An absence of a relationship between overt attention and emotional distortions to time: an eye-movement study

Ruth S Ogden[1], Frederieke Turner[1] & Ralph Pawling[1]

[1]School of Psychology, Liverpool John Moores University, Liverpool, UK

Abstract

Emotional distortions to time are consistently reported in laboratory studies, however their underlying causes remain unclear. One suggestion is that emotion induced changes in attentional processes may contribute to emotional distortions to time. The current study tested this possibility by examining the relationship between eye-movement and perceptions of the duration of emotional events. Participants completed a verbal estimation task in which they estimated the duration of positively, negatively and neutrally valenced images from the International Affective Picture System images. Time to first fixation and dwell time were recorded throughout. The results showed no significant relationships between measures of eye-movement and measures of emotional distortion to time, despite the emotion manipulation successfully influencing the time before the participants first fixated on the to-be-timed stimulus. This suggests that for suprasecond intervals emotion induced changes in overt attention processing do not contribute towards emotional distortions to time.

Key words: time perception, emotion, attention, eye-tracking, arousal.

1. Introduction

A wealth of experimental evidence demonstrates that emotion distorts the perceived duration of events (see Lake, LeBar & Meck, 2016 and Lake, 2016 for recent reviews). The most commonly reported finding is that high arousal negatively valenced stimuli are perceived as lasting for subjectively longer than neutrally valenced stimuli of the same physical duration. This has been demonstrated in studies using a wide range of stimuli, including static images such as the IAPS (e.g. Gil & Droit-Volet, 2012), emotional facial expressions (e.g. Droit-Volet, Brunot, & Niedenthal, 2004), emotional sounds (e.g. Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007) and negatively valenced somatosensory stimulation such as pain (e.g. Fayolle, Gil, & Droit-Volet, 2015). Emotional distortions to time are also evident in clinical conditions, for example people with phobia over-estimate the presence of phobia triggers relative to non-phobics (Watts & Sharrock, 1984). The extent to which negatively valenced stimuli distort time appears to be determined by their arousal level, with high arousal negative stimuli producing greater lengthening's of duration than low arousal negatively valenced stimuli (see Gil & Droit-Volet, 2012 and Ogden et al., 2019). Indeed, there is some evidence to suggest that some low arousal negative stimuli e.g. sadness, may have little or no effect on perceived duration (e.g. Gil & Droit-Volet, 2012) whereas other negatively valenced stimuli e.g. rotten food, are perceived as lasting for less time than neutrally valenced food items (Gil, Rousset & Droit-Volet, 2009).

Whilst the duration of high arousal negatively valenced stimuli are consistently lengthened relative to neutral stimuli, the duration of positively valenced stimuli are often subjectively shortened. For example, positively valenced images are perceived as shorter than neutrally valenced ones (e.g. Smith, McIver, Di Nella & Crease, 2011) and happy music is perceived as shorter than neutral music (Droit-Volet, Bigand, Ramos & Bueno, 2010). Experiencing positive somatosensory stimulation, for example, pleasant touch, has also been shown to shorten the perceived duration of ongoing events (Ogden, Moore, Redfern & McGlone, 2015). However, the distorting effects of positive stimuli are inconsistent; the perceived duration of positively valenced facial expressions are often overestimated relative to neutral ones (e.g. Droit-Volet, 2005). Furthermore, there is also evidence positively valenced IAPS images have no effect on perceived duration (van Hedger, Necka, Barakzai & Norman, 2017) even when high and low arousal images are judged separately (Ogden, Henderson, McGlone & Richter, 2019).

To date, emotional distortions to time have typically been explained by the arousal theory which suggests that changes in physiological arousal cause distortions to the perceived duration of events (see Droit-Volet & Meck, 2007 and Lake, 2016 for review). Here, increases in physiological arousal are associated with the subjective lengthening of duration (van Hedger et al., 2017; Piovesan et al., 2019; Ogden et al., 2019) whereas interventions which reduced physiological arousal (from baseline levels) are associated with subjective shortenings of perceived duration (see Ogden et al., 2019 for example). However, it has also been suggested that emotional modulation of attentional processes may contribute towards emotional distortions to time (e.g. Angrilli, Cherubini, Pavese & Manfredini, 1997; Burle & Cassini, 2001; Lake, 2016; Ogden, 2013; Wittmann, 2009).

The framework of Scalar Expectancy Theory (SET: Gibbon, Church & Meck, 1984) proposes that time is processed by a pacemaker-accumulator clock. The pacemaker is constantly emitting output. To enable timing, at the start of a to-be-timed-event the switch between the pacemaker and the accumulator closes enabling the transfer of output from the pacemaker to the accumulator. At the end of the to-be-timed-event the switch opens and accumulation ceases. The amount of accumulated output forms the representation of duration, with more output equating to more time.

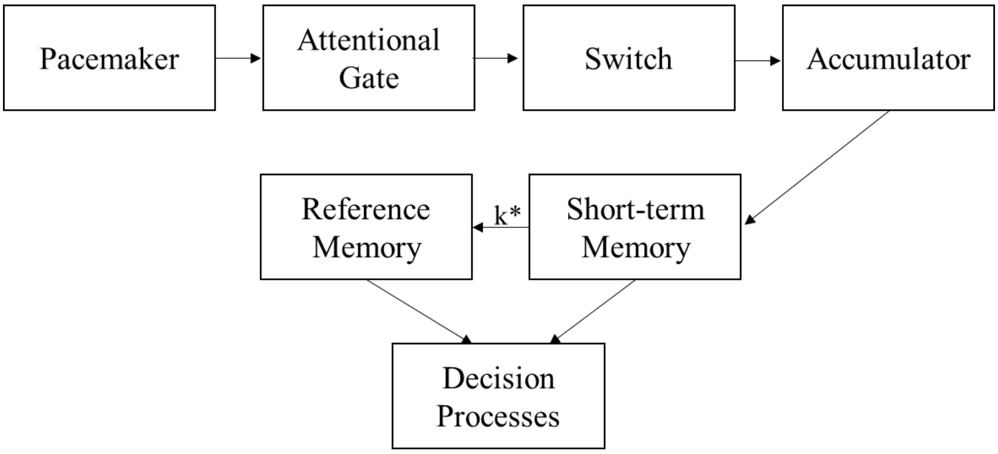
In its original form, SET did not describe attentional processing during timing. However, its application to human timing led to the suggestion that the switch may represent attention to the to-be-timed stimulus. Here, delays in attending to a to-be-timed event would increase switch closure latency, resulting in less accumulation and a shortening of perceived duration. Later models based on SET, for example, the Attention Gate Model (AGM (Figure 1) (Block & Zakay, 1996; Zakay & Block, 1995 1996), have explicitly incorporated attention into the timing process. The AGM identifies two core ways in which attention can affect time perception; *orientation latency effects* which affect switch operation (selective attention) and *sustained attention effects* which affect gate operation (see Fernandes & Garcia-Marques, 2020 and Matthews & Meck, 2016 for recent reviews).

The AGM proposes that in addition to the switch, there is an attentional gate which can open and close *throughout* the to-be-timed-event. The extent to which the gate opens and closes during a to-be-timed event is determined by the amount of attention paid to time. When attention to time is high, the gate remains closed and output from the pacemaker is transferred to the accumulator without loss. As attention to time decreases the gate opens, resulting in a reduced rate of transfer from the pacemaker to the accumulator and a shorter perception of duration. This gate could therefore be considered a form of *sustained attention to time.* Sustained attention effects, such as those described in the AGM, are multiplicative in that the degree of underestimation increases with increasing stimulus duration. In time estimation tasks, sustained attention effects can be inferred from differences in the slope of the estimation functions. Greater attention to time is therefore associated with a steeper slope function whereas reduced attention to time is associated with a flatter slope function (see Buhusi & Meck, 2009, Coull, Vidal, Nazarian, & Macar, 2004 for discussion).

