THE EFFECT OF EMOTION ON TIME PERCEPTION FOR COMPLEX VISUAL
STIMULI

BY

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Abstract

Activation and attention have opposite effects on time perception. Emotion can both increase physiological activation (which leads to overestimation of time) and attract attention (which leads to underestimation of time). Although the effect of emotion on time perception has received a growing amount of attention, the use of different time estimation tasks and stimuli makes it difficult to compare findings across studies. The effect of emotion on the temporal perception of complex stimuli (e.g. scenes) is particularly under-researched. This thesis presents a systematic assessment of the effect of two key emotional dimensions, arousal and valence, on time perception for visual stimuli. Studies were designed to control for factors that may modulate emotion effects, such as image repetition and carry over from one emotion to another. The stimuli were complex images standardized for arousal (high or low) and valence (positive or negative) as well as neutral images. The first study compared three time estimation tasks to determine which were sensitive to emotion effects. The selected task, temporal bisection, was used to test time perception in three duration ranges: short (400 to 1600ms), middle (1000 to 4000ms), and long (2000 to 6000ms). Results of bisection point analyses revealed that the duration of attention-capturing stimuli (e.g. high arousal or negative images) was underestimated compared to that of other stimuli (e.g. low arousal or neutral images). These findings are at odds with activational effects of emotion (overestimation of emotional stimuli), which are typically found in studies of time perception for facial expression. Better temporal sensitivity in the long range than in short and middle ranges suggests that participants used different timing strategies to perform the bisection task at longer stimulus durations. To test the effect of emotion on time perception using a discrete rather than dimensional classification of emotion, experiments were replicated using emotional facial expressions as stimuli. Time estimates in the short and middle ranges did not show attentional effects, but pointed to activational effects of emotion. Facial expression had no impact on time perception in the long duration range. Taken together, these experiments show that the effect of emotion on time perception varies according to both duration and stimulus type.

Emotional facial expressions have short lived activational effects whereby the duration of arousing stimuli is overestimated, whereas complex emotional scenes have protracted attentional effects through which the duration of attention-capturing stimuli is underestimated.

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Table of Contents

Abstract.....	2
Acknowledgements.....	4
List of Figures.....	9
Prospective and Retrospective Time Estimation	13
Attentional Models for Prospective Timing	14
Memory-based Models for Retrospective Timing.....	15
A Dual-process Contingency Model.....	15
Scalar Properties of Timing	17
Scalar Expectancy Theory.....	19
Activation and the Speed of the Pacemaker	21
Attention.....	22
The attentional gate	23
Attention effects on the switch	23
Switching vs. gating	25
Time Estimation Tasks	27
Classical timing paradigms	27
Attention and activation effects in classical timing tasks.....	29
Scalar timing violations in classical timing tasks.....	32
Comparison paradigms	33
Temporal bisection.....	34
Time Perception for Emotional Stimuli	38
Discrete and Dimensional Models of Emotion	39
Attentional Effects of Emotion	40
Activational Effects of Emotion	43
Time Perception for Complex Emotional Images	44
Time Perception for Emotional Facial Expressions.....	49
Repetition Effects of Emotional Stimuli	50
Study 1: Methodology for Studying Time Perception	53
Study 1 Goals.....	54
Method	55

Participants.....	55
Apparatus.	56
Stimuli.	56
Procedure.	63
Results.....	64
Temporal bisection.....	65
Analog Scale.....	71
Reproduction.	74
Discussion	76
Analog scale and reproduction.....	76
Temporal bisection.....	77
Carry-over effects of emotion.	78
Scalar timing.....	80
Study 2: The Effect of Duration Range.....	82
Absolute or Proportional Effects of Emotion	83
Attentional effects of emotion on an attentional gate.....	83
Attentional effects of emotion on an attentional switch.....	84
Activational effects of emotion.....	84
Study 2 Goals.....	87
Method	88
Participants.....	88
Apparatus.	88
Stimuli.	88
Task.....	88
Procedure.	89
Results.....	89
Short duration range.....	91
Middle duration range.....	95
Long duration range.....	98
Weber ratios.....	101
Discussion	103
Emotion effects in the short duration range.....	103
Dynamic effects of emotion.....	104
Temporal sensitivity and scalar variance.	105
Sex effects.	108
Effect sizes and the between-subjects design.	109

Study 3: Arousal and Valence as Within-subjects Variables	111
Study 3 Goals.....	112
Method	113
Participants.....	113
Apparatus.	113
Stimuli.	113
Task	113
Procedure.	114
Results.....	114
Short duration range.....	119
Middle duration range.....	123
Long duration range.....	127
Weber ratios.....	132
Discussion	133
Dynamic effects of emotion.....	134
Temporal sensitivity and scalar timing.....	136
Complex stimuli vs. facial expressions	138
Study 4: Time Perception for Emotional Facial Expressions	139
Study 4 Goals.....	139
Sex Congruency Effects.....	140
Method	141
Participants.....	141
Apparatus.	141
Stimuli.	141
Task	141
Procedure.	142
Results.....	144
Short duration range.....	147
Middle duration range.....	151
Long duration range.....	155
Weber ratios.....	159
Discussion	160
Time perception for facial expression in the short range	160
Dynamic effects of emotion on time perception for facial expressions	163
Temporal sensitivity	164

General Discussion.....165

References.....179

Appendix A.....195

Appendix B.....201

Appendix C209

Appendix D.....216

List of Figures

Figure 1. The Scalar Expectancy Theory model of timing.....	21
Figure 2. Activational and attentional effects on the components of the internal clock.....	26
Figure 3. Example of an analog scale used to report time estimates.....	28
Figure 4. Proportional and absolute effects of emotion on $T_{\text{corrected}}$ values in classical timing tasks.....	30
Figure 5. Effects of underestimation and overestimation on the proportions of long responses and point of subjective equality.....	35
Figure 6. Stimuli, emotion design, time estimation task, and stimulus durations used in each study.....	52
Figure 7. Example images from the International Affective Picture System.....	60
Figure 8. Study 1, temporal bisection task: proportions of long responses for emotional and neutral trials as a function of stimulus duration	68
Figure 9. Study 1, temporal bisection task: mean point of subjective equality for emotional and neutral trials	69
Figure 10. Study 1, analog scale task: mean duration estimates for emotional trials as a function of stimulus duration.....	71
Figure 11. Study 1, analog scale task: mean $T_{\text{corrected}}$ values for emotional trials as a function of stimulus duration	73
Figure 12. Study 1, analog scale task: mean $T_{\text{corrected}}$ values for male and female participants as a function of stimulus duration. Results are collapsed across trial type (emotional and neutral).....	73
Figure 13. Study 1, analog scale task mean $T_{\text{corrected}}$ values for emotional and neutral trials as a function of stimulus duration. Results are collapsed across all arousal/valence conditions	74
Figure 14. Study 1, reproduction task: mean duration estimates for emotional trials as a function of stimulus duration.....	74
Figure 15. Study 1, reproduction task: mean $T_{\text{corrected}}$ values for emotional trials as a function of stimulus duration.....	75
Figure 16. Predictions of attentional effects of emotion on an attentional gate, attentional effects of emotion on the switch, and activational effects of emotion on the pacemaker.....	85

Figure 17. Study 2, 400 to 1600ms: proportions of long responses for emotional and neutral trials as a function of stimulus duration.....	92
Figure 18. Study 2, 400 to 1600ms: mean point of subjective equality for emotional and neutral trials	93
Figure 19. Study 2, 400 to 1600ms: mean difference limen for emotional and neutral trials for male and female participants.....	94
Figure 20. Study 2, 1000 to 4000ms: proportions of long responses for emotional and neutral trials as a function of stimulus duration.....	96
Figure 21. Study 2, 1000 to 4000ms: mean point of subjective equality for emotional and neutral trials	97
Figure 22. Study 2, 1000 to 4000ms: mean point of subjective equality for emotional and neutral trials separated according to valence for male and female participants.....	97
Figure 23. Study 2, 2000 to 8000ms: proportions of long responses for emotional and neutral trials as a function of stimulus duration.....	99
Figure 24. Study 2, 2000 to 8000ms: mean point of subjective equality for emotional and neutral trials.....	100
Figure 25. Study 2, 2000 to 8000ms: mean point of subjective equality for emotional and neutral trials separated according to valence for male and female participants	100
Figure 26. Study 2: mean Weber ratio for emotional and neutral trials of each duration range	102
Figure 27. Study 3, 400 to 1600ms: proportions of long responses for emotional trials as a function of stimulus duration.....	120
Figure 28. Study 3, 400 to 1600ms: mean dPSEs.....	121
Figure 29. Study 3, 400 to 1600ms: mean dDLs	122
Figure 30. Study 3, 1000 to 4000ms: proportions of long responses for emotional trials as a function of stimulus duration.....	124
Figure 31. Study 3, 1000 to 4000ms: mean dPSEs	125
Figure 32. Study 3, 1000 to 4000ms: mean dDLs	126
Figure 33. Study 3, 2000 to 6000ms: proportions of long responses for emotional trials as a function of stimulus duration.....	128
Figure 34. Study 3, 2000 to 6000ms: mean dPSEs	129

Figure 35. Study 3, 2000 to 6000ms: mean dPSEs for male and female participants.....	130
Figure 36. Study 3, 2000 to 6000ms: mean dDLs	131
Figure 37. Study 3, 2000 to 6000ms: mean dDLs for male and female participants.....	132
Figure 38. Study 3: mean dWRs for all duration ranges	133
Figure 39. Example images from the Karolinska Directed Emotional Faces	143
Figure 40. Study 4, 400 to 1600ms: proportions of long responses for emotional trials as a function of stimulus duration.....	148
Figure 41. Study 4, 400 to 1600ms: mean dPSEs.....	149
Figure 42. Study 4, 400 to 1600ms: mean dDLs	150
Figure 43. Study 4, 1000 to 4000ms: proportions of long responses for emotional trials as a function of stimulus duration.....	152
Figure 44. Study 4, 1000 to 4000ms: mean dPSEs	153
Figure 45. Study 4, 1000 to 4000ms: mean dDLs	154
Figure 46. Study 4, 2000 to 6000ms: proportions of long responses for emotional trials as a function of stimulus duration.....	156
Figure 47. Study 4, 2000 to 6000ms: mean dPSEs	157
Figure 48. Study 4, 2000 to 6000ms: mean dDLs	158
Figure 49. Study 4: mean dWRs for all duration ranges.	159

The effect of emotion on time perception for complex visual stimuli

Making duration estimates is a recurrent part of everyday life. Processing durations in the seconds-to-minutes range, referred to as interval timing, is thought to underlie many important behaviours in humans and animals (Matell & Meck, 2000). A large number of our daily activities, such as crossing a busy street or playing sports, require precise temporal information processing, and while humans can often produce accurate estimates without the use of a watch or clock, our subjective sense of time is easily influenced by emotion. For example, consider how some emotionally charged events such as car accidents can appear to be happening in slow motion while others can appear to fly by.

