data plotted in Figure 8 were representative of individual subject's data. Appendix C presents stimulus duration/BP normalized *p*(Long) plots at each duration range for individual participants.

Response latency. Figure 9 displays latency to respond (ms) from picture offset in the testing phase of the temporal bisection task across stimulus duration (1-7). The middle durations were associated longer latencies than the durations on the extremes. This effect was supported by a 3 (duration range) x 2 (emotion) repeated-measures factorial ANOVA that yielded only a significant effect of duration, for which Tukey's HSD revealed that the middle 3 durations were associated with longer response latencies than durations 1, 2, 6, and 7. Results for the primary analysis of response latency can be found in Table 7.

Training Phase

Participants took an average of 1.33 training blocks (8 trials per block) to pass the training phase for a given session. Participants took longer to pass session 1 ($M = 1.56$ training blocks) in comparison to sessions 2 ($M = 1.17$ training blocks) and 3 ($M = 1.27$ training blocks). This effect was verified by a one-way repeated-measures ANOVA of training blocks that revealed an effect of session, $F(2, 94) = 9.21$, $p = .0002$, 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 duration range as the independent variable did not yield an effect, $F(2, 94) = 1.31$, *ns*.

Rating Phase

Fear. Figure 10 shows fear ratings of the fear-evoking and neutral pictures plotted as a function of pretests and posttests as a function of sessions. Fear-evoking pictures were rated as more fear evoking than the neutral pictures. This was verified by a 3 (session) x 2 (emotion) x 2 (test) repeated-measures factorial ANOVA that yielded not only significant effects of emotion, test, and session, but also an emotion x test interaction, an emotion x session interaction, and a session x test interaction. The source of the interactions involving emotion was a decrease in reported fear that occurred over tests and sessions in response to the fear evoking pictures, but not to the neutral pictures. This was supported by a 3 (session) x 2 (test) repeated-measures factorial ANOVA restricted to the fear pictures that yielded significant effects of test, $F(1, 47) = 11.28$, $p = .002$, and session, $F(2, 94) = 12.68$, $p < .0001$ (Tukey's HSD indicated that session 1 differed from the others), and an ANOVA restricted to the neutral pictures in which no effects were observed. The session x test interaction 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 one-way repeated-measures *t*-test of test restricted to session 1 yielded a significant effect, $t(47) = 3.75$, $p = .0005$, and a 2 (session) x 2 (test) repeated-measures factorial ANOVA restricted to sessions 2 and 3 yielded a significant effect of test, $F(1, 47) = 5.72$, $p = .02$, but no session x test interaction $F(1, 47) = .49$, *ns*. Results for the primary analysis of fear ratings can be found in Table 8.

Arousal. Figure 11 shows arousal ratings of the fear-evoking and neutral pictures plotted as a function of test. Fear-evoking pictures were rated as more arousing than the neutral pictures. This was verified by a 3 (session) x 2 (emotion) x 2 (test) repeated-measures factorial ANOVA that yielded not only an effect of emotion, test, and session, but also an emotion x test, emotion x session, and emotion x test x session interaction. The source of these interactions was a decrease in reported arousal that occurred over tests and sessions in response to the fear evoking pictures, but not to the neutral pictures. This was supported by a 3 (session) x 2 (test) repeated-measures factorial ANOVA restricted to the fear pictures that yielded significant effects of test, $F(1, 47) = 10.16$, $p = .003$, session, $F(2, 94) = 13.74$, $p < .0001$ (Tukey's HSD indicated that all sessions differed from each other), and a session x test interaction, $F(2, 94) = 6.73$, $p = .002$, and an ANOVA restricted to the neutral pictures, in which no effects were observed. The session x test interaction in the fear condition ANOVA was due to the pretest-posttest effect being restricted the session 1. This was verified by a repeated measures *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) x 2 (test) repeated-measures factorial ANOVA on the fear condition that was restricted the 2nd and 3rd sessions that resulted in no effect of test, $F(1, 47) = 1.03$, *ns*, and no session x test interaction, $F(1, 47) = .26$, *ns*. Results for the primary analysis of arousal ratings can be found in Table 8.

Valence. Figure 12 shows valence ratings of the fear-evoking and neutral pictures plotted as a function of test. Fear-evoking pictures were rated as more negative than the neutral pictures. This was confirmed by a 3 (session) x 2 (emotion) x 2 (test) ANOVA that yielded a significant effect of emotion. No other effects were significant. Results for the analysis of valence ratings can be found in Table 8.

Rating and BP Correlations

PLM BP values from the fear condition did not correlate with fear picture ratings of fear, $r(46) = -.20$, *ns*, arousal, $r(46) = -.24$, *ns*, or valence, $r(46) = .06$, *ns*. The same was true for the BP values from the neutral condition and neutral picture ratings of fear, $r(46) = -.12$, p = ns, arousal, $r(46) = -.24$, *ns*, and valence, $r(46) = -.11$, *ns*. The difference in BP between the neutral condition and the fear condition was also not correlated with the difference between the ratings of the fear and neutral pictures on fear, $r(46) = -.10$, *ns*, arousal, $r(46) = -.06$, *ns*, or valence, $r(46) = -.03$, *ns*. All of the aforementioned correlations were also conducted restricted to one duration range at a time; again, no significant effects were observed.

All of the correlation analyses that were conducted using the BP values obtained from the PLM (Killeen et al., 1997) were also conducted with BP values obtained from the Church and Deluty (1977) technique. The results were essentially the same; no significant correlations were observed, with the exception of a moderate negative correlation between the BP values and arousal ratings to the neutral pictures in the medium duration range, $r(46) = -.29$, $p = .05$.

Discussion

Fear pictures were judged to be longer than neutral pictures, on the measures of *p*(Long) and BP, and the extent to which fear-evoking pictures were overestimated was greater at the long duration range than at the short duration range on the measure of BP. This outcome provides evidence for a non-additive mechanism underlying the difference in temporal judgments occasioned by fear *vs.* neutral cues.

Within the context of the SET clock model, 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, multiplicative effects have been interpreted as evidence for an increase in the pacemaker's pulse emission rate under the fear condition relative to the neutral condition.

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, a larger effect of emotion at the longer duration range could result from (a) and increase in pacemaker rate or (b) an increase in pacemaker rate and a change (either 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 mean slope and y-intercept, derived from duration range by BP functions. As increased pacemaker speed should result in proportional increases in the effect of emotion across duration ranges and changes switch latency should result in the same effect 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 and no effect was observed on the measure of y-intercept. This suggests that only the pacemaker was involved in the observed fear overestimation.

Gamma was not affected by any of the factors, suggesting that temporal sensitivity did not differ across sequence groups, duration ranges, or emotion conditions. Additional support for this pattern can be found in the superposition of duration range and emotion, as superposition of stimulus duration/BP normalized functions will only occur when changes in the difference limen are proportional to changes in the BP across conditions. The Weber ratio analysis, however, did not support these analyses in that there was a small, but statistically significant, increase in Weber ratio in the fear condition relative to the neutral condition (indicating a decrease in temporal sensitivity associated with fear), and from the short to the long duration range (indicating an increase in temporal sensitivity as duration range increased).

A Duration Range x Duration interaction was observed on the measure of *p*(Long). This was not expected, as the duration ranges were designed to be equally discriminable; i.e., the longest duration of each range was four times larger than the shortest duration, and the five intermediate durations were linearly spaced. It is not clear why this interaction occurred, but it does not seem to be pervasive, as it was isolated to only the longest duration of long duration range. It should be noted that interaction does not represent a violation of scalar timing, as superposition of duration ranges was still observed when the plots were normalized by BP.

In the current experiment, participants rated and timed pictures that were designated as either emotion-evoking or neutral, based on normative ratings of fear, arousal, and valence. In line with previous studies on the effects of emotion on timing, the current experiment found that the ratings were in agreement with the normative ratings, inasmuch as participants rated the emotion-evoking pictures as more fear evoking, higher in arousal, and more negative in valence than the neutral pictures. Owing, in part, to a design that employed a total of 6 rating phases per participant (3 sessions that each included a pretest and posttest rating), the current experiment allowed for the observation of changes in ratings with repeated exposure to the pictures in the testing phase of the temporal bisection task. The general finding was that participants rated the fear-evoking pictures a progressively less fear evoking and arousing with subsequent ratings, but their valence ratings did not change.

The conclusion that the present findings were mediated by the pacemaker is at variance with the conclusions drawn by Grommet et al. (2011) and Gil et al. (2007), both who found that negatively valenced/highly arousing pictures were overestimated relative to neutral pictures but that the effects were additive, rather than multiplicative. Grommet et al. used 250-1000 ms and 400-1600 ms duration ranges (the same as the short and medium duration ranges used in the present experiment), and Gil et al. used 400-1600 ms and 600-2400 ms duration ranges. The spacing of these duration ranges (difference between arithmetic means) was 375 ms and 500 ms for Grommet et al. Gil et al., respectively. When the BP analysis for the present experiment was restricted to the short duration range (250-1000 ms) *vs.* the medium duration range (400-1600 ms) or medium *vs.* long (550-2200 ms) the spacing of the duration ranges was 375 ms and the results were consist with those of Grommet et al. and Gil et al. As the present experiment, however, employed three duration ranges, an additional/more sensitive measure of the emotion x duration range interaction on BP was permitted, the comparison of the difference in effect of emotion at the short duration range to the difference in effect at the long duration range. The spacing between these two duration ranges was 750 ms, resulting in greater magnitude differences in the effect of emotion between duration ranges; that is, 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.

In summary, the results of Grommet et al., Gil et al., and the present experiment are consistent in that an emotion x duration range interaction on BP was not observed when the analysis was restricted to more closely space duration ranges. An emotion x duration range interaction was only observed in the present experiment when the more widely spaced duration range comparison (short *vs.* long) was included. Both of these results (the failure to observe an interaction with closely spaced duration ranges and successfully observing the interaction when using widely spaced duration ranges), when taken together, support the interpretation that increased duration range spacing was responsible for the interaction observed in the present experiment.

In accord with the findings of present experiment, Droit-Volet et al. (2010) observed an emotion x duration range interaction on BP. As was also the case in Gil et al. (2007), there were several differences between the features of Droit-Volet et al. and the present experiment (e.g., timed stimulus modality and arousal level evoked by stimuli), but one feature that was similar between Droit-Volet et al. and the short and long duration range conditions of the present experiment was the wide spacing between duration ranges (mean difference between duration ranges in Droit-Volet et al. = 600 ms). This is consistent with the view that the spacing between duration rages is related to detecting an emotion x duration range interaction on the measure of BP, and that while features of Droit-Volet et al.'s methodology that differed from those of the present experiment may have contributed to their observation of an emotion x duration range interaction, those features are not necessary components for the observation of this interaction.

Experiment 2

In the SET clock model, as applied to the temporal-bisection task, a memory module stores separate distributions of the representations of the short and long anchor durations. On each test trial, a comparison is presumed to be made between the contents in the accumulator and the reference memory. Penney et al. (1998; 2000) demonstrated that overestimation of the duration of auditory stimuli relative to visual stimuli occurred only when auditory and visual stimuli were manipulated within an individual session in a within-subjects fashion. They argued that overestimation occurs in circumstances that allow for the values that are stored in memory to be mixed across modalities. That is, 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 own distribution of values. Alternatively, if high-rate and low-rate duration representations are stored in the same memory bank, that is, 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. Memory mixing is assumed to occur when (a) anchor durations are the same for both conditions, and (b) durations are presented within the same session.

It should be noted that the memory mixing hypothesis prediction that overestimation can only occur between conditions manipulated in a within-subjects manner is restricted to preparations in which the reference memory is formed during the experiment. For example, Wearden, Todd, and Jones (2006) observed overestimation when stimulus modality (auditory *vs.* visual) was manipulated between subjects in a verbal estimation task in which on each trial participants were presented with a stimulus and then instructed to type in their estimate of the stimulus duration. In this preparation, the standard that participants were instructed to refer to (the reference memory that applies to the label for a given duration, e.g., 500 ms) was formed prior to the start of the experiment, and was presumably common to both groups. This differs from the current experiment, in which the temporal-bisection task was employed. Prior to each testing phase, participants were trained to respond “short” to the shortest stimulus duration (550 ms) and “long” to the longest stimulus duration (2200 ms). In one session, only fear-evoking pictures were presented. In another session, only neutral pictures were presented, and in a third session type 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 was 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, then this would suggest that fear overestimation is 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; e.g., in the memory stage, presentation durations of fear stimuli may be stored as longer than they were timed in the clock stage.

A secondary question addressed by Experiment 2 asked, what are the contents of the mixed referent memory? That is, does fear overestimation occur because participants recall memories for stimulus durations encoded only for fear pictures, only for neutral pictures, or for a combination of both fear and neutral pictures? If the effect occurs due to recall of only memories for fear durations, then stimulus durations from the neutral trials of the mixed session would be underestimated relative to stimulus durations from the fear and neutral trials in the unmixed sessions. If this result were to be observed, overestimation of fear-evoking pictures in the mixed session would be due to temporal underestimation of neutral pictures relative to fear reference memories. Alternatively, if the effect occurs due to recall of only memories for neutral durations, then stimulus durations for the fear trials of the mixed session would be overestimated relative to stimulus durations for the fear and neutral trials in the unmixed sessions. If this result were to be observed, overestimation of fear-evoking pictures in the mixed session would be due to temporal overestimation of fear-evoking pictures relative to neutral reference memories. The final possibility is that the effect occurs due to recall of memories for a combination (e.g., the arithmetic mean) of fear and neutral durations. If this is the case, stimulus durations for the fear trials of the mixed session would be overestimated relative to stimulus durations for the fear and neutral trials in the unmixed sessions, and stimulus durations for the neutral trials of the mixed session would be underestimated relative to stimulus durations for the fear and neutral trials in the unmixed sessions. If this result were to be observed, overestimation of fear-evoking pictures in the mixed session would be due to temporal overestimation of fear-evoking pictures and temporal underestimation of neutral pictures, relative to the combination of fear and neutral reference memories.

Method

Participants

Forty-eight Queens College, City University of New York (CUNY), introductory psychology students served as participants. None of these students participated in Experiment 1. They received credit toward the research requirements of their course in exchange for their participation.

Setting and Materials

Experiment 2 used the same setting and materials used in Experiment 1.

Experimental Design

Sequence of session (fear unmixed: only fear-evoking pictures presented *vs.* neutral unmixed: only neutral pictures presented *vs.* mixed: fear-evoking and neutral pictures presented in a random order across trials) was counterbalanced across participants, with participants each being randomly assigned to one of the six possible sequence combinations with the constraint that eight participants were assigned to each sequence (see Table 9). Within sessions, the order of the 7 linearly-spaced durations (from 550-2200 ms) was random across trials. A different random order was generated on each session for each participant.

Procedure

General. Each participant was exposed to three sessions. Sessions differed in terms of the number and type of emotion-based pictures to which participants were exposed; that is, each of the three sessions corresponded to either fear-evoking pictures presented in an unmixed fashion, neutral pictures presented in an unmixed fashion, or fear-evoking and neutral pictures presented in a mixed fashion. Each session was preceded and followed by a rating phase. Between 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. The script that the experimenter followed while interacting with participants can be found in Appendix D.

Rating phase. Participants were exposed to all 6 IAPS pictures (3 fear-evoking and 3 neutral) regardless of session type. Each picture was shown for 1,375 ms and the presentation sequence of the pictures was random. Following the presentation of each picture, participants used the SAM (Lang et al., 2008) to rate the picture in regard to valence and arousal, and then 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 (see Appendix B) and participants made their ratings using a pen. After a participant made all three ratings, the participant pressed the spacebar on the computer keyboard and another picture to be rated was presented following a 500 ms delay. This process continued until all 6 pictures had been rated.

Training phase. Participants were exposed to IAPS pictures that were presented for either the shortest (550 ms) or longest (2200 ms) duration to which the participants were exposed to 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 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 the short or long duration, respectively. Following the participant's key press, feedback in the form of "correct" or "not correct" was displayed for 2000 ms. After the feedback terminated, a fixation point was presented for 1000-3000 ms (randomly determined) before the presentation of the next picture. Blocks of twelve pictures (6 short and 6 long, in random order) continued to be presented until the participant completed a block with no errors.

Testing phase. Participants were exposed to 2 blocks of 84 trials (168 trials in total) per session. Each block contained 12 presentations of each of the 2 durations used in the training phase (anchor durations) and 5 linearly-spaced intermediate probe durations that fell between the 2 training durations.

The difference in treatment between the three sessions was as follows: (a) The fear-unmixed session consisted of exposure to only the 3 fear-evoking pictures, (b) the neutral-unmixed session was the same as the fear-unmixed session except that the 3 neutral pictures were used instead of the fear pictures, and (c) the mixed session consisted of exposure to all 6 pictures (3 fear-evoking and 3 neutral). The presentation sequence of all picture/duration combinations was random within each block with the following constraints: each of the 3 fear pictures was presented 4 times per block in the fear-unmixed session, each of the 3 neutral pictures was presented 4 times per block in the neutral-unmixed session, and each of the 6 pictures was presented 2 times per block in the mixed session.

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. Following the “S” or “L” key press, there was a 1000-3000 ms (randomly determined) ITI during which a fixation point was presented. After the termination of the ITI, the next picture was presented. This phase ended following the response to the last picture presentation.

Data Analysis

Testing phase.

p(Long). A 7 (duration) x 2 (emotion: fear *vs.* neutral) x 2 (session type: unmixed *vs.* mixed) 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 emotion x session type, using the PLM (Killeen et al., 1997). The median proportion of variance accounted for by the fit to 192 functions (48 participants x 2 emotions x 2 trial types) was .99 (range: .59–1). A 2 (emotion: fear *vs.* neutral) x 2 (session type: unmixed *vs.* mixed) repeated-measures ANOVA was conducted on the BP and gamma scores. The results obtained with PLM yielded the same conclusions as when BP and sensitivity (Weber ratio) were evaluated with the linear regression analysis procedure described by Church and Deluty (1977).