In addition to the gate, the AGM also proposed an attentional role for the switch in determining stimulus meaning, with the detection of a relevant stimulus prompting the closure of the switch and the commencement of accumulation. The switch in the AGM model operates in a similar manner to that proposed in SET. Delays in attending to the start of a to-be-timed-event, perhaps due to distraction or other cognitive demands, will increase the latency with which the switch closes (Lejeune, 1998). This results in a delay to the process of accumulation, resulting in less accumulation and a shorter perception of duration. Conversely, cues which increase the speed at which a stimulus is detected reduce switch closure latency resulting in an increase in perceived duration. Critically, unlike the gate, the opening and closing of the switch is proposed to be an all or nothing event; i.e. it is either fully open or fully closed. However the degree of latency of switch opening and closure can vary. These types of effects can be termed attention *orientation latency effects* and reflect the effect of selective attention on time estimation. Latency effects are generally considered to be additive in that, within a given task, regardless of stimulus duration the effect of switch latency remains the same. In duration estimation tasks they are therefore inferred from differences in the intercept of the estimation functions with increases in orientation latency decreasing intercept values and decreases in orientation latency increasing intercept values (see Wearden, O'Rourke, Matchwick, Min, & Maeers, 2010 and Williams and Meck, 2016 for discussion).

Evidence for orientation latency effects in timing can be found in endogenous and exogenous cueing tasks. For example, Mattes and Ulrich (1998) observed that duration estimates for stimuli preceded by valid endogenous spatial and modality cues increased proportionally with the validity of the cue. An expansion of subjective duration is also observed when to-be-timed stimuli are exogenously cued (e.g. Seifried & Ulrich, 2011). Together, these and other similar studies demonstrate that selective attention to non-temporal stimulus properties i.e. location and modality can influence duration processing, supporting the role of the switch in timing. However, although lengthening's of the perceived duration of valid endogenously cued stimuli were also observed by Enns, Brehaut & Shore (1999), they suggested that this effect could not simply be explained by faster detection of stimulus onset suggesting that multiple attentional processes can influence perceived duration. Although the AGM makes specific predictions for the switch and the gate, the precise formulation of the switch and gate remain debated (see Lejeune 1998, 2000 and Zakay 2000 for discussion). Indeed, some papers simply describe the attentional gate as a form of switch, rather than an addition to the switch.

Figure 1: A modified schematic of the AGM



Attention is known to be captured by emotional stimuli, which often distract from ongoing tasks more readily than neutral stimuli (see Pourtois, Schettino & Vuilleumier, 2013 and Vuilleumier, 2005 for review). This capture is greatest and most consistently demonstrated for negatively valenced stimuli. For example, in the emotional Stroop task colour naming is slowed to a greater extent for emotional than neutral words (e.g. Williams, Matthews & MacLeod, 1996). Similarly, in visual search tasks emotional targets are identified more quickly than neutral ones (Nummenmaa, Hyona, & Calvo, 2006) and angry or threatening faces are identified more quickly that neutral of happy ones in a crowd scene (Bradley et al., 1997; Hansen & Hansen, 1988). Finally, in cueing tasks emotional invalid cues impose a high cost on attentional orientation than neutral invalid cues (Koster, Crombez, Van Damme, Verschuere & De Houwer, 2004). Collectively, these findings (and others) suggest that emotional stimuli are preferentially attended to in the environment, possibly via a neural system specialised for such a purpose (see Pourtois et al., 2013 and Vuilleumier, 2005 for review). Given these effects of emotion on attentional processes, it is plausible that emotional modulation of attention may also act as a mechanism for emotional distortions to time perception. More rapid orientation to emotional stimuli may reduce orientation latency resulting in faster switch closure and longer perceptions of duration. Predictions for the effect of the preferentially processing of emotional stimuli over neutral (sustained attention) are however more complex. One obvious possibility is that enhanced processing of emotional components of a to-be-timed stimulus may distract from the timing of the stimulus, leading to greater opening of the attentional gate and shorter perceptions of duration. Alternatively, however, it is possible that preferential sustained attention for emotional stimuli over neutral stimuli may contribute towards the lengthening effects observed for some emotional stimuli. This later possibility assumes that during any timing task the process of timing is competing with ongoing, task irrelevant, mental activities. Following this logic, in a verbal estimation task, emotional stimuli may be better than neutral stimuli at capturing and maintaining attention on the timing task itself. This may facilitate the processing of the temporal structure of the stimulus, leading to longer perceptions of duration.

Previous research has theorized that emotional modulation of attention may explain the relative underestimation of the duration of some emotional stimuli. For example, Ogden et al., (2015) suggested that pleasant touch shortened the perceived duration of ongoing events because it’s appetitive nature (Pawling, Trotter, McGlone & Walker, 2017) distracted participants’ attention away from the concurrent timing task (a sustained attention effect). Similarly, it has been suggested that the perceived duration of rotten food (Gil et al., 2009), shameful expressions (Gil & Droit-Volet, 2011), unattractive faces (Ogden, 2013) and highly sexual taboo words (Tipples, 2010) are underestimated because attention is dedicated to the processing of stimulus features and not time. For example, when attention is dedicated to avoiding rotten food (Gil et al., 2009) and shameful expressions (Gil & Droit-Volet, 2011), locating atypical features in face-space and reading sexually explicit content, there is reduced sustained attention to time resulting in shorter perceived durations.

Lui, Penney and Schirmer (2011) tested this proposal using a discrimination task in which participants compared the duration of two neutral stimuli (S1 and S2) separated by the brief presentation of an emotional or neutral image. When an emotional image (positive or negative) was interposed between S1 and S2, participants were more likely to judge S2 as shorter than S1. Lui et al., (2011) suggested that the shortening of S2 could not be explained by a pacemaker effect and therefore instead demonstrated an attentional effect on timing in which attention capture by the emotional stimulus and subsequent emotion regulation attempts, distracted from timing during S2 presentation.

Interestingly, changes in attentional processing have not been exclusively associated with shortenings of perceived duration. Instead, enhanced attentional orientation towards emotional stimuli has been used as an explanation for some additive lengthening's of perceived duration. For example, Ogden, Moore, Redfern & McGlone (2014) suggested that painful stimuli were estimated as lasting for longer than non-painful stimuli because of an increase in arousal *and* because the pain stimuli captured attention more effectively than the neutral stimulus, leading to reduced switch latency effects and a longer perception of duration. Grommet, Droit-Volet, Gil Hemmes, Baker & Brown, (2011) also suggested that the attention capture by threatening stimuli uniquely lengthened perceived duration independently of arousal. These suggestions are supported by Mella, Conty & Pouthas' (2011) examination of the effects of modulations of top-down attention to emotion. During a temporal discrimination task, participants were instructed to focus attention on either time, emotion or time and emotion during a temporal discrimination task in which physiological arousal was also recorded. Attending to emotion increased physiological arousal and perceived duration for emotional stimuli whereas attending to only time removed emotion effects for physiological arousal and time judgements. When attention was divided, emotion affected timing but not physiological arousal. Top down modulation of attention to emotion therefore determined the lengthening effect of emotion on perceived duration.

The role of attention in emotional distortion to time has also be inferred from comparisons of neural activity during the timing of emotional and neutral events. Gan, Wang, Zhang, Li & Luo (2009) examined ERPs resulting from the temporal discrimination of neutral and emotionally valenced facial stimuli. Enhanced P160 and P240 amplitudes were observed for emotional in comparison with neutral stimuli suggesting more rapid orientation to the emotional than neutral stimuli. Similarly, in a temporal production task, Tamm, Uusberg, Allik & Kreegipuu (2014) observed emotional modulation of early posterior negativity which indicated more rapid activation of early attentional mechanisms for positively valenced stimuli. Early P1 and the late positive potentials were however similar for positive and negatively valenced stimuli. Although this may be suggestive of an attentional contribution to emotional distortions to time, the authors acknowledge that their behavioural results were complex and did not provide a clear indication of how attention contributed to emotional distortions to time.

