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Effects of Emotional Valence and Arousal on Time Perception

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Abstract

We examined the influence of emotional arousal and valence on estimating time intervals. A reproduction task was used in which images from the International Affective Picture System served as the stimuli to be timed. Experiment 1 assessed the effects of positive and negative valence at a moderate arousal level and Experiment 2 replicated Experiment 1 with the addition of a high arousal condition. Overestimation increased as a function of arousal during encoding of times regardless of valence. For images presented during reproduction, overestimation occurred at the moderate arousal level for positive and negative valence but underestimation occurred in the negative valence high arousal condition. The overestimation of time intervals produced by emotional arousal during encoding and during reproduction suggests that emotional stimuli affect temporal information processing in a qualitatively different way during different phases of temporal information processing.

Keywords

Time perception; attention; arousal; emotional valence; clock speed; emotions

1. Introduction

The intense involvement in a work of art seems to make us lose track of time. Though our retrospective judgments of how long such an experience lasts seem to make us think that time has flown, it is also the case that emotion changes our encoding and reproduction of memories for time. A general consensus of recent studies is that the arousal related to emotional stimuli increases the speed of an internal timing mechanism (Droit-Volet et al., 2004, 2013; Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Grommet et al., 2011). Emotions can be thought of categorically, such as happy, sad, or angry, but they can also be conceptualized as in a two dimensional space in which valence is on one axis and arousal is on the other (Lang et al., 2003). Valence refers to how pleasant or unpleasant a stimulus is. Arousal refers to levels of activation as reflected in physiological responses such as skin conductance, heart rate, and the startle response (Bradley et al., 2001; Mikels et al., 2005). Specific emotions can be placed on this two-dimensional space. For example, happiness is considered to be moderately arousing with positive valence, excitement is highly arousing with positive valence, sadness is moderately arousing with negative valence, and anger is highly arousing with negative valence. In fact, people are more consistent in their ratings of

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arousal and valence than in applying categorical labels (Bradley & Lang, 2007a) suggesting that these dimensions accurately reflect emotional experience. Thus, emotions might impact time perception through valence and/or arousal.

Clock models of timing, such as Scalar Expectancy Theory (SET), propose that temporal information is processed using an internal mechanism for counting time. This clock-like structure (pacemaker/timer) emits pulses at a given rate that pass through a switch and get added to an accumulator (Gibbon, 1977; Gibbon et al., 1984). The accumulation is transferred to a short-term memory store and, depending on environmental conditions, to a long-term memory store when it is appropriate to encode the duration of an event. Decisions are made about the temporal information when accumulated stores are compared to representations in long-term memory. Another component of SET is that estimates demonstrate the scalar property. The scalar property, a version of Weber's law, stipulates that as target duration increases the variability of temporal estimates will increase proportionally such that the coefficient of variation (standard deviation divided by the mean) will remain constant.

Research has suggested that in general, increased arousal increases the speed of the internal clock (Fetterman & Killeen, 1995; Meck, 1996; Penton-Voak et al., 1996; Treisman et al., 1990; Wearden & Penton-Voak, 1995). The effects of increased clock speed on time estimation differ depending on whether the change in clock speed occurs during the encoding or reproduction of a temporal memory (Meck, 1996; Penton-Voak et al., 1996). If clock speed is increased only when subjects are encoding the time, more pulses accumulate during encoding than would accumulate at normal clock speed. When that time is later reproduced with a clock running at normal speed, it will take more time for the accumulating pulses to match the memory representation encoded with the fast clock and reproductions will overestimate the time. On the other hand, if duration is encoded at a normal clock speed but clock speed is increased when subjects are reproducing the duration, estimates are shorter because an increase in clock speed during retrieval causes subjects to reach the target duration encoded in memory more quickly than normal.

These same effects are noted when arousal is induced by emotional stimuli. Watts & Sharrock (1984) required subjects with phobias to view images of phobic stimuli during encoding and then provide temporal estimates of the exposure duration. Phobic subjects overestimated the duration of the images more than non-phobic subjects, which is consistent with an increase in clock speed during the encoding of the duration of the fearful stimuli. Langer et al. (1961) found that subjects underestimated duration when they were fearful while reproducing a previously learned interval, which is consistent with an increase in clock speed during reproduction. More recently, Droit-Volet et al. (2004) demonstrated that estimates of the duration of emotional faces increased with increasing arousal level during encoding. These results are all consistent with the interpretation that arousal induced by emotional stimuli increases clock speed.

Much of the research that directly addresses the impact of emotions on temporal processing has utilized the International Affective Picture System (IAPS) (Lang et al., 2008), a large set of photographic images that have been rated on levels of arousal and valence. Using these

images Angrilli et al. (1997) assessed differences in time perception due to valence and arousal, and found an interaction between them. When low arousal stimuli were presented during encoding, estimates of positive images were longer than estimates of negative images. However, the pattern of results reversed when high arousal images were presented: estimates of negative images were longer than estimates of positive ones. One interpretation of these results is that clock speed slows for negative images at low arousal level but speeds up for highly arousing negative images relative to positive ones.

Attention also influences time perception because attentional resources are limited and must be shared across timing and non-timing processes (Brown, 1997, 2008; Macar et al., 1994; Penney et al., 2000; Zakay & Block, 1997). In the attentional allocation model, attention to time modulates the accumulating pulses in SET (Penney et al., 2000; Zakay & Block, 1997). When attention is distracted from time during encoding fewer pulses accumulate making encoded durations shorter. When attention is distracted during reproduction of a previously learned time the slower accumulation of pulses results in it taking longer to reach a criterion number of pulses and estimates are longer (Macar et al., 1994; Penney et al., 2000). Inversely, increasing attention to time during encoding lengthens later estimates and increased attention to time during reproduction shortens them (Macar et al., 1994; Penney et al., 2000). Thus, increased attention to time generates the same pattern of results as increased clock speed. This makes it difficult to separate clock speed changes from changes in attention allocation when working with processes that can affect both mechanisms, such as emotions. For example, rather than interpret their results as a clock speed effect, Angrilli et al. (1997) proposed that the longer estimates of positive than negative images when arousal was low might be caused by the negative images distracting attention away from timing during encoding, leading to shortened estimates.