Response latency. A 7 (duration) x 2 (emotion: fear *vs.* neutral) x 2 (session type: unmixed *vs.* mixed) repeated-measures ANOVA was conducted on the latency to respond (ms) from picture offset in the testing phase of the temporal bisection task.

Training phase. One-way repeated-measures ANOVAs of session coded 1-3 and fear unmixed *vs.* neutral unmixed *vs.* mixed were conducted on the number of training blocks that participants took to complete the training phase.

Rating phase. A 3 (session: 1-3) x 2 (emotion: fear *vs.* neutral) x 2 (test: pretest *vs.* posttest) repeated-measures ANOVA was conducted on the ratings from all 3 scales (fear, valence, and arousal).

Rating and BP correlations. Pearson's *r* was calculated for the BP values and picture ratings of fear, arousal, and valence at each of the emotion and session type combinations (fear-unmixed, neutral-unmixed, fear-mixed, and neutral-mixed).

Additionally, the difference in BP from neutral to fear in the unmixed sessions and neutral to fear in the mixed session was calculated for each participant, as was the difference in fear, arousal, and valence ratings. Then Pearson's *r* was calculated to determine the correlation between the difference in BP with the difference in fear, arousal, and valence in the unmixed sessions and the mixed session.

α level and additional analyses. An α level of .05 was used for all statistical tests. The above tests were also conducted with sequence group as a variable, but as this variable never interacted with emotion (the primary variable of interest) it was removed from the reported analyses. Additional analyses were conducted, as needed, to parse effects that were observed in the primary analyses.

Results

Testing Phase

***p*(long).** Figure 13 presents *p*(Long) as a function of stimulus duration. The left panel represents responding to the fear-evoking *vs.* neutral pictures in the unmixed sessions and the right panel represents responding to the fear-evoking *vs.* 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 or neutral). This was confirmed by a 7 (duration) x 2 (emotion) x 2 (session type) repeated-measures factorial ANOVA yielded only a significant effect of duration. Tukey's HSD indicated that *p*(Long) differed at all stimulus durations. Results for the primary analysis of *p*(Long) can be found in Table 10.

A tendency for fear overestimation to be confined to the mixed session can be seen on a close examination of Figure 13, as the fear plot is above or equal to the neutral plot at every stimulus duration in the mixed session, whereas the fear and neutral plots interweave in the comparison of the unmixed sessions. Fear overestimation in the mixed session, but not between the unmixed sessions, can be seen more clearly in Figure 14 in which *p*(Long) is presented at each condition (fear-single, neutral-single, fear-mixed, and neutral-mixed), collapsed across stimulus duration. This effect was confirmed by a planned comparison in which separate repeated-measures *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, $t(47) = 3.03$, $p = .004$, whereas the unmixed session comparison did not, $t(47) = .14$, *ns*.

As the comparison of fear *vs*. neutral from the unmixed sessions did not yield an effect of emotion, these conditions were pooled and compared to fear *vs*. neutral from the mixed session in a one-way repeated-measures ANOVA with fear mixed *vs.* neutral mixed *vs.* combined unmixed as levels, which did not yield a significant effect, $F(2, 94) = .36$, *ns*.

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 than in the mixed session. To examine the possibility that failure to observe differences between fear *vs.* neutral in the unmixed sessions was due to more exposure to the timed pictures, a 7 (duration) x 2 (emotion) x 2 (session type) x 2 (trial block: 1^{st} 84 trials *vs.* 2^{nd} 84 trials) repeated-measures factorial ANOVA was conducted. This analysis yielded only one effect involving trial block, a trial block x duration interaction, $F(6, 282) = 5.05$, $p < .0001$. As can be seen in Figure 15, the first trial block is associated with a larger *p*(Long) than the second trial block, but only at the longer durations. This was confirmed by a trial x duration analysis that was restricted to durations 1-4 in which no trial block x duration interaction was observed, $F(3, 141) = 1.74$, *ns*. More importantly, trial block did not interact with emotion or session type, 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.

BP and gamma. Figure 16 shows the BP (as calculated using the PLM) plotted as a function of session type (unmixed *vs.* mixed) for the fear and neutral emotion conditions. The pattern of effect was consistent with fear overestimation restricted to the mixed session, which was observed in the *p*(Long) data (see Figure 14), but an emotion (fear *vs.* neutral) x session type (unmixed *vs.* mixed) repeated-measures ANOVA yielded no significant effects for BP or gamma. Correlated-samples *t*-tests on the effect of emotion were also conducted on the unmixed sessions, $t(47) = .02$, *ns*, and in the mixed session, $t(47) = 1.42$, *ns*, as planned comparisons, but neither achieved significance. Results for the primary analyses of BP and gamma can be found in Table 11. Means and standard deviations for BP and gamma are presented in Table 12.

The analyses conducted on the BP and gamma values obtained from the PLM were also conducted using the BP, difference limen, and Weber ratio values obtained from the linear regression analysis described by Church and Deluty (1977). In agreement with the PLM analyses, no significant effects of emotion or session type were observed. Results for the analyses of BP, difference limen, and Weber ratio can be found in Table 13. Means and standard deviations for BP, difference limen, and Weber Ratio are presented in Table 14.

The long duration range in Experiment 1 and the mixed session in Experiment 2 exposed participants to the same procedure. In order to explore the differences that may have led to an effect of emotion in the long duration range of Experiment 1 and no effect of emotion in the mixed session of Experiment 2, a 2 (experiment: Experiment 1 *vs.* Experiment 2) x 3 (session) x 2 (emotion) mixed-factorial ANOVA restricted to the long duration range from Experiment 1 and the mixed session from Experiment 2 was conducted on the BPs and gammas obtained using the PLM. This analysis supported previously observed findings with a significant effect of emotion, $F(1, 90) = 15.61$, $p = .0002$, and an experiment x emotion interaction, $F(1, 90) = 4.21$, $p = .04$, on BP. The analysis also yielded an experiment x session interaction, $F(2, 90) = 4.33$, $p = .02$, on BP that can be seen in Figure 17. This interaction is related to Experiment 2 being associated with a larger mean BP than Experiment 1 in session 2, but not in the other sessions. This was confirmed by the absence of an effect of experiment, $F(1, 60) = 2.32$, *ns*, and the absence of an experiment x session interaction, $F(1, 60) = .07$, *ns*, when a 2 (experiment) x 2 (session 1 *vs.* session 3) independent-samples ANOVA was conducted. There were no other effects. Of particular note, there was no evidence of carryover effects being responsible for the absence of effect on BP in the mixed session of Experiment 2 (i.e., no experiment x session x emotion interaction, $F(1, 90) = .89$, *ns*). The analyses conducted on the BP and gamma values obtained from the PLM were also conducted using the BP, difference limen, and Weber ratio values obtained from the linear regression analysis described by Church and Deluty (1977). The effects on BP were confirmed, and no effects on difference limen and Weber ratio were observed.

Response latency. Figure 18 displays latency to respond (ms) from picture offset in the testing phase of the temporal bisection task across stimulus durations. The middle durations were associated longer latencies than the durations on the extremes. This effect was supported by a duration x emotion: fear *vs.* neutral x session type: unmixed *vs.* mixed repeated-measures ANOVA that yielded a significant effect of duration. Tukey's HSD indicated that the second, third, and forth durations (825, 1100, and 1375 ms) were associated with longer latencies than the durations on the extremes. Results for the primary analysis of response latency can be found in Table 15.

Training Phase

Participants took an average of 1.18 training blocks (12 trials per block) to pass the training phase for a given session, and took longer to pass session 1 ($M = 1.38$ training blocks) in comparison to sessions 2 ($M = 1.08$ training blocks) or 3 ($M = 1.08$ training blocks). This effect was verified by a one-way repeated-measures ANOVA of training blocks that revealed an effect of session, $F(2, 94) = 9.18$, $p = .0002$, 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 coded in terms fear unmixed *vs.*

neutral unmixed *vs.* mixed as the independent variable did not yield a significant effect, $F(2, 94) = .16$, *ns*.

Rating Phase

Fear. Figure 19 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 neutral pictures, and fear ratings to fear-evoking pictures decreased with repeated ratings. These trends were verified by a 3 (session: 1-3) x 2 (emotion) x 2 (test: pretest *vs.* posttest) repeated-measures factorial ANOVA that yielded significant effects of emotion, test, session, and an emotion x session interaction. The emotion x session interaction was parsed by a pair of one-way repeated-measures ANOVAs for session that were restricted to one emotion at a time. These analyses revealed a significant effect of session, $F(2, 94) = 39.71$, $p < .0001$ (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 ANOVA also yielded a session 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) x 2 (test) repeated-measures factorial 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 x test interaction. The analysis for sessions 2 and 3 did not yield the interaction, $F(1, 47) = .01$, *ns.* Results for the primary analysis of fear ratings can be found in Table 16.

Given the effect of emotion on fear ratings, a 3 (session: fear unmixed *vs.* neutral unmixed *vs.* mixed) x 2 (test: pretest *vs.* posttest) repeated-measures factorial ANOVA was conducted to determine whether or not the sessions differed in terms of fear ratings. There were no differences. The ANOVA yielded no effect of session, $F(2, 94) = 2.54$, *ns*, nor a session x test interaction, $F(2, 94) = .52$, *ns*.

Arousal. Figure 20 shows arousal ratings of the fear-evoking and neutral pictures plotted as a function of tests across sessions. Fear-evoking pictures were rated as more arousing than neutral pictures, and while arousal ratings to both the fear-evoking and neutral pictures decreased with repeated ratings, there was 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 a 3 (session: 1-3) x 2 (emotion) x 2 (test: pretest *vs.* posttest) repeated-measures ANOVA that yielded not only an effect of emotion, test, and session, but also an emotion x session interaction, and an emotion x test interaction. The emotion x session interaction was parsed by a series of three 2 (emotion) x 2 (session) repeated-measures factorial ANOVAs that were conducted by removing one session at a time. The analysis that included sessions 1 and 2, $F(1, 47) = 5.28$, $p = .03$, and the analysis that included sessions 1 and 3, $F(1, 47) = 4.77$, $p = .03$, both yielded an emotion x session interaction. The analysis for sessions 2 and 3 did not yield the interaction, $F(1, 47) = .18$, *ns.* The emotion x test interaction could not be parsed. Results for the primary analysis of arousal ratings can be found in Table 16.

Given the effect of emotion on arousal ratings, a 3 (session: fear unmixed *vs.* neutral unmixed *vs.* mixed) x 2 (test: pretest *vs.* posttest) repeated-measures factorial ANOVA was conducted to determine whether or not the sessions differed in terms of arousal ratings. There were no differences. The ANOVA yielded no effect of session, $F(2, 94) = .27$, *ns*, nor a session x test interaction, $F(2, 94) = .36$, *ns*.

Valence. Figure 21 shows valence ratings of the fear-evoking and neutral pictures plotted as a function of tests across sessions. Fear-evoking pictures were rated as more negative than the neutral pictures, and ratings to both picture types (fear-evoking and neutral) increased across sessions. This was confirmed by a 3 (session: 1-3) x 2 (emotion) x 2 (test: pretest *vs.* posttest) ANOVA that yielded a significant effect of emotion and session. Tukey's HSD indicated that pictures were rated more positively on session 3 than on session 1. No other effects were significant. Results for the primary analysis of valence ratings can be found in Table 16.

Given the effect of emotion on valence ratings, a 3 (session: fear unmixed *vs.* neutral unmixed *vs.* mixed) x 2 (test: pretest *vs.* posttest) repeated-measures factorial ANOVA was conducted to determine whether or not the sessions differed in terms of valence ratings. There were no differences. The ANOVA yielded no effect of session, $F(2, 94) = 1.13$, *ns*, nor a session x test interaction, $F(2, 94) = .54$, *ns*.

Rating and BP Correlations

PLM BP values increased as valence ratings to neutral pictures increased in the neutral-unmixed session, $r(46) = .29$, $p = .05$. Additionally, fear PLM BP values in the unmixed condition became progressively smaller relative to neutral PLM BP values in the unmixed condition as fear ratings for fear-evoking pictures became progressively larger relative to fear ratings to neutral pictures, $r(46) = -.34$, $p = .02$.

As with the PLM data, fear BP values in the unmixed condition became progressively smaller relative to neutral BP values in the unmixed condition as fear ratings for fear-evoking pictures became progressively larger relative to fear ratings to neutral pictures, $r(46) = -.36$, $p = .02$. There were no other significant correlations.

Discussion

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

Gamma and Weber ratio values were not affected by either of the factors (emotion or session type), suggesting that temporal sensitivity did not differ across conditions.

As in Experiment 1, fear-evoking pictures were rated as more fear-evoking, arousing, and negative than neutral pictures. These findings confirm that the presence or absence of fear was effectively manipulated. Furthermore, no effects of session (coded as fear single *vs.* neutral single *vs.* mixed cue) were observed, supporting the assertion that the failure to observe temporal overestimation of fear pictures relative to the neutral pictures in the unmixed sessions was not due to differences in emotional evocativeness caused by presenting pictures in unmixed *vs.* mixed fashion (e.g., fear pictures only producing fear in the mixed session).

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 there is a single memory store to which timed values from both conditions (experimental and control) associated with the clock-stage manipulation are compared. Overestimation should not be observed between fear and neutral in the unmixed sessions because new reference memories should be formed during the training phase of each session; therefore, 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 an intermediate value between the values associated with fear and neutral.

Unlike Penney et al. (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 were observed between the fear-mixed or neutral-mixed condition with the combined data from the unmixed sessions. It should be noted, however, that Penney et al. used a different method than the current experiment to make this determination. They compared responding to auditory stimuli from an unmixed group and responding to visual stimuli from an unmixed group to a mixed (auditory and visual) group. In the current experiment a similar analysis (a between-subjects comparison of fear-unmixed, neutral-unmixed, and mixed at session 1) was not a viable means of testing the effect of emotion, as the effect of emotion was much smaller than the modality effect observed by Penney et al.

A visual inspection of Figures 14 and 16 suggests that responses to the neutral pictures in the mixed session may differ from the other three emotion and session type combinations on the measures of *p*(Long) and BP. This may be viewed as a tentative endorsement of the view that memory-mixing occurs due to a bias toward fear reference memories. Overlapping data in the fear and neutral in the unmixed sessions represents time perception without a mixed memory;

therefore, if responding to the fear-evoking pictures in the mixed session did not differ from responding to the fear-evoking and neutral pictures in the unmixed sessions, and responding to the neutral pictures in the mixed session differed from all emotion and session type combinations, this could be taken as evidence that fear referents were used exclusively in the mixed session.

General Discussion

Taken together, the results of Experiments 1 and 2 replicated the finding that, in some circumstances, the presentation duration of fear-evoking pictures is overestimated relative to that of neutral pictures (e.g., Anderson, Reis-Costa, Misanin, 2007; Watts & Sharrock, 1984).

Experiment 1 demonstrated that when multiple duration ranges are used in the temporal bisection task, the effect of emotion on BP interacts with duration range in that greater overestimation of fear-evoking pictures relative to neutral pictures is observed at a longer (550-2200 ms) duration range in comparison to a shorter (250-1000 ms) range. 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. These results reconcile a discrepancy in the literature in which Droit-Volet et al. (2010) observed greater overestimation in an emotion-evoking condition relative to a neutral condition at a larger duration range than at a shorter duration range, while Gil et al. (2007) and Grommet et al. (2011) observed emotion-based overestimation, but no differences in this effect across duration ranges. The results of Experiment 1 in the current study indicated that emotion-based overestimation of duration increased as duration range increased, but only in the more widely spaced duration ranges that resembled the spacing employed by Droit-Volet et al. and not in the more closely spaced duration ranges that resembled the spacing employed by Gil et al. and Grommet et al.

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 session. 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 if the manipulation occurs within a single session. Alternatively, when emotion-evoking and neutral cues are presented in separate sessions, subjects may store and retrieve separate memories on emotion-evoking and neutral trials. Given that the origin of the fear-overestimation effect is that fear stimuli are associated with a faster pacemaker than neutral stimuli (an effect that is located in the clock stage of SET), the presence of a common memory store for fear and neutral trials is a necessary condition for the behavioral expression of temporal overestimation of fear stimuli.

Although the effects of the Experiment 2 were consistent with Penney et al.'s (1998; 2000) memory mixing hypothesis, the methodology employed differed. Penney et al. (2000) compared the performance of a group that was only exposed to auditory stimuli to that of a group that was only exposed to visual stimuli in a between-subjects manipulation, and responding to auditory and visual stimuli presented in the same session in a within-subjects manipulation. Durations of auditory cues were overestimated relative to visual cues in the within-subjects manipulation, but no differences were observed in the between-subjects manipulation. Furthermore, participants in the groups that were exposed to only auditory or visual stimuli overestimated stimulus duration in comparison to the visual stimuli in the mixed session, but not in comparison to auditory stimuli in the mixed condition. Owing to the relatively smaller effects observed in IAPS picture-based manipulations of fear on timing (Grommet et al., 2011) relative to the modality effect observed by Penney et al. (2000), the current study was designed in order for emotion and session type to be manipulated in a completely within-subjects fashion. While this more sensitive design yielded evidence in favor of memory mixing (an effect of emotion isolated to the mixed-cue comparison), it was not sufficiently sensitive to identify the locus of that effect (fear-exclusive *vs.* neutral-exclusive *vs.* intermediate value reference memory).

Gamma values did not vary across duration ranges. This finding is consistent with scalar timing (Gibbon, 1991; Gallistel & Gibbon, 2000) and is consistent with previous findings in temporal bisection with human (e.g., Allan, 2002) and animal (e.g., Church, 1984) observers. Difference limen values increased as duration range increased, a finding that is consistent with scalar timing in that it was accompanied by increases in BP as duration range increased and the aforementioned gamma invariance. These findings, however, were complicated by a small but significant effect in which Weber ratios increased as duration range increased, consistent with decreased temporal sensitivity at longer duration ranges and inconsistent with scalar timing.