Emotions can both capture attention (Lundqvist & Öhman, 2005; Öhman, Flykt, & Esteves, 2001) and increase physiological activation (Russell & Mehrabian, 1977). Given that models of time perception predict opposite effects of attention and activation on duration estimates, it is unclear what effect emotional stimuli should have on time perception. Researchers have tried to answer this question using a multitude of methods. Most recently, the effect of emotional facial expression on time perception has received a growing amount of attention and the findings seem to fit nicely within models of cognitive timing. Still, the perceived duration of more complex emotional stimuli (e.g. a picture of a car accident or the sound of a person crying) is under-researched. The handful of studies that have examined how emotional variables affect time perception for complex stimuli have shown mixed results, and these results are sometimes at odds with cognitive models of time perception. It is likely that these conflicting data were obtained because the studies in question used different time estimation tasks, durations, experimental designs, or stimuli. These results highlight the need for a systematic and comprehensive study of how emotional factors can influence timing mechanisms and distort our sense of time. The goal of the present thesis is to conduct this systematic assessment of the effect of affective variables on time perception for visual stimuli through a series of four studies.

In the first study, three time estimation tasks will be compared in order to determine which are sensitive to emotion effects. Two key emotional dimensions

– arousal and valence – will be manipulated to systematically test the effect of emotion on time perception for complex visual stimuli. In the second study, the effect of visual emotional stimuli on time perception will be compared across three duration ranges. Study 3 will adopt a within-subjects design similar to the one used in recent research on emotional facial expression in order to assess the mechanisms through which complex emotional stimuli change our subjective feeling of the passage of time. Finally, the fourth study will use the same design as Study 3 but using emotional facial expressions as stimuli, in order to provide a direct comparison between the effects of complex emotional scenes and emotionally charged facial expressions on time perception.

It is important that any research on the perceived duration of emotional stimuli be situated firmly within our theoretical understanding of time perception itself. Therefore, before broaching the topic of how emotions may affect our sense of time, the following sections will review our current understanding of time perception. Models of cognitive timing will be discussed in order to show how they were modified and ultimately combined to form today's leading model of human time perception.

Prospective and Retrospective Time Estimation

Time estimates can be made with or without prior knowledge. In what has been coined a *prospective* duration judgement, participants know that they will be asked to estimate a duration (Zakay & Block, 1997). Conversely, participants in a *retrospective* time estimation paradigm are not made aware that they will have to estimate the length of an experienced time interval (Zakay & Block, 1997). In both cases, the estimates are made *after* exposure to a target duration. Prospective and retrospective time estimation both involve making a duration estimate for an interval of time that has already passed (interval timing). This is different from situations in which one is asked to predict duration; the focus of the present thesis is on interval timing as opposed to judging how long an event that has yet to occur will take. Prospective duration judgements offer the advantage that participants can make estimates for multiple stimuli, whereas most retrospective studies can only collect one time estimate per participant because participants become aware of the temporal

aspect of the task after the first estimate is requested. Under prospective conditions, subjects focus their attention on time and accumulate important temporal information. Under retrospective conditions, however, subjects make a duration judgement based on information stored in memory, and recall events that occurred during the target duration to infer its length. Therefore, different cognitive processes likely underlie prospective and retrospective duration judgements.

Attentional Models for Prospective Timing

Many investigators have argued that temporal information processing (attention directed to the passage of time) plays a key role in prospective duration judgements (Casini & Macar, 1997; Macar, Grondin, & Casini, 1994; Zakay, 1989). Thomas and Weaver (1975) proposed an attentional model of timing in which task demands determine how much attention is divided between two processors: a temporal one and a non-temporal one. Given their suggestion that drawing attention to non-temporal information limits the amount of attention available to process temporal information, Thomas and Weaver posited the existence of a common pool of attentional resources. Subsequent studies supported the idea that the more attention is directed toward non-temporal information processing (such is the case when task demands are high) the less attention is available for the temporal processor. For example, Macar, Grondin, and Casini (1994) told participants which percentage of their attention to direct to the temporal aspect of a word and time estimation task, and which percentage to allocate to its non-temporal aspect (e.g. 25% to duration and 75% to the word task). It was found that duration judgements shortened as the amount of attention devoted to time diminished. The predictions of the attentional model, however, only hold under prospective conditions, in which participants know in advance that they will be asked to make duration judgements. In contrast, there is evidence that under retrospective conditions, subjective durations increase with the quantity and complexity of non-temporal information processing (Ornstein, 1969). Time estimation using a retrospective paradigm is thus best described using memory-based models of timing.

Memory-based Models for Retrospective Timing

Retrospective time estimation requires an explicit reasoning process likely involving recall (Zakay & Block, 2004). It has been proposed that these judgements depend on the retrieval of contextual information that was encoded with the event information. Memory-based models of cognitive timing are thus preferred to explain unanticipated duration judgements. These models suggest that retrospective time estimates are not timed but rather, deduced using information stored in memory. Intervals for which more events can be recalled feel longer than intervals for which few events are remembered. In the *storage size model*, time judgements are relative to how much information is processed during an interval; the greater the amount of information and its complexity, the larger the size of the memory storage and hence, the longer the duration judgement (Ornstein, 1969; Thomas & Brown, 1974; Vroom, 1970). This model was criticized for relying on vague concepts that cannot be measured (Block, 1990). The *contextual change model* proposes that judgements are correlated with the number of changes in cognitive context happening during a target interval (Block, 1978, 1989). Remembered durations increase as a function of the number of contextual changes stored in memory and available for retrieval. Changes can be environmental variations, modifications in cognitive strategies, or alterations of mood state (Block & Reed, 1978). Finally, the *segmentation model* is an elaboration of the contextual change model. It proposes that duration judgements reflect the number of segmentations (by high priority events or contextual changes) that took place during a target interval. A high number of segmentations would thus lead to a longer duration judgement than would an interval with little segmentation, perhaps because the segmentation is seen as a contextual change (Poynter, 1989; Poynter, 1983).

A Dual-process Contingency Model

A theoretical difficulty arises because, for prospective time judgements, greater complexity predicts shorter time estimates but for retrospective time judgements, greater complexity predicts longer time estimates. This dissociation led theorists to develop two sets of models to explain these as two independent processes. Zakay (1993) attempted to solve the problem instead by creating the

dual-process contingency model – a comprehensive model that could account for both attention-based and memory-based duration judgements. The model is “contingent” given that different weights can be assigned to two processors; a timer, and a memory-based processor. The duration judgement process either selects only one source of information or integrates from two sources. In a prospective task, when one is attending to time, judgements are dominated by the timer. However, in a retrospective task, judgements would be dominated by the memory-based processor. The dual-process contingency model thus eliminated the need for separate timing models for prospective and retrospective duration judgements.

According to the dual-process contingency model (Zakay, 1993) duration judgements also depend at least in part on the measurement method used, and no single method can claim to be consistently better in terms of accuracy. Zakay considered two types of duration judgements: absolute and relative. An absolute duration judgement involves comparison of a target interval with an internal subjective time unit but without referring to another external interval. Conversely, in a relative duration judgement, another interval serves as a standard to which a target interval is compared. The two methods require different memory processes: in the relative method, a representation must be retrieved from long-term memory whereas with the absolute method, there is no need for retrieval from long-term memory. Therefore, relative and absolute duration judgements assign different weights to the timer and memory-based processes. Zakay asked participants to provide time estimates under all combinations of retrospective/prospective and absolute/relative conditions using intervals of 12 and 15 seconds. The results showed support for the dual-process contingency model, particularly for situations in which time estimates were mostly based on information from a single processor (e.g. prospective absolute time estimates, which are based on information from the timer but not the memory-based processor). Results were more variable (and not as easily predicted by the model) when duration estimates required that information be drawn from both processors (e.g. retrospective absolute time estimates, which require access to both the timer and memory-based processor).

Although the dual-process contingency model helped resolve some contradictions found in the duration judgement literature and provided a framework for future time estimation research, it could not explain exactly how weight is assigned to each of the two processors. Zakay (1993) proposed that the contribution of each processor to the duration judgement depends on retrievability (ease of retrieving information from a specific process) and attentiveness (a function of the degree of attention allocated to a processor at the time of the target interval and judgement making). A few years later, however, Zakay and colleague Richard Block would make an important contribution to what is now the most widely-used cognitive model of interval timing by incorporating the role of attention described in the dual-process contingency model to the model known as Scalar Expectancy Theory (Zakay & Block, 1996).

Scalar Properties of Timing

Today's predominant model of cognitive timing (Scalar Expectancy Theory) is largely based on the work of Treisman (1963). At the time, an important question in the field of timing was whether timing behaviours exhibit two properties that have been observed in a number of sensory qualities such as weight changes, light intensity, sound frequency, etc. These two properties, known as the *scalar properties*, are mathematical relationships that link certain stimulus characteristics (e.g. intensity) to measurable changes in behaviour (e.g. perception of change). The first scalar property is the *mean accuracy property*. For timing behaviours, mean accuracy is the requirement that time estimates vary linearly with the duration being timed. To conform to this property, mean duration judgements must increase linearly with real time. To be deemed scalar, however, time estimates need to also conform to a second property known as the *scalar property of variance* or *scalar variance* (Wearden & Lejeune, 2008).

Scalar variance is defined as conformity to a linear form of Weber's law. Weber's law is a psychometric principle that states that the smallest amount of change in the magnitude of a stimulus needed to produce a noticeable difference is proportional to the original stimulus (Grondin, 2010). Weber's law may thus be expressed as:

$$\Delta\phi = c\phi$$

in which ϕ is the magnitude of a constant stimulus, $\Delta\phi$ is the just noticeable difference, and c is a constant. Accordingly, the ratio between $\Delta\phi$ and ϕ is also a constant (Grondin, 2010). If scalar variance holds for time, duration judgements should be proportional to the length of the duration being timed and the standard deviation of duration judgements should grow proportionally to the interval being timed (Treisman, 1963). There are three ways of testing the scalar property of variance (Wearden & Lejeune, 2008). The method to use depends on the time estimation task. The first method is to calculate the coefficient of variation (CV) of each stimulus duration (t):

$$\text{Coefficient of variation (CV)} = \frac{s}{m}$$

in which s is the standard deviation and m is the mean duration estimate for duration t . For the scalar property of variance to hold, CV s need to remain constant across different values of t . The second method is to perform a regression analysis of s against m . If results conform to the scalar variance property, the regression should yield a linear function with a high r^2 . The third method uses a measure called the Weber ratio to test for scalar variance across multiple duration ranges. Because this method is specific only to certain types of time estimation tasks, the mathematics of the test for scalar variance using Weber ratios will be explained after time estimation tasks have been presented (p.36).