Whilst the attentional explanations in the above studies are theoretically plausible, they are often made post-hoc and in the absence of objective evidence that attentional processing was indeed different for one class of stimuli than another. This is problematic because, as Wearden (2016, pg 144) highlights *"... since increased attention to content diverts attention away from timing, shortening perceived duration, and increased arousal causes the internal clock to tick faster, thus lengthening perceived duration, any possible result can be accommodated simply by changing the balance of these two opposing processes."*. To substantiate the specific effects of attentional processing during emotional distortions to time, it is therefore necessary to obtain objective measures of attention allocation during timing and to then establish whether these measures relate to distortions to time. This suggestion echoes recent articles which have recommended that attentional onset and offset latencies should be objectively measured and related to perceive duration (Matthews & Meck, 2016).

One appropriate way to obtain objective measures of attentional allocation during timing is through the measurement of eye-movements (Wearden, 2016). Shifts in spatial attention can occur *covertly*, with attention shifted to new locations or objects within the existing visual field, without eye or head movements. Alternatively, *overt* shifts of attention involve movements of the eyes, in order that the viewer gazes directly at the object of interest and brings the object into foveal vision (Posner, 1980). Overt attention shifts can therefore be captured using eye-movement tracking technology (Parkhurst, Law & Niebur, 2002, Soto, Heinke, Humphreys, & Blanco, 2005, Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999 and see Eckstein, Guerra-Carrillo, Singley, & Bunge, 2017 and Rayner, 2009 for reviews). Eye-tracking has been used for several decades to measure overt attentional shifts; both those that are exogenous, meaning they are automatic and stimulus driven (e.g. Bannerman, Milders, & Sahraie, 2010; Hood & Atkinson, 1993), and those that are endogenous, meaning that they are guided by top-down processes (e.g. Gowen, Abadi, Poliakoff, Hansen & Miall, 2007; Sears, Thomas, LeHuquet & Johnson,2010).

Critically, eye-tracking methods have been used successfully to demonstrate the effects of emotion on the allocation of attention. For example, Nummenmaa et al., (2006; see Carretie, 2014 for review) demonstrated that emotionally valenced images captured exogenous overt visual attention more readily than neutrally valenced images. Fearful or threatening faces preferentially also capture attention, as measured by gaze direction in a dot-probe task, in a manner assumed to represent endogenous guidance (Bradley, Mogg & Millar, 2000; Mogg, Garner & Bradley, 2007; see Brosch, Pourtois, Sander & Vuilleumier, 2011 for discussion of endogenous and exogenous contributions to dot-probe). Similarly, endogenous overt attention is more readily captured by human gaze when gazing faces have salient emotional expressions (eg. Bayliss, Schuch & Tipper, 2010; Matthews, Fox, Yiend & Calder, 2003) and whilst these effects have typically been explored with reaction time measures, the same effects have been demonstrated in children by measuring eye-movements (Matsunaka & Hiraki, 2014). Eye tracking has also been used to demonstrate preferential attentional allocation toward emotional rather than neutral scenes (Calvo & Lang, 2005), as well as toward emotional content in dynamic scenes (Subramanian, Shankar, Sebe & Melcher, 2014).

Recording eye-movements during a time perception task and establishing the relationship between measures of eye-movement and distortion to time is therefore a logical first step in objectively measuring and establishing the contribution of overt attentional allocation to emotional distortions to time.

1.1 The current study

The current study sought to quantify overt attentional allocation during temporal processing by recording eye-movements during a verbal estimation task. Furthermore, it aimed to test the relationship between emotional distortions to time and overt attention allocation during timing. Participants completed a verbal estimation task in which they were asked to estimate, in milliseconds, the presentation duration of high arousal positive, high arousal negative and neutrally valenced IAPS images which appeared on the left or right of the centre of the screen. During this task two measures of eye-movements were recorded on each trial; time-to-first fixation (TOFF) and dwell time. TOFF was defined as the duration in milliseconds from target onset to the first fixation on the target and is therefore a measure of latency in overt attentional orientation toward the to-be-timed stimulus. Dwell time was defined as the total duration in milliseconds of fixations that participants made to the to-be-timed-stimulus during its presentation and is therefore a measure of sustained overt attention to the to-be-timed-event throughout its time on screen. Distortion to time was defined as the difference between estimates given for the neutral stimuli and the positive and negative stimuli. In addition, because differences in the slope and intercept of verbal estimation gradients have previously used differentiate the effects of changes in attentional latency (intercept) and changes in sustained attention to time (slope) (see Wearden et al., 2010), the differences in slopes and intercepts of the estimation functions from the neutral to the positive and negative conditions were calculated. The relationship between changes in estimates, slopes and intercepts, TOFF and dwell time was then calculated to test the relationship between attentional processing and emotional distortions to time. This analysis strategy replicates that used in by Ogden et al., (2019) to establish the relationship between objective measures of arousal and emotional distortions to time. High arousal stimuli were used because for negatively valenced stimuli, they have been shown to elicit the greater distortions to subjective time than low arousal images (e.g. Gil & Droit-Volet, 2012; Ogden et al., 2019). Low arousal images were not studied because of their inconsistent effects on perceived time.

It was expected that negatively valenced stimuli would be estimated as longer than neutrally valenced and positively valenced stimuli, replicating previous findings (e.g. Gil & Droit-Volet, 2012). Positively valenced stimuli were expected to be estimated as shorter than negatively and neutrally valenced stimuli, replicating Ogden et al., (2015). Furthermore, it was expected that dwell time and TOFF would be predictive of emotional distortions to the perceived duration of positive and negatively valanced stimuli. Specifically, because emotional stimuli capture and hold attention more efficiently than neutral stimuli, it was expected that dwell times would be longer for the emotional than the neutral stimuli, reflecting better sustained attention for emotional stimuli. The AGM suggests that increased sustained attention throughout a to-be-timed event will result in greater accumulation and longer perceptions of duration. Therefore, it was expected that there would be a positive relationship between changes in dwell times from positive and negative stimuli to neutral stimuli and changes in estimate and slope measures for these conditions. Furthermore, because emotional stimuli are orientated to more quickly than neutral stimuli (see Pourtois et al., 2013 and Vuilleumier, 2005 for review), it was expected that switch closure times would be faster for the emotional stimuli than the neutral, resulting in shorter TOFF measures for the emotional than neutral stimuli. SET suggests that more rapid attentional orientation results in more rapid switch closure, greater accumulation and a longer perception of duration. We therefore expect that there would be a negative relationship between changes in TOFF times from positive and negative stimuli to neutral stimuli and changes intercept for these conditions.

2. Method

2.1 Participants

Fifty participants, with normal vision, were recruited through volunteer sampling from Liverpool John Moores University and the general population via email advertisement. Participants were given a £5 shopping voucher in exchange for participation. Participants were aged 18 to 35 (M=20.68, SD=3.37) with 37 females and 13 males. The study was approved by Liverpool John Moores University Research Ethics Committee and all participants gave informed written consent. The study was conducted in accordance with the principles expressed in the Declaration of Helsinki.

2.2 Apparatus

Recording of Eye-movements: Eye-tracking was carried out using a Tobii Pro X3-120 monitor mounted eye-tracker, sampling at 120Hz. Participants sat approximately 500mm away from the monitor. Prior to beginning the task each participant underwent a five-point calibration procedure and the experimenter repeated the calibration if they judged it to be unacceptable. Calibration was repeated at the half-way point during the task. Participants completed three practise trials to orient them to the demands and timing of the task. All stimuli were presented against a white background on a monitor with an actual screen size of 475mm (width) by 295mm (height).

Stimulus selection: Stimuli were colour digital images selected from the IAPS (Lang, Bradley & Cuthbert, 1997). Three categories of images were selected which constituted the three experimental conditions: high arousal negative, high arousal positive and neutral. Four images selected for each condition (see Table 1 for image numbers). The images were selected according to IAPS standard ratings for arousal and for valence. The high arousal negative images (valence 1.50 – 2.00, arousal 6.00 – 7.50) included images of injured hands and dead or mutilated people, the high arousal positive images (valence 6.50 – 7.50, arousal 6.00 – 7.50) included images depicting soft pornography, and the neutral images (valence 4.00 - 5.00, arousal 1.50 – 3.00) included pictures of household items.