Lejeune (1998) suggested an additional role of attention in time perception. Rather than attention affecting the accumulation of pulses, attention might affect the latency of the switch that allows pulses to enter the accumulator. An effect of attention on switch latency is distinguishable from an effect on the allocation of attention to temporal information. If a condition continuously alters attention allocation towards time, the distortions in timing will be proportional to the cue duration (e.g., a 10% effect on pulse accumulation will result in a 10% change in subjective duration for all intervals — Droit-Volet et al., 2004; Efron et al., 2006). In contrast, if switch latency were altered, this would affect all target durations by the same absolute amount (Brown et al., 2007; Lejeune, 1998).

The purpose of the current experiments was to further explore the impact of emotional valence and arousal on temporal information processing. Since changes in clock speed or attention allocation have different behavioral effects depending on whether they are manipulated during encoding or reproduction, we manipulated emotional content during both stages of the timing task. In Experiment 1, we chose photo sets in which arousal level was fixed and focused on the effects of valence (positive, negative, and neutral) as a within subjects factor. In Experiment 2, we manipulated levels of arousal (low, moderate, and high) as a within subjects factor and included valence as a between subjects factor (positive and negative).

1.1. Experiment 1

In Experiment 1 emotional stimuli were presented during both the encoding and reproduction phases. Consequently, the duration of estimates will arise from an interaction of the effect of valence during encoding with the effect of valence during reproduction. If these effects are equal at encoding and reproduction, then trials in which the valence is consistent across phases might be expected to show no effect of valence because the effect of altered processing during encoding would be exactly offset by an equal effect in the opposite direction during reproduction. If positive and negative cues have opposite effects on temporal processing then trials on which there is mismatch in valence would be expected to produce exaggerated effects on estimates relative to trials in which the images were neutral during either encoding or reproduction. As a result of these predictions we designed the experiment to be able to detect the interaction of specific encoding valences (positive, neutral or negative) with the specific valences at reproduction. Based on the Angrilli et al. (1997) result, we anticipated that positive stimuli during encoding would be estimated as longer than negative and neutral stimuli, since we used only moderately arousing images. This is anticipated based on the ideas that the positive stimuli either increase clock speed or attention to time and/or negative stimuli reduce clock speed or attention to time. Since encoding and retrieval valences might interact to attenuate or exaggerate effects on estimates, we also included trials with neutral stimuli so we could assess independent effects of valence on encoding and/or reproduction retrieval. Additionally, since there is evidence that sub-second and supra-second intervals might be processed in different ways, with supra-second intervals requiring more cognitive resources, (Rammsayer & Troche, 2014) we studied the impact of emotions on timing in both ranges.

2. Method

2.1. Participants

Fifty-seven college students (50 female, seven male) were recruited from the Barnard College subject pool and participated for course credit. All subjects gave informed consent in accordance with the IRB of Barnard College. Their mean age was 19.02 (18.87 for females, 20.00 for males).

2.2. Materials

Experimental events were presented using the psychophysical toolbox (Brainard, 1997; Pelli, 1997) compiled into a Matlab[®] (2007a) executable program presented on Microsoft XP[®] OS PCs. Responses were recorded by keypress on a standard keyboard. Photographic images from the International Affective Picture System (IAPS; Lang et al., 2008) were displayed as 21 × 21 cm squares in the center of the screen for the target duration.

We created three valence category sets of 72 photos each: Positive (valence: 5.75–9; arousal: 3.7–5), Negative (valence: 1–4.5; arousal: 3.7–5), and Neutral (valence: 4.5–5.5; arousal: 1.5–3.7) using the ratings provided by IAPS. Positive photos contained images of baby animals, people enjoying themselves, and food. Negative photos contained images of people in misery, aggressive animals, images of snakes and spiders, and weapons. Neutral photos mainly consisted of images of household objects, but also included images of inactive

people. Subjects viewed a unique image for each phase of each trial and images were only presented twice to minimize changes in emotional states or temporal estimates due to repeatedly viewing the same stimulus (Bradley & Lang, 2007a; Ono & Kawahara, 2005).

2.3. Procedure

The experimental session began with detailed instructions informing participants of the nature of the task. A trial began with the presentation of an image in the center of the screen that remained for one of two target durations, 0.8 s or 3.5 s. The image disappeared when the target duration elapsed and an inter-stimulus interval randomly chosen between 1 and 3 s was followed by the appearance of a second image. Subjects were required to press the space bar when the second image had been on the screen for the same amount of time as the first. The amount of time from image onset until the subjects pressed space bar was recorded by the computer with ms precision. An inter-trial interval of random duration between 3 and 5 s separated trials (Fig. 1). Participants were told not to count.

The experiment contained three within-subject factors: the valence level during encoding, or encoding valence (positive, negative, neutral), the valence level during reproduction or reproduction valence (positive, negative, neutral), and the target time (0.8 s, 3.5 s). There were six trials for each of the 18 conditions, which were presented in random order for each participant. Photos from each of the three categories were randomly divided in half; one half was presented during the encoding and the other half was presented during the reproduction. This meant that every participant viewed a different set of images in encoding and reproduction thus eliminating any systematic impact a particular image may have had on each phase of the task. The same condition was not presented more than three times in a row. After being presented with the image during reproduction, subjective ratings of this image were collected using the rating method provided with IAPS, the Self-Assessment Manikin (SAM). Subjects rated how happy/sad they felt and how aroused they felt using the illustrations of a cartoon person (Fig. 2). Participants were required to press a number between 1 and 9, where 1 represented the minimum (sad, least arousing) and 9 the maximum (happy, most arousing), with 5 being the neutral choice. Each scale was measured separately.