A series of experiments conducted by Treisman (1963) established that Weber's law holds for time. Scalar variance for interval timing is an important characteristic that shaped models of time estimation. The scalar properties of timing have since been observed in a large number of studies with both animal (e.g. Dews, 1970; Gibbon, 1977; for a review, see Lejeune & Wearden, 2006) and human subjects (for a review, see Wearden & Lejeune, 2008). Although there are reports of violations of the scalar properties, a review by Lejeune and Wearden (2006) explains that the reported violations are not at odds with the idea that timing mechanisms operate in a scalar fashion. Instead, Lejeune and Wearden were able to demonstrate that studies that fail to show *empirical scalar timing* – behaviours that directly conform to both scalar properties – still show *theoretical scalar timing*. Theoretical scalar timing is the situation in which

“additional processes” cause time estimates to violate one or both scalar properties (Lejeune & Wearden, 2006). In other words, it is now well-established that timing mechanisms are scalar and that without additional sources of variance, time estimates conform to the scalar properties.

Scalar Expectancy Theory

Gibbon (1977) and colleagues (Church, 1984; Gibbon, Church, & Meck, 1984) developed what is now the leading model of cognitive timing: Scalar Expectancy Theory, or SET. The model was directly based on Treisman’s (1963) work showing that timing behaviours conform to the scalar properties, and on a multi-component internal clock model he proposed. In fact, the main difference between SET and Treisman’s model (Treisman, 1963; Wearden, 2005) was application rather than structure (see Wearden, 2005). Treisman’s model was developed to describe data obtained from human subjects, whereas Gibbon, et al. (1984) were looking to build a model that could account for a large amount of data on both human and animal timing. The SET model, which is illustrated in Figure 1, has three components: clock, memory, and decision (Church, 1984; Gibbon, 1977; Gibbon et al., 1984). The clock module consists of a pacemaker that emits pulses over time and an accumulator responsible for keeping track of the number of pulses emitted. The number of accumulated pulses ultimately guides duration estimates, with a larger number of pulses leading to longer duration estimates (i.e. one feels like more time has passed). Thus, when the rate of the pacemaker increases, more pulses are emitted and durations are overestimated; conversely, factors that reduce the speed of the pacemaker lead to shorter duration estimates.

There is evidence that organisms can “start” their internal clock at the beginning of an important event or stimulus (Meck & Church, 1984; Zakay, 2000). SET and other models of scalar timing posit the existence of a switch located between the pacemaker and the accumulator (Figure 1). At the beginning of an interval or upon some other start signal, the switch closes, which allows the pulse stream to reach the accumulator. At the end of the interval, the switch opens, ending the flow of pulses into the accumulator. The delay between the start of an interval to be timed and the closure of the switch is known as the

switch closure latency. Longer switch closure latencies result in fewer pulses flowing into the accumulator. The delay between the closure of the switch (to mark the start of the timing process) and its reopening (at the end of the interval to be timed) is known as the switch opening latency. The longer the switch opening latency, the more pulses can flow into the accumulator. In other words, the amount of time for which the switch is in the closed position dictates the perceived length of the interval, with longer closures producing the feeling that more time has passed.

Once the switch has reopened, the raw material (pulses) contained in the accumulator is transferred to the memory component of the SET model (see Figure 1). This component has two parts: a working memory store to which the accumulator transfers the pulse count, and a reference memory store, which contains labels in clock units that correspond to pulse counts. To make a duration judgement, the decision module compares the pulse count from working memory to those stored in reference memory, and provides the answer in clock units if necessary. For example, to reproduce an interval, one compares a time value stored in long-term memory to the on-going count of time units in the accumulator until a match is found and a response can be made.

The components of the SET model operate independently, meaning that different variables can have an impact on specific components (Church, 1984). Objective physiological arousal and attention are two factors that have been shown to alter the sense of subjective time by influencing the functioning of the internal clock. Given that this thesis is concerned with the impact of emotional stimuli on time perception, and that emotions are both physiologically arousing (Russell & Mehrabian, 1977) and capture attention (Lundqvist & Öhman, 2005; Öhman et al., 2001), it is important to discuss the specific effects of these two factors on SET components.

Figure 1. The Scalar Expectancy Theory model of timing (adapted from Church, 1984).

Activation and the Speed of the Pacemaker

Objective arousal is defined as a state of physiological activation thought to be linked to the *intensity* of motivational behaviours and engagement (Bradley, Codispoti, Cuthbert, & Lang, 2001). To avoid confusion with subjective arousal, which will be discussed later, objective arousal will from now on be referred to as *activation*. There is a large literature showing a link between activation and the speed of the pacemaker (Penton-Voak, Edwards, Percival, & Wearden, 1996). When activation levels increase, so does the speed at which pulses are emitted (see Figure 2). Increased activation thus leads to a larger number of pulses being accumulated, which in turn leads to longer duration estimates (i.e. one feels like more time has passed). Activation can be manipulated in a number of ways. For instance, the speed of the pacemaker increases when body temperature rises above normal, which means that durations are overestimated when one's body temperature is elevated (i.e. one feels like more time has passed; Fox, Bradbury, & Hampton, 1967; Hoagland, 1933; Wearden & Penton-Voak, 1995). Conversely, the speed of the pacemaker decreases and durations appear shorter when body temperature dips below the norm (for a review of body temperature and subjective time, see Wearden &

Penton-Voak, 1995). Another way to manipulate activation levels is to administer stimulant drugs. Studies show that animal subjects make longer duration responses (overestimation of time) when under the influence of amphetamines (for a review see Meck, 1996). Taken together, these studies show that increases in activation lead to a lengthening of subjective time, and thus yield longer duration estimates by speeding up the pacemaker.

Pacemaker effects are proportional with real time, meaning that a pacemaker operating at an increased speed will have a more pronounced effect when timing longer intervals than when timing shorter ones. For example, imagine a pacemaker that is operating at twice its normal speed. If all other components of the SET model are operating normally, the mean accuracy property of scalar timing implies that mean time estimates for a stimulus duration (T_s) should centre around $2T_s$. If $T_s = 6$ seconds, estimates should centre around 12 seconds (an overestimation magnitude of 6 seconds). If, however, $T_s = 10$ seconds, estimates should centre around 20 seconds (an overestimation magnitude of 10 seconds). The magnitude of the overestimation for the longer stimulus duration is larger than that of the shorter stimulus duration. The proportional nature of pacemaker effects can help determine whether distortions in time perception stem from changes in the speed of the pacemaker.

Attention

Attention is another factor known to influence time perception. Although it is now well established that the allocation of attentional resources can have an impact on the functioning of the internal clock, the SET model developed by Gibbon et al. (1984) did not originally factor in the role of attention. It was Zakay and Block (1996; 1997) who incorporated work on attention into the SET model to create the Attentional Gate Model (AGM). The AGM offers an alternative explanation to the simple attentional model proposed by Thomas and Weaver (Thomas & Weaver, 1975). As previously discussed, the simple attention model put forth that the opposing effects of temporal and non-temporal information processing were due to their drawing on a common pool of attentional resources (Thomas & Weaver, 1975). Any amount of attention directed toward non-temporal information drew away from the amount available for processing time.

Although the AGM also posits that attention is divided between external stimuli and time, it does not necessarily assume a limited capacity attentional pool (Block & Zakay, 1997; Zakay & Block, 1996).

The attentional gate

The AGM offers a pacemaker-accumulator clock model equipped with an attention-driven gate. The gate, which is located between the pacemaker and switch, is proposed to open when one attends to time (see Figure 2). The width of its opening can vary as a function of the amount of attention directed to the temporal aspect of the task (Zakay & Block, 1996). The more attentional resources are directed to the passage of time, the wider the opening of the gate, allowing more pulses to pass on to subsequent components such as the switch and the accumulator (Zakay & Block, 1996; Zakay, 2000). Conversely, when attention is directed to non-temporal information, the opening of the gate is narrow, which means that fewer pulses are accumulated, leading to shorter duration estimates (Zakay, 1989, 1992, 1993). In consequence, when attending to a high-demand task or complex stimulus during the interval to be estimated, durations feel shorter (Burle & Casini, 2001; Lejeune, 1998; Zakay, 2005).

Like changes in the speed of the pacemaker, attention effects on the gate are proportional with real time. The direction of the effect, however, is opposite. Stimuli that capture attention *reduce* the number of pulses that flow into the accumulator, and durations are underestimated in a way that is proportional with real time. Take the hypothetical example of an attention-grabbing stimulus that reduces the opening of the attentional gate by half. If all other components of the SET model operate normally and accurately, mean time estimates for stimulus duration T_s should centre around $\frac{1}{2}T_s$ (e.g. mean time estimates for $T_s = 6$ seconds should centre around 3 seconds, and mean time estimates for $T_s = 10$ seconds should centre around 5 seconds).

Attention effects on the switch

While it is agreed that the SET model needs to account for the role of attention on time perception, there is on-going debate about whether it was necessary to append a new component (the gate). Zakay (2000) believes that a new structure is necessary, but Lejeune (1998) argues that the functional

characteristics of the attentional gate can instead be ascribed to the switch that is already part of the SET model (see Figure 2). The AGM posits that both a switch and a gate are necessary because they are driven by separate systems that operate independently. Zakay suggests that the switch is controlled by perceptual information processing. Its role is to close at the beginning of an interval to be timed, and to reopen at the end of the interval. Although the specific perceptual mechanisms guiding the operation of the switch have not been established, Zakay argues that the closing and opening of the switch is not influenced by attention (Zakay, 2000).

According to a review of the impact of attention on time perception by Lejeune (1998), perceptual information processing and attention are inextricably linked and thus, only one structure is necessary. Lejeune proposed that the SET model can account for the influence of attention on time perception by adopting the notion of an *attentional switch* that closes when one is paying attention to the temporal aspect of an event and opens when attention is directed away from time (Allan, 1979; Meck, 1983). Not only is this more parsimonious than the AGM model, but it also provides a precise mechanism (attention) responsible for the operation of the switch. As outlined in SET, the switch operates in an all-or-none fashion. Lejeune thus posits that changes in the amount of attention devoted to temporal information can cause it to flicker between its open and closed positions (Lejeune, 1998). For example, attention to non-temporal information can delay the closure of the switch, which results in fewer pulses being accumulated. Unlike effects on the AGM's gate, which are proportional with real time, switch effects are theorized to be *absolute*. Therefore, under Lejeune's attentional switch account, the magnitude of attentional effects is independent of the length of the interval being timed. For example, if an attention-capturing stimulus delays the closure of the switch by 1 second, the mean time estimate for stimulus duration T_s should centre around $T_s - 1$. Mean time estimates for $T_s = 6$ seconds should centre around 5 seconds (underestimation of 1 second), and mean time estimates for $T_s = 10$ seconds should centre around 9 seconds (underestimation of 1 second). Thus, the magnitude of the underestimation caused by attention effects on the switch does not vary as a function of the duration being timed.

Switching vs. gating

Whether it is necessary to append a gate to the SET model or not, it remains that inattention to time lowers the number of pulses that reach the accumulator (Lejeune, 1998; Zakay, 2000). A low pulse count in the accumulator produces short time estimates, thus attention-capturing events will seem shorter than those that do not capture attention (Lejeune, 1998; Zakay, 2005; Zakay & Block, 1996). Proportional effects of attention (i.e. greater effects of attention at longer durations) would support the attentional gate account whereas absolute effects of attention (i.e. a constant shift in the time estimations across durations) would be in line with the attentional switch hypothesis.