To confirm the emotional qualities of the images, a separate group of 40 new participants (16 male, mean age 28.45 years, SD = 5.53) rated them for arousal and valence (see Table 2). Participants completed their ratings online through the recruitment platform Prolific. The concepts of valence and arousal were explained to the participants during instructional screens at the start of the study. Ratings were made using the 9 point rating scale of the Self-Assessment Manikin (SAM; Lang, 1980). For valence, the scale went from a frowning, unhappy figure to a smiling happy figure and for arousal level the scale went from a relaxed, sleepy figure to an excited figure. Each participant viewed and rated the images in a random order. A mixed ANOVA with a within-subjects factor of emotion valence (positive negative and neutral) and a between subjects factors of gender (male and female) was conducted on the valence and arousal ratings. For valence, there was a significant main effect of emotional valence $F(2, 76) = 144.59$, $p < .001$, $\eta_p^2 = .79$. Bonferroni post-hoc tests confirmed significantly lower valence scores for the negative images than the neutral ($p < .001$) and positive images ($p < .001$). The positive images were rated as significantly more positive than the neutral images ($p < .001$). There was also a significant effect of gender $F(1, 38) = 6.02$, $p = .02$, $\eta_p^2 = .14$ with males (M = 4.38, SE = .15) rating the images as significantly more positive than females (M = 3.90, SE = .12). There was no significant interaction between emotion valence and gender $F(2, 76) = .32$, $p = .73$, $\eta_p^2 = .008$.

For arousal, there was a significant main effect of emotional valence $F(2, 76) = 39.24$, $p < .001$, $\eta_p^2 = .51$. Bonferroni post-hoc tests confirmed significantly higher arousal scores for the negative images ($p < .001$) and positive images ($p < .001$) when compared to neutral images. The positive images were also rated as significantly more arousing than the negative ($p < .01$). There was no significant effect of gender $F(1, 38) = 1.77$, $p = .19$, $\eta_p^2 = .04$. There was also no significant interaction between emotion valence and gender $F(2, 76) = 2.40$, $p = .10$, $\eta_p^2 = .06$.

The three conditions of stimuli were also compared in terms of mean luminance calculated from their RGB values and no significant differences between the conditions were found ($X^2(2) = 1.4$, $p = .49$).

Table 1: IAPS numbers

High Arousal Negative	*High Arousal Positive*	*Neutral*
3110	4660	7010
9405	4680	7050
9410	4690	7150
9187	4668	7175

Table 2. Valence and arousal means and standard deviations for image levels

Image type	*Valence M*	*Valence SD*	*Arousal M*	*Arousal SD*
High Arousal Negative	1.39	0.46	4.12	3.14
High Arousal Positive	6.22	1.52	5.79	1.94
Neutral	4.64	1.38	1.79	1.19

2.3 Procedure

The basic experimental procedure was as follows. Participants viewed the monitor from a distance of 60cm and completed the initial five-point calibration exercise. They then completed three practice trials of the verbal estimation task followed by a further 72 trials of the verbal estimation task in which they had to judge how long a target was presented on the screen. Participants then re-completed the calibration exercise followed by a further 72 trials of the verbal estimation task. Overall, experiment lasted for approximately 30 minutes and eye movements were recorded throughout.

Eye-movements calibration: Participants completed a five-point calibration procedure that required them to make saccades to five locations (the centre and four corners of the screen) dictated by a moving white dot (diameter 1.4°). When the dot stopped moving on reaching each of the five locations the participants were instructed to fixate on it until it moved again. Calibration accuracy, represented by error bars in each location, was visually inspected and the procedure repeated if considered necessary.

Verbal estimation task: A modified version of verbal estimation was developed for this task. Participants were informed that, on each trial, they would see a fixation cross which they were to orient their eyes toward. They were instructed that this fixation cross would be followed by a target stimulus, and that their task was to estimate, in milliseconds, how long the target stimulus was presented on the screen for. Participants were informed that the target was always presented for between 500ms and 2500ms. Participants were instructed not to count during image presentation.

At the start of each trial a black fixation cross (23mm by 23mm, 2.2°) was presented in the centre of the screen on a white background for 500ms. This was followed by the target stimulus in the form of an IAPS image. The target stimuli had dimensions of 70mm (6.7°) by 46mm (4.4°) and were presented so that their centres were 109mm 10.4° from the vertical edge of the screen and 144mm 13.7° from the top of the screen. Following target offset participants were instructed to verbalise their estimate and it was recorded by the experimenter. On each trial the target was presented for one of six durations; 1000ms, 1200ms, 1400ms, 1600ms, 1800ms or 2000ms. There were three conditions of target stimulus; negatively valenced, positively valenced and neutrally valenced. In each condition, four different images were used (see Tables 1 and 2 for details). There were a total of 147 trials, 3 practice trials, 48 negative, 48 positive and 48 neutral. On 50% of trials the target stimulus was presented in the left-hand side of the computer screen. On the remaining 50% of trials the target was presented in the right-hand side of the computer screen. All trials were presented in a random order and no performance feedback was given.

2.4 Data analysis:

Time estimation was assessed using three measures: 1) mean verbal estimate, 2) slope and 3) intercept. Mean verbal estimate was calculated as the average estimate given for each emotional condition. To calculate the slope and in the intercept of the verbal estimate functions (see Figure 2), linear regressions were conducted separately on each condition of each participants' data. The slope and intercept of each regression function for the three emotional conditions was then extracted.

Measures of dwell time and TOFF were generated within Tobii Pro Studio (version 3.4.8.1348) through the creation of areas of interest. These were centred on the target stimuli and made 10 pixels larger on either side of the stimulus rectangle to account for small errors in eye position tracking. Mean, minimum and maximum dwell times and TOFF, and their standard deviations were calculated at the participant level within Tobii Studio and these statistics were first visually inspected for outliers / artefacts. Data from two participants was excluded due to TOFF measures which were greater than three SD above the mean.

3. Results

Table 3: Descriptive statistics for the measures of temporal perception and eye-movements.

Trial Type	*Mean estimate ms (SD)*	*Mean TOFF ms (SD)*	*Mean dwell time ms (SD)*	*Mean Slope (SD)*	*Mean Intercept (SD)*
Negative	1404.23 (267.42)	23.73 (5.99)	1235.00 (97.81)	0.98 (0.29)	-56.89 (459.10)

Neutral	1374.82	25.11	1218.10	0.89	43.92
	(272.39)	(6.57)	(110.31)	(0.34)	(522.86)
Positive	1363.55	23.80	1228.80	0.83	121.15
	(265.95)	(4.91)	(94.33)	(0.26)	(439.11)

Table 3 shows means and SDs for the average estimate, TOFF, dwell time, slope and intercept for the positive, negative and neutral conditions.

3.1 Eye-movements

A mixed ANOVA with within subjects factors of emotional valence (positive, negative and neutral) and stimulus duration (1000ms, 1200ms, 1400ms, 1600ms, 1800ms or 2000ms), presentation location (left or right) and a between subjects factor of participant gender (male or female) was used to assess the effect of stimulus valence on TOFF. This analysis showed a significant main effect of emotional valence $F(2, 92) = 7.81$, $p = .006$, $\eta_p^2 = .15$. Bonferroni corrected post-hoc tests confirmed that TOFFs were significantly shorter in the negative (p = .001) and positive condition (p = .002) than the neutral condition. There was no significant difference between the positive and negative conditions (p = .99). There were no significant main effects of duration $F(5, 230) = 2.16$, $p = .06$, $\eta_p^2 = .04$, gender $F(1, 46) = .03$, $p = .87$, $\eta_p^2 = .001$ or location $F(1, 46) = 3.05$, $p = .09$, $\eta_p^2 = .03$. There were no significant two way interactions between emotional valence and stimulus duration $F(10, 470) = 1.71$, $p = .08$, $\eta_p^2 = .04$, gender and duration $F(5, 230) = 1.11$, $p = .34$, $\eta_p^2 = .02$, gender and emotion $F(2, 92) = 2.26$, $p = .11$, $\eta_p^2 = .05$, gender and location $F(1, 46) = 3.05$, $p = .09$, $\eta_p^2 = .06$, emotion and location $F(2, 92) = 2.17$, $p = .06$, $\eta_p^2 = .03$ and location and duration $F(5, 230) = .378$, $p = .87$, $\eta_p^2 = .008$. Furthermore, there were no significant three way interactions between emotion, location and gender $F(2, 92) = 2.87$, $p = .06$, $\eta_p^2 = .06$, emotion, duration and gender $F(10, 460) = 1.51$, $p = .20$, $\eta_p^2 = .04$, emotion, location and duration $F(10, 460) = 1.40$, $p = .21$, $\eta_p^2 = .03$, duration, location and gender $F(5, 230) = .37$, $p = .87$, $\eta_p^2 = .008$ and no significant four-way interaction between emotion, location, duration and gender $F(10, 460) = 1.40$, $p = .2$, $\eta_p^2 = .03$. These findings suggest that the emotion manipulation affected eye-movements resulting in short TOFF for emotional than neutral stimuli.