Gamma was also invariant when there was an effect of emotion on BP. This may be taken as being consistent with an effect of emotion that is the product of pacemaker based effects; that is, larger values in working memory on fear trials in the mixed session 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 by the fact that an effect of emotion on difference limen was not observed in either experiment and the effects on BP were small (under 100 ms), therefore, potentially resulting in an undetected effect on gamma. Furthermore, whereas the Weber ratios remained invariant across emotion conditions in Experiment 2 (consistent with the gamma results), in Experiment 1 Weber ratios under the fear condition were larger than those associated with the neutral condition (consistent with decreased temporal sensitivity in the fear condition). Finally, as faster clocks have higher resolution that slower clocks, increased pacemaker speed may be associated with increased sensitivity (Gibbon, 1977; Wearden, Edwards, Fakhri, & Percival, 1998), which would result in decreases in gamma, and therefore, obscure whether or not gamma should be expected to remain invariant across emotion conditions.

Participants in Experiment 1 and Experiment 2 displayed inverted U-shaped response-latency functions. This outcome is consistent with both human (Rodríguez-Gironés & Kacelnik, 1998) and animal (Brown et al., 2011; Maricq & Church, 1983; Meck, 1983) findings. Rodríguez-Gironés and Kacelnik (1998) suggested that human observers require more processing time to decide whether to respond “short” or “long” when faced with an intermediate stimulus duration as opposed to a duration that close to the one of the trained values. An alternative explanation has been offered by Brown et al. (2011) and Maricq and Church (1983) in respect to how rats may approach the temporal bisection task. In their view, long response latencies at intermediate stimulus durations may reflect discrimination learning, in that the inverted U-shape forms with repeated testing and then eventually gives way to a reduction in the probability of responding to the intermediate values. There was little opportunity for discrimination learning in the present procedure, given the absence of feedback on all trials in the test phase. In any case, the present data support the former (processing time) view, as an effect of training (session) on response latency was not observed in either Experiment 1 or 2, suggesting that the inverted U-shaped function did develop over the course of testing. All participants responded on all trials of all sessions (a new trial was not presented until the participant responded).

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 fear evoking, higher in arousal, and more negative in valence than the neutral pictures. The general finding across both studies was that participants rated the fear-evoking pictures a progressively less fear evoking and arousing 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.

Interestingly, correlations between BP and ratings were not observed (with the exception of a moderate correlation restricted to the neutral pictures in the medium duration range of Experiment 1 and a couple of moderate correlations restricted to the unmixed sessions in Experiment 2). This suggests that while the presentation durations of fear stimuli were overestimated relative to neutral stimuli when presented within the same session, the degree to which they were overestimated was not modulated by the strength of the emotion, as measured by fear, arousal, and valence ratings.

Droit-Volet et al. (2010), Gil et al. (2007), and Grommet et al. (2011) used multiple duration ranges in the temporal bisection task to ask whether the overestimation of emotion-evoking stimuli is additive or multiplicative with respect to duration range. The purpose in asking this question was the dissociation of two clock-stage mechanisms that may be responsible for the observed overestimation, pacemaker rate *vs.* switch latency, with multiplicative effects interpreted as evidence for pacemaker rate increases in the fear condition, and additive effects interpreted as evidence for decreases in switch latency at stimulus onset in the fear condition. These interpretations, however, have been complicated by recent studies that have called into question whether multiplicative effects are sufficient to implicate pacemaker rate increases as the source of effect.

Matthews (2011) designed an experiment that yielded multiplicative effects that could not logically be attributed to differences in pacemaker rate between conditions. In his study, participants gave verbal estimates of the duration of blank intervals that occurred between the presentations of two squares that were presented on a computer monitor. In the *same* condition the square that preceded the timed interval was the same as the square that followed the interval. In the *different* condition, the square that followed the timed interval was a different size (larger or smaller) than the square that preceded the interval. Participants judged the intervals in the *different* condition to have been presented for a longer amount of time than those in the *same* condition. Furthermore, the overestimation of *different* relative to *same* was multiplicative in that the magnitude of the effect was larger at shorter stimulus durations than it was at longer durations, a result that is analogous to larger overestimation at a shorter duration range in comparison to a longer duration range in the temporal bisection task. Matthews noted that multiplicative effects are often taken as evidence for the role of the pacemaker as the source of overestimation, but that his procedure does not allow for this interpretation; that is, for Matthews' participants the initially presented square did not differentially signal whether or not the size of the square would change after the timed interval on a given trial, therefore, it is not possible for the intervals in the *same* condition to be associated with a different pacemaker rate than in the *different* condition. Matthews cautions that his results raise concerns about interpreting multiplicative effects as indicative of increases in pacemaker rate. He suggests that his results were likely the result of a serial process in which participants processed the second square before the timing of the interval ended (conceptualized as the opening of the switch in the clock stage of SET). He also suggests that the time that participants take to process the second square is dependent on its relationship with the first square, in that the second square should be processed more quickly on a *same* trial than on a *different* trial due to repetition priming in which sequential presentations of the same stimulus are processed faster (Pariyadath & Eagleman, 2008; Eagleman & Pariyadath, 2009), and that this effect may diminish as the interval between the first and second square increases. Matthews' interpretation of his results does not apply, however, to the pattern of results as observed in Experiment 1 in the current study in which the extent to which fear-evoking pictures were overestimated relative to neutral pictures increased as duration range increased; that is, an interaction in which overestimation increases as duration range decreases can be explained through switch-based repetition priming effects, but this explanation is not applicable in the case of an interaction in which overestimation increases as duration range increases.

There are other instances in which the pacemaker has not been invoked in cases of multiplicative effects on time estimation. In one such instance, Allman, DeLeon, and Wearden (2011) had children with and without a diagnosis of autism make temporal judgments of pictures presented via computer monitor in a temporal bisection task that included two duration ranges. The participants with autism judged the presentation duration of the pictures to be longer than the participants without autism did, and the extent to which participants with autism overestimated in comparison to participants without autism increased as duration range increased. This multiplicative effect, however, could not be explained in terms of children with autism possessing faster pacemakers than children without autism, as memory mixing is not possible in this between-subjects design. Allman et al. suggest that their results are due to children with autism storing memories for stimulus durations as shorter than they actually are.

Within the context of SET, this shortening occurs through the shrinking of a constant (*K**) that is multiplied against the value of perceived durations as those values are encoded into reference memory. As the effects of *K** are multiplicative, a smaller *K** for children with autism than for children without autism would result in the observed pattern of effect, a multiplicative effect in which overestimation increases with duration range.

Allman et al.'s (2011) results and interpretation offer an alternative explanation for the results of Droit-Volet et al. (2010) and Experiment 1 of the current study; that is, perhaps fear did not increase pacemaker speed, and instead it shortened 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 value for *K** would result in fear overestimation regardless of session type (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, make it impossible to dissociate between the clock speed account and the flickering switch account using timing behavior as a measure (both accounts predict an emotion x duration range interaction).

In the decisional bias account, subjects exhibit a response bias toward calling stimulus durations “short” *vs.* “long;” e.g., participants would be biased to be more likely to call stimuli “short” in then neutral condition than they would in the fear condition. In order for this account to explain the emotion x duration range interaction observed Experiment 1, the “short” *vs.* “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. The dissociation between pacemaker and decision based effects within SET remains an empirical and theoretical challenge.

In summary, the results of the current experiments are in agreement with previous findings on the role of emotion on timing, in that fear stimuli were overestimated relative to neutral stimuli. The results support an interpretation based arousal-mediated effects on pacemaker rate and are consistent with Penney et al.’s (1998; 2000) memory mixing account of the conditions necessary for the expression of pacemaker based effects. Future studies should employ more sensitive measures to determine if the source of the observed memory-mixing effect was due to a fear-exclusive, neutral-exclusive, or intermediate value reference memory. If, as suggested by the trends in the current data, memory mixing occurs as a result of fear-referent bias, then whether this bias occurs due to a failure to encode or recall neutral duration is still yet to be determined.

Table 1

Experimental Design for Experiment 1

Group	Session 1	Session 2	Session 3
Short-Medium-Long	250-1000 ms	400-1600 ms	550-2200 ms
Short-Long-Medium	250-1000 ms	550-2200 ms	400-1600 ms
Medium-Short-Long	400-1600 ms	250-1000 ms	550-2200 ms
Medium-Long-Short	400-1600 ms	550-2200 ms	250-1000 ms
Long-Short-Medium	550-2200 ms	250-1000 ms	400-1600 ms
Long-Medium-Short	550-2200 ms	400-1600 ms	250-1000 ms

Note. $n = 8$ for each sequence group.

Table 2

Analysis of Variance of p(Long) for Testing Phase for Experiment 1

Source	df	SS	MS	F
Emotion	1	7448.23	7448.226687	56.76**
Error	47	6167.85	131.231	
Duration	6	2552967.51	425494.585	818.82**
Error	282	146539.77	519.645	
Duration Range	2	5419.35	2709.676753	2.32
Error	94	109782.37	1167.898	
Emotion x Duration	6	2257.358	376.226301	4.272**
Error	282	24855.737	88.141	
Emotion x Duration Range	2	53.53009258	26.76504629	0.41
Error	94	6067.502	64.548	
Duration x Duration Range	12	5247.602513	437.300209	2.08*
Error	564	118439.567	209.99	
Emotion x Duration x Duration Range	12	1368.634259	114.052855	1.34
Error	564	47927.001	84.977	

Note. p-values ≤ .05 are marked by an * after the F-value, except where $p \leq .01$, in which a ** was used. An N of 48 was used for this analysis.

Table 3

Analyses of Variance of Bisection Point and Gamma (Pseudo-Logistic Model) in Experiment 1

Source	df	SS	MS	F
Bisection Point				
Emotion	1	251511.8709	251511.8709	39.63**
Error	47	298267.62	6346.12	
Duration Range	2	20589690.96	20589690.96	182.28**
Error	94	5309071.69	56479.49	
Emotion x Duration Range	2	37156.04694	18578.02347	3.41*
Error	94	512620.92	5453.41	
Gamma				
Emotion	1	0.00708328	0.00708328	0.77
Error	47	0.43051799	0.00915996	
Duration Range	2	0.05215763	0.02607881	1.46
Error	94	1.68075839	0.01788041	
Emotion x Duration Range	2	0.01026925	0.00513463	0.56
Error	94	0.85742796	0.00912157	

Note. p-values ≤ .05 are marked by * after the F-value, except where $p \leq .01$, in which ** was used. An N of 48 was used for these analyses.

Table 4

*Means and SEMs (in parentheses) of Bisection Point and Gamma under each emotion condition and duration range in Experiment 1**

250-1000 ms		400-1600 ms		550-2200 ms	
Bisection					
Fear	Neutral	Fear	Neutral	Fear	Neutral
600.4 (17.3)	642.8 (19.1)	935.6 (22.2)	979.2 (26.4)	1230.8 (36.3)	1322.1 (48.7)
Gamma					
.25 (.02)	.25 (.02)	.23 (.01)	.26 (.02)	.27 (.03)	.28 (.02)

* $N = 48$

Table 5

Analysis of Variance of Bisection Point, Difference Limen, and Weber Ratio (Church & Deluty Method) in Experiment 1

Source	df	SS	MS	F
Bisection Point				
Emotion	1	200705.7892	200705.7892	33.39**
Error	47	282481.28	6010.24	
Duration Range	2	21298787.67	10649393.83	245.29**
Error	94	4081061.46	43415.55	
Emotion x Duration Range	2	23323.66110	11661.83055	2.40
Error	94	456640.14	4857.87	
Difference Limen				
Emotion	1	115.6935985	115.6935985	0.12
Error	47	45010.9197	957.6791	
Duration Range	2	689180.9215	344590.4607	163.25**
Error	94	198418.3282`	2110.8333	
Emotion x Duration Range	2	373.6104214	186.8052107	0.16
Error	94	111487.4260	1186.0364	
Weber Ratio				
Emotion	1	0.00434778	0.00434778	4.33**
Error	47	0.04718872	0.00100402	
Duration Range	2	0.01306508	0.00653254	4.54*
Error	94	0.13536825	0.00144009	
Emotion x Duration Range	2	0.00101758	0.00050879	0.44
Error	94	0.10748042	0.00114341	

Note. *p*-values $\leq .05$ are marked by * after the *F*-value, except where $p \leq .01$, in which ** was used. An *N* of 48 was used for these analyses.

Table 6

*Means and SEMs (in parentheses) of BP, Difference Limen, and Weber Ratio for Experiment 1**

250-1000 ms		400-1600 ms		550-2200 ms	
Bisection					
Fear	Neutral	Fear	Neutral	Fear	Neutral
607.3 (15.5)	640.7 (17.0)	948.1 (20.8)	996.2 (25.8)	1251.5 (36.5)	1328.3 (40.0)
Difference Limen					
95.0 (3.4)	93.2 (3.3)	156.3 (4.9)	160.0 (4.8)	212.9 (9.8)	214.8 (8.6)
Weber Ratio					
.16 (.007)	.15 (.005)	.17 (.005)	.16 (.005)	.17 (.008)	.17 (.007)

* *N* = 48

Table 7

Analysis of Variance for Latency to Respond in Testing Phase of Experiment 1

Source	df	SS	MS	F
Emotion	1	3671169.818	3671169.818	1.91
Error	47	90541383	1926412	
Duration	6	267241327.4	44540221.2	13.74**
Error	282	913992010	3241106	
Duration Range	2	8218377.376	4109188.688	0.43
Error	94	892693335	9496738	
Emotion x Duration	6	6084293.444	1014048.907	0.85
Error	282	653494054	2317355	
Emotion x Duration Range	2	12922432.57	6461216.28	2.45
Error	94	248055520	2638889	
Duration x Duration Range	12	40804873.91	3400406.16	1.29
Error	564	1490675584	2643042	
Emotion x Duration x Duration Range	12	32807981.58	2733998.46	1.13
Error	564	1359639204	2410708	

Note. p-values $\leq .01$ are marked by ** after the F-value. An N of 48 was used for this analysis.

Table 8

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

Source	df	SS	MS	F
Fear				
Emotion	1	1976.333333	1976.333333	62.28**
Error	47	1491.388889	31.731678	
Session	2	64.88541667	32.44270833	14.11**
Error	94	216.114583	2.299091	
Test	1	8.05787037	8.05787037	14.89**
Error	47	25.442130	0.541322	
Emotion x Session	2	28.21875000	14.10937500	7.40**
Error	94	179.225694	1.906656	
Emotion x Test	1	3.34259259	3.34259259	5.10*
Error	47	30.824074	0.655831	
Session x Test	2	3.29976852	1.64988426	4.26*
Error	94	36.366898	0.386882	
Emotion x Session x Test	2	1.50810185	0.75405093	1.56
Error	94	45.491898	0.483956	
Arousal				
Emotion	1	1397.520833	1397.520833	45.70**
Error	47	1437.201389	30.578753	
Session	2	162.8344907	81.4172454	10.91**
Error	94	701.387731	7.461572	
Test	1	14.81481481	14.81481481	8.21**
Error	47	84.796296	1.804177	
Emotion x Session	2	42.38541667	21.19270833	5.59**
Error	94	356.059028	3.787862	
Emotion x Test	1	8.61342593	8.61342593	5.32**
Error	47	76.108796	1.619336	
Session x Test	2	9.58449074	4.79224537	2.60
Error	94	173.304398	1.843664	
Emotion x Session x Test	2	9.66782407	4.83391204	4.13*
Error	94	110.109954	1.171382	
Valence				
Emotion	1	756.0468750	756.0468750	32.54**
Error	47	1092.147569	23.237182	
Session	2	0.97337963	0.48668981	0.16
Error	94	281.971065	2.999692	
Test	1	3.08391204	3.08391204	1.74
Error	47	83.110532	1.768309	
Emotion x Session	2	6.00347222	3.00173611	1.93
Error	94	146.385417	1.557292	
Emotion x Test	1	2.01446759	2.01446759	1.97
Error	47	47.957755	1.020378	
Session x Test	2	0.63310185	0.31655093	0.27
Error	94	109.422454	1.164069	
Emotion x Session x Test	2	3.90393519	1.95196759	2.84
Error	94	64.707176	0.688374	

Note. p-values ≤ .05 are marked by * after the F-value, except where $p \leq .01$, in which ** was used. An N of 48 was used for these analyses.

Table 9

Experimental Design for Experiment 2

Group	Session 1	Session 2	Session 3
1	Fear Unmixed	Neutral Unmixed	Mixed
2	Fear Unmixed	Mixed	Neutral Unmixed
3	Neutral Unmixed	Fear Unmixed	Mixed
4	Neutral Unmixed	Mixed	Fear Unmixed
5	Mixed	Fear Unmixed	Neutral Umixed
6	Mixed	Neutral Unmixed	Fear Unmixed

Note. n = 8 for each sequence group.

Table 10

Analysis of Variance of p(Long) in Testing Phase for Experiment 2

Source	df	SS	MS	F
Emotion	1	364.5833333	364.5833333	1.05
Error	47	16320.685	347.249	
Session Type	1	162.0370370	162.0370370	0.24
Error	47	31136.326	662.475	
Duration	6	1587057.783	264509.630	562.15**
Error	282	132690.481	470.534	
Emotion x Session Type	1	558.8624339	558.8624339	1.81
Error	47	14484.540	308.182	
Emotion x Duration	6	1089.590567	181.598428	1.88
Error	282	27173.058	96.358	
Session Type x Duration	6	656.2861690	109.3810282	0.73
Error	282	41968.962	148.826	
Emotion x Session Type x Duration	6	278.9920222	46.4986704	0.52
Error	282	25424.133	90.156	

Note. p-values ≤ .01 are marked by an ** after the *F*-value. An *N* of 48 was used for this analysis.