A study by Burle and Casini (2001) explicitly tested whether attention modulates the closure and opening of an all-or-nothing switch (Allan, 1979; Lejeune, 1998; Meck, 1983) or the width of the opening of an attentional gate (Zakay & Block, 1996; Zakay, 2000). To begin, Burle and Casini created two activation levels by varying the intensity of an external stimulation (auditory clicks). Therefore, the speed of the pacemaker was faster in the high activation level (high click rate) than it was in the low activation level (low click rate). Attention was then manipulated using a dual-task paradigm in which participants had to perform a reaction time task and a time estimation task. Performance on the time estimation task alone was compared to performance in the dual-task condition for both levels of activation. Duration estimates in the dual-task condition were shorter than in the single-task condition, but the magnitude of the effect did not vary according to click intensity. If attention narrows the opening of an attentional gate, it will reduce the number of pulses that can flow into the accumulator. Narrowing of the gate will not, however, stop the flow of pulses altogether. Therefore, the magnitude of the underestimation should vary according to the speed at which pulses are being emitted. Burle and Casini found that the magnitude of the underestimation did not vary according to the level of activation, showing that attention acts in an all-or-nothing fashion (i.e. blocks all pulses from flowing into the accumulator). The results were thus in line with the existence of an all-or-none attentional switch such as the one described by Lejeune. However, as Burle and Casini explain, finding absolute effects of attention consistent with an all-or-nothing switch does not rule out the

existence of an attentional gate. The conclusion that attention effects on time perception are absolute in nature is based on failing to reject the null hypothesis (i.e., failure to find proportional effects). Thus, it is important to note that proportional effects may have been present but were too weak to reach significance.

Figure 2. Activational and attentional effects on the components of the internal clock. Top panel: activation effects on the pacemaker; middle panel: attention effects on the gate; bottom panel: attention effects on the switch.

Time Estimation Tasks

Time perception can be studied using various paradigms, and duration estimates can vary according to task demands (Gil & Droit-Volet, 2011). As outlined in cognitive models of time perception, duration estimates are guided by the clock, memory, and decision components as well as by an attentional switch or gate (Gibbon, 1977; Gibbon et al., 1984; Lejeune, 1998; Zakay, 2000). As the involvement of each component may vary from one time estimation task to another, one could expect different tasks to yield different conclusions about time perception (Gil & Droit-Volet, 2011). The following sections will present different time estimation tasks and discuss the effects of attention and activation on performance in each.

Classical timing paradigms

The majority of time estimation methods can be placed in one of four categories; verbal estimation, reproduction, production, and comparison (Zakay & Block, 1997). Verbal estimation, reproduction, and production tasks are known as *classical timing procedures* (Wearden & Lejeune, 2008). In a *verbal estimation* paradigm, participants are exposed to a target duration and report its perceived length in clock units. Estimates can be given orally, written on paper, or reported using a computer. Reporting on an analog scale is a form of verbal estimation in which participants choose a point along a graduated line depicting clock units (see Figure 3 for an example). This method allows for specific estimation even when the order of estimation is small (seconds or shorter) because tick marks can be placed between time units (e.g. closer to 3 than to 2 seconds; Grondin, 2008). Although verbal estimation can be used to provide specific time estimates, results from analog scale tasks have been found to have much larger variances than other classical timing methods (Angrilli, Cherubini, Pavese, & Manfredini, 1997; Danziger & Du Preez, 1963). Verbal estimation tasks have been proposed to act upon different components of the SET model. For instance, it has been suggested that the attentional demands of the task draw attention away from the passage of time, thus affecting the gate or switch component of the internal clock (Thomas & Weaver, 1975; Zakay & Block, 1996, 1997). Moreover, in order to report their time estimates on an analog scale,

participants must convert their subjective experience of time into clock units, a process which may depend greatly on the comparison module of the SET model (Gibbon, 1977; Gibbon et al., 1984).

Figure 3. Example of an analog scale used to report time estimates. Participants place a mark along the scale (print version) or click along when the scale is displayed onscreen (computerized version).

In a *reproduction* paradigm, participants try to reproduce the duration of a target interval. This is typically done by pressing and holding a button or by tapping the same button twice to indicate the start and the end of the interval. Accuracy in reproduction paradigms is examined by comparing the target and response durations. This paradigm offers the advantage that it requires no mention of clock units in the target and response phases; however, duration reproductions are susceptible to inter-participant differences in motor delays (Droit-Volet, 2010). Variations in the reproduction tasks have also been found to depend on a participant's working memory capacity (Baudouin, Vanneste, Isingrini, & Pouthas, 2006) suggesting that duration estimates are primarily guided by the memory component of the SET model (Gibbon, 1977). Angrilli et al. (1997) found that the reproduction task led to a larger underestimation of durations than the analog scale task also used in their study. They also reported that the variance of reproduction time estimates was three times smaller than the variance of analog scale ratings, which was in line with a study by Danziger and Du Preez (1963).

In the last classical timing paradigm, the *production* paradigm, participants are asked to delimit a time period they believe corresponds to one stated verbally or displayed in the form of a numerical value (e.g. "2 seconds").

They typically perform the time production by pressing a button to mark the start of the duration and another to mark the end (Wearden & McShane, 1988). In what is called the production by waiting method, the start of the duration to be produced is indicated by the experimenter and participants press a button to mark the end of the duration (Gil & Droit-Volet, 2011; Penton-Voak et al., 1996). Like the verbal estimation and reproduction paradigms, production is an absolute estimation method in that it provides investigators with a precise duration response, which can be compared to the target interval. Baudouin et al. (2006) found that unlike reproductions, which are guided by working memory capacities, the production of durations is modulated by the speed of the pacemaker. Given that it requires the production of a duration stated verbally, the production task is not ideal for sub-second durations. For example, it may be difficult for participants to produce an interval of 250ms. Production is better suited for longer intervals ranging from seconds to minutes. The production task is seldom used in studies of sub-second duration ranges, and to date, it has only been used in one study of time perception for emotional stimuli (Gil & Droit-Volet, 2011).

Attention and activation effects in classical timing tasks. In order to determine whether attention or activation effects are present in a classical timing task, as well as to determine which components of the internal clock are influenced by experimental manipulations, two questions need to be answered. Firstly, are durations for emotional images underestimated or overestimated compared to a control condition, and secondly, is the effect absolute or proportional with real time? Classical timing tasks offer the advantage that time estimates can be directly compared to real durations. That is, it is easy to see whether time estimates provided using the analog scale, reproduction, and production tasks are shorter or longer than the duration being timed. To analyse the results, time estimates for each stimulus duration are usually converted to $T_{corrected}$ (Angrilli et al., 1997; McConchie & Rutschmann, 1970; Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007; Treisman, 1963) which are calculated as follows:

$$T_{corrected} = \frac{(T_{estimated} - T_{target})}{T_{target}}$$

$T_{\text{estimated}}$ is the mean duration estimate provided by a participant for a given stimulus duration (T_{target}). $T_{\text{corrected}}$ values thus represent the amount of over- or underestimation as a proportion of the target duration. Negative $T_{\text{corrected}}$ values reflect a true underestimation of time (one believes less time has passed) whereas positive $T_{\text{corrected}}$ values are reflective of an overestimation. Figure 4 shows the four scenarios that can result from the combination of the direction of emotion effects (underestimation or overestimation) with the mathematical nature of emotion effects (absolute or proportional with real time) assuming accurate time estimation for neutral stimuli. $T_{\text{corrected}}$ values are plotted as a function of stimulus duration. It should be noted that because $T_{\text{corrected}}$ values are relative measures that express the amount of underestimation or overestimation as a proportion of the target duration, proportional effects of emotion will produce linear functions.

Figure 4. Proportional and absolute effects of emotion on $T_{\text{corrected}}$ values in classical timing tasks.

Proportional underestimation. Underestimation of emotional stimuli points to an attentional effect of emotion, that is, it suggests that emotional stimuli diverted attention away from the passage of time more than did the neutral stimuli. If the effect is proportional with real time, (e.g. if the magnitude of the underestimation increases with stimulus duration) it can be inferred that emotion narrowed the opening of an attentional gate (Figure 4, top left). Statistically, attentional effects of emotion on the gate would cause a significant effect of trial type (emotional vs. neutral) that does not interact with stimulus duration. That is, the duration of emotional images would be underestimated compared to the duration of neutral images and the amount of underestimation would be a constant proportion of the stimulus duration.

Absolute underestimation. If the underestimation of emotional stimuli is absolute (i.e. if the amount by which the duration of emotional trials is underestimated does not vary according to the duration being timed) emotional stimuli are posited to have delayed the closure of an attentional switch. When plotting $T_{\text{corrected}}$ values against stimulus duration, results would look like the bottom left panel of Figure 4 (assuming accurate time estimation for neutral stimuli). Statistically, the attentional effect of emotion on the switch would lead to a significant interaction between stimulus duration and trial type (emotional or neutral), and lower $T_{\text{corrected}}$ values for emotional images than for neutral ones.

Proportional overestimation. Contrary to the underestimation of stimuli that attract attention, the duration of stimuli that increase activation (thereby increasing the speed of the pacemaker) is overestimated. Pacemaker effects are proportional with real time. Thus, if the speed of the pacemaker is faster for emotional stimuli than for control stimuli, the magnitude of the overestimation should increase proportionally with stimulus duration (Figure 4, top right). Proportional overestimation is characterized by a significant overestimation of emotional trials (higher $T_{\text{corrected}}$ values) compared to neutral trials as well as the absence of a Trial Type X Duration interaction.

Absolute overestimation. The last panel of Figure 4 (bottom right) shows the scenario of absolute overestimation of emotional stimuli compared to neutral stimuli. This scenario shows a significant interaction between trial type and duration in which the $T_{\text{corrected}}$ values of emotional stimuli are higher than

the $T_{\text{corrected}}$ values of neutral stimuli. This is an unlikely scenario because it is at odds with both attentional and activation effects of emotion. Attentional effects of emotion would lead to underestimation rather than overestimation and activational effects should be proportional with real time (Droit-Volet, Fayolle, & Gil, 2011). To date, no studies report finding absolute overestimation of emotional stimuli using an analog scale, a production, or a reproduction task. There are, however, studies that found this particular pattern using a different task (temporal bisection, which will be discussed in a later paragraph), hence why this scenario is presented here (Gil & Droit-Volet, 2011; Grommet, Droit-Volet, Gil, Hemmes, Baker, & Brown, 2011). In both studies, it was mentioned that proportional effects of emotion may have been present but too weak to be detected statistically.