A mixed ANOVA with within subjects factors of emotional valence (positive, negative and neutral) and stimulus duration (1000ms, 1200ms, 1400ms, 1600ms, 1800ms or 2000ms), presentation location (left or right) and a between subjects factor of participant gender (male or female) was used to assess the effect of stimulus valence on dwell time. This analysis showed a significant main effect of duration $F(5, 230) = 1806.26$, $p < .0011$, $\eta_p^2 = .98$.There were no significant main effects of emotion $F(2, 92) = 2.56$, $p = .08$, $\eta_p^2 = .05$, gender $F(1, 46) = .04$, $p = .56$, $\eta_p^2 = .008$ or location $F(1, 46) = .005$, $p = .95$, $\eta_p^2 < .001$. There were no significant two way interactions between emotional valence and stimulus duration $F(10, 460) = 1.45$, $p = .16$, $\eta_p^2 = .03$, gender and duration $F(5, 230) = 1.67$, $p = .14$, $\eta_p^2 = .04$, gender and emotion $F(2, 92) = .16$, $p = .85$, $\eta_p^2 = .004$, gender and location $F(1, 46) = .95$, $p = .33$, $\eta_p^2 = .02$,emotion and location $F(2, 92) = 1.14$, $p = .33$, $\eta_p^2 = .02$ and location and duration $F(5, 230) = .08$, $p = .99$, $\eta_p^2 = .002$. Furthermore, there were no significant three way interactions between emotion, location and gender $F(2, 92) = .19$, $p = .83$, $\eta_p^2 = .004$, emotion, duration and gender $F(10, 460) = 122$, $p = .27$, $\eta_p^2 = .03$, emotion, location and duration $F(10, 460) = .85$, $p = .58$, $\eta_p^2 = .02$, duration, location and gender $F(5, 230) = 1.05$, $p = .39$, $\eta_p^2 = .02$ and no significant four-way interaction between emotion, location, duration and gender $F(10, 460) = 1.10$, $p = .36$, $\eta_p^2 = .02$. These findings suggest that emotional valence, gender and stimulus location did not influence dwell times

3.2 Time estimates

Figure 2 shows mean verbal estimates plotted against stimulus presentation duration for the positive, negative and neutral conditions. Examination of Figure 2 suggests that estimates were longer for the negative than neutral and positive conditions.

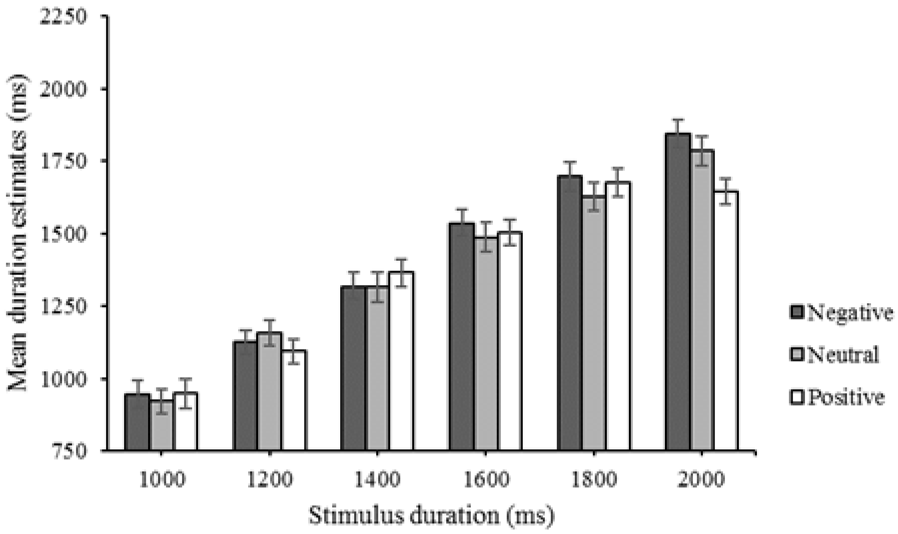


Figure 2: Mean verbal estimates for the negative, neutral and positive stimuli plotted against the stimulus presentation duration. Error bars show standard error of the mean.

A mixed ANOVA with within subjects factors of emotional valence (positive, negative and neutral) and stimulus duration (1000ms, 1200ms, 1400ms, 1600ms, 1800ms or 2000ms), presentation location (left or right) and a between subjects factor of participant gender (male or female) was used to assess the effect of stimulus valence on perceived duration. This analysis showed a significant main effect of emotional valence $F(2, 94) = 5.49$, $p = .006$, $\eta_p^2 = .11$. Bonferroni corrected post-hoc tests confirmed that estimates were significantly longer in the negative than neutral condition ($p < .01$) and positive conditions ($p < .02$). There was no significant difference between the positive and neutral conditions ($p =.99$). There was also a significant main effect of duration $F(5, 230) = 121.07$, $p < .001$ $\eta_p^2 = .73$ and a significant interaction between emotional valence and stimulus duration $F(10, 470) = 4.91$, $p < .001$ $\eta_p^2 = .10$. There were no significant main effects of gender $F(1, 46) = 1.79$, $p = .19$, $\eta_p^2 = .04$ or location $F(1, 46) = 1.59$, $p = .21$, $\eta_p^2 = .03$. There were also no significant two way interactions between gender and emotion $F(2, 92) = .65$, $p = .52$, $\eta_p^2 = .01$, gender and location $F(1, 46) = .34$, $p = .86$, $\eta_p^2 = .001$, emotion and location $F(2, 92) = 2.14$, $p = .23$, $\eta_p^2 = .04$ and location and duration $F(5, 230) = 1.58$, $p = .17$, $\eta_p^2 = .03$. Furthermore, there were no significant three way interactions between emotion, location and gender $F(2, 92) = 2.14$, $p = .13$, $\eta_p^2 = .04$, emotion, duration and gender $F(10, 460) = .47$, $p = .91$, $\eta_p^2 = .01$, emotion, location and duration $F(10, 460) = 1.21$, $p = .28$, $\eta_p^2 = .03$, duration, location and gender $F(5, 230) = 1.21$, $p = .28$, $\eta_p^2 = .03$ and no significant four-way interaction between emotion, location, duration and gender $F(10, 460) = 1.00$, $p = .44$, $\eta_p^2 = .02$. These finding suggest that emotional valence influenced duration estimates, with longer estimates for negative than neutral and positive stimuli. There were however no effects of gender or stimulus location.

Further analysis was conducted on the slope and intercept of the estimate functions. For slope values there was a significant effect of emotion $F(2, 94) = 12.71$, $p < .001$, $\eta_p^2 = .21$ with a significantly steeper slope in the negative than neutral ($p < .03$) and positive conditions ($p < .001$) but no significant difference between the neutral and positive conditions ($p = .18$). For intercept values there was a significant effect of emotion on intercepts $F(2, 94) = 7.01$, $p = .001$ $\eta_p^2 = .13$ with significantly smaller intercepts in the negative than positive condition ($p < .001$) but no significant difference between the positive neutral ($p = .36$) or negative and neutral conditions ($p = .17$).