Table 11

Analysis of Variance of Bisection Point and Gamma (Pseudo-Logistic Model) in Experiment 2

Source	Df	SS	MS	F
Bisection Point				
Emotion	1	8208.485208	8208.485208	0.30
Error	47	1277615.57	27183.31	
Session Type	1	13343.33521	13343.33521	0.32
Error	47	1987356.63	42284.18	
Emotion x Session Type	1	11985.88021	11985.88021	0.62
Error	47	915262.65	19473.67	
Gamma				
Emotion	1	0.00006648	0.00006648	0.01
Error	47	0.49830747	0.01060229	
Session Type	1	0.02681580	0.02681580	1.16
Error	47	1.08213246	0.02302409	
Emotion x Session Type	1	0.02392838	0.02392838	2.79
Error	47	0.40372036	0.00858979	

Note. No significant effects. An *N* of 48 was used for these analyses.

Table 12

*Means and SEMs (in parentheses) of BP and Gamma for Experiment 2**

Single Cue		Mixed Cue	
Bisection Point			
Fear	Neutral	Fear	Neutral
1268.7 (46.1)	1265.9 (42.8)	1269.5 (46.6)	1298.4 (43.7)
Gamma			
.28 (.02)	.25 (.01)	.28 (.02)	.30 (.03)

* $N = 48$

Table 13

Analysis of Variance of Bisection Point, Difference Limen, and Weber Ratio (Church & Deluty Method) in Experiment 2

Source	df	SS	MS	F
Bisection Point				
Emotion	1	6204.248615	6204.248615	0.22
Error	47	1347772.07	28676.00	
Session Type	1	267.3872940	267.3872940	0.01
Error	47	1763689.26	37525.30	
Emotion x Session Type	1	5927.577522	5927.577522	0.31
Error	47	891411.02	18966.19	
Difference Limen				
Emotion	1	1982.755851	1982.755851	0.85
Error	47	109406.4509	2327.7968	
Session Type	1	2.61704465	2.61704465	0.00
Error	47	136869.0611	2912.1077	
Emotion x Session Type	1	3771.156007	3771.156007	2.21
Error	47	80091.6893	1704.0785	
Weber Ratio				
Emotion	1	0.00060005	0.00060005	0.65
Error	47	0.04315790	0.00091825	
Session Type	1	0.00014164	0.00014164	0.09
Error	47	0.07206789	0.00153336	
Emotion x Session Type	1	0.00197282	0.00197282	1.35
Error	47	0.06864330	0.00146050	

Note. No significant effects. An *N* of 48 was used for these analyses.

Table 14

*Means and SEMs (in parentheses) of Bisection Point, Difference Limen, and Weber Ratio for Experiment 2**

Single Cue		Mixed Cue	
Bisection Point			
Fear	Neutral	Fear	Neutral
1295.8 (44.6)	1273.3 (40.8)	1282.3 (45.1)	1282.0 (39.0)
Difference Limen			
226.5 (8.9)	211.2 (7.0)	217.8 (10.8)	220.3 (9.0)
Weber Ratio			
.18 (.007)	.17 (.005)	.17 (.005)	.17 (.006)

* *N* = 48

Table 15

Analysis of Variance for Latency to Respond in Testing Phase of Experiment 2

Source	df	SS	MS	F
Emotion	1	365893.0001	365893.0001	0.33
Error	47	51930550.3	1104905.3	
Session Type	1	6325.232224	6325.232224	0.01
Error	47	40927447.2	870796.7	
Duration	6	23116986.50	3852831.08	9.48**
Error	282	114583350.6	406323.9	
Emotion x Session Type	1	406.7066819	406.7066819	0.00
Error	47	14582787.9	310272.1	
Emotion x Duration	6	2888128.760	481354.793	1.55
Error	282	87344149.0	309731.0	
Session Type x Duration	6	1559544.573	259924.096	0.85
Error	282	86563160.0	306961.6	
Emotion x Session Type x Duration	6	1560051.554	260008.592	0.92
Error	282	79772950.2	282882.8	

Note. p-values ≤ .01 are marked by an ** after the F-value. An N of 48 was used for this analysis.

Table 16

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

Source	df	SS	MS	F
Fear				
Emotion	1	1390.335648	1390.335648	56.40**
Error	47	1158.664352	24.652433	
Session	2	38.28125000	19.14062500	18.05**
Error	94	99.663194	1.060247	
Test	1	8.61342593	8.61342593	17.39**
Error	47	23.275463	0.495223	
Emotion x Session	2	21.15393519	10.57696759	6.67**
Error	94	149.012731	1.585242	
Emotion x Test	1	1.94675926	1.94675926	1.35
Error	47	67.942130	1.445577	
Session x Test	2	2.72337963	1.36168981	3.85
Error	94	33.221065	0.353416	
Emotion x Session x Test	2	1.84143519	0.92071759	1.90
Error	94	45.436343	0.483365	
Arousal				
Emotion	1	2102.335648	2102.335648	71.63**
Error	47	1379.442130	29.349833	
Session	2	181.3761574	90.6880787	13.28*
Error	94	641.901620	6.828741	
Test	1	50.70370370	50.70370370	23.76**
Error	47	100.296296	2.133964	
Emotion x Session	2	23.75810185	11.87905093	3.79*
Error	94	294.630787	3.134370	
Emotion x Test	1	11.66898148	11.66898148	5.89*
Error	47	93.108796	1.981038	
Session x Test	2	9.34143519	4.67071759	2.69
Error	94	163.491898	1.739276	
Emotion x Session x Test	2	6.84837963	3.42418981	1.83
Error	94	175.540509	1.867452	
Valence				
Emotion	1	163.7870370	163.7870370	7.64**
Error	47	1007.546296	21.437155	
Session	2	15.37847222	7.68923611	4.20*
Error	94	172.232639	1.832262	
Test	1	2.08333333	2.08333333	2.31
Error	47	42.472222	0.903664	
Emotion x Session	2	8.99421296	4.49710648	2.64
Error	94	160.172454	1.703962	
Emotion x Test	1	2.37037037	2.37037037	2.64
Error	47	42.185185	0.897557	
Session x Test	2	0.21875000	0.10937500	0.09
Error	94	112.725694	1.199210	
Emotion x Session x Test	2	1.64004630	0.82002315	0.74
Error	94	104.637731	1.113167	

Note. p-values $\leq .05$ are marked by * after the F-value, except where $p \leq .01$, in which ** was used. An N of 48 was used for these analyses.

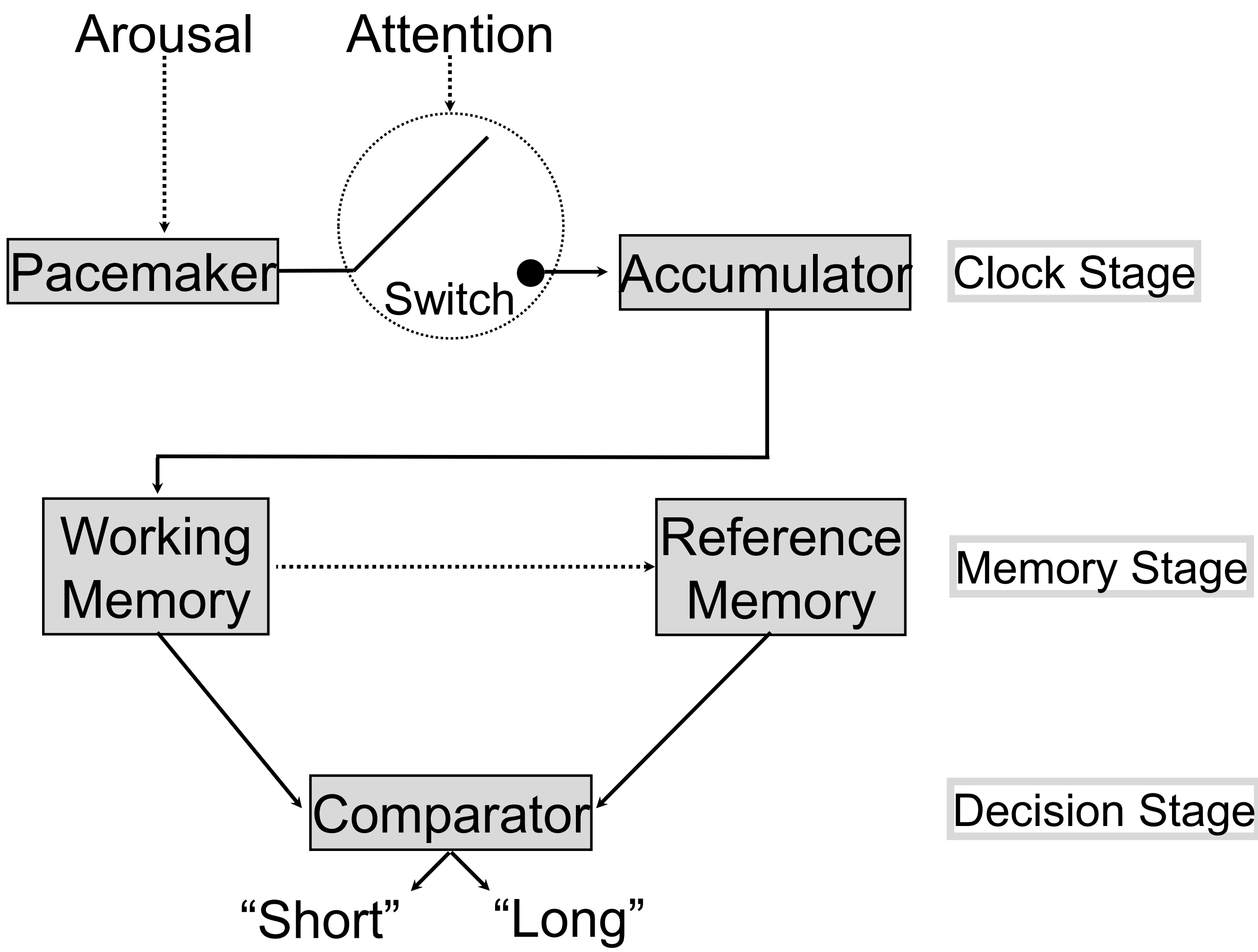


Figure 1. Temporal Information Processing Version of Scalar Expectancy Theory as applied to the Temporal Bisection Task (Adapted from Gibbon, Church, & Meck, 1984).

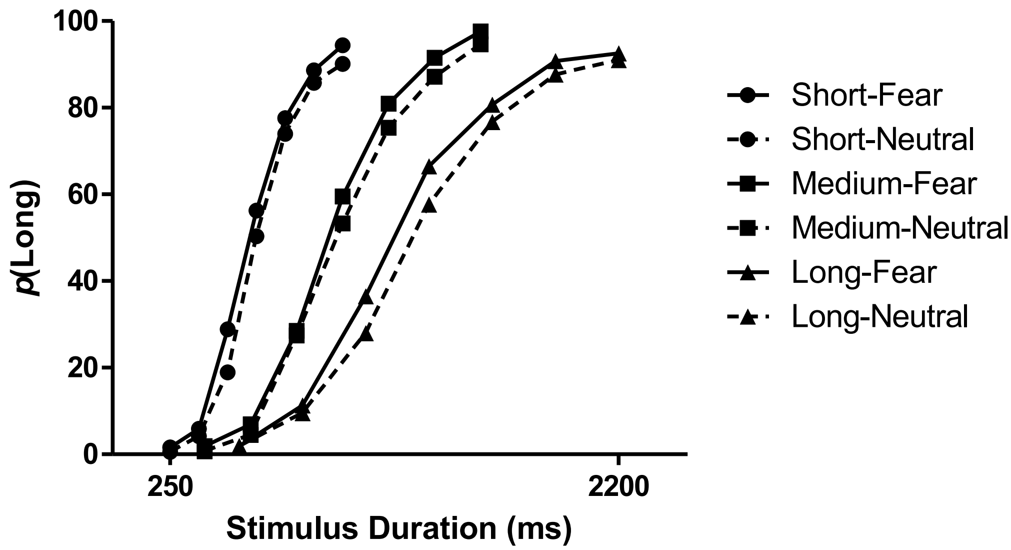


Figure 2. Mean percent "long" presented as a function of stimulus duration (ms) across duration ranges. Solid lines are the fear plots and the dashed lines are the neutral plots. Circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

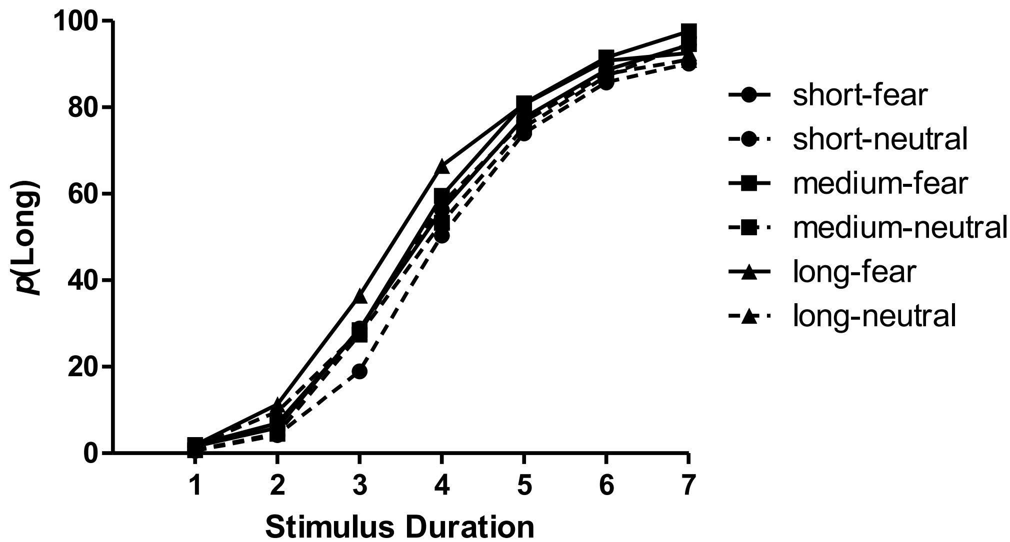


Figure 3. Mean percent "long" at each emotion and duration range combination, presented as a function of normalized stimulus duration (duration scaled 1-7 for all duration ranges). Solid lines are the fear plots and dashed lines are the neutral plots. Circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

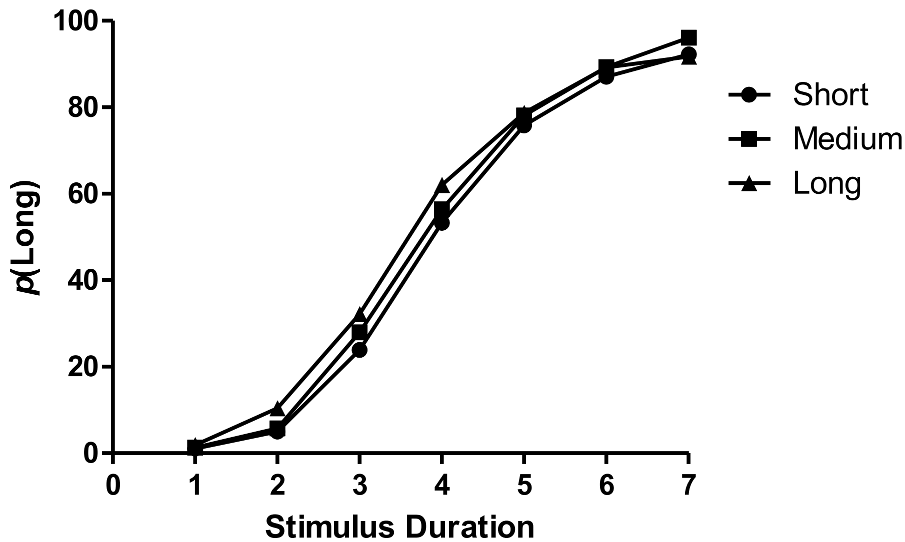


Figure 4. Mean percent “long,” collapsed across emotion and presented as a function of normalized stimulus duration (duration scaled 1-7 for all duration ranges) at all three duration ranges. Circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

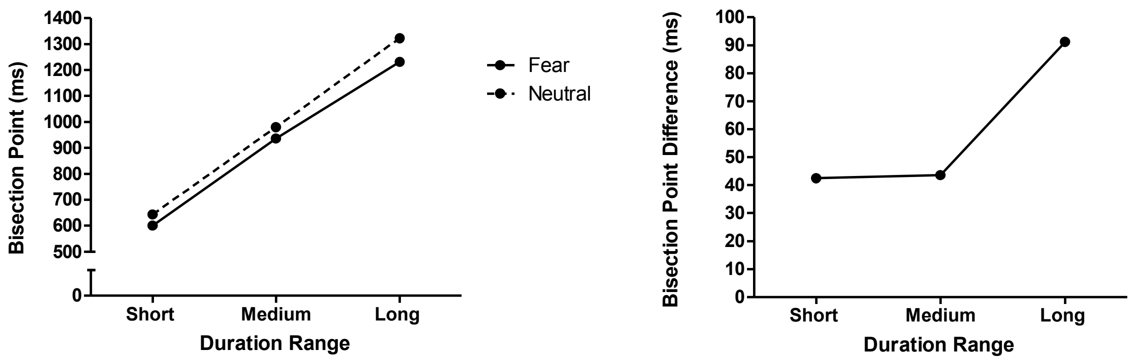


Figure 5. Left panel presents BP (ms) (calculated using the PLM) as a function of duration range for the fear and neutral conditions. Solid line represents the fear condition and dashed line represents the neutral condition. Right panel presents the emotion x duration range interaction more clearly. The y-axis is BP for the neutral cue minus BP for the fear cue.