Scalar timing violations in classical timing tasks. Although classical timing procedures have been used in numerous studies of animal and human time perception, some problems with these methods have been identified. For instance, time estimates from the verbal estimation task often violate the scalar property of variance by showing smaller CVs at longer stimulus durations than at short ones (Wearden, 1999; Wearden & Lejeune, 2008). An explanation for this unusual pattern of variance has not been found. Another problem with the use of classical timing procedures in human time perception research is that they often yield results that violate the mean accuracy of scalar timing. Indeed, classical tasks commonly show a deviation from linear timing known as a form of Vierordt's Law (Wearden & Lejeune, 2008). This strange violation is characterized by disproportionately long estimates (the feeling that more time has passed) for the shortest stimulus durations that become disproportionately short (the feeling that less time has passed) as stimulus durations increase. In other words, short stimulus durations are overestimated whereas longer stimulus durations are underestimated. Vierordt-like effects, which have been reported in the verbal estimation, reproduction, and the production task, are most often observed when participants do not receive feedback on their duration judgements. It was initially believed that Vierordt-like effects surfaced when participants used a counting strategy to perform the time estimation task, but Wearden (2003) confirmed the presence of Vierordt-type effects in the

reproduction task even when stimulus durations are too short to be counted. He offered an explanation for the violation of the mean accuracy property in the reproduction task which revolves around the motor requirement of this task. Although outside the scope of this thesis, Wearden's explanation suggests that even in the presence of Vierordt-like effects, data still conform to theoretical scalar timing, that is, the underlying timing mechanism operates in a scalar fashion despite not producing scalar timing behaviours. Given that it depends on the motor aspect of the task, Wearden's suggestion cannot be extrapolated to explain Vierordt-like effects in the production and verbal estimation tasks. There is surprisingly little research on the cause of the deviations from the mean accuracy property for classical tasks, perhaps because recent time perception research has favoured the use of timing tasks that do not typically produce unexplained violations of scalar timing. Indeed, current studies of human time perception have favoured tasks from the time estimation paradigm known as *comparison* (Droit-Volet, Brunot, & Niedenthal, 2004; Effron et al., 2006; Effron, Niedenthal, Gil, & Droit-Volet, 2006; Grommet et al., 2011; Smith, McIver, Di Nella, & Crease, 2011; Tipples, 2008).

Comparison paradigms

In a *comparison* paradigm, participants compare a target duration to one or more standard durations. One such task is temporal generalization, in which participants first learn to recognize an anchor duration and must then report whether stimulus durations are shorter or longer than the anchor. Alternatively, participants can be trained to recognize a pair of durations known as the short and long anchor durations and must then report whether stimulus durations were closer to the short or long anchor. This method, called *temporal bisection*, is often used for its ability to attribute variance in duration judgements to specific components of the SET model (Allan & Gibbon, 1991). Unlike classical timing procedures, temporal bisection has been shown to yield scalar results (Wearden & Lejeune, 2008). This task was first developed for use in animal studies by Church and Deluty (1977). Today, it is widely used in both animal (e.g., Machado & Keen, 1999; Machado & Arantes, 2006) and human studies of time perception (e.g. Droit-Volet et al., 2004; Effron et al., 2006; Grommet et al.,

2011; Smith, Harper, Gittings, & Abernethy, 2007; Smith et al., 2011; Tipples, 2008). Given its prevalence, the temporal bisection task and how to interpret its results will be discussed in detail.

Temporal bisection

The temporal bisection task was developed to test the predictions of internal clock models of timing (Church & Deluty, 1977). This procedure has been used for various signal lengths (from milliseconds to seconds) and across different modalities (e.g. visual, auditory). With human subjects, it is generally administered by means of a computer and participants key in their answers on a keyboard or response box. In the training phase of a temporal bisection task, participants learn to discriminate between two signals of different lengths referred to as the short and long anchor durations. In the test phase, participants are presented with stimuli of varying durations. Stimulus duration can be equal to either one of the anchors or to an intermediary length. Following each stimulus presentation, participants indicate whether its duration was closest to the short or long anchor signal.

Proportions of long responses

Results are analysed by plotting the proportions of “long” responses as a function of stimulus duration. The response curve takes the shape of a cumulative form of the normal distribution (see Figure 5). To conform to the mean accuracy property of scalar timing, proportions of long responses need to increase monotonically with stimulus duration. Temporal bisection offers the advantage that results nearly always conform to the mean accuracy property. Shifts or translations of the response curve (the psychophysical function) provide information about the effect of the independent variables. In the study of timing, curve-shift paradigms offer an advantage over simple measures such as response time, given that simple measures can be open to different interpretations (Edmonds, Stellar, & Gallistel, 1974; Meck, 1996). In the temporal bisection task, participants who are overestimating durations produce more “long” responses than participants who are underestimating. This means that for a given stimulus duration, a participant who is overestimating will have a higher proportion of long responses than one who is not. Because this effect is typically

seen at all stimulus durations except anchors (which tend not to show much variance) the response curve for those who overestimate appears “shifted” to the left (see Figure 5). Conversely, the response curve for participants who underestimate durations appears shifted to the right.

Figure 5. Effects of underestimation and overestimation on the proportions of long responses and point of subjective equality.

Point of subjective equality

Leftward or rightward shifts of the psychophysical function can be quantified using the point of subjective equality (PSE). The PSE is defined as follows:

$$\text{Point of subjective equality (PSE)} = d(p = .5)$$

In which $d(p = .5)$ is the duration for which the proportion of long responses is 0.5. In other words, it is the stimulus duration for which participants are equally likely to respond “short” or “long”. To calculate the PSE, the proportions of long responses are first plotted as a function of stimulus duration (see Figure 5). Next, a psychometric function is fitted to the response curve by transforming the proportions of long responses to z-scores. Linear

regression is used to fit a straight line to the central duration points. Finally, the slope and intercept of the regression line are used to find the duration corresponding to the proportion of long responses of 0.5, which is the PSE (Church & Deluty, 1977). Low PSE values signal an overestimation of time, that is, stimuli are perceived to last longer than they actually do. High PSE values, on the other hand, are indicative of an underestimation of time.

Difference limen

The steepness of the response curve is an indication of temporal sensitivity, also referred to as temporal discriminability. It is the degree of discriminability used by participants in order to categorize durations as short or long. Temporal sensitivity is quantified using the difference limen (DL), which represents the smallest amount of change required to shift from answering “short” to answering “long”. Participants with a high degree of temporal sensitivity will produce a very steep psychophysical function and consequently, a low DL. A steep response function points to greater sensitivity than does a shallower (flatter) response function (higher DL). DLs are calculated using the same psychometric function fitted to find the PSEs using the following formula:

$$\text{Difference limen (DL)} = \frac{d(p = .75) - d(p = .25)}{2}$$

In which $d(p = .75)$ is the duration at which participants respond “long” 75% of the time, and $d(p = .25)$ is the duration at which participants respond “long” 25% of the time (Church & Deluty, 1977). With human subjects, temporal sensitivity is closely linked to motivation. An unmotivated or distracted participant may not perform to the best of his ability, leading him to produce a higher proportion of long responses for short durations and a lower proportion of long responses for longer durations than would a motivated participant. This flattens the shape of the unmotivated participant’s response curve, thus leading to a higher DL indicative of poor temporal sensitivity.

Weber ratio and scalar variance

The Weber ratio (WR), which is closely related to the DL, can be used to test whether results from a temporal bisection task conform to the scalar

property (Gibbon, 1977). In time perception experiments, the WR is defined as the DL divided by the PSE¹.

$$\text{Weber ratio (WR)} = \frac{\text{DL}}{\text{PSE}}$$

If results are scalar, the DL should be a linear function of the stimulus duration range. Thus, to test the scalar property, more than one time range must be used. For example, in one range, participants could perform the temporal bisection task for stimulus durations between 400 and 1600ms, and in another, for durations between 1000 and 4000ms. If timing conforms to the scalar property of variance (see p.17 for a discussion) duration judgements should be proportional to the interval being timed (Treisman, 1963). That is, DLs will increase with the duration range, but WRs will remain constant (Church & Deluty, 1977). This test for scalar timing is particularly useful when trying to ascribe effects of certain variables to a specific component of the SET model. For instance, changes in the speed of the pacemaker create effects that are proportional with real time (see p.21). Thus, if a given factor affects time

¹ Early studies using the temporal bisection task found that rats bisect the temporal interval at the geometric mean. Thus, the Weber ratio was first defined by Church and Deluty (1977) as the difference limen divided by the geometric mean:

$$\text{Geometric mean} = \sqrt[n]{x_1 x_2 \dots x_n}$$

in which $x_1, x_2, \dots, x_n$ represent the lengths of each stimulus duration and n is the total number of stimulus durations used. It was later discovered that when the ratio between the short and long anchor durations is large ($\frac{\text{long anchor}}{\text{short anchor}} \geq 4$) the bisection point centers around the arithmetic mean (Kopec & Brody, 2010):

$$\text{Arithmetic mean} = \frac{x_1 + x_2 + \dots + x_n}{n}$$

Yet, in modern studies of the effect of emotion on time perception, the Weber ratio is calculated by dividing the difference limen (DL) by the point of subjective equality (PSE). It should be noted, however, that using the PSE as denominator can be misleading. For example, a non-significant difference in temporal sensitivity between two groups (i.e. equal DLs) could be rendered significant if the two groups have radically different PSEs. Temporal sensitivity analyses should be treated independently from time estimation analyses. Weber ratio analyses in the present thesis were conducted using both the PSE and the arithmetic mean as a denominator. For easy comparison to modern studies, only the results of Weber ratio analyses using the PSE are reported. Unless explicitly noted, PSE and arithmetic mean analyses showed the same results.

perception by changing the speed of the pacemaker (a proportional effect), results should still conform to scalar timing and WRs should remain constant across different duration ranges. When it comes to attention, WRs can be used to delineate between the attentional gate and attentional switch accounts (see p. 25). Attention effects on a gate that widens or narrows as the allocation of attentional resources changes is expected to produce proportional effects, and thus, would not violate scalar timing. The attentional switch account, on the other hand, posits that attention affects the opening/closing of an all-or-nothing switch and that the magnitude of the effect does not vary as a function of the duration being timed. This would result in lower WRs (greater temporal sensitivity) with increasing duration ranges. Accordingly, effects of attention that violate the scalar property of variance point to the attentional switch explanation.

Time Perception for Emotional Stimuli

Given the impact of attention and activation on theoretical models of time perception, it is unclear what effect emotions should have on duration judgements. On the one hand, emotions are physiologically arousing (Russell & Mehrabian, 1977), thus emotional stimuli would be expected to increase the speed of the pacemaker and lead to overestimation of durations. In a given time interval more pulses will be emitted by the pacemaker, so one will feel that relatively more time has passed under conditions of emotional activation and the duration will be overestimated. On the other hand, emotional events are also known to capture attention (Lundqvist & Öhman, 2005; Öhman et al., 2001) and thus may divert attention away from the passage of time. Attentional capture by emotional stimuli should limit the flow of pulses from the pacemaker to the accumulator (by narrowing the opening of the gate or delaying the switch closure) resulting in decreased estimates of duration (i.e. one will feel that relatively less time has passed). Furthermore, attention and activation may act on different timescales, so that different effects may be observed in different duration ranges. The following chapters will discuss the potential effects of emotional variables on attention and activation and their implications for the internal clock.