3.3 The relationship between eye-movements and distortions to time

To test the relationship between distortions to time and eye-movements, the difference in slope, intercept, TOFF and dwell time for the negative and neutral and negative and positive conditions was calculated. The relationship between estimates, slopes, intercepts, TOFF and dwell time was assessed using Pearson's correlation and *p*-values were adjusted for multiple comparisons. Examination of Table 4 shows that there were no significant relationships between these measures.

Table 4: Correlation coefficients for the relationship between TOFF, dwell time, slope and intercept.

		TOFF	Dwell Time
Negative –neutral	*Estimate*	.01	.01
	Slope	.16	.05
	Intercept	-.07	-.14
Negative – positive	*Estimate*	.20	-.24
	Slope	-.01	.12
	Intercept	-.21	-.15
Neutral – positive	*Estimate*	-.05	-.01
	Slope	.10	.19
	Intercept	-.15	.18

4. Discussion

This study tested the relationship between emotional distortions to time and overt attentional processing as indexed by eye-movements. Two measures of eye-movements were recorded; TOFF which measured the latency of overt attentional orientation to the to-be-timed stimulus, and dwell time, which measured sustained overt attention to the to-be-timed stimulus throughout its presentation. Distortion to time was defined as the difference between the estimates, slopes and intercepts given for neutral stimuli and positive and negative stimuli.

The results show that high arousal negatively valenced stimuli were perceived as lasting for longer than neutrally and high arousal positively valenced stimuli. These findings replicate previous findings using similar stimuli (e.g. Gil & Droit-Volet, 2012), confirming that the data are typical of that seen in other studies. There was no difference in the perceived duration of positive and neutrally valenced stimuli suggesting that positively valenced stimuli did not distort time in this instance. This replicates previous findings obtained with IAPS stimuli (e.g. Ogden et al., 2019).

The eye-movement recordings showed that TOFF was significantly shorter for positively and negatively valenced stimuli than neutral stimuli, suggesting faster orientations of overt attention to emotional stimuli than neutral stimuli. This replicates findings by authors reporting faster attentional orienting toward emotional over neutral stimuli (Koster et al., 2004; Milstein & Dorris, 2007) and similar effects for reward (Nummenmaa et al., 2006). Dwell times were unaffected by emotional valence suggesting that sustained overt attention was similar for all conditions. Examination of the correlational analysis revealed no significant relationships between any measures of distortion to time and measures of overt attention indexed by eye-movements.

These results provide a number of key findings. For overt orientation latency, indexed by TOFF, there was no consistent association between more rapid overt attentional orientation and a lengthening of perceived duration. For positively valenced stimuli, despite more rapid overt attentional orientation to the positive than neutral stimuli, there was no significant difference in duration estimates for these two conditions. This suggests that for positively valenced stimuli, more rapid attentional orientation to the to-be-timed-stimulus does not always result in longer perceptions of duration. For negatively valenced stimuli, although overt attentional orientation was more rapid, and estimates were longer than for neutrally valenced stimuli, there was no direct relationship between TOFF and perceived duration for these conditions. Indeed, the intercept values for negatively valenced stimuli were significantly lower than those for neutrally valenced stimuli, rather than greater as would be expected if smaller switch latencies were affected duration estimates. Therefore, for negative stimuli although the effects of emotion on TOFF and estimates were in the predicted direction, the changes were unrelated to one another.

The absence of consistent duration lengthening effects for stimuli with more rapid overt attentional orientation is inconsistent with the effects of changes in switch latency proposed in SET. According to SET, more rapid switch closure should result in more accumulation and a longer perception of duration. Therefore, in the current study, both positive and negatively valenced stimuli should have been perceived as significantly longer than neutral stimuli because both were orientated to more quickly than the neutral stimuli. However, lengthening was not observed for the positive stimuli. This therefore suggests that for supra-second duration estimation, the relatively small gains in overt attentional orientation afforded by emotional valence are insufficient to consistently influence duration experience. It remains possible however that during sub-second timing even relatively small changes in attention orientation latency may be sufficient to systematically affect subjective timing. This is because these changes would constitute a greater proportion of the overall stimulus duration for short (sub-second) than longer (supra second) epochs. Future research should explore this possibility.

For sustained attentional processing, indexed by dwell time, despite longer estimates for the negative than neutral and positive stimuli there was no significant difference in dwell times for the three conditions. This suggests that despite similar sustained overt attentional processing across the three conditions, duration estimates differed. Therefore, in the current paradigm sustained attention to time was unaffected by emotion and did not contribute significantly to the relative lengthening of the perceived duration of the negatively valenced stimuli. It is possible however, that because the participants' task was to judge duration, rather than to make explicit judgements about emotion, that this may have weakened the effect of emotion on dwell times. This suggestion is reminiscent Mella and Pouthas' (2011) observation that attention sharing between time and emotion removed the effect of emotion on skin conductance response measures. Furthermore, it remains possible however that measurement error may have weakened any observable effects and other measures of sustained attention may be better able to capture the relationship between sustained attentional processing and distortions to time. Future research should therefore establish how the explicit processing of time affects affective responses to emotional stimuli.

Collectively, the findings for attention orientation latency and sustained attention suggest that emotional distortions to time are not directly related to changes in overt-attentional processing. This raises two possibilities. Firstly, the findings could be interpreted as supporting suggestions that changes in physiological arousal are the primary cause of emotional distortions to time. The two major models of duration perception, SET (Gibbon et al., 1984) and the Striatal Beat Frequency model (SBF, Matell & Meck, 2004), suggest that emotional distortions to time occur because arousal acts on the core timing network to distort duration. In SET (Figure 1), arousal is thought to influence the rate at which the pacemaker emits output. Increases in arousal speed up the pacemaker leading to longer perceptions of duration whereas decreases in arousal slow pacemaker rate leading to shorter perceptions of duration. In SBF, time is processed by the oscillation frequencies of cortical neurons which are in turn detected by the striatum. Increases in arousal increase cortical-striatal dopamine levels leading to more rapid oscillations and longer perceptions of duration whereas decreases in arousal reduce dopamine levels slowing the oscillation rate (see Cheng, Tipples, Narayanan & Meck, 2016 for discussion).

There is good experimental evidence to support arousal as a causal mechanism in emotional temporal distortions. More arousing images distort time to a greater extent than less arousing images (Gil & Droit-Volet, 2012). Furthermore, recent studies examining the relationship between physiological arousal, indexed by changes in the autonomic nervous system (ANS) and distortions to time have demonstrated that the reactivity of the sympathetic nervous system is directly predictive of distortions to the perceived duration of emotional stimuli (van Hedger et al., 2017; Piovesan, Mirams, Poole, Moore & Ogden, 2018; Ogden et al., 2019). Indeed, in the current study, the observation of larger slope values for the high arousal negative stimuli than the other stimuli, supports a role for arousal in the distortions observed.

It is therefore possible that the effect of physiological arousal on duration processing "wipes out" any observable effect of emotion induced changes in attentional processes. However, caution should perhaps be taken with this interpretation. Firstly, changes in physiological arousal only appear to be consistently predictive of distortions to the perceived duration of high arousal negatively valenced stimuli (Ogden et al., 2019). Other mechanisms must therefore be contributing to distortions to the duration of positively valenced stimuli and low arousal negatively valenced stimuli. Secondly, changes in physiological arousal only account for a relatively small proportion of the variance in distortions to time. For example, in Piovesan et al., (2018), ANS responses to pain only accounted for between 15 and 20% of the variance in distortions to the perceived duration of pain. Similarly, in Ogden et al. (2019), ANS responses to high arousal negatively valenced IAPS only accounted for 12.90% of the variance in distortions to their perceived duration. Indeed, in the current study, whilst males rated the images as more arousing than females, there was no difference in the estimates of males and females. Therefore, whilst changes in physiological arousal are predictive of perceived duration, their predictive value is relatively small and does not preclude the influence of factors such as emotion induced changes in attentional processing.