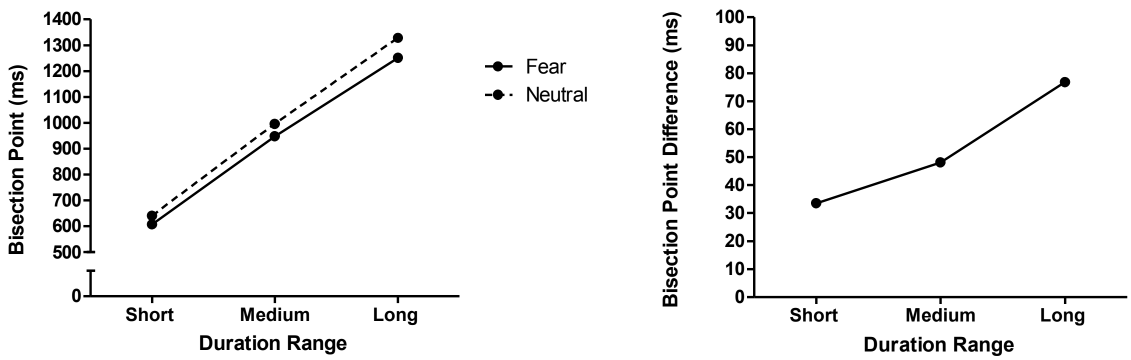


Figure 6. Left panel presents BP (ms) (calculated using the Church and Deluty, 1977, method) as a function of duration range for the fear and neutral conditions. Solid line represents the fear condition and dashed line represents the neutral condition. Right panel presents the emotion x duration range interaction more clearly. The y-axis is BP for the neutral cue minus BP for the fear cue.

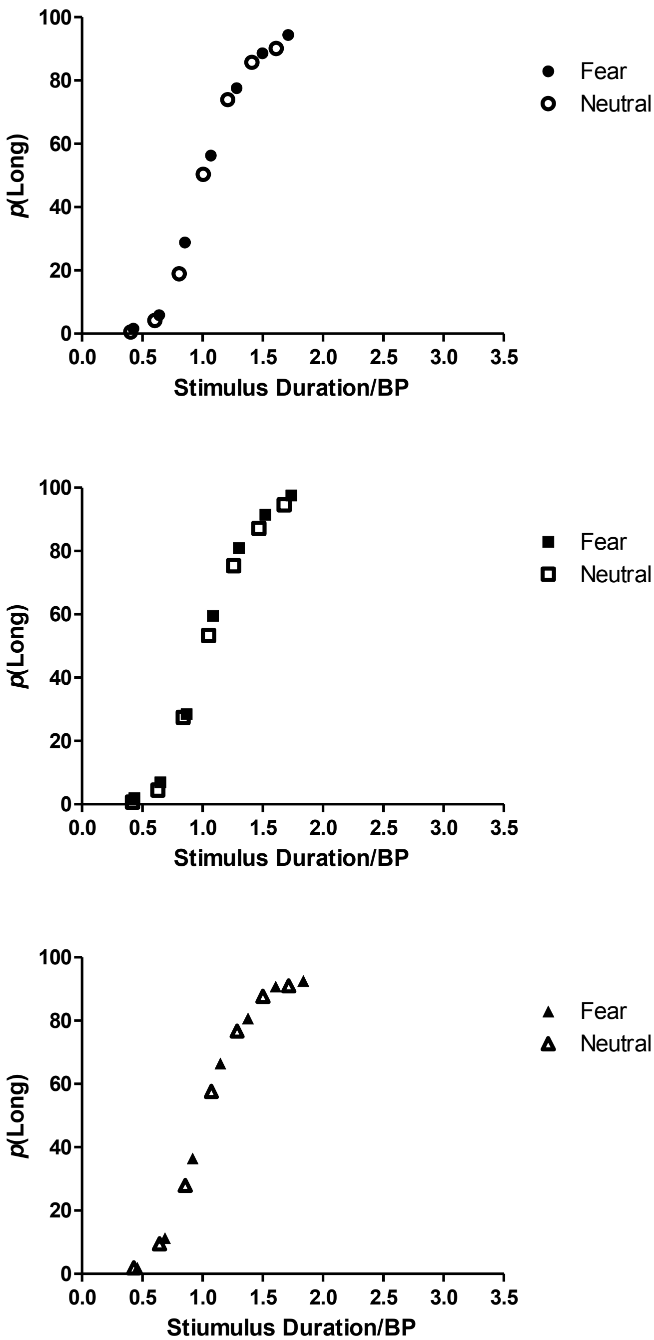


Figure 7. Mean percent "long" as a function of stimulus duration/BP. Solid markers are the fear plots and open makers are the neutral plots. Circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

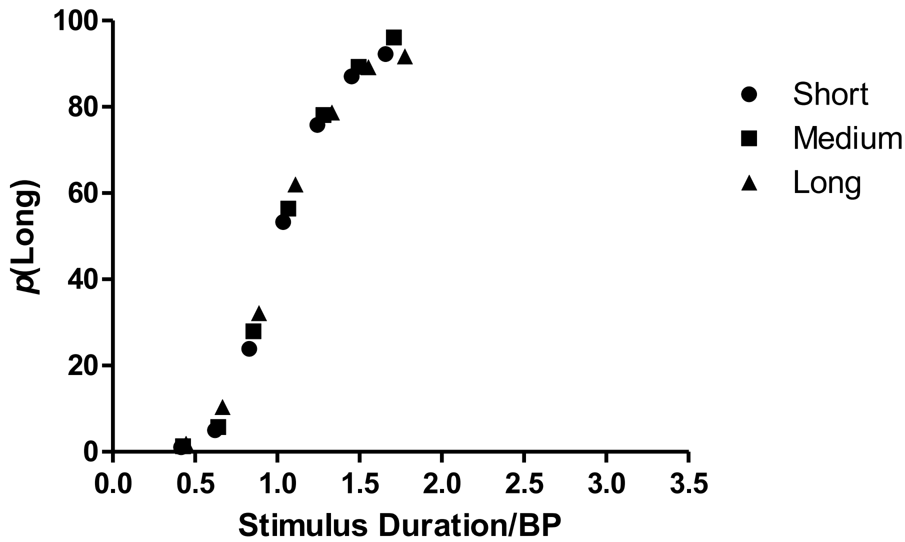


Figure 8. Mean percent "long" as a function of stimulus duration/BP at each duration range. Circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

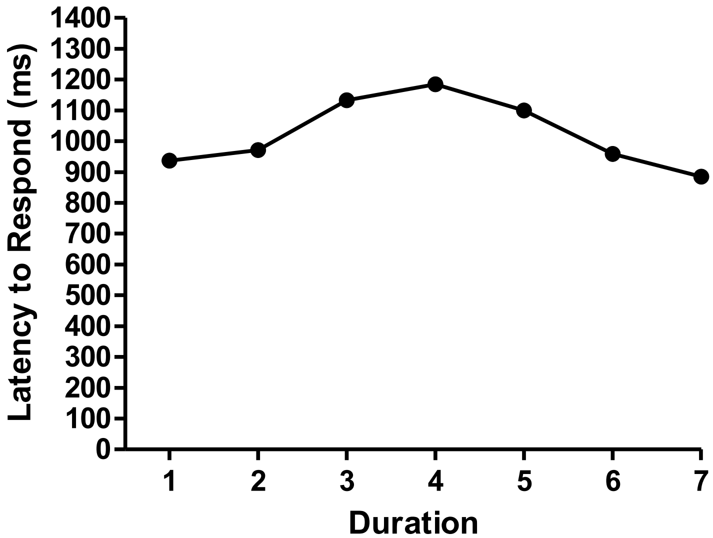


Figure 9. Latency to respond (ms) after picture offset in the testing phase as a function of stimulus duration for Experiment 1.

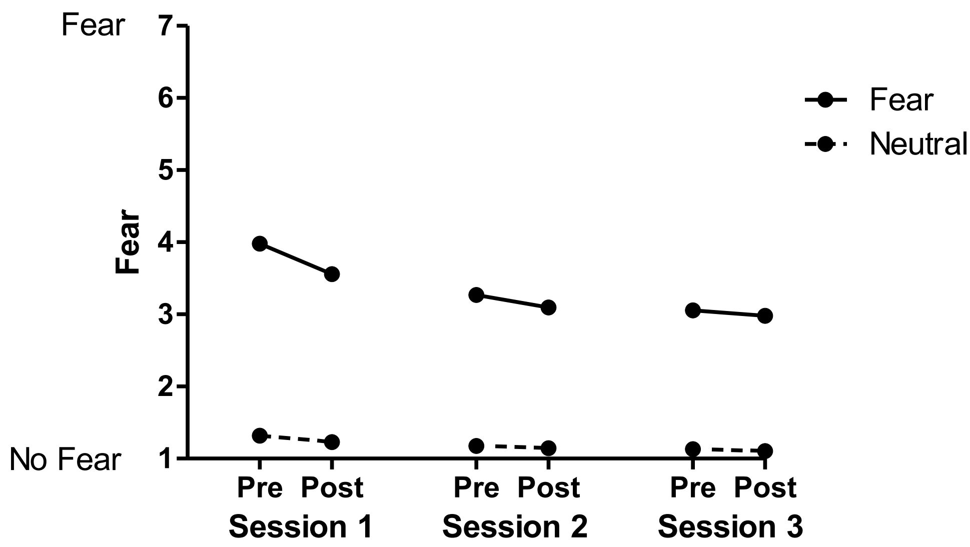


Figure 10. Fear ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures for Experiment 1. Fear evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines.

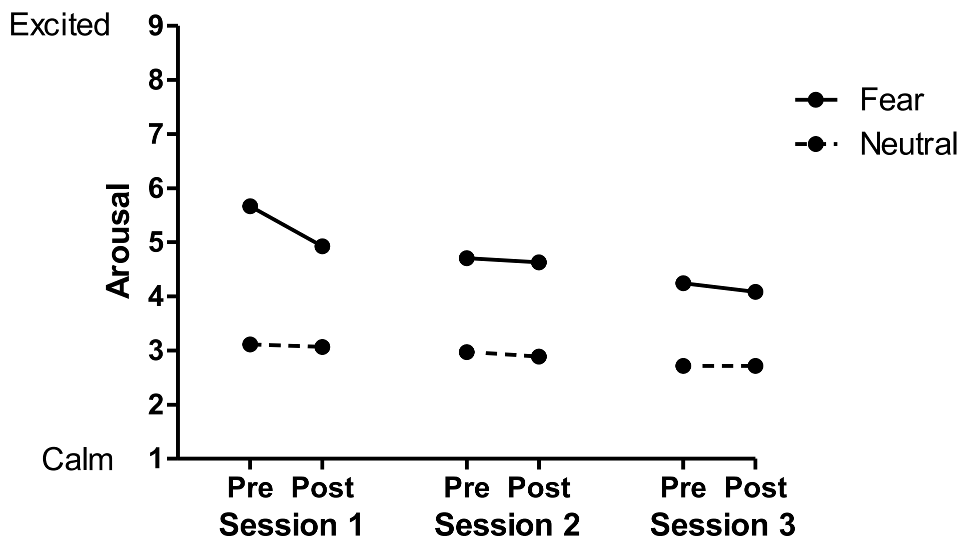


Figure 11. Arousal ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures for Experiment 1. Fear evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines.

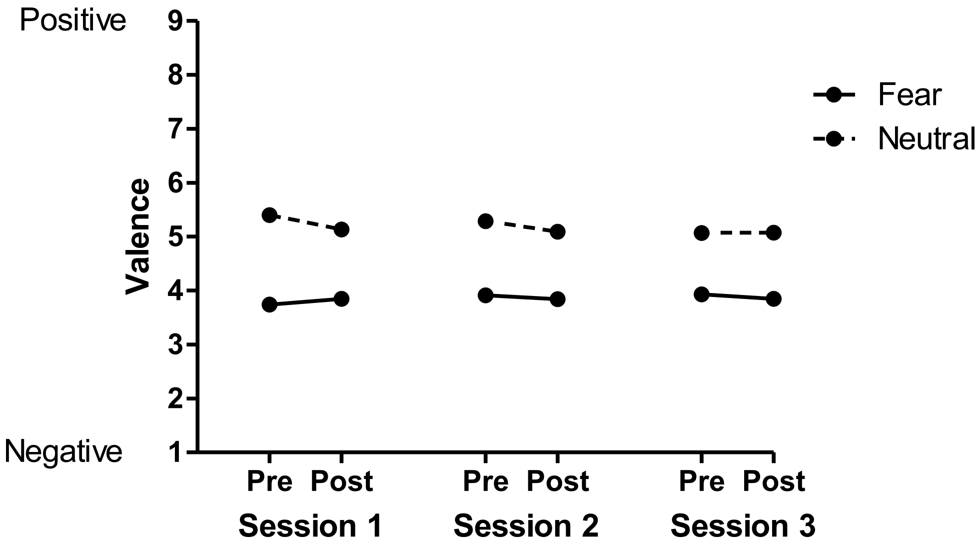


Figure 12. Valence ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures for Experiment 1. Fear evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines.

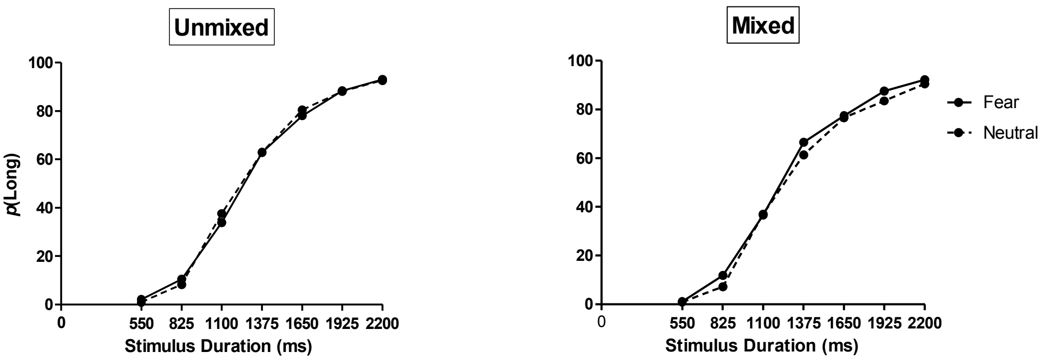


Figure 13. Mean percent "long" presented as a function of stimulus duration (ms). The solid lines are the fear plots and the dashed lines are the neutral plots. Left panel represents the unmixed sessions and right panel represents the mixed session.

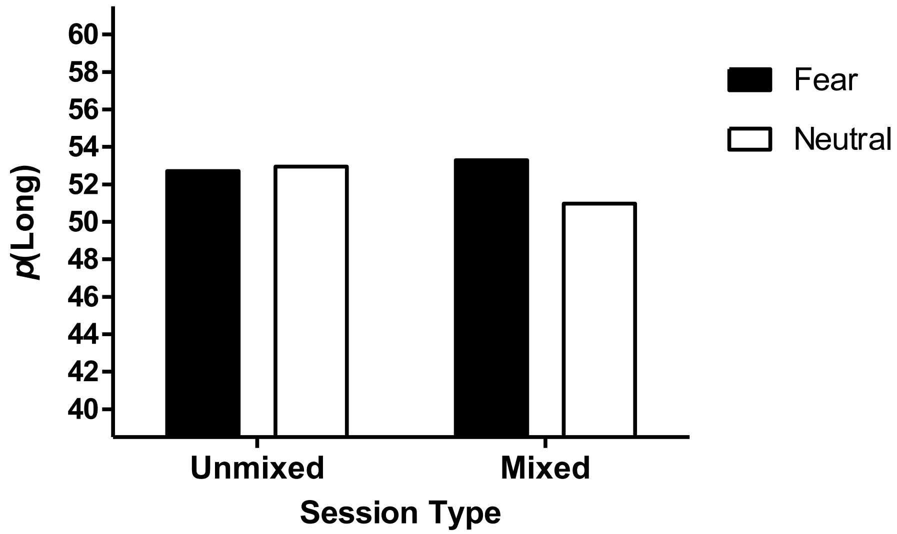


Figure 14. Mean percent “long” as a function of session type, and collapsed across stimulus duration. The black bars represent the fear conditions and the white bars represent the neutral conditions. The y-axis has been truncated so that the lowest point on the axis is 40 ms and the highest point is 60 ms.

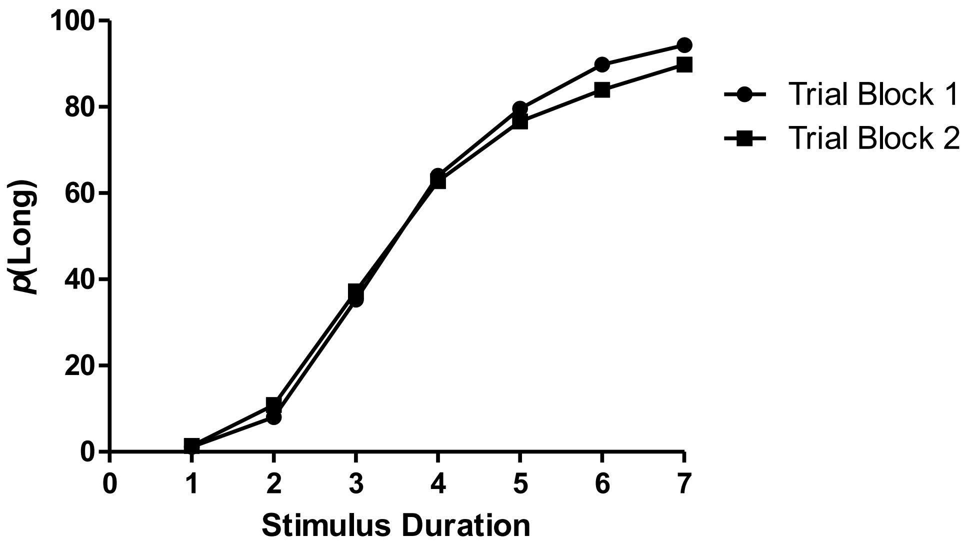


Figure 15. Mean percent "long," collapsed across emotion and session type, and presented as a function of normalized stimulus duration (duration scaled 1-7 for all duration ranges) at both trial blocks. Circle and square symbols represent trial block 1 (first 84 of the 168 trials in a session) and trial block 2 (second 84 trials), respectively.