As a check to be sure that participants were paying attention to the content of the images, there were ten trials intermixed throughout the experiment in which subjects were asked a yes/no question about the specific content of the image after it was presented during reproduction. In these trials, subjects did not rate the image on scales of valence or arousal, but were required to respond by pressing the 'y' key for yes or the 'n' key for no. There were four additional trials in which the yes/no question occurred directly after the encoding. In these trials, there was no reproduction phase and estimates of time were not measured. There was a total of 112 trials, which took participants between 30 to 45 min to complete.

2.4. Data Analysis

Estimates were averaged for each condition for each participant. If participants answered two or more yes/no questions incorrectly they were removed from analysis. None of the participants were removed from this experiment. Data points that fell beyond two standard deviations of the mean for each condition for each subject were removed on the assumption

that due to the length of the experiment subjects may have been distracted at some point and estimates larger than two standard deviations from the mean did not represent a valid estimate of time. In total 0.49% of the data were removed from the analysis. All reported results are from this trimmed data set. Mean estimates represent subjects' temporal accuracy. Variability (precision) of temporal estimates was assessed with the coefficient of variation (CV), which was computed by dividing the standard deviation by the mean of each condition for each subject.

In order to assess whether changes caused by the emotional stimuli were caused by attention allocation (or clock speed) or switch latency we subtracted the average estimates for the neutral image conditions from the average estimates for the positive and negative image conditions and divided the difference by the neutral image average, yielding a proportion by which the valenced estimates deviated from estimates of the neutral cue in each condition. We refer to this measure as proportional error and calculated it for each subject. A positive proportional error reflects overestimation with respect to neutral estimates and a negative proportional error is underestimation.

We also computed averages and standard deviations of the arousal and valence ratings for each photograph across all subjects. Since subjects were asked to rate only a subset of photos, not all subjects rated all photos. The ratings were used to verify that our subjects' ratings were consistent with the IAPS ratings.

3. Results

In order to detect the interactions of specific encoding valences with specific reproduction valences, individuals' means were submitted to a 3 (encoding valence: positive, negative, neutral) \times 3 (reproduction valence: positive, negative, neutral) \times 2 (target time) repeated measures ANOVA. There was a main effect of target time. As would be expected estimates of 3.5 s were greater than 0.8 s, $F(1, 56) = 579.33, p < 0.001$. There was a main effect of the encoding valence, $F(2, 112) = 9.69, p < 0.001$. Estimates provided when encoding times while viewing the positive and negative images were not significantly different from each other, but they were significantly longer than estimates of the neutral images (Positive, Negative: $F(1, 56) < 1$; Positive, Neutral: $F(1, 56) = 14.98, p < 0.001$; Negative, Neutral: $F(1, 56) = 15.47, p < 0.001$). There was also a main effect of the reproduction valence, $F(2, 112) = 5.39, p < 0.01$. Again, estimates when reproducing times in the presence of positive and negative images did not differ significantly, but they were significantly longer than estimates of the neutral images (Positive, Negative: $F(1, 56) < 1$; Positive, Neutral: $F(1, 56) = 7.97, p < 0.01$; Negative, Neutral: $F(1, 56) = 9.30, p < 0.01$). There were no significant interactions (see Fig. 3).

CVs were also submitted to a 3 (encoding valence: positive, negative, neutral) \times 3 (reproduction valence: positive, negative, neutral) \times 2 (target time) repeated measures ANOVA. CVs were larger for the 0.8 s target than for 3.5 s target, $F(1, 56) = 103.93, p < 0.001$. There were no other significant main effects or interactions.

Proportional errors (deviations from the neutral estimates) were analyzed with a 2 (valence: positive, negative) \times 2 (phase: encoding, reproduction) \times 2 (target duration) repeated measures ANOVA and there were no significant effects. This is consistent with the hypothesis that both positive and negative stimuli changed estimates in proportion to the interval being timed.

Our participants provided ratings of images presented during the reproduction phase of some trials. Before comparing our participants' ratings with those of IAPS, we checked whether ratings differed based on the target time. Ratings of arousal and valence were analyzed with separate 3 (valence: positive, negative, neutral) by 2 (target time) repeated measures ANOVAs. There were no effects of target time on either the valence or arousal ratings (valence ratings: $F(1, 68) < 1$; arousal ratings: $F(1, 68) = 2.17, p > 0.14$). Therefore valence ratings and arousal ratings were each collapsed over target duration. Both the valence and arousal ratings provided by our subjects correlated positively with the valence and arousal ratings provided by IAPS (arousal: $r = 0.88, p < 0.001$; valence: $r = 0.49, p < 0.001$).

4. Discussion

In Experiment 1 we assessed the effect of valence on temporal information processing. The results showed that there were no differences in temporal estimates when viewing positive and negative images but both were overestimated in comparison to estimates of neutral images (Fig. 3). The positive and negative images had a higher level of arousal than the neutral images. Thus the overestimation of the positive and negative images shown during encoding is consistent with an increase in clock speed due to an increase in arousal (Fetterman & Killeen, 1995; Meck, 1996; Penton-Voak et al., 1996; Treisman et al., 1990; Wearden & Penton-Voak, 1995). Conversely, increased clock speed during reproduction should lead to shorter estimates of time, which our data did not show. Instead, estimates of positive and negative images during reproduction were also longer than estimates of neutral images. Consequently, consideration of the effects of valence during both phases of the experiment leads one to inconsistent conclusions. The overestimation that occurred when viewing emotional stimuli during encoding would suggest an increase in clock speed or attention allocated to time. In contrast, the overestimation of emotional stimuli during the reproduction is consistent with a decrease in clock speed or attention to time. We return to this conundrum in the general discussion.

Attention to time can operate through two different processes: sustained attention or switch latency. These two attentional mechanisms can be differentiated behaviorally. Changes in estimates due to switch latency would create an additive difference at all target durations. Thus, for shorter targets, the change in estimates would be proportionally larger than for longer targets because the switch latency would be constant across target duration. Our analysis shows that proportional error was constant across durations and valence conditions demonstrating that the increase in estimates when viewing positive and negative images was not an additive change. This suggests that attentional focus, rather than switch latency, is influenced by emotional stimuli. However, since the pattern of results predicted by alterations in clock speed is the same as that predicted by alterations in attentional focus, this

analysis does not help differentiate the impact emotional stimuli have on these mechanisms. We address this in Experiment 2.