A second possibility is that emotional distortions to time are the result of emotion induced changes to other forms of attentional processing, not captured by the overt measures of eye-movements taken in the current study. Covert attentional processing refers to a shift in the spatial location of attentional focus in the absence of eye-movements (Posner, 1980). Covert attentional shifts can occur exogenously as a reflexive response to stimuli appearing in the periphery (e.g. Nakayama & Mackeben, 1989). Although often used to inform subsequent shifts in overt attention, covert attention itself can influence early visual processing (see Phelps et al., 2006 for discussion). Indeed, it has been suggested that covert attention may be critical in selectively processing the emotional content of the visual scene (Phelps et al., 2006). SET and the AMG do not distinguish between overt and covert attentional effects on timing. The findings of this paper therefore raise the possibility that, for supra-second duration ranges, emotional enhancement of covert attentional allocation may have a greater influence on perceived duration than overt attentional allocation. This suggestion is supported by evidence suggesting that emotion can distort time in the absence of conscious awareness of emotional stimulation (Yamada & Kawabe, 2011). Further research examining the role of covert attentional processing in temporal distortion therefore warranted.

The findings of the current study offer initial evidence that, in the 1 to 2 second duration range, emotional modulation of overt attention is not related to emotional distortion to time. However, because this study used single duration range, only high arousal stimuli and only one temporal task, it is possible that future studies may reveal circumstances in which emotional modulation of attention is predictive of emotional distortions. The current study also used a relatively small number of images as stimuli and it is possible that through habituation this attenuated the emotional modulation of attention observed. We therefore encourage replication of the current study and emphasise the need for future studies to systematically assess the effect of duration range, arousal level and temporal task on the relationship between overt attention and emotional distortions to time.

4.1 Conclusions

The findings of this study show that emotion induced changes in overt attentional processing are not predictive of emotional distortions to time. For positively valenced stimuli, although attentional orientation was enhanced by emotion, there was no emotional distortion to perceived duration. For negative stimuli, despite more rapid attentional orientation and subjectively lengthening of perceived duration, attention and distortions to time were unrelated to one another. These findings demonstrate that there is a complex relationship between overt attentional processing and the perceived duration of events. They also caution against the assumption that emotional modulations of attentional processing are causal factor in the in the emotional modulation of temporal processing.

References

Angrilli, A., Cherubini, P., Pavese, A., & Manfredini, S. (1997). The influence of affective factors on time perception. *Perception & Psychophysics*, *59*(6), 972-982.

Bannerman, R. L., Milders, M., & Sahraie, A. (2010). Attentional bias to brief threat-related faces revealed by saccadic eye movements. *Emotion*, *10*(5), 733-783.

Bayliss, A. P., Schuch, S., & Tipper, S. P. (2010). Gaze cueing elicited by emotional faces is influenced by affective context. *Visual Cognition*, *18*(8), 1214-1232.

Block, R. A., & Zakay, D. (1996). Models of psychological time revisited. *Time and mind*, *33*, 171-195.

Bradley, B. P., Mogg, K., Millar, N., Bonham-Carter, C., Fergusson, E., Jenkins, J., & Parr, M. (1997). Attentional biases for emotional faces. *Cognition & Emotion*, *11*(1), 25-42.

Bradley, B. P., Mogg, K., & Millar, N. H. (2000). Covert and overt orienting of attention to emotional faces in anxiety. *Cognition & Emotion*, *14*(6), 789-808.

Brosch, T., Pourtois, G., Sander, D., & Vuilleumier, P. (2011). Additive effects of emotional, endogenous, and exogenous attention: behavioral and electrophysiological evidence. *Neuropsychologia*, *49*(7), 1779-1787.

Buhusi, C. V., & Meck, W. H. (2009). Relativity theory and time perception: single or multiple clocks?. *PLOS ONE*, *4*(7), e6268.

Burle, B., & Casini, L. (2001). Dissociation between activation and attention effects in time estimation: Implications for internal clock models. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 195–205.

Calvo, M. G., & Lang, P. J. (2005). Parafoveal semantic processing of emotional visual scenes. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(3), 502-519.

Carretié, L. (2014). Exogenous (automatic) attention to emotional stimuli: a review. *Cognitive, Affective, & Behavioral Neuroscience*, *14*(4), 1228-1258.

Cheng, R. K., Tipples, J., Narayanan, N. S., & Meck, W. H. (2016). Clock speed as a window into dopaminergic control of emotion and time perception. *Timing & Time Perception*, *4*(1), 99-122.

Coull, J. T., Vidal, F., Nazarian, B., & Macar, F. (2004). Functional anatomy of the attentional modulation of time estimation. *Science*, *303*(5663), 1506-1508.

Droit-Volet, S., Bigand, E., Ramos, D., & Bueno, J. L. O. (2010). Time flies with music whatever its emotional valence. *Acta Psychologica*, *135*(2), 226-232.

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

Droit-Volet, S., Brunot, S., & Niedenthal, P. (2004). Perception of the duration of emotional events. *Cognition and Emotion*, *18*(6), 849-858.

Effron, D. A., Niedenthal, P. M., Gil, S., & Droit-Volet, S. (2006). Embodied temporal perception of emotion. *Emotion, 6*(1), 1-9.

Eckstein, M. K., Guerra-Carrillo, B., Singley, A. T. M., & Bunge, S. A. (2017). Beyond eye gaze: What else can eyetracking reveal about cognition and cognitive development?. *Developmental Cognitive Neuroscience*, *25*, 69-91.

Enns, J. T., Brehaut, J. C., & Shore, D. I. (1999). The duration of a brief event in the mind's eye. *The Journal of general psychology*, *126*(4), 355-372.

Fayolle, S., Gil, S., & Droit-Volet, S. (2015). Fear and time: Fear speeds up the internal clock. *Behavioural Processes*, *120*, 135-140.

Fernandes, A. C., & Garcia-Marques, T. (2020). A meta-analytical review of the familiarity temporal effect: Testing assumptions of the attentional and the fluency-attributional accounts. *Psychological Bulletin*, *146*(3), 187.

Gan, T., Wang, N., Zhang, Z., Li, H., & Luo, Y. J. (2009). Emotional influences on time perception: evidence from event-related potentials. *Neuroreport*, *20*(9), 839-843.

Gibbon, J., Church, R. M., & Meck, W. H. (1984). Scalar timing in memory. *Annals of the New York Academy of Sciences*, *423*(1), 52-77.

Gil, S., Rousset, S., & Droit-Volet, S. (2009). How liked and disliked foods affect time perception. *Emotion*, *9*(4), 457-463.

Gil, S., & Droit-Volet, S. (2011). Time perception in response to ashamed faces in children and adults. *Scandinavian Journal of Psychology*, *52*(2), 138-145.

Gil, S., & Droit-Volet, S. (2012). Emotional time distortions: the fundamental role of arousal. *Cognition & Emotion*, *26*(5), 847-862.

Gowen, E., Abadi, R. V., Poliakoff, E., Hansen, P. C., & Miall, R. C. (2007). Modulation of saccadic intrusions by exogenous and endogenous attention. *Brain Research*, *1141*, 154-167.

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

Hansen, C. H., & Hansen, R. D. (1988). Finding the face in the crowd: an anger superiority effect. *Journal of Personality and Social Psychology*, *54*(6), 917-924.

van Hedger, K., Necka, E. A., Barakzai, A. K., & Norman, G. J. (2017). The influence of social stress on time perception and psychophysiological reactivity. *Psychophysiology*, *54*(5), 706-712.

Hood, B. M., & Atkinson, J. (1993). Disengaging visual attention in the infant and adult. *Infant Behavior and Development, 16*(4), 405-422.

Koster, E. H., Crombez, G., Van Damme, S., Verschuere, B., & De Houwer, J. (2004). Does imminent threat capture and hold attention?. *Emotion*, *4*(3), 312-317.

Lake, J. I. (2016). Recent advances in understanding emotion-driven temporal distortions. *Current Opinion in Behavioral Sciences*, *8*, 214-219.

Lake, J. I., LaBar, K. S., & Meck, W. H. (2016). Emotional modulation of interval timing and time perception. *Neuroscience & Biobehavioral Reviews, 64*, 403-420.