Discrete and Dimensional Models of Emotion

Emotions can be categorized using two types of frameworks: discrete or dimensional. Discrete models place emotions into distinct categories, such as Ekman's six basic emotions: anger, disgust, fear, happiness, sadness, and surprise (Ekman, 1992). Ekman's model as well as other discrete theories of emotion (e.g. Izard, 2007) typically posit that secondary emotions are the result of the combination of two or more basic emotions (e.g. contempt = anger + disgust). Studies of the impact of emotion on time perception for emotional facial expressions often use stimuli from discrete emotional categories (e.g. angry, happy, and sad faces). These studies will be reviewed on p.49. Proponents of categorical models of emotion find that discrete emotions are particularly functional and easy to relate to real life situations (Izard, 2007). Discrete emotions, which can reliably be identified by adults and children, offer a convenient way to simultaneously describe all the components of a given emotion (e.g. *anger* to describe feelings of frustration that arise when a goal is not met; Izard, Ackerman, Schoff, & Fine, 2000; Izard, 2007). Still, some have argued that the discrete approach has limited scientific value. In a review of discrete emotional models, Barrett (2006) reports that there is accumulating evidence that emotions are not, as is often assumed under the discrete framework, a collection of categories in which each emotion has observable properties that differ from other emotions as well as distinct causal mechanisms.

Perhaps because of the problems associated with discrete emotion models, a large number of studies have taken a dimensional approach to emotion categorization. Dimensional models place emotions along a number of continua. The two dimensions that have been shown to account for the majority of the variance in emotional categorization are subjective arousal and valence (Greenwald, Cook, & Lang, 1989; Lang, Greenwald, Bradley, & Hamm, 1993). Arousal, which can range from low to high, is thought to reflect stimulus intensity (i.e. the degree of motivational intensity produced by the stimulus; Bradley et al., 2001). Valence, which can range from negative (unpleasant) to positive (pleasant), has been linked to the appetitive/defensive motivational system (i.e. the system responsible for producing an approach or withdrawal reaction; Bradley et al., 2001). Emotions are described according to where they

are positioned on these two continua. For example, the discrete emotion of *happiness* would rate highly on the arousal scale and receive a high score on the valence scale (indicating positive or pleasant content). Dimensional models have high scientific value in that emotional space can be parsed in a way that is easy to manipulate, and given that results are more easily generalized to other affective states than is the case with a discrete approach. Moreover, the availability of databases that provide standardized affective material rated for arousal and valence, such as the widely used International Affective Picture System (IAPS; Center for the study of emotion and attention 1995) and the International Affective Digitized Sounds database (Bradley & Lang, 1999) has allowed for the study of the effect of emotion on a multitude of behavioural and cognitive processes.

Attentional Effects of Emotion

An attentional bias for emotional compared to neutral stimuli has been well documented across a number of modalities (e.g. visual, auditory), using various measures (e.g. heart rate, startle reflex) and tasks (e.g. visual search, dot-probe, etc.; for a review, see Yiend, 2010). For instance, visual search experiments in which participants must find an emotional target (e.g. an angry face) amongst an array of distractor stimuli (e.g. neutral faces) have found that positive and negative facial expressions are detected more rapidly, and are more distracting, than neutral faces (Lundqvist & Öhman, 2005). The effect of emotion on picture processing has also been extensively studied using heart rate deceleration, which is known to reflect attentional orienting (Bradley, Cuthbert, & Lang, 1990; Bradley, Cuthbert, & Lang, 1991; Graham & Clifton, 1966). The data show an effect of valence whereby viewing negative images produces more pronounced heart rate deceleration than viewing positive images (Bradley et al., 1990; Hare, Wood, Britain, & Frazelle, 1971). Therefore, heart rate data shows increased attention to negative stimuli compared to positive ones.

More recently, the effect of arousal and valence on attention has also been studied using event-related potentials (ERPs), which are measures of brain activity recorded from the scalp using electroencephalography (EEG). The late positive potential (LPP), a positive-going ERP that arises starting at about 250ms

following the presentation of a stimulus, reflects allocation of attention to the stimulus. For picture stimuli, the LPP was found to be highly sensitive to the emotional nature of the image presented. A larger LPP, indicating greater allocation of attentional resources to the image, was measured following positive and negative stimuli than following a neutral image (Hajcak & Olvet, 2008). The effect of valence on the magnitude of the LPP recorded during picture presentation differed across recording sites. At superior recording sites, the LPP for positive and negative images was larger than the LPP for neutral images, but there was no difference between the LPP for positive and for negative stimuli. At inferior sites, the LPP elicited by negative pictures was greater than the LPP elicited by neutral and pleasant pictures (Hajcak & Olvet, 2008). This increased attention to negative images compared to positive and neutral images is in line with other research showing a bias for negative valence stimuli using the LPP (e.g. Ito, Larsen, Smith, & Cacioppo, 1998) or other ERPs (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Carretié, Mercado, Tapia, & Hinojosa, 2001).

It has been proposed that increased attention to negative stimuli such as threatening images, also known as the negativity bias, is the result of evolutionary processes (Lang, Davis, & Öhman, 2000). It should be noted, however, that some studies have failed to find a bias for negative images in high arousal stimuli. For example, Rozenkrants, Olofsson, and Polich (2008) found that high arousal images produced larger LPPs than low arousal stimuli, regardless of valence. They concluded that arousal, rather than valence, was responsible for increasing attentional resources directed toward emotional stimuli. Another study (published the same year as the study by Rozenkrants et al.) may offer an explanation. Franken, Muris, Nijs, and van Strien (2008) tested the effect of high arousal positive, high arousal negative, and neutral IAPS images on the LPP as well as other ERPs linked to attention. They found that for equal levels of arousal (i.e. equal subjective arousal ratings), high arousal positive and high arousal negative images produce similar increases in the magnitude of the LPP, which were in turn larger than the amplitude of the LPP produced after viewing neutral images (i.e. very low arousal images of neutral valence). Franken and colleagues argued that previous studies that found valence effects

for high arousal stimuli did not use high arousal positive images that were *as arousing* as high arousal negative images. Indeed, the majority of EEG experiment on the effect of arousal and valence used stimuli from the IAPS database, which contains a limited number of high arousal positive images (e.g. erotica) but contains an abundance of high arousal negative (e.g. mutilation), low arousal positive (e.g. kittens), low arousal negative (e.g. bugs), and neutral images (e.g. furniture). For this reason, experiments that require a large number of high arousal positive stimuli tend to also include images of extreme sports (e.g. white water rafting, bungee jumping) that may not be as arousing as erotic scenes or flesh wounds. It is also possible that high arousal images differ in biological relevance. For instance, erotic and most threatening stimuli are biologically relevant, but thrill seeking (as a positive stimulus) is not. Taken together, the above studies suggest that, at least as far as EEG markers of attention are concerned, attention is preferentially directed to negative or highly arousing stimuli compared to other stimuli (i.e. low arousal positive or neutral images).

Another possible explanation for inconsistent findings (e.g. is there a negativity bias or not?) may be the differences in the time course of attentional effects of arousal and valence. Olofsson, Nordin, Sequeria, and Polich (2008) reviewed over 50 studies in which ERPs were recorded while participants viewed picture stimuli that varied in emotional arousal and valence. They grouped their findings into three distinct time windows that follow picture onset: 100-200ms, 200-300ms, and 300ms or more. The 100-200ms time window showed increased attention to negative images compared to positive images (Smith, Cacioppo, Larsen, & Chartrand, 2003) even for high arousal stimuli (e.g. threat or nudity; Carretié et al., 2004; Carretié, Mercado, Hinojosa, Martín-Loeches, & Sotillo, 2004). Thus, in the early stages of picture processing, attention is directed to stimuli of negative valence. Arousal effects whereby attention is directed to arousing stimuli regardless of valence, have been found to start in the 200-300ms time window (Olofsson et al., 2008). ERPs such as the early posterior negativity (thought to reflect the early attentional processes responsible for selecting which stimuli will be processed in priority; Di Russo & Taddei, 2006) show that arousal effects of emotion in the 200-300ms window

happen automatically (e.g. even when many stimuli compete). Arousal effects are proposed to exist so that attention can be directed toward stimuli that have intrinsic value (Schupp, Stockburger, et al., 2006; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). In the longest duration window ($> 300\text{ms}$) attention is preferentially directed to arousing stimuli. Taken together, these studies show that attentional capture by emotional stimuli begins with an early negativity bias that subsides in the 200-300ms window to leave way for arousal effects of emotion whereby arousing stimuli are preferentially attended.

According to the SET model of cognitive timing, stimuli that capture attention reduce the number of pulses that reach the accumulator either by narrowing the opening of an attentional gate or by delaying the closure of an attentional switch (Church, 1984; Lejeune, 1998; Zakay & Block, 1996; Zakay & Block, 1997). The duration of stimuli that capture a large amount of attention is thus judged as being shorter than the duration of stimuli that capture less attention. Given that emotions attract attention, the SET model predicts a relative underestimation of the duration of emotional images compared to neutral images. Moreover, given the attentional bias for high arousal and negative images, these stimuli are predicted to direct more pulses away from the passage of time, hence leading to shorter duration estimates than low arousal positive stimuli.

Activational Effects of Emotion

Contrary to attentional effects, which reduce duration estimates, the SET model predicts that activational effects increase duration estimates. Namely, activation increases the speed of the internal pacemaker, thereby allowing more pulses to reach the accumulator. A larger number of pulses will produce longer duration estimates, hence why increasing activation also lengthens duration estimates (i.e. one feels like more time has passed). The link between activation and overestimation has been shown using a number of manipulations such as increasing body temperature, administering stimulant drugs, or using flickering stimuli (Droit-Volet & Wearden, 2002; Fox et al., 1967; Penton-Voak et al., 1996). For picture stimuli, arousal (i.e. subjective ratings of arousal provided by participants) is highly correlated with autonomic activation (Gavazzeni, Wiens, &

Fischer, 2008; Greenwald et al., 1989; Lang et al., 1993), which in turn has been shown to affect the speed of the pacemaker (Penton-Voak et al., 1996; Wearden & Penton-Voak, 1995).

Activation can be measured using the galvanic skin response, also known as the skin conductance response. Other measures, such as pupil dilation (Bradley, Miccoli, Escrig, & Lang, 2008), have also been shown to correlate with physiological activation, but skin conductance response remains the best index. Increases in skin conductance are representative of increased activation. A number of studies have shown that skin conductivity increases with stimulus arousal, regardless of valence (Lang et al., 1993). Although smaller than the literature on the effect of emotion on attention, the literature on the effect of emotion (particularly arousal) on activation is robust and consistently shows this linear relationship between arousal and activation (Angrilli et al., 1997; Gavazzeni et al., 2008; Greenwald et al., 1989; Lang et al., 1993). Therefore, arousal ratings can reliably be used as indices of activation, with high arousal stimuli causing more activation than low arousal stimuli, which in turn are more activating than neutral stimuli. Given that SET predicts longer duration judgements when activation is high, high arousal stimuli (e.g. images of mutilation or sex) are expected to receive longer duration estimates than low arousal stimuli (e.g. bugs or kitten), which in turn are expected to receive longer duration estimates than neutral stimuli (e.g. chairs or plants).