Another prediction of the SET clock model is that estimates will exhibit the scalar property. As estimates increase, the standard deviation of estimates will increase linearly with the mean, yielding a constant CV. Our results showed that the CV for the 0.8 s target was larger than the CV for the 3.5 s target which violates the scalar property. There were no other significant effects on CV suggesting that the difference in precision across target durations was due to the target duration rather than due to the emotional content of the stimuli. Prior studies have also found that estimates of millisecond durations are less precise than estimates of durations in the seconds range (Buhusi & Meck, 2005; Lewis & Miall, 2003). It seems likely that there is a lower limit on the latency with which a participant could respond in the reproduction. Perhaps this latency contributes more to variability on the short duration trials than long ones resulting in a violation of the scalar property across these two target times.

4.1. Experiment 2

Since the positive and negative images in Experiment 1 evoked a higher level of arousal than the neutral images, differing arousal levels were confounded with valence. We designed Experiment 2 to specifically address this issue. Two groups of subjects were exposed to stimuli of either positive or negative valence. Within each group, subjects were exposed to stimuli with three levels of arousal (low, moderate, high). This design allowed us to investigate the effects of arousal level, as well as the interaction between valence and arousal. We thought it possible that clock speed was affected by arousal levels, whereas attentional mechanisms were affected by emotional valence. By combining these manipulations we hoped that the pattern of results might allow us to differentiate the impact of these two aspects of emotional stimuli on clock speed and attention.

5. Method

5.1. Participants

Eighty-five college students were recruited from the Barnard College subject pool and participated for course credit. All subjects gave informed consent in accordance with Barnard College's IRB. Students were placed randomly in either the positive or negative valence conditions. Subjects that answered two or more yes/no questions about stimulus content incorrectly were removed from analysis. This resulted in the removal of ten subjects (three from the negative and seven from the positive valence conditions). Two additional subjects were removed (from the negative valence condition) because their estimates were the same for both target durations suggesting that they did not complete the task as directed. For analysis the negative valence condition had 37 subjects (35 female, two male; average age: 19.49, female: 19.47, male: 20) and the positive valence condition had 36 subjects (33 female, three male; average age: 19.50, female: 19.30, male: 21.67).

5.2. Materials

Experimental events were presented and recorded as in Experiment 1. Subjects were presented with stimuli that differed in arousal levels (low, moderate, high). The neutral images from Experiment 1 were categorized as low arousal and the positive and negative images used in Experiment 1 were categorized as moderate for Experiment 2. A third category of high arousal level was constructed for each level of valence (positive and negative) from IAPS. Seventy-two images were selected as positive high arousal (valence: 5–9; arousal: 5–9) and 72 were selected as negative high arousal (valence: 1–4.5; arousal: 5–9). Positive high arousal photos contained images of exciting sporting events (sky-diving, rock climbing), money, and erotic images. Negative high arousal photos contained images of mutilated bodies, torture, and destruction of inanimate objects. Since the majority of our participants in the first experiment were female, we used the IAPS ratings provided for females to choose the high arousal images because images rated as positive high arousal differed between men and women, specifically relating to erotic images.

5.3. Procedure

The procedure was the same as Experiment 1 except for the additional manipulation of arousal. The three within-subjects factors were: arousal level at encoding, or encoding arousal (high, moderate, low arousal), arousal level at reproduction or reproduction arousal (high, moderate, low arousal), and target time (0.8 s, 3.5 s). Valence was manipulated as a two-level (positive, negative) between-subjects factor.

5.4. Data Analysis

Means and CVs were calculated, trimmed, and analyzed identically to Experiment 1. Removing data points that were larger than two standard deviations from the mean eliminated 0.46% of the data. The proportional error was calculated as in Experiment 1 except that low arousal estimates replaced neutral valence estimates ((estimate — low arousal estimate) / low arousal estimate). Ratings for the viewed photographs were also calculated and analyzed as in Experiment 1 in order to verify that our subjects perceived the IAPS images similarly to the normative ratings provided.

6. Results

Mean estimates were analyzed with a 2 (valence: positive, negative) \times 3 (encoding arousal: low, moderate, high) \times 3 (reproduction arousal: low, moderate, high) \times 2 (target time) mixed measures ANOVA with the first variable as a between subjects factor. As expected there was a main effect of target time. Estimates of 3.5 s were longer than estimates of 0.8 s, $F(1, 71) = 863.81$, $p < 0.001$. As in Experiment 1, there was no main effect of valence and estimates increased with increases in encoding arousal level, $F(2, 142) = 6.22$, $p < 0.01$ (dark bars in Fig. 4).

The main effect of reproduction arousal level was not significant (light bars Fig. 4) but there were two significant interactions; reproduction arousal by valence, $F(2, 142) = 4.63$, $p < 0.05$ and reproduction arousal by target time, $F(2, 142) = 8.18$, $p < 0.001$. The three-way interaction of encoding arousal level, reproduction arousal level, and valence failed to reach

significance, $F(2, 142) < 1$. Looking more closely at the reproduction arousal by valence interaction, we performed separate one-way repeated measures ANOVAs on the positive and negative subgroups. In the negative valence condition, there was a main effect of reproduction arousal level, $F(2, 72) = 6.12, p < 0.01$ (Fig. 5, light bars). We found that estimates for highly arousing negative images tended to be shorter than estimates for negative images that were rated as low or moderately arousing, which did not differ from each other (High, Moderate: $F(1, 36) = 8.55, p < 0.01$; High, Low: $F(1, 36) = 3.12, p < 0.09$; Moderate, Low: $F(1, 36) = 1.76, p < 0.20$). Though there was a tendency toward longer estimates with increasing reproduction arousal for positive images (Fig. 5, dark bars) the separate ANOVA showed no significant effects.