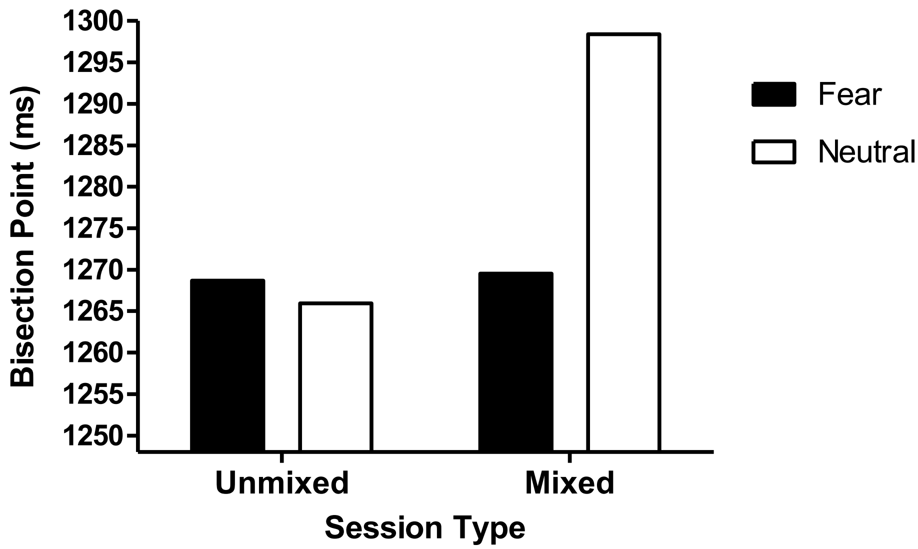


Figure 16. BP (ms) (calculated using the PLM) as a function of session type for the fear and neutral conditions. The black bars represent the fear condition and the white bars represent the neutral condition. The y-axis has been truncated so that the lowest point on the axis is 1250 ms.

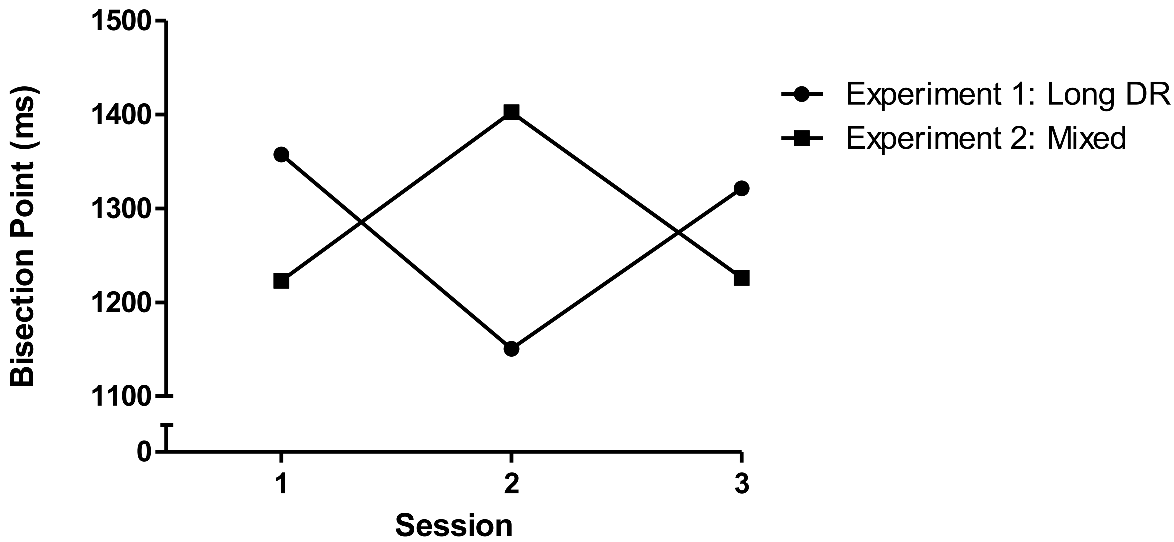


Figure 17. BP (ms) (calculated using the PLM) as a function of session for the long duration range of Experiment 1 and the mixed session of Experiment 2. The circle markers represent the long duration range of Experiment 1 and the square markers represent the mixed session of Experiment 2. The y-axis has been segmented to indicate that the lowest point on the axis is 1110 ms.

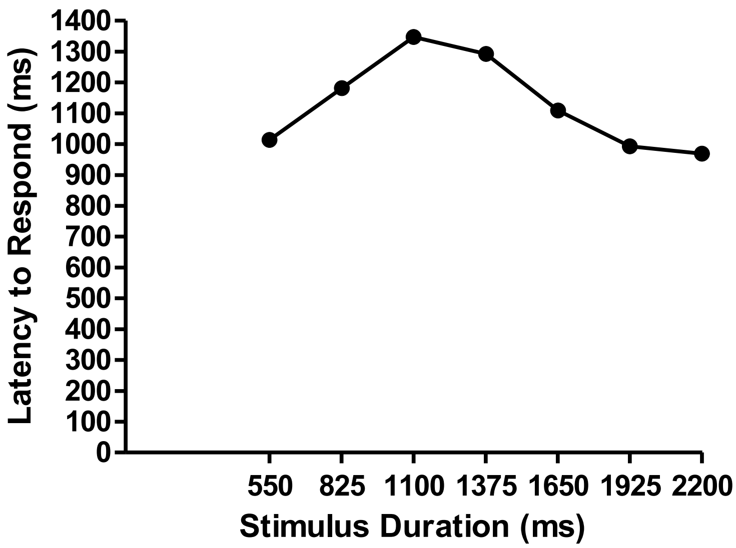


Figure 18. Latency to respond (ms) after picture offset in the testing phase as a function of stimulus duration for Experiment 2.

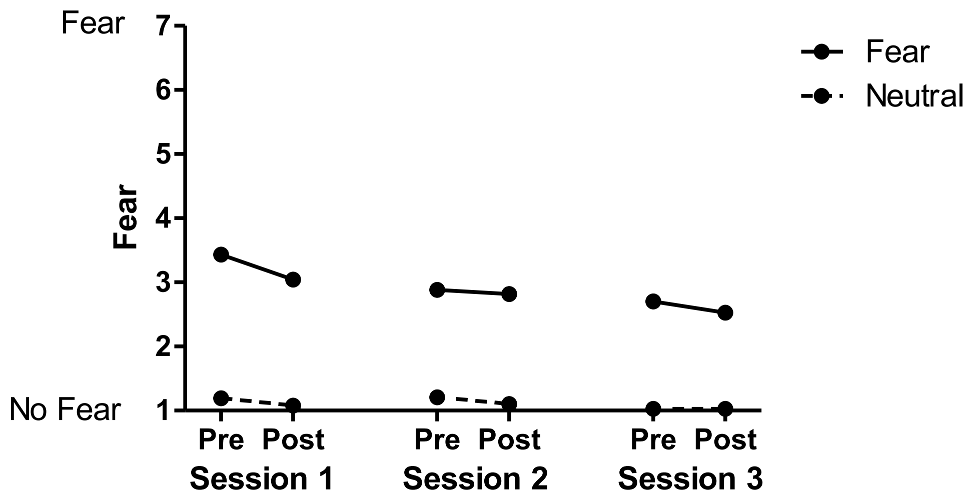


Figure 19. Fear ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures for Experiment 2. Fear evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines.

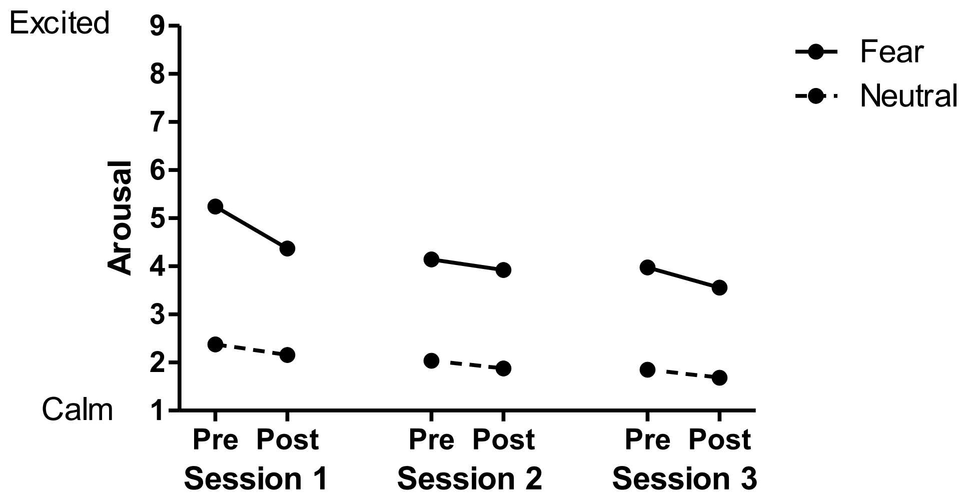


Figure 20. Arousal ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures for Experiment 2. Fear evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines.

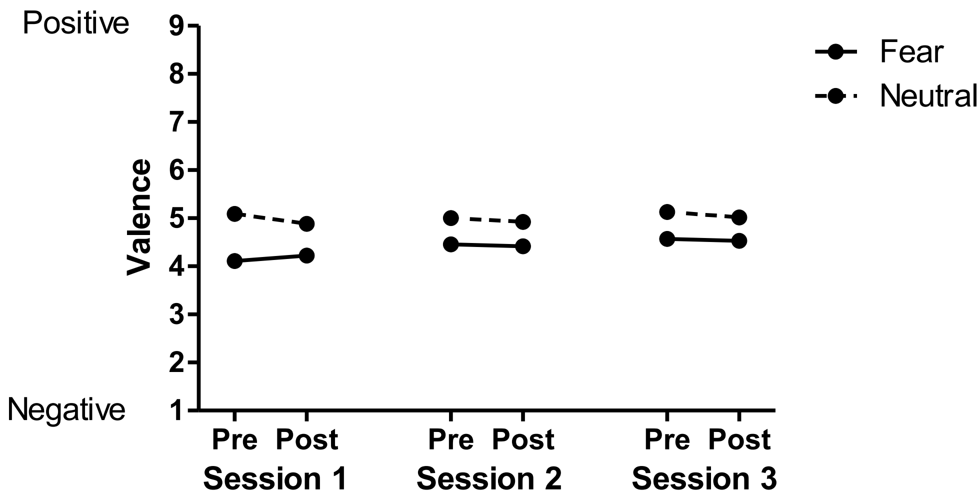


Figure 21. Valence ratings as a function of pretests and posttests across sessions for fear-evoking and neutral pictures for Experiment 2. Fear evoking pictures are represented by solid lines. Neutral pictures are represented by dashed lines.

Appendix A

Script used by experimenter when working with participants in Experiment 1

Greeting

"Welcome and thank you for participating in this study. In this session you will be asked to rate pictures based on how they make you feel. You will do this both at the beginning and at the end of the session. Between those two ratings, the same pictures will be shown to you many times and you will be asked to judge the duration of time these pictures were presented to you. This entire study takes between 2 and 3 hours, with each session lasting a maximum of 1 hour. At the end of the third session, you will be told the purpose of the study and will have the opportunity to ask questions about the meaning of the results. You will receive a total of three credits for your participation is this study."

Consent Form

(Give participant consent form.)

"Please read this consent form carefully and sign below if you agree to participate. You are only signing that you have been informed about the experiment. You will not give away any rights by signing that you consent to participate."

(Wait for participant to sign and date the consent form.)

(Check to make sure that the participant has signed and dated on the proper lines.)

"Do you have any questions about the experiment or the consent form?"

(Answer any questions.)

Rating Phase 1

(Give participant ratings packet.)

SAM (Valence)

"During the next part of the study I will ask you to rank pictures on 3 measures after you view them. First you will rank pictures based on a happy through unhappy scale that ranges from a smile to a frown. At one extreme of the happy vs. unhappy scale, you felt happy, pleased, satisfied, contented, and hopeful. If you felt completely happy while viewing the picture, you can indicate this by bubbling in the figure to the left like this (demonstrate with SAM). The other end of the scale is when you felt completely unhappy, annoyed, unsatisfied, melancholic, despaired, and bored. You can indicate feeling completely unhappy by bubbling in the figure at the right, like this (demonstrate with SAM). The figures also allow you to describe intermediate feelings of pleasure, by placing an "X" over any of the other pictures. If you felt completely neutral (neither happy nor unhappy), place an "X" over the figure in the middle. If, in your judgment, your feeling of pleasure or displeasure falls between two of the pictures, then bubble in the space between the figures, like this (demonstrate with SAM). This permits you to make more finely graded ratings of how you feel in reaction to the pictures."

"Do you have any questions about the Happy versus Unhappy scale?"

SAM (Arousal)

"The excited vs. calm dimension is the second type of feeling displayed here. At one extreme of the scale you felt stimulated, excited, frenzied, jittery, wide-awake, and aroused. If you felt completely aroused while viewing the picture, bubble in the figure at the left of the row, like this (demonstrate with SAM). On the other hand, at the other end of the scale, you felt completely relaxed, calm, sluggish, dull, sleepy, and un-aroused. You can indicate you felt completely calm by bubbling in the figure at the right of the row, like this (demonstrate with SAM). As with the happy-unhappy scale, you can represent intermediate levels bubbling in any of the other figures. If you are not at all excited nor at all calm, bubble in the figure in the middle of the row. Again, if you wish to make a more finely tuned rating of how excited or calm you feel, bubble in the spaces between the pictures, like this (demonstrate with SAM)."

"Do you have any questions about the Excited versus Calm scale?"

Mikels et al. (Fear)

"The last feeling for you to rate is fear. Rate this feeling on a 1 through 7 scale. A rating of 1 means that you felt not at all fearful when viewing the picture (demonstrate on scale). A rating of 7 means that you felt a great amount of fear when viewing the picture (demonstrate on scale). As with the other scales, you can represent intermediate levels of fear by choosing any of the other numbers. To be clear, only whole numbers should be chosen."

"Do you have any questions about the Fear scale?"

General Rating

"Some of the pictures may prompt emotional experiences; others may seem relatively neutral. Your rating of each picture should reflect your immediate personal experience, and no more. Please rate each one AS YOU ACTUALLY FELT WHILE YOU WATCHED THE PICTURE. You must press the spacebar to begin and please note that you must press the spacebar for the next picture to appear after you have made your rating."

"Do you have any questions about any of the scales?"

"What hand do you write with?"

(Place packet on that side of the keyboard, and initiate the Rating program on the computer.)

Training Phase

"During the next part of the experiment you will be shown a green square. Following the presentation of the green square, press the "S" key if you think that it was there for a short period of time and press the "L" key if you think it was there for a long period of time. Press the spacebar when you are ready to begin."

Testing Phase

"In this part of the experiment you will be shown the pictures that you rated earlier. As you just did with the green square, please make judgments about whether the pictures are shown for a short time or a long time. It is very important that you look directly at the pictures throughout this task. Press the "S" key if you think the picture was shown for a period of time closer to the SHORT duration. Press the "L" key if you think the picture was shown for a period of time closer to the LONG duration. Come and get me when the computer screen tells you that the session is over. Press the spacebar to begin."

(Initiate Testing program on computer.)

Rating Phase 2

(Give the participant the second rating packet.)

"Are you comfortable with the procedure for rating pictures on the happy vs. unhappy dimension, the excited vs. calm dimension, and the rating of fear as discussed previously? If not, I can review these directions with you."

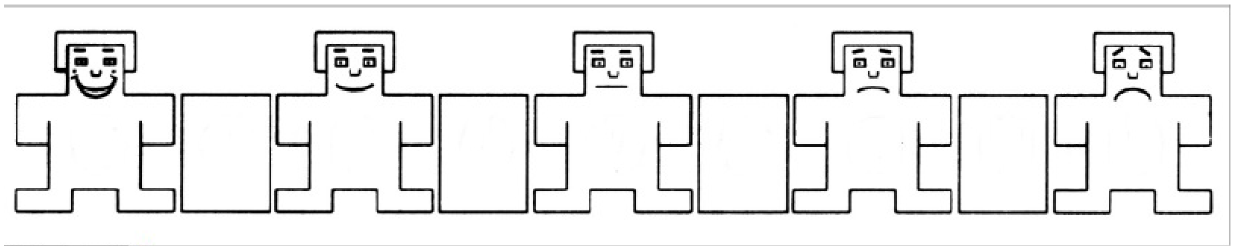
(If the participant indicates that he or she is comfortable with the procedure, place the rating packet on the side of the keyboard that corresponds to his or her writing hand and initiate the

Rating program on the computer. If the participant indicates that he or she is uncomfortable with the procedure, read the instructions from Rating Phase 1.)