Time Perception for Complex Emotional Images

Very few studies have examined time perception for complex emotional images. In the first such study, Angrilli et al. (1997) used standardized images from the IAPS (Center for the study of emotion and attention 1995) that varied according to arousal and valence. Images from four emotional image sets; high arousal negative (e.g. a baby with an eye tumour), high arousal positive (e.g. an erotic couple), low arousal negative (e.g. a rat in the dirt), and low arousal positive (e.g. a happy baby), as well as neutral images (e.g. an umbrella) were randomly presented for 2, 4, or 6 seconds. Each emotional set was composed of three images, whereas the neutral set contained six images. Participants were asked to estimate the duration of each image by either placing a mark along a

graduated time scale similar to the one shown in Figure 3 (the analog task) or by reproducing the duration by holding down a button. Angrilli et al. found no main effects of arousal or valence, but a significant interaction of these two factors was observed. For low arousal stimuli, the presentation of duration of negative images was estimated to be shorter than that of positive images. Conversely, high arousal negative images were estimated to last longer than their positive counterparts. Angrilli et al. reported that time estimation values for neutral stimuli were in between those of emotional stimuli, however, neutral images were only included as “fillers” and were excluded from statistical analyses. Therefore it is not possible to know which types of emotional stimuli were significantly underestimated or overestimated relative to neutral stimuli.

To explain the interaction between arousal and valence, Angrilli and colleagues proposed the existence of two different time estimation mechanisms: an attention-based mechanism in low arousal situations and what they called an emotion-based mechanism in high arousal conditions. Although Angrilli et al. did not interpret their results in light of internal clock models of time perception, findings for both high and low arousal conditions can be explained using the SET model. Firstly, Angrilli et al. (1997) proposed that an attention-based mechanism was responsible for the relative underestimation of negative images compared to positive images in the low arousal condition. This conclusion was supported by heart rate recordings. Physiological recordings taken during the experiment showed that negative images elicited cardiac deceleration and positive images accelerated heart rate, showing that negative images attracted more attention than positive images (see also Bradley et al., 1990; Bradley et al., 1991; Graham & Clifton, 1966). According to SET, viewing negative images resulted in a lower pulse count than viewing positive images because attention to non-temporal information prevented or delayed the closure of the switch or narrowed the opening of an attentional gate.

The effect of valence for the high arousal condition, however, was in the opposite direction: the duration of negative images was thought to be longer than the duration of positive images, a result that is inconsistent with attentional effects of emotion. Angrilli et al. (1997) suggested that when arousal is high, time estimates are mainly influenced by an activation-based mechanism.

Although Angrilli and colleagues interpret their findings as an avoidance reaction to negative stimuli, results can also be interpreted in light of the SET model, which would suggest that the duration of high arousal negative images (i.e. a dead cut body, a smashed face, and a baby with a n eye tumour) was overestimated because negative stimuli are more physiologically activating than high arousal positive images (i.e. a naked couple, an erotic couple, and a couple kissing), and thus increased the speed of the pacemaker (Cacioppo & Gardner, 1999; Gibbon et al., 1984; Taylor, 1991). Although the interaction between arousal and valence was robust at all durations, the pattern of effects observed by Angrilli et al. was complicated by a significant interaction of duration and arousal, which did not interact with valence. At the shortest duration (2 seconds) high arousal images were thought to last longer than low arousal images, regardless of valence. However, the relative overestimation shifted to an underestimation in longer durations (4 and 6 seconds). Angrilli et al. hence put forth that a change in timing strategy occurred between 2 and 4 seconds. Specifically, it was posited that activation-based mechanisms guided time estimates in the early phase of processing whereas attention-based mechanisms prevailed for longer durations. Some difficulties in interpreting Angrilli et al.'s findings include the lack of a statistical analysis of time perception for neutral images, the use of classical timing tasks only, and a very small number of stimuli.

To date, the experiment by Angrilli et al. (1997) is one of only two published time perception studies in which both the emotional arousal and valence of visual stimuli were systematically varied. The other, conducted by Smith, McIver, Di Nella, and Crease (2011), also found evidence for dynamic effects of emotion on time estimates. In this study, Smith and colleagues (2011) used images from the IAPS in a temporal bisection task. Participants made duration judgements for images presented between 100 and 300ms, as well as 400 and 1600ms. Arousal and valence were found to have different effects in the short and the long duration ranges. In the short range (100 to 300ms) the duration of high arousal images (both positive and negative) was judged to be significantly shorter than that of low arousal images (positive and negative). Moreover, the duration of high arousal negative images was underestimated in comparison to the duration of all other stimuli. Activational effects of emotion

predict an overestimation of high arousal images compared to low arousal images, which is in stark contrast to what Smith et al. (2011) found. Instead, their results are consistent with attentional effects of emotion whereby high arousal negative images attracted more attention than high arousal positive images, which in turn attracted more attention than low arousal and neutral images. It should be noted that valence effect in this study may be due to differences in arousal for high arousal stimuli. Indeed, statistical analysis of the stimuli used by Smith and colleagues (2011) reveals that high arousal negative images had significantly higher arousal ratings than high arousal positive images. Note that their high arousal positive images included extreme sports but not erotica or nudity, which may explain why high arousal negative images captured more attention.

In the 400 to 1600ms range, the duration of low arousal negative images was underestimated in comparison to that of neutral, high arousal negative, and low arousal positive images. This complex pattern is not easily explained by attentional or activation accounts of time perception. The relative underestimation of low arousal negative images compared to neutral and low arousal positive images points to attentional effects of emotion whereas the underestimation of low arousal negative images compared to high arousal negative images points to activation effects. What is clear is that emotion effects in the long range differed from effects seen in the short range. On the basis of these findings, Smith and colleagues (2011) suggested that different neural structures may be involved in time perception for the 100 to 300ms and 400 to 1600ms ranges.

Although they did not systematically vary stimulus arousal and valence, two more studies tested the effect of emotion on time perception for complex images from the IAPS database. Gil, Rousset, and Droit-Volet (2009) used the temporal bisection task to assess the impact of liked and disliked foods on time estimates. Images of liked and disliked foods as well as neutral images were displayed for 400 to 1600ms. Participants underestimated the duration of disliked food images compared to that of liked foods, which in turn was underestimated compared to the duration of neutral images. These findings are consistent with attentional effects of emotion. However, unlike Angrilli et al.

(1997) and Smith et al. (2011), Gil and colleagues (2009) did not systematically vary emotional arousal and valence. Liked foods, which were positive in valence, were significantly more arousing than disliked foods, which were of negative valence. Thus it is difficult to determine whether emotion effects were due to arousal or valence of the stimuli. Nonetheless, the results were in line with attentional effects of emotion whereby the duration of attention-capturing stimuli (disliked and liked foods) was underestimated compared to the duration of neutral images. The study included only one duration range, so it was not possible to test whether attentional effects were proportional (attentional gate) or absolute (attentional switch).

Grommet and colleagues (2011) used fear-inducing (i.e. highly arousing images of a snake, a bear, and a shark) and neutral images from the IAPS in a temporal bisection task. Participants judged the duration of images presented in two different ranges: 250 to 1000ms and 400 to 1600ms. In both ranges, duration estimates were longer (overestimation) for fear-inducing than for neutral images, a result which is consistent with activational effects of emotion. Given that two different duration ranges were used and that the pattern was consistent across ranges, Grommet and colleagues were able to test whether effects were proportional. They found that although the overestimation suggested increased pacemaker speed when viewing fear-inducing images compared to when viewing neutral images, there was no increase in the magnitude of the overestimation in the long (400-1600ms), compared to the short (100-300ms) duration range. Thus, the findings showed an absolute rather than proportional overestimation of fear-inducing stimuli. Absolute effects are inconsistent with increased pacemaker speeds, and so the authors proposed that fear-inducing images caused the switch to close faster (or stay closed longer) for fear-inducing images than for neutral images. Nonetheless, Grommet et al. also put forth that activation effect may have been present, but too weak to be detected by tests of proportionality. In all, the small literature on time perception for complex emotional images shows a number of inconsistencies and leads to no firm conclusions about the effect of emotion on time perception for complex images.

Time Perception for Emotional Facial Expressions

In contrast to the few studies of complex emotional images, a relatively large number of studies have used facial expressions to test the effect of emotion on time perception (Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Tipples, 2008). Contrary to experiments in which emotional dimensions are manipulated (e.g. arousal and valence; Smith et al., 2011), studies conducted using facial expressions adopt a discrete approach to emotion categorization. Moreover, some authors have proposed that the 2 to 6 second range used by Angrilli et al. (1997) may have been too long to show activational effects (Droit-Volet et al., 2004) and thus, facial expression studies typically use a temporal bisection task with 400 and 1600ms anchor durations. Results of temporal bisection using facial expressions as stimuli are generally in line with activational effects of emotion whereby the duration of arousing expressions is overestimated compared to less arousing expressions or to neutral faces. For example, Droit-Volet et al. (2004) found that the duration of emotional facial expressions (anger, happiness, and sadness) was systematically overestimated in comparison with baseline (neutral) expressions. Similarly, Effron, Niedenthal, Gil and Droit-Volet (2006) also report that the duration of angry and happy faces was overestimated compared to neutral faces (their study did not include sad faces). Tipples (2008), whose study included angry, happy, fearful, and neutral faces, found a significant overestimation of the duration of angry stimuli (deemed to be the “most arousing” expression) compared to all other stimuli. The overestimation of arousing facial expressions is consistent with activational effects of emotion on the speed of the pacemaker. According to SET, stimuli that increase activation also increase the speed at which the pacemaker emits pulses. For a given interval, arousing stimuli will therefore accumulate a larger number of pulses than low arousal stimuli. Although Droit-Volet (2004) and Tipples (2008) both suggest that the overestimation of arousing images was indeed caused by a sped up pacemaker, neither study included a second duration range that would have allowed for the critical tests of proportionality. On the one hand, Droit-Volet et al. were able to show evidence that activational effects can surface when short durations (below 2 seconds) are used. On the other hand, it is hard to make a direct comparison between their findings and those of Angrilli et al.

(1997) given that they used different time estimation tasks. The facial expression literature, which mostly uses comparable stimuli and tasks, is largely consistent with activational effects of emotion. In contrast, the literature on more complex emotional images (e.g. IAPS) shows varied results but often reports attentional effects of emotion.