As noted above there was a significant reproduction arousal by target time interaction. We analyzed the interaction by examining the effect of arousal during reproduction separately for each target time with one-way repeated measures ANOVAs. Looking first at the 0.8 s condition, estimates increased as arousal increased resulting in a significant effect of reproduction arousal level, $F(2, 142) = 4.001, p < 0.05$. The analysis of only the 3.5 s target, also showed a significant effect of reproduction arousal, $F(2, 142) = 4.540, p < 0.05$. Here though the significant effect arose because estimates for the high arousal condition were smaller than estimates for the moderate and low arousal conditions (High, Moderate: $F(1, 71) = 7.944, p < 0.01$; High, Low: $F(1, 71) = 3.970, p = 0.05$; Moderate, Low: $F(1, 71) < 1$; see Fig. 6).

CVs were analyzed with a 2 (valence: positive, negative) \times 3 (encoding arousal: low, moderate, high) \times 3 (reproduction arousal: low, moderate, high) \times 2 (target time) mixed measures ANOVA with the first variable as a between subjects factor. There was a main effect of target duration, $F(1, 71) = 88.070, p < 0.001$. As in Experiment 1, the CV was larger for the 0.8 s target than for the 3.5 s target. There was also a main effect of reproduction arousal level, $F(2, 142) = 3.775, p < 0.05$. CVs increased with increasing arousal levels indicating that the variability increased disproportionately to the increase in mean estimates as arousal levels increased. This could be largely driven by the low mean estimates in the high arousal negative condition rather than by a change in variability. There were no other main effects or interactions.

Proportional errors (relative to the low arousal condition) were submitted to a 2 (arousal: high, moderate) \times 2 (phase: encoding, reproduction) \times 2 (target time) \times 2 (valence: positive, negative) mixed measures ANOVA with valence as a between subjects factor. There was a main effect of target time, $F(1, 71) = 8.351, p < 0.01$. The proportional error for 0.8 s was significantly larger than the proportional error for 3.5 s demonstrating that there was a larger relative change in estimates for 0.8 s than for estimates of 3.5 s. There was also a target time by phase interaction, $F(1, 71) = 4.659, p < 0.05$. As in Experiment 1, the duration of the target during encoding did not affect proportional error, $F(1, 71) < 1$. For the reproduction phase there was a main effect of target time, with a significantly larger proportional error for 0.8 s, $F(1, 71) = 15.347, p < 0.001$. Our analysis also showed a target time by arousal interaction, $F(1, 71) = 4.907, p < 0.05$. At the moderate level of arousal there were no significant effects of target time (main effect: $F(1, 71) < 1$), but at the high level of arousal

there was a main effect of target time, $F(1, 71) = 10.361, p < 0.01$. More highly arousing images had a greater proportional error than moderately arousing ones.

Before comparing our participants' ratings with those of IAPS, we again checked whether the ratings differed based on the target time. Ratings of arousal and valence were submitted to separate 2 (valence condition) $\times 2$ (target time) $\times 3$ (arousal: low, moderate, high) ANOVAs. For arousal ratings, there were no significant effects of target time; therefore arousal ratings were collapsed across the target times, $F(1, 136) < 1$. The arousal ratings provided by our subjects positively correlated with ratings provided by IAPS for both positive and negative valence conditions (Negative: $r = 0.720, p < 0.001$; Positive: $r = 0.706, p < 0.001$). For valence ratings, there was a target time by valence interaction, $F(1, 136) = 3.998, p < 0.05$. Thus, valence ratings were not collapsed across target time for the correlation analysis. The valence ratings provided by our subjects positively correlated with the ratings provided by IAPS at both levels of target duration for both positive and negative valence conditions (0.8 s Negative: $r = 0.612, p < 0.001$; 0.8 s Positive: $r = 0.654, p < 0.001$; 3.5 s Negative: $r = 0.673, p < 0.001$; 3.5 s Positive: $r = 0.658, p < 0.001$).

7. Discussion

The goal of Experiment 2 was to assess the effects of emotional arousal and valence on temporal estimation and we hoped to be able to differentiate whether the effects were mediated by changes in clock speed and/or attention. Based on the results of Experiment 1, we expected that estimates would increase with increasing arousal level during encoding and indeed found this in Experiment 2. As in Experiment 1, though the effect of encoding arousal on estimates was consistent with a clock speed explanation, the effect of arousal level during reproduction was not. Though estimates increased with increasing arousal during encoding they did not consistently decrease when arousal levels increased during reproduction. Increasing arousal during reproduction tended to increase rather than decrease estimates. Specifically, during reproduction estimates of both positive and negative moderately arousing images as well as positive high arousal images tended to be longer than estimates of images with low arousal (neutral images). Only in the case of the negative high arousal did estimates decrease, as would be predicted by a clock speed increase during reproduction. Therefore, our results suggest that increases in clock speed caused by increases in arousal affect temporal perception during the encoding, but clock speed increases are not a major contributor to the effects of arousal on temporal perception during reproduction in emotional contexts.

Additionally, increasing arousal during the reproduction generated a different pattern of estimates for each target time. Estimates of 0.8 s tended to increase with increasing arousal level. However, estimates of 3.5 s were highest for the moderate arousal images. The increase in estimates from low arousal (neutral images) to moderate arousal (positive and negative images) across both target times replicates Experiment 1. However, we found that estimates of 3.5 s shortened with the high arousal condition added in Experiment 2. This could imply that the highly arousing state caused the clock speed increase to override other mechanisms affecting temporal perception during reproduction at lower arousal levels, but

this explanation does not clarify why the lower level of arousals are not strongly affected by clock speed or why this effect is only apparent for the longer target time.