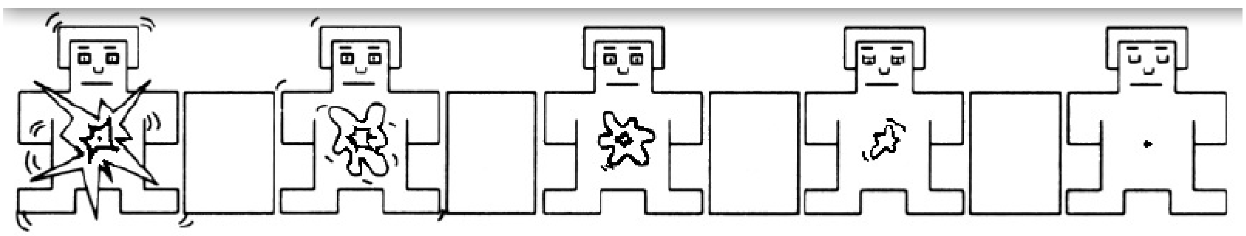
Appendix B

SAM (Lang et al., 2008) and Mikels et al. (2005) rating scales

Happy vs. Unhappy



Excited vs. Calm

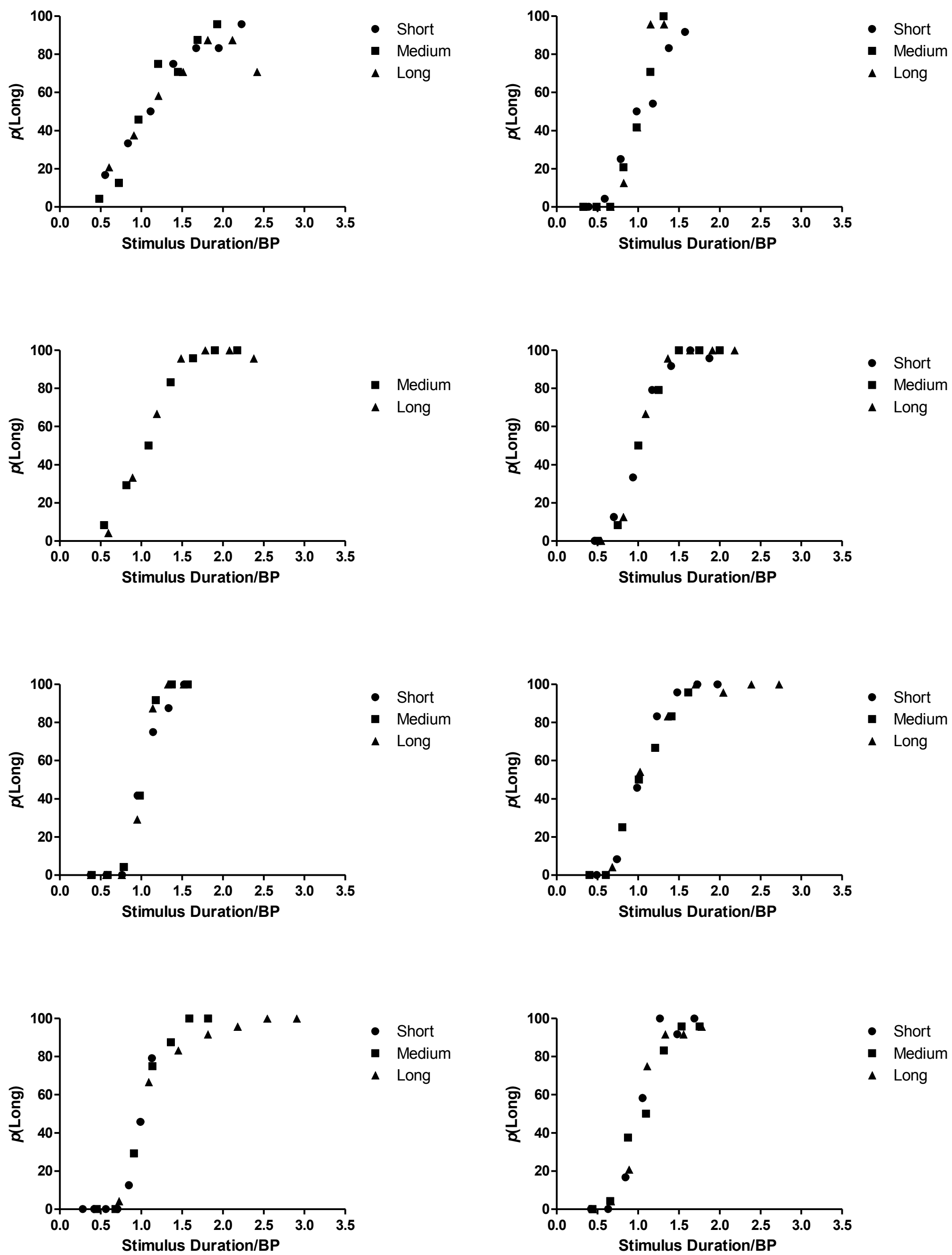


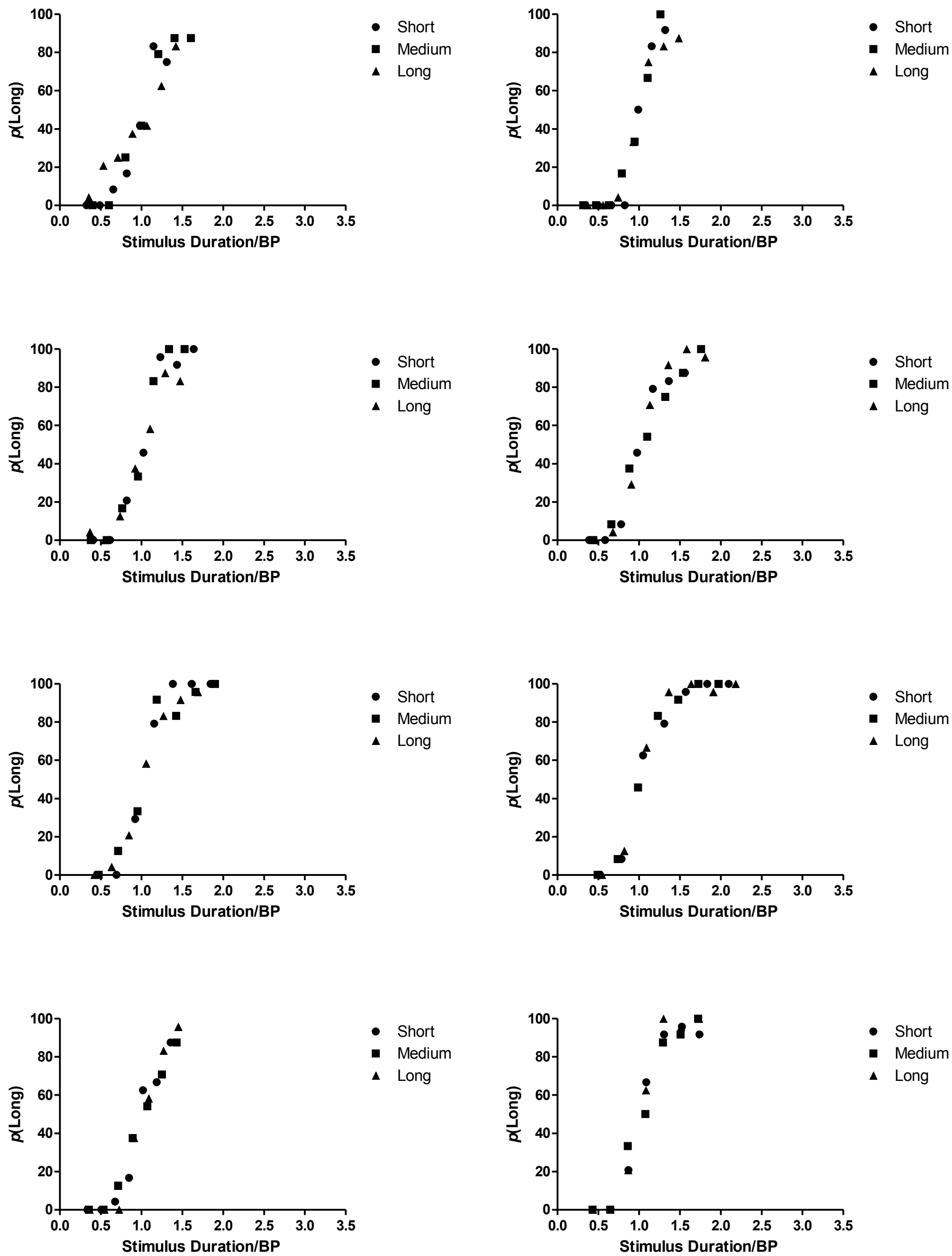
Fear Scale

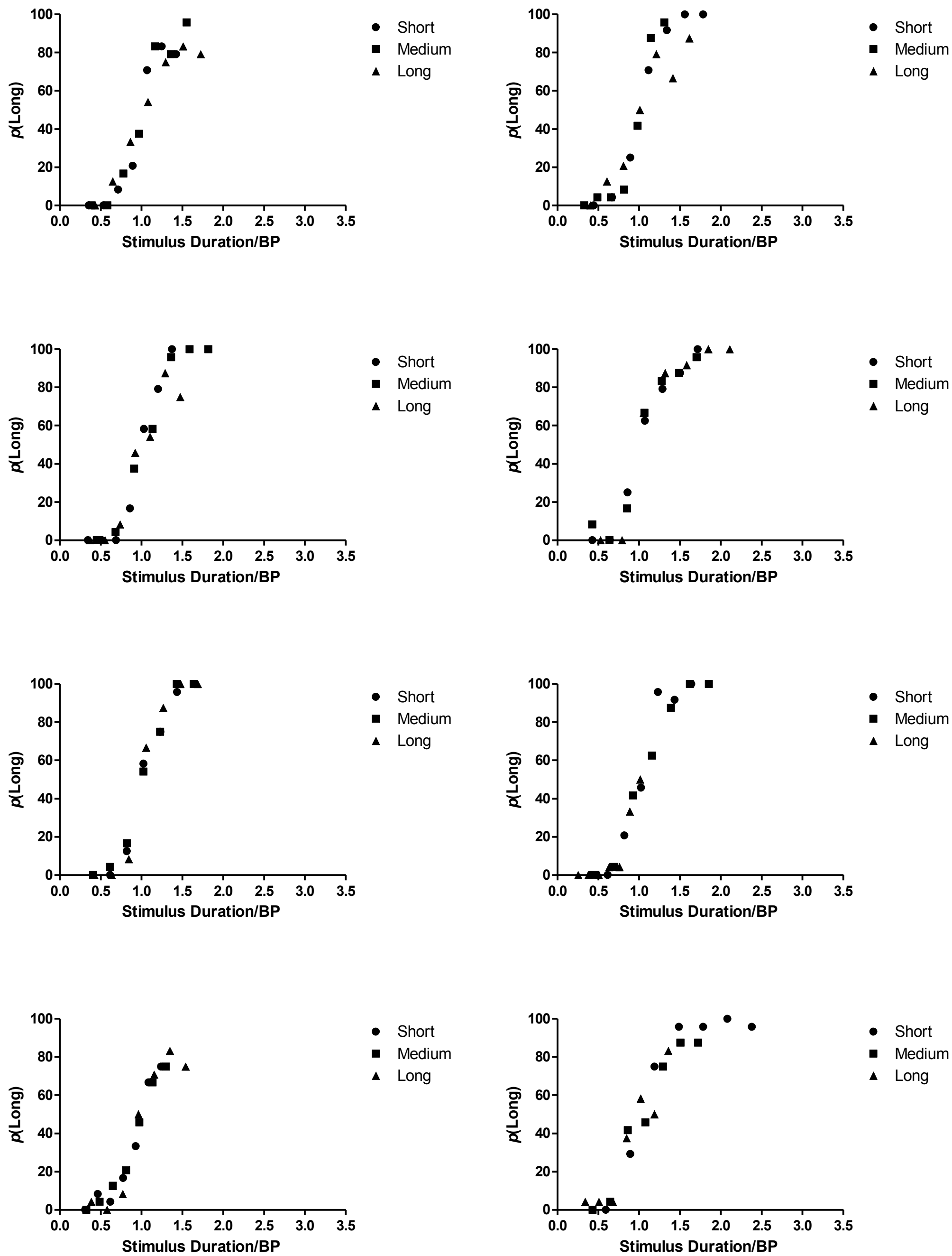
1-------------------2-------------------3-------------------4-------------------5-------------------6---------------7

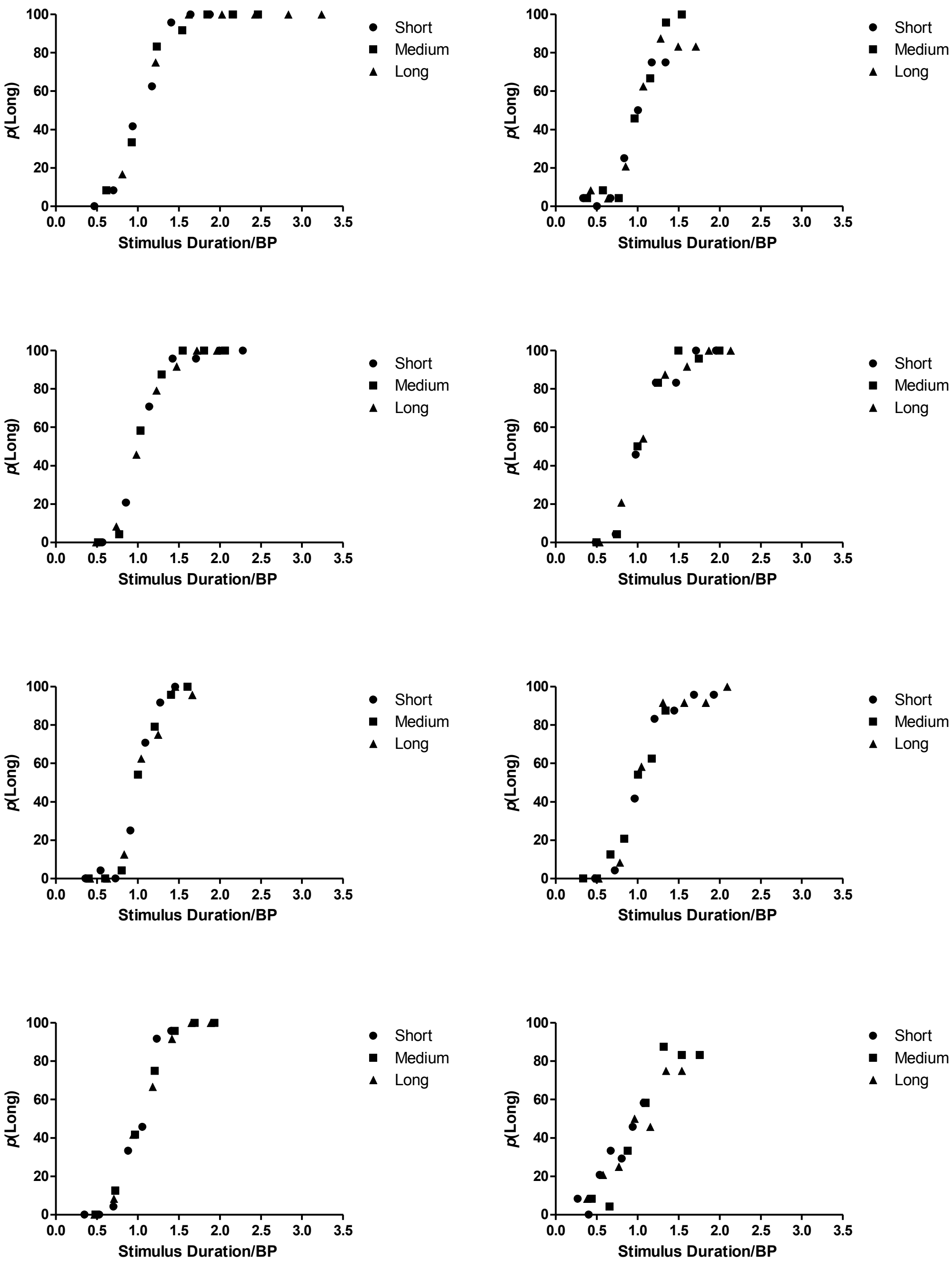
Appendix C

p(Long) as a function of stimulus duration/BP at each duration range for individual participants. Circle, square, and triangle symbols identify the short, medium, and long duration ranges, respectively.

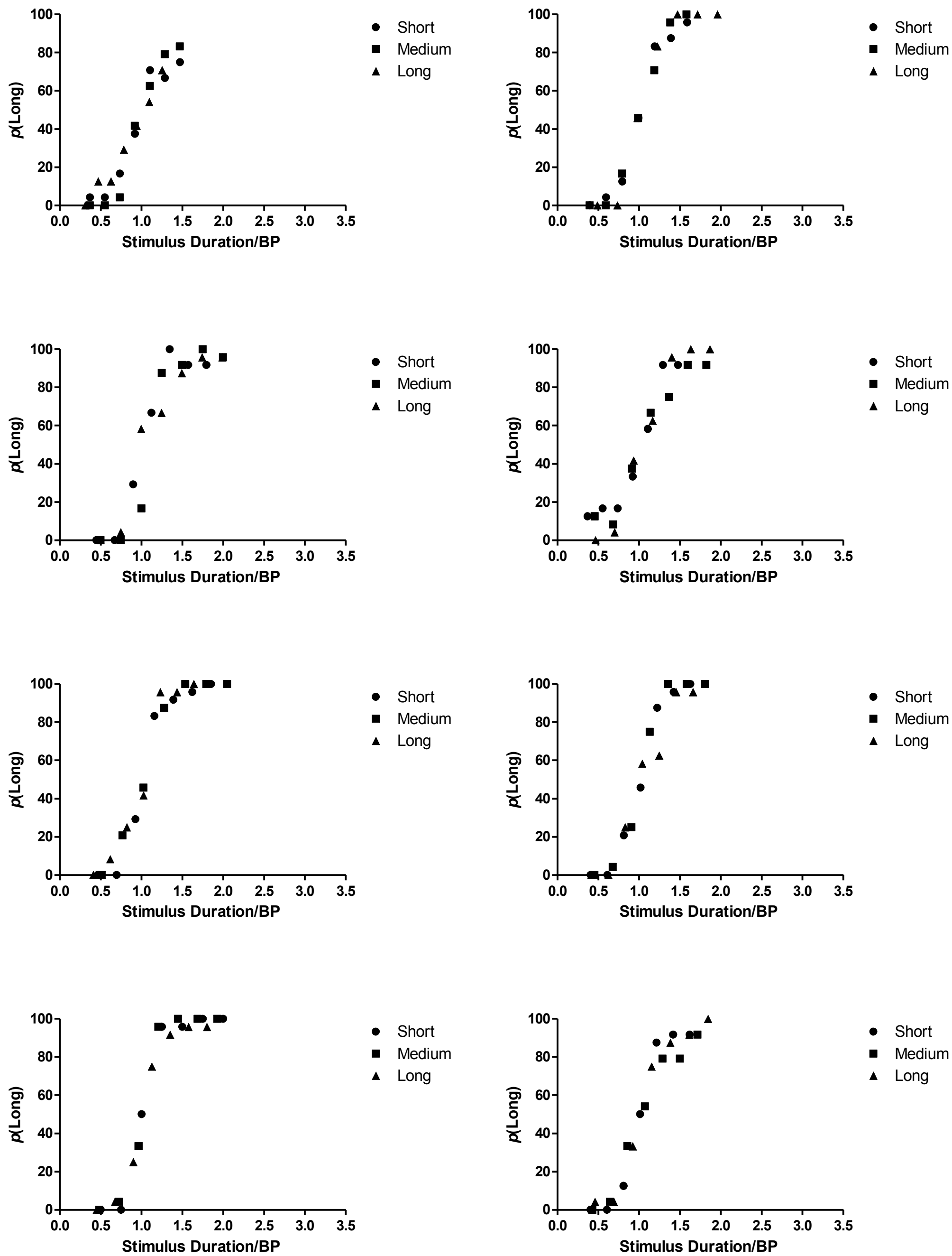



100
80
60
40
20
0
p(Long)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Stimulus Duration/BP
Short
Medium
Long