Lang, P. J. (1980). Behavioral treatment and biobehavioral assessment: Computer applications. In J. Sidowski, J. Johnson, & T. Williams (Eds.), Technology in mental health care delivery systems (pp. 119–137). Norwood, NJ: Ablex.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). International affective picture system (IAPS): Technical manual and affective ratings. *NIMH Center for the Study of Emotion and Attention*, *1,* 39-58.

Lejeune, H. (1998). Switching or gating? The attentional challenge in cognitive models of psychological time. *Behavioural Processes*, *44*(2), 127-145.

Lejeune, H. (2000). Prospective timing, attention and the switch: A response to 'Gating or switching? Gating is a better model of prospective timing' by Zakay. *Behavioural Processes*, *52*(2-3), 71-76.

Lui, M. A., Penney, T. B., & Schirmer, A. (2011). Emotion effects on timing: attention versus pacemaker accounts. *PLOS ONE*, *6*(7), e21829.

Pawling, R., Trotter, P. D., McGlone, F. P., & Walker, S. C. (2017). A positive touch: C-tactile afferent targeted skin stimulation carries an appetitive motivational value. *Biological Psychology*, *129*, 186-194.

Matell, M. S., & Meck, W. H. (2004). Cortico-striatal circuits and interval timing: coincidence detection of oscillatory processes. *Cognitive Brain Research*, *21*(2), 139-170.

Matsunaka, R., & Hiraki, K. (2014). Fearful gaze cueing: gaze direction and facial expression independently influence overt orienting responses in 12-month-olds. *PloS ONE, 9*(2), e89567.

Mathews, A., Fox, E., Yiend, J., & Calder, A. (2003). The face of fear: Effects of eye gaze and emotion on visual attention. *Visual Cognition*, *10*, 823–835.

Matthews, W. J., & Meck, W. H. (2016). Temporal cognition: Connecting subjective time to perception, attention, and memory. *Psychological Bulletin*, *142*(8), 865.

Mattes, S., & Ulrich, R. (1998). Directed attention prolongs the perceived duration of a brief stimulus. *Perception & Psychophysics, 60*(8), 1305-1317.

Milstein, D. M., & Dorris, M. C. (2007). The influence of expected value on saccadic preparation. *Journal of Neuroscience*, *27*(18), 4810-4818.

Mella, N., & Pouthas, V. (2011). Electrophysiological evidence for an accumulation process in the timing of emotional stimuli. In *Multidisciplinary Aspects of Time and Time Perception* (pp. 173-185). Springer, Berlin, Heidelberg.

Mella, N., Conty, L., & Pouthas, V. (2011). The role of physiological arousal in time perception: psychophysiological evidence from an emotion regulation paradigm. *Brain and Cognition*, *75*(2), 182-187.

Mogg, K., Garner, M., & Bradley, B. P. (2007). Anxiety and orienting of gaze to angry and fearful faces. *Biological Psychology, 76*(3), 163-169.

Nakayama, K., & Mackeben, M. (1989). Sustained and transient components of focal visual attention. *Vision Research*, *29*(11), 1631-1647.

Noulhiane, M., Mella, N., Samson, S., Ragot, R., & Pouthas, V. (2007). How emotional auditory stimuli modulate time perception. *Emotion*, *7*(4), 697-704.

Nummenmaa, L., Hyönä, J., & Calvo, M. G. (2006). Eye movement assessment of selective attentional capture by emotional pictures. *Emotion*, *6*(2), 257-268.

Ogden, R. S. (2013). The effect of facial attractiveness on temporal perception. *Cognition & Emotion*, *27*(7), 1292-1304.

Ogden, R. S., Henderson, J. Richter, M., & McGlone, F. (2019). Time distortion under threat: Sympathetic arousal predicts time distortion only in the context of negative, highly arousing stimuli. *PLoS ONE, 4*(5), e0216704.

Ogden, R. S., Moore, D., Redfern, L., & McGlone, F. (2015). Stroke me for longer this touch feels too short: the effect of pleasant touch on temporal perception. *Consciousness and Cognition*, *36*, 306-313.

Ogden, R. S., Moore, D., Redfern, L., & McGlone, F. (2014). The effect of pain and the anticipation of pain on temporal perception: A role for attention and arousal. *Cognition and Emotion*, *29*(5), 910-922.

Parkhurst, D., Law, K., & Niebur, E. (2002). Modeling the role of salience in the allocation of overt visual attention. *Vision Research*, *42*, 107–123.

Phelps, E. A., Ling, S., & Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychological Science*, *17*(4), 292-299.

Piovesan, A., Mirams, L., Poole, H., Moore, D., & Ogden, R. (2019). The relationship between pain-induced autonomic arousal and perceived duration. *Emotion*, *19*(7), 1148–1161.

Pourtois, G., Schettino, A., & Vuilleumier, P. (2013). Brain mechanisms for emotional influences on perception and attention: what is magic and what is not. *Biological Psychology*, *92*(3), 492-512.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3-25.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *The Quarterly Journal of Experimental Psychology*, *62*(8), 1457-1506.

Sears, C. R., Thomas, C. L., LeHuquet, J. M., & Johnson, J. C. (2010). Attentional biases in dysphoria: An eye-tracking study of the allocation and disengagement of attention. *Cognition and Emotion*, *24*(8), 1349-1368.

Seifried, T., & Ulrich, R. (2011). Exogenous visual attention prolongs perceived duration. *Attention, Perception, & Psychophysics*, *73*(1), 68-85.

Smith, S. D., McIver, T. A., Di Nella, M. S., & Crease, M. L. (2011). The effects of valence and arousal on the emotional modulation of time perception: evidence for multiple stages of processing. *Emotion*, *11*(6), 1305-1313.

Soto, D., Heinke, D., Humphreys, G. W., & Blanco, M. J. (2005). Early, involuntary top-down guidance of attention from working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(2), 248-261.

Subramanian, R., Shankar, D., Sebe, N., & Melcher, D. (2014). Emotion modulates eye movement patterns and subsequent memory for the gist and details of movie scenes. *Journal of Vision*, *14*(3), 31-31.

Tamm, M., Uusberg, A., Allik, J., & Kreegipuu, K. (2014). Emotional modulation of attention affects time perception: Evidence from event-related potentials. *Acta Psychologica*, *149*, 148-156.

Theeuwes, J., Kramer, A. F., Hahn, S., Irwin, D. E., & Zelinsky, G. J. (1999). Influence of attentional capture on oculomotor control. *Journal of Experimental Psychology: Human Perception & Performance, 25(6),* 1595–1608.

Tipples, J. (2010). Time flies when we read taboo words. *Psychonomic Bulletin & Review*, *17*(4), 563-568.

Vuilleumier, P. (2005). How brains beware: neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, *9*(12), 585-594.

Watts, F. N. and Sharrock, R. 1984. Fear and time-estimation. *Perceptual and Motor Skills*, *59*, 597–598.

Wearden, J. H. (2015). Mission: Impossible? Modelling the verbal estimation of duration. *Timing & Time Perception*, *3*(3-4), 223-245.

Wearden, J. H., O'Rourke, S. C., Matchwick, C., Min, Z., & Maeers, S. (2010). Task switching and subjective duration. *Quarterly Journal of Experimental Psychology*, *63*(3), 531-543.

Williams, J. M. G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop task and psychopathology. *Psychological Bulletin*, *120*(1), 3-24.

Wittman, M. (2009). The inner experience of time. *Philosophical Transactions of The Royal Society B*, *364*, 1955–1967.

Yamada, Y., & Kawabe, T. (2011). Emotion colors time perception unconsciously. *Consciousness and Cognition*, *20*(4), 1835-1841.

Zakay, D. (2000). Gating or switching? Gating is a better model of prospective timing (a response to ‘switching or gating?’ by Lejeune). *Behavioural Processes*, *52*(2-3), 63-69.

Zakay, D., & Block, R. A. (1995). An attentional-gate model of prospective time estimation. *Time and the dynamic control of behavior*, 167-178.

Zakay, D., & Block, R. A. (1997). Temporal cognition. *Current Directions in Psychological Science, 6(1)*, 12–16.