We were also interested in differentiating how emotional stimuli might affect attention to time. Again, switch latency would be demonstrated by an additive change across targets, whereas attention allocation would be illustrated by a proportional change across targets. Our analysis of the proportional errors demonstrated no differences in the proportional error across target durations as a result of varying arousal during encoding. This replicates the results of Experiment 1 and suggests that attention allocation is as good an explanation of the effects of encoding arousal as a clock speed explanation.

However, the results for the reproduction were not as simple. As in Experiment 1, there were no differences in the proportional errors at the moderate arousal level. This, again, suggests that attention allocation might be the underlying mechanism if it worked in the opposite direction that it worked during encoding. However, proportional errors were larger for the 0.8 s target when the images were highly arousing consistent with an attention switch effect in only that condition.

In assessing the scalar property of Experiment 2, we expected the CVs to differ across target times as in Experiment 1. Our analysis demonstrates this, which we again attribute to the difference in precision of millisecond durations and second durations, perhaps mediated by a disproportionate contribution of motor latency variability to estimates at the short duration. CVs also increased with increasing arousal level when emotional stimuli were present during the reproduction. Increasing arousal levels caused estimates to vary more as estimates increased. Yet, this only occurred when emotional stimuli were presented during reproduction. The arousal level of stimuli during the encoding did not affect variability. This pattern suggests that in addition to whatever variability arises from memory storage during encoding there is additional factor modulated by arousal that occurs at the time of reproduction. Again, we suspect that this effect on CV is largely the result of shortened mean estimates in the highly arousing negative condition rather than due to change in variability.

8. General Discussion

Previous research found that temporal estimates increased with increasing arousal levels when emotional stimuli were presented during encoding and decreased with increasing arousal during duration reproduction (Droit-Volet et al., 2004; Langer et al., 1961; Watts & Sharrock, 1984). Studies that included stimuli of different valence either did not show effects of valence (Droit-Volet et al., 2004), showed effects of valence without accounting for arousal level (Noulhiane et al., 2007) or showed that arousal affected time estimates differently as a function of valence (Angrilli et al., 1997).

Our design was most similar to that of Angrilli et al. (1997) but we did not replicate their results. Our results showed equivalent impact of arousal during the encoding across different target durations, whereas Angrilli et al. (1997) found little effect of arousal at target durations of 4 s and longer. The difference in the durations studied might be one factor that

contributed to the differences in our findings (Elbert et al., 1991). Another salient difference between the studies is that unlike the Angrilli et al. study our subjects viewed multiple images at each level of valence, arousal, and target duration, raising the possibility that differences might have arisen from differences in habituation to images across the studies.

Our results are most consistent with those of Droit-Volet et al. (2004) in that valence did not affect duration estimates of emotional images but estimates increased with increasing arousal when the emotional images were present during the encoding. Our task differs from theirs in many ways. They used facial expressions of anger, happiness, and sadness and they used a temporal bisection task. Also, their study did not explicitly assess differences in valence when arousal levels are matched (happiness is assumed to be less arousing than anger). Nonetheless, images of angry faces, considered to be the most arousing emotion of their set, were estimated as longer than images of sad faces. They attribute this increase in estimates to increases in clock speed mediated by increasing arousal during encoding (Fetterman & Killeen, 1995; Meck, 1996; Penton-Voak et al., 1996; Treisman et al., 1990; Wearden & Penton-Voak, 1995).

To reiterate the SET framework, an increased clock speed would cause more pulses to accumulate in the accumulator during encoding. When clock speed returns to a normal rate and the duration is estimated, the estimate will be larger than the actual duration because it will take longer for the accumulating duration to match the remembered duration. When clock speed is normal during the encoding, but sped up during the estimation phase, estimates will be shorter than the actual time. This is because it will take less time for the number of pulses stored in memory during encoding to accumulate when clock speed is increased. Though our data are consistent with the effects of arousal on clock speed during the encoding they are inconsistent with a clock speed effect during reproduction.

Overall, for the positive images shown during reproduction, estimates tended to increase with increasing arousal level. However, when negative emotional stimuli were presented during the reproduction, estimates were *shortest* for the high arousal images. The longer estimates with increasing arousal are consistent with an attentional competition effect during the reproduction. The task required attention to be paid to both time and the emotional content of stimuli. Emotional stimuli attract attention and emotionally salient details attain more focus than peripheral non-emotional details (Ochsner, 2000; Phelps, 2006). Consequently, presenting an emotionally arousing stimulus during reproduction may distract subjects from the dimension of time leading to overestimation during reproduction. Brown et al. (2007), using a similar procedure, found that rats' responses to fearful stimuli led to overestimations during reproduction and Aum et al. (2004) demonstrated similar effects when pigeons were presented with a positive food reward during production trials. Combined these results demonstrate that positive and negative stimuli may sometimes be overestimated during reproduction because they distract attention from the non-emotional details, including time.

For the bulk of our data emotional stimuli alter clock speed and attention but there may be a different influence of each process on encoding and reproduction. We suggest that clock speed and attention to time may be increased by arousal during the encoding but that during

the reproduction the emotional content of images may actually distract attention from time. Participants may pay more attention to time during the encoding because they know they must learn the target time for later testing. Because they are paying attention to time, changes in clock speed due to arousal have a big impact on encoded durations. In contrast, during reproduction, participants are distracted by the emotional content of the images and do not direct full attention to time as they do during the encoding. Here more arousing content may also be more distracting. The occasional testing of subjects about the content of images could have contributed to this distraction. As a consequence of the decreased attention to time there would be a tendency toward overestimation during reproduction. Clock speed might still increase with arousal during this phase, but not enough to offset the decrease in attention allocation. Furthermore, the attentional effect on reproduction might have been particularly strong because the procedure of the current experiments only required subjects to learn two distinctive times. Subjects' estimates during the reproduction phase might have been guided by well-learned long-term memories of the two criterion times which might somehow make the reproductions particularly vulnerable to distraction.