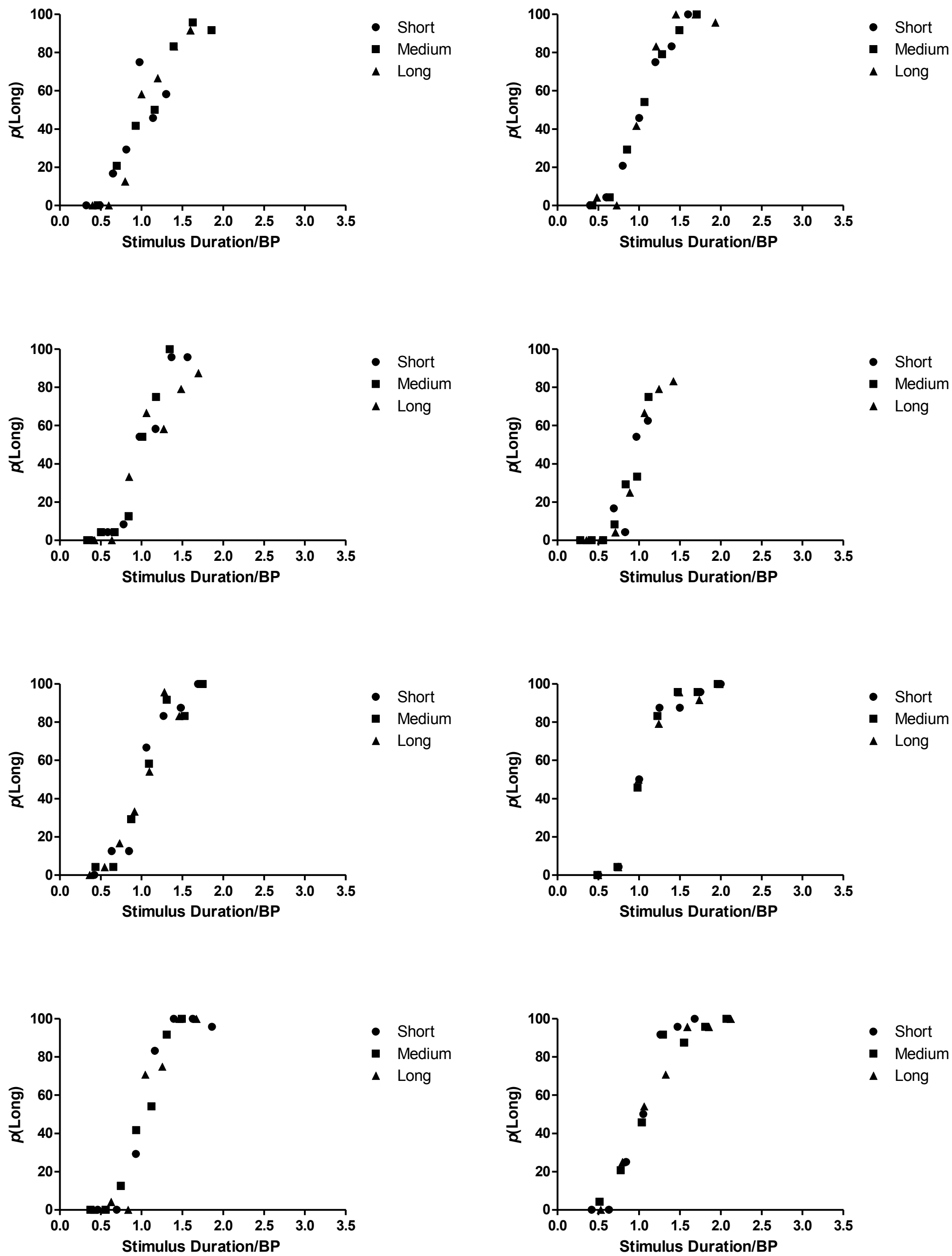

p(Long)
Stimulus Duration/BP
Short
Medium
Long
0
20
40
60
80
100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5



p(Long)
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Stimulus Duration/BP
Short
Medium
Long
p(Long)
Stimulus Duration/BP
Short
Medium
Long
p(Long)
Stimulus Duration/BP
Short
Medium
Long
p(Long)
Stimulus Duration/BP
Short
Medium
Long
p(Long)
Stimulus Duration/BP
Short
Medium
Long
p(Long)
Stimulus Duration/BP
Short
Medium
Long
p(Long)
Stimulus Duration/BP
Short
Medium
Long
p(Long)
Stimulus Duration/BP
Short
Medium
Long



p(Long)
Stimulus Duration/BP
Short
Medium
Long
0
20
40
60
80
100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5



p(Long)
Stimulus Duration/BP
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
0 20 40 60 80 100
Short
Medium
Long

Appendix D

Script used by experimenter when working with participants in Experiment 2

Greeting

"Welcome and thank you for participating in this study. First you will be asked to rate pictures based on how they make you feel. Following that you will be asked to judge the duration of time that pictures are presented to you. Finally, you will be asked to make ratings on your feelings about the pictures that you timed. This entire study takes between 1 and 2 hours. At the end of study, you will be told the purpose of the study and will have the opportunity to ask questions about the meaning of the results. You will receive a total of two credits for your participation is this study."

Consent Form

(Give participant consent form.)

"Please read this consent form carefully and sign below if you agree to participate. You are only signing that you have been informed about the experiment. You will not give away any rights by signing that you consent to participate."

(Wait for participant to sign and date the consent form.)

(Check to make sure that the participant has signed and dated on the proper lines.)

"Do you have any questions about the experiment or the consent form?"

(Answer any questions.)

Rating Phase 1

(Give participant ratings packet)

<u>SAM (Valence)</u>

"During the next part of the study I will ask you to rank pictures on 3 measures after you view them. First you will rank pictures based on a happy through unhappy scale which ranges from a smile to a frown. At one extreme of the happy vs. unhappy scale, you felt happy, pleased, satisfied, contented, and hopeful. If you felt completely happy while viewing the picture, you can indicate this by bubbling in the figure to the left like this (demonstrate with SAM). The other end of the scale is when you felt completely unhappy, annoyed, unsatisfied, melancholic, despaired, and bored. You can indicate feeling completely unhappy by bubbling in the figure at the right, like this (demonstrate with SAM). The figures also allow you to describe intermediate feelings of pleasure, by placing an "X" over any of the other pictures. If you felt completely neutral (neither happy nor unhappy), place an "X" over the figure in the middle. If, in your judgment, your feeling of pleasure or displeasure falls between two of the pictures, then bubble in the space between the figures, like this (demonstrate with SAM). This permits you to make more finely graded ratings of how you feel in reaction to the pictures.

"Do you have any questions about the Happy versus Unhappy scale?"

SAM (Arousal)

"The excited vs. calm dimension is the second type of feeling displayed here. At one extreme of the scale you felt stimulated, excited, frenzied, jittery, wide-awake, and aroused. If you felt completely aroused while viewing the picture, bubble in the figure at the left of the row, like this (demonstrate with SAM). On the other hand, at the other end of the scale, you felt completely relaxed, calm, sluggish, dull, sleepy, and un-aroused. You can indicate you felt completely calm by bubbling in the figure at the right of the row, like this (demonstrate with SAM). As with the happy-unhappy scale, you can represent intermediate levels bubbling in any of the other figures. If you are not at all excited nor at all calm, bubble in the figure in the middle of the row. Again, if you wish to make a more finely tuned rating of how excited or calm you feel, bubble in the spaces between the pictures, like this (demonstrate with SAM).

"Do you have any questions about the Excited versus Calm scale?"

Mikels (Fear)

"The last feeling for you to rate is fear. Rate this feeling on a 1 through 7 scale. A rating of 1 means that you felt not at all fearful when viewing the picture (demonstrate on scale). A rating of 7 means that you felt a great amount of fear when viewing the picture (demonstrate on scale). As with the other scales, you can represent intermediate levels of fear by choosing any of the other numbers. To be clear, only whole numbers should be chosen.

"Do you have any questions about the Fear scale?"

General Rating

"Some of the pictures may prompt emotional experiences; others may seem relatively neutral. Your rating of each picture should reflect your immediate personal experience, and no more. Please rate each one AS YOU ACTUALLY FELT WHILE YOU WATCHED THE PICTURE. You must press the spacebar to begin and please note that you must press the spacebar for the next picture to appear after you have made your rating."

"Do you have any questions about any of the scales?"

"What hand do you write with?" (Place packet on that side)

Training Phase

"During the next part of the experiment you will be shown asome pictures. Following the presentation of each picture, press the "S" key if you think that it was there for a short period of time and press the "L" key if you think it was there for a long period of time. Press the spacebar when you are ready to begin."

Testing Phase

"In this part of the experiment you will be shown the pictures. Please make judgments about whether the pictures are shown for a short time or a long time. It is very important that you look directly at the pictures throughout this task. Press the "S" key if you think the picture was shown for a SHORT duration. Press the "L" key if you think the picture was shown for a LONG duration. Come and get me when the computer screen tells you that the session is over. Press the spacebar to begin."

(Initiate Testing program on computer.)

Rating Phase 2

(Give the participant the second rating packet.)

"Are you comfortable with the procedure for rating pictures on the happy vs. unhappy dimension, the excited vs. calm dimension, and the rating of fear as discussed previously? If not, I can review these directions with you."

(If the participant indicates that he or she is comfortable with the procedure, place the rating packet on the side of the keyboard that corresponds to his or her writing hand and initiate the Rating program on the computer. If the participant indicates that he or she is uncomfortable with the procedure, read the instructions from Rating Phase 1.)

Bibliography

Allan, L. G. (2002). The location and interpretation of the bisection point. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 55*(1), 43-60.

Allan, L. G., & Gibbon, J. (1991). Human bisection at the geometric mean. *Learning and Motivation, 22*(1-2), 39-58. doi:10.1016/0023-9690(91)90016-2

Allman, M. J., DeLeon, I. G., & Wearden, J. H. (2011). Psychophysical assessment of timing in individuals with autism. *American Journal on Intellectual and Developmental Disabilities, 116*(2), 165-178. doi:10.1352/1944-7558-116.2.165

Anderson, M. J., Reis-Costa, K., & Misanin, J. R. (2007). Effects of September 11th terrorism stress on estimated duration. *Perceptual and Motor Skills, 104*(3, Pt 1), 799-802. doi:10.2466/PMS.104.3.799-802

Brown, B. L., Höhn, S., Faure, A., von Hörsten, S., Le Blanc, P., Desvignes, N., & ... Doyère, V. (2011). Temporal sensitivity changes with extended training in a bisection task in a transgenic rat model. *Frontiers in Integrative Neuroscience,5,* doi:10.3389/fnint.2011.00044

Callu, D., El Massioui, N., Dutrieux, G., Brown, B. L., & Doyere, V. (2009). Cognitive processing impairments in a supra-second temporal discrimination task in rats with cerebellar lesion. *Neurobiology of Learning and Memory, 91*(3), 250-259. doi:10.1016/j.nlm.2008.12.002

Church, R. M. (1984). Properties of the internal clock. *Annals of the New York Academy of Sciences, 423,* 566-582. doi:10.1111/j.1749-6632.1984.tb23459.x

Church, R. M., & Deluty, M. Z. (1977). Bisection of temporal intervals. *Journal of Experimental Psychology: Animal Behavior Processes, 3*(3)*,* 216-228. doi:10.1037/0097-7403.3.3.216

Droit-Volet, S., & Gil, S. (2009). The time-emotion paradox. *Philosophical Transactions of the Royal Society B: Biological Sciences 364,* 1943-1953. doi: 10.1098/rstb.2009.0013

Droit-Volet, S., & Meck, W. H. (2007). How emotions colour our perception of time. *Trends in Cognitive Sciences, 11*(12)*,* 504-513. doi:10.1016/j.tics.2007.09.008

Droit-Volet, S., Mermillod, M., Cocenas-Silva, R., & Gil, S. (2010). The effect of expectancy of a threatening event on time perception in human adults. *Emotion, 10*(6)*,* 908-914. doi:10.1037/a0020258

Eagleman D. M., Pariyadath, V. (2009). Is subjective duration a signature of coding efficiency? P*hilosophical Transactions of The Royal Society B: Biological Sciences, 364*(1525)*,* 1841-1851.

Gallistel, C. R., & Gibbon, J. (2000). Time, rate, and conditioning. *Psychological Review, 107*(2)*,* 289-344. doi:10.1037/0033-295X.107.2.289

Gibbon, J. (1977). Scalar expectancy theory and Weber's law in animal timing. *Psychological Review, 84*(3)*,* 279-325. doi:10.1037/0033-295X.84.3.279

Gibbon, J. (1981). Two kinds of ambiguity in the study of psychological time. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analysis of behavior: Discriminative properties of reinforcement schedules* (Vol. 1; pp. 157-189). Cambridge , MA: Ballinger.

Gibbon, J. (1986). The structure of subjective time: How time flies. *Psychology of Learning and Motivation, 20,* 105-135.

Gil, S., Niedenthal, P. M., & Droit-Volet, S. (2007). Anger and time perception in children. *Emotion, 7*(1)*,* 219-225. doi:10.1037/1528-3542.7.1.219

Grommet, E. K., Droit-Volet, S., Gil, S., Hemmes, N. S., Baker, A., & Brown, B. L. (2011). Time estimation of fear cues in human observers. *Behavioural Processes, 86*(1)*,* 88-93. doi:10.1016/j.beproc.2010.10.003

Hillman, C. H., Hsiao-Wecksler, E. T., & Rosengren, K. S. (2005). Postural and eye-blink indices of the defensive startle reflex. *International Journal of Psychophysiology, 55*(1)*,* 45-49. doi:10.1016/j.ijpsycho.2004.06.002

Killeen, P. R., Fetterman, J. G., & Bizo, L. A. (1997). Time's causes. In C. M. Bradshaw & E. Szabadi (Eds.), *Time and behaviour: Psychological and neurobehavioural analyses.* (pp. 79-131). Amsterdam Netherlands: North-Holland/Elsevier Science Publishers.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). International affective picture system (IAPS): Affective ratings of pictures and instruction manual *Technical Report A-8*. Gainesville, FL: University of Florida.

Lejeune, H. (1998). Switching or gating? The attentional challenge in cognitive models of psychological time. Behavioural Processes, 44(2), 127-145. doi:10.1016/S0376-6357(98)00045

Maricq, A., & Church, R. (1983). The differential effects of haloperidol and methamphetamine on time estimation in the rat. *Psychopharmacology, 79*(1)*,* 10-15.

Matthews, W. J. (2011). Can we use verbal estimation to dissect the internal clock? Differentiating the effects of pacemaker rate, switch latencies, and judgment processes. *Behavioural Processes, 86*(1)*,* 68-74. doi:10.1016/j.beproc.2010.09.006

Meck, W. H. (1983). Selective adjustment of the speed of internal clock and memory processes. *Journal of Experimental Psychology: Animal Behavior Processes, 9*(2)*,* 171-201. doi:10.1037/0097-7403.9.2.171

Mikels, J. A., Fredrickson, B. L., Larkin, G. R., Lindberg, C. M., Maglio, S. J., & Reuter-Lorenz, P. A. (2005). Emotional category data on images from the International Affective Picture System. *Behavior Research Methods, 37*(4)*,* 626-630. doi:10.3758/BF03192732

Pariyadath, V., & Eagleman, D. M. (2008). Brief subjective durations contract with repetition. *Journal of Vision, 8*(16)*,* 1-6. doi:10.1167/8.16.11

Penney, T. B., Allan, L. G., Meck, W. H., & Gibbon, J. (1998). Memory mixing in duration bisection. In D. A. Rosenbaum, C. E. Collyer (Eds.), *Timing of behavior: Neural, psychological, and computational perspectives* (pp. 165-193). Cambridge, MA US: The MIT Press.

Penney, T. B., Gibbon, J., & Meck, W. H. (2000). Differential effects of auditory and visual signals on clock speed and temporal memory. *Journal of Experimental Psychology: Human Perception and Performance, 26*(6)*,* 1770-1787. doi:10.1037/0096-1523.26.6.1770

Rodríguez-Gironés, M. A., & Kacelnik, A. (1998). Response latencies in temporal bisection: Implications for timing models. In V. De Keyser, G. d'Ydewalle, A. Vandierendonck (Eds.), *Time and the dynamic control of behavior* (pp. 51-70). Ashland, OH US: Hogrefe & Huber Publishers.

Stubbs, A. (1968). The discrimination of stimulus duration by pigeons. *Journal of the Experimental Analysis of Behavior, 11*(3)*,* 223-238. doi:10.1901/jeab.1968.11-223

Tipples, J. (2008). Negative emotionality influences the effects of emotion on time perception. *Emotion, 8*(1)*,* 127-131. doi:10.1037/1528-3542.8.1.127

Watts, F. N., & Sharrock, R. (1984). Fear and time estimation. *Perceptual and Motor Skills, 59*(2)*,* 597-598. doi:10.2466/pms.1984.59.2.597

Wearden, J. H. (1991). Human performance on an analogue of an interval bisection task. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 43B*(1)*,* 59-81.

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

Wearden, J. H., Todd, N. P. M., & Jones, L. A. (2006). When do auditory/visual differences in duration judgements occur? *The Quarterly Journal of Experimental Psychology, 59*(10)*,* 1709-1724. doi:10.1080/17470210500314729