The exception to the generalization that arousing images during reproduction increased estimates was that estimates of highly arousing negative images were shorter than estimates for positive or neutral images. Perhaps with the highly arousing negative images clock speed effects were so strong that they offset attentional effects leading to shorter reproductions. However, an alternative account of the short reproductions in this condition arises from the specifics of our estimation procedure. Because the reproduction procedure required the subjects to terminate the stimulus it is possible that subjects literally attempted to avoid viewing the highly arousing negative images by removing them from the screen prior to the elapsed duration. However, when free-viewing the images of IAPS, subjects view negative images for as long as positive ones and both are viewed for longer than neutral images (Lang, 1995). Only in free-viewing trials in which subjects were phobic of the image content did viewing times shorten (Bradley & Lang, 2007b). Thus we cannot be certain about the mechanism underlying the very brief reproductions in the presence of the highly arousing negative cues.

In conclusion, we return to the questions with which we started the paper. In fact, it appears that emotions can directly influence time perception. So whether a work of art induces strong positive or negative emotions the accompanying arousal will tend to alter the flow of time. Sometimes, the content that evokes the emotion will cause a strong enough distraction from attending to time that time is perceived to slow and perhaps, even stand still. It is in this complex interaction of perception, attention and memory that the flow of time is felt (Droit-Volet, 2013). For the artist who wishes to control the flow of time as part of their art we can only suggest that they become scientists and experiment with different degrees of arousal, distraction and drawing conscious attention to time in order to create the desired experience.

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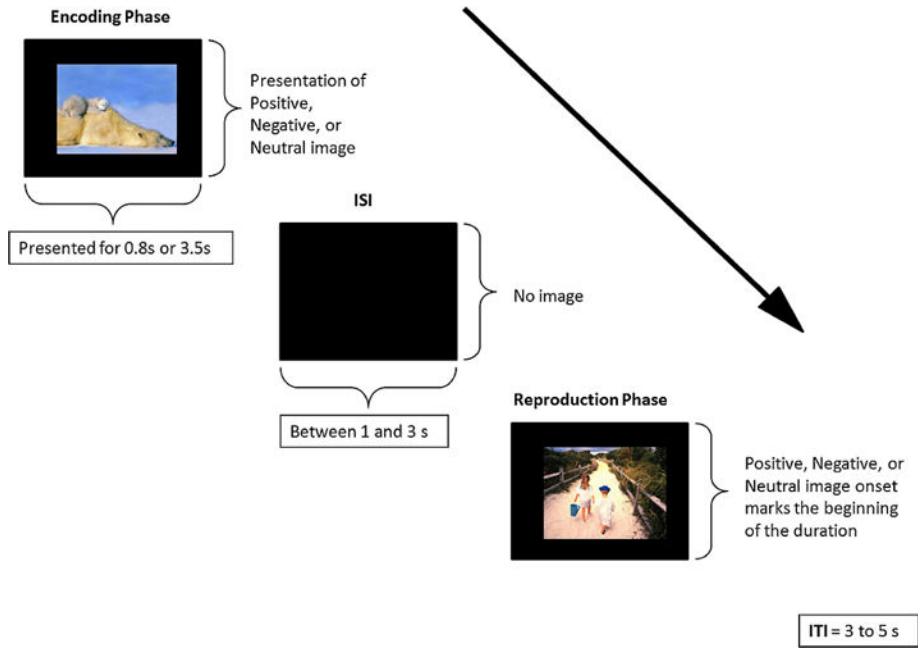


Figure 1. The events of each trial are depicted. During encoding, a positive, negative, or neutral IAPS image was presented for 0.8 or 3.5 s. A blank screen lasting between 1 and 3 s served as the inter-stimulus interval. Reproduction began with the onset of a positive, negative, or neutral image marking the beginning of the duration to be reproduced and ended with a keyboard press. This figure is published in color in the online version.

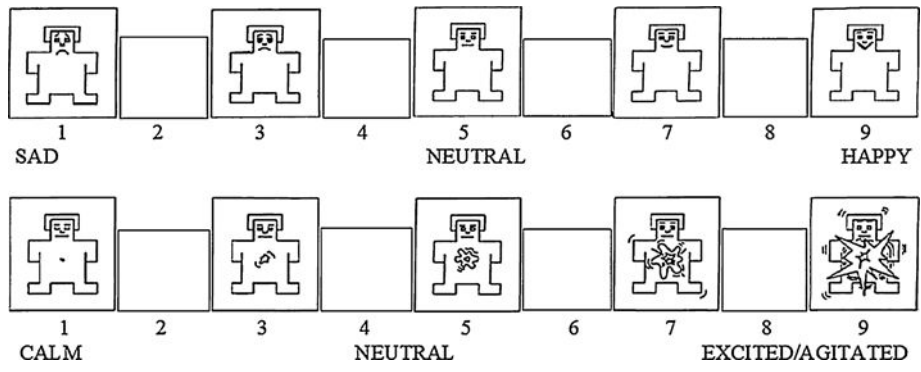


Figure 2. SAM (self-assessment manikin) presented to our subjects (with images borrowed from Lang et al., 2008). The first SAM is the scale for pleasantness and the second SAM is the scale for arousal.

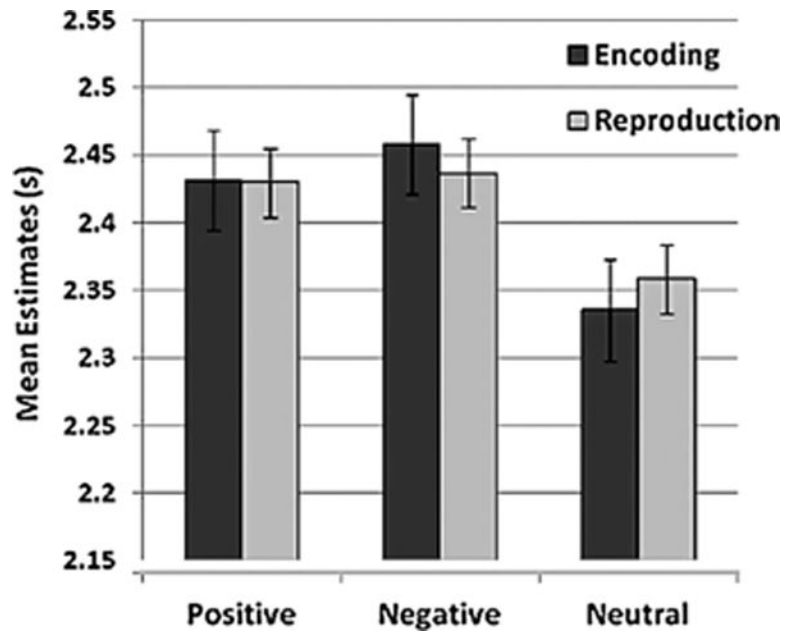


Figure 3.

In Experiment 1 estimates for the neutral images were lower than estimates for the negative or positive images in both the encoding and reproduction phases of the timing task. Estimates are collapsed over target time and error bars are standard error.

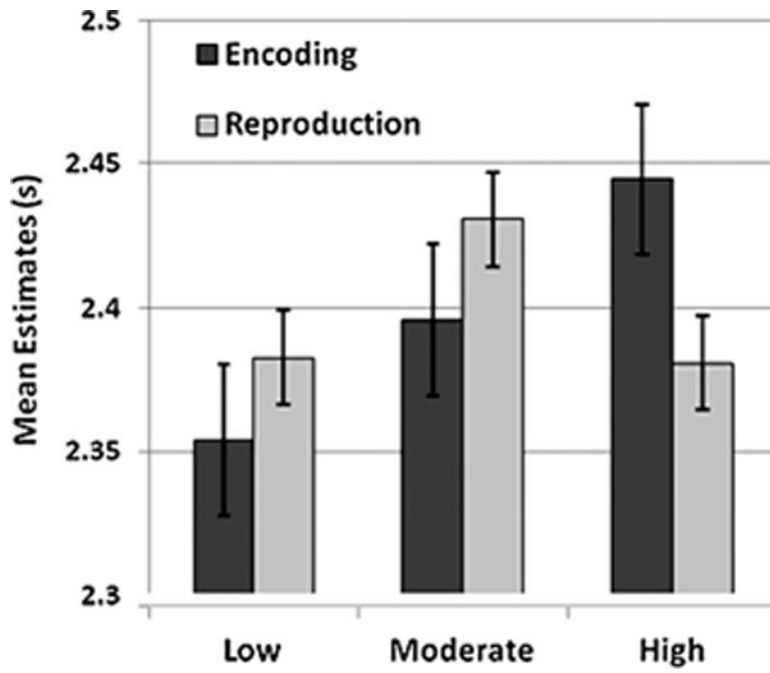


Figure 4. In Experiment 2, estimates increased with increasing arousal level. Estimates are collapsed over valence and target time. There was not a significant interaction between encoding arousal level and reproduction arousal level. Error bars are standard error.

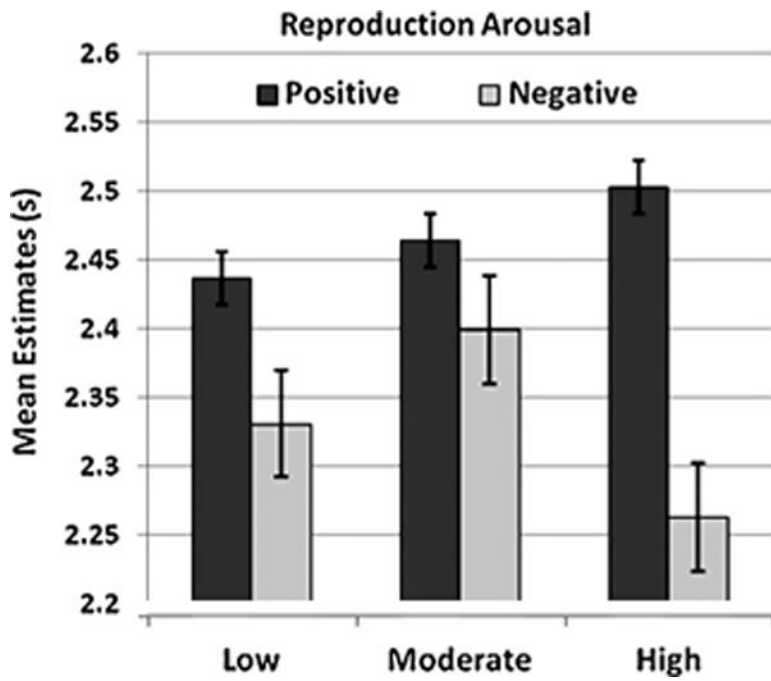


Figure 5. In the reproduction phase of Experiment 2, arousal level did not significantly affect estimates in the positive condition but estimates significantly decreased at the highest level of arousal in the negative condition. Estimates are collapsed over target time. Error bars are standard error.

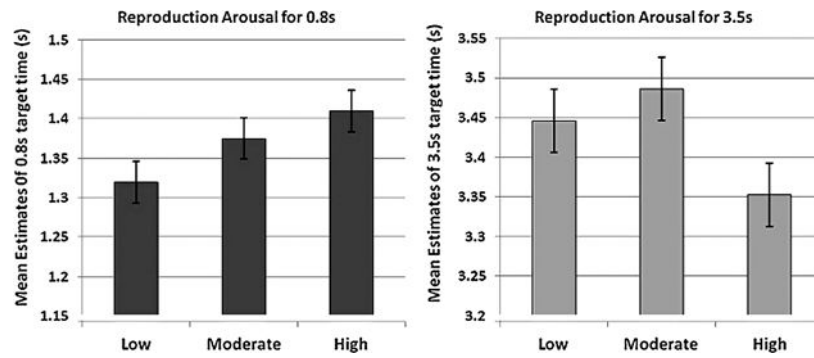


Figure 6. In the reproduction phase of Experiment 2, estimates of 0.8 s increased with increasing arousal level. However, estimates of 3.5 s decreased at the highest arousal level.