Repetition Effects of Emotional Stimuli

Although temporal bisection has been the preferred time estimation task in recent studies of the impact of emotional stimuli on time perception (Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Grommet et al., 2011; Smith et al., 2011; Tipples, 2008) it is worth noting that it requires a larger stimulus set than what is needed for classical methods such as analog scale estimation or reproduction, an issue that is often addressed by repeating stimuli throughout the experiment (e.g. Droit-Volet, Brunot, & Niedenthal, 2004). All studies of the effect of emotion on time perception repeat the same stimuli several times throughout the experiment (e.g. Angrilli et al., 1997; Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Smith et al., 2011; Tipples, 2008). While stimulus repetition allows for a large number of trials (which is especially necessary with the temporal bisection paradigm), there are potential problems with this research design. Morel et al. (2009) tested the impact of image repetition on brain activity for fearful, happy, and neutral facial expressions using EEG and magneto-encephalography (MEG). They found that image repetition differentially affected neural responses at three distinct time processing stages (between 40-50ms, near 170ms, and between 280 and 320ms following stimulus onset). In the first stage, the topography of neural activation following repeated images varied according to facial expression. In the middle stage of processing, neural activation was greater for emotional expressions than for the neutral facial expression, but only upon the first presentation of each image. In the third stage of processing, neural activity was enhanced for fear compared to happy and neutral expressions in the first presentation but all facial expressions showed similar activation in subsequent presentations of the stimuli. Similarly, Ishai, Pessoa, Bickle, and Ungerleider (2004) found more dramatic repetition suppression (decreased activation in the cortex with

repeated presentation of a stimulus) for fearful than for neutral facial expressions (see also Ishai, Bickle, & Ungerleider, 2006). In an ERP study of the processing of complex emotional images, Codispoti, Ferrari, and Bradley (2007) found that image repetition differently affected the processing of emotional and neutral IAPS images in the 300 to 600ms time window but not in the 150 to 300ms window. Taken together, electrophysiological studies show that repetition has different effects on stimuli belonging to different arousal and valence categories. Therefore, the results from experiments in which images are repeated may not show the true effect of emotion on time perception. Given that image repetition can modulate emotion effects on time perception for visual stimuli, images in this thesis will only be presented once over the course of each experiment. Figure 6 shows the stimuli, task, and durations used in each study of this thesis. Study 1 compares the effects of emotional arousal and valence on time perception for complex stimuli using three time estimation tasks (analog scale, reproduction, and temporal bisection). Next, the effect of arousal and valence on temporal bisection will be compared across three duration ranges in a between-subjects design (Study 2). In Study 3, arousal and valence will be manipulated within-subjects in three duration ranges. Finally, the within-subjects series of experiments will be repeated using facial expression stimuli instead of complex images.

Figure 6. Stimuli, emotion design, time estimation task, and stimulus durations used in each study. Emotion design indicates whether emotional variables were manipulated between-subjects or within-subjects. IAPS indicates that stimuli were taken from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008). KDEF indicates that stimuli were taken from the Karolinska Directed Emotional Faces (Lundqvist, Flykt, & Öhman, 1989).

Study 1: Methodology for Studying Time Perception

The impact of emotional variables on subjective time has been examined using myriad methods (see p.26) and stimuli (see p.44), thus making it difficult to compare the findings across studies. To that effect, the first study of this thesis compared different approaches used to study time perception and determined which methods are sensitive to the effects of emotional variables. Despite the numerous differences between time estimation tasks, the impact of task on duration estimates for emotional stimuli was not systematically addressed until recently. Gil and Droit-Volet (2011) used five tasks; temporal bisection, generalization, verbal estimation, production, and reproduction, to test the effect of facial expression (angry and neutral) on duration judgements. Gil and Droit-Volet (2011) found that the duration of angry faces was overestimated compared to the duration of neutral faces, but only when using the temporal bisection, verbal estimation, or time production tasks. It was posited that no effects were found in the temporal generalization and reproduction tasks because these two tasks heavily rely on memory processes. This explanation is in line with the findings of Baudouin et al. (2006) who reported that reproductions vary according to individual differences in working memory capacities, because participants need to retain the target duration in order to recreate it. In the temporal generalization task, participants memorize a standard duration (1000ms) to which they subsequently compare seven possible test durations. On each trial, they report whether the test duration was “the same” or “not the same” as the standard duration. Gil and Droit-Volet (2011) posited that memorization of the standard duration reduced the contrast between angry and neutral facial expressions. To address why calling upon memory processes overshadowed emotion effects in the temporal generalization task but not in the similar temporal bisection task, the authors suggest that participants do not make temporal bisection decisions based on standard durations stored in memory. Instead, temporal bisection decisions are made using a criterion duration value that participants adjust as the experiment progresses (Allan, 2002; Gibbon, 1981; Wearden & Ferrara, 1996). Overall, the results of the study by Gil and Droit-Volet (2011) highlight the role of task

differences in time perception experiments and illustrate why it can be difficult to compare time perception performance across different tasks.

In addition to varying time estimation tasks, another factor that makes comparison across different studies difficult is the use of non-standardized material. When emotional stimuli are used to assess the impact of emotion on cognitive activity, it is crucial to verify that the stimuli accurately reflect the intended emotion. In their studies, Angrilli et al. (1997) and Smith et al. (2011) used images from the IAPS (Lang, Bradley, & Cuthbert, 1997), which have been rated for emotional valence and arousal by a large number of participants. They used the IAPS ratings to select five groups of images: highly arousing with negative valence; highly arousing with positive valence; slightly arousing with negative valence; slightly arousing with positive valence; and neutral (non-arousing with neither positive nor negative valence). IAPS images belonging to those categories were also used in Studies 1, 2, and 3 of this thesis.

Study 1 Goals

The primary goal of Study 1 was to test the effect of emotion on duration judgements for complex images using three different time estimation tasks; temporal bisection, which is the task most commonly used in the literature (Droit-Volet et al., 2004; Effron et al., 2006; Gil, Niedenthal, & Droit-Volet, 2007; Gil et al., 2009; Grommet et al., 2011; Smith et al., 2011; Tipples, 2008) as well as the analog scale and reproduction tasks used by Angrilli et al. (1997). Previous studies of emotional time perception have randomly intermixed emotions of different valence and arousal (Angrilli et al., 1997; Droit-Volet et al., 2004; Noulhiane et al., 2007; Smith et al., 2011). Therefore, it can be difficult to delineate any effects of emotional perception that are mediated through effects of emotional state (induced by viewing a number of emotional stimuli), which may well carry over from trial to trial and build up over the course of the experiment. Even without mood induction, it is possible that emotional images may still change how all images (emotional or not) are processed. Some precedence for this sort of emotional context effect comes from the emotional Stroop literature, which shows that the disruptive effect of emotional words on a colour-naming task is only robust when emotion is blocked as opposed to when

valence varies from trial to trial (McKenna & Sharma, 2004). This suggests that, in the context of the emotional Stroop task, emotional interference does not emerge on a trial by trial basis from each stimulus, but it instead builds up over successive trials of a single valence (e.g. negative words). In the context of time perception, it is possible that different types of emotion have different effects on time perception, which may be washed out if different emotions are randomly intermixed. Some have argued that the processing of emotional events differs from the experience of emotion (Davidson, 1992; Heller, 1993) whereas others posit that emotional stimuli only influence temporal perception when internal simulation (embodiment) occurs (Chambon, Droit-Volet, & Niedenthal, 2008; Effron et al., 2006), although of course, both are possible. It is conceivable that viewing a number of emotionally charged images alters basic time perception mechanisms, and so it might influence duration estimates for all images in a block and not just emotional images. Therefore, to eliminate the potential for carry over between emotions, Studies 1 and 2 used a between-subjects design in which participants saw only images belonging to one valence/arousal combination, mixed with neutral trials².

Finally, Study 1 extended previous research by using a large set of *unique* emotional stimuli. Previous studies of emotional time perception have used very small numbers of trials (e.g. 18 trials; Angrilli et al., 1997) and have repeated the same images several times throughout the experiment (e.g. Droit-Volet et al., 2004; Smith et al., 2011). Given that both perceptual and emotional processes are altered with repeated exposure, the use of unique images on each trial is an important experimental design consideration. Emotion effects were tested using images selected from the same database of standardized images used by Smith et al. (2011), Grommet et al. (2011) and Angrilli and colleagues (IAPS database; Lang et al., 1997). Images were presented for 2 to 6 seconds to match the range of durations used by Angrilli and colleagues.

Method

Participants. One hundred twelve first year undergraduate psychology students (63 women and 49 men; age 17-40) from Victoria University of

² Studies 3 and 4 will use a within-subjects design for comparison purposes.

Wellington received course credit for their participation. Age means and ranges for participants in each time estimation task are provided in Table 1 and the number of male and female participants in each emotion group is shown in Table 2. All had normal or corrected-to-normal vision. The study was approved by the School of Psychology Human Ethics Committee at Victoria University of Wellington.

Apparatus. Stimuli were presented using Dell PCs running Psychology Software Tools' E-Prime Suite version 1.0 (Schneider, Eschman, & Zuccolotto, 2002a, 2002b). Pictures (measuring 135.5 X 101.6mm) were viewed on the computers' 17" flat LCD monitors, at a resolution of 1280 x 1024 pixels.

Stimuli. Coloured images were taken from the IAPS (Lang et al., 1997). This database, which has been used extensively in emotion research, consists of photographs depicting scenes or objects that vary in emotional content. Five image groups were defined; high arousal negative (35 images), high arousal positive (35 images), low arousal negative (35 images), low arousal positive (35 images), and neutral (35 images). Arousal and valence rating means and ranges for the selected images are provided in Table 3 (ratings from Lang, Bradley, & Cuthbert, 2008). Example images are shown in Figure 7.

Table 1

Mean Age and Range of Study 1 Participants

	N	Min	Max	Mean	SEM
Temporal Bisection					
Men	18	17	31	19.50	0.85
Women	30	17	40	20.67	0.97
Analog Scale					
Men	15	18	23	19.80	0.46
Women	17	18	21	18.88	0.23
Reproduction					
Men	16	18	21	18.56	0.22
Women	16	17	23	18.81	0.37

Note: SEM= Standard error of the mean.

Table 2

Number of Male and Female Participants per Emotion Group for Study 1

	High arousal negative	High arousal positive	Low arousal negative	Low arousal positive
Temporal Bisection				
Male	5	4	5	4
Female	7	8	7	8
Analog Scale				
Male	4	4	3	4
Female	4	4	5	4
Reproduction				
Male	4	4	4	4
Female	4	4	4	4

Table 3

Mean Arousal and Valence Ratings and Ranges of Selected International Affective Picture System Images

Image group	Arousal		Valence	
	Mean	Range	Mean	Range
High arousal, negative	6.84 (0.04)	6.51-7.35	2.30 (0.11)	1.45-3.79
High arousal, positive	6.59 (0.07)	5.18 -7.35	7.05 (0.07)	6.44-8.10
Low arousal, negative	4.63 (0.05)	4.00-5.00	2.85 (0.07)	1.95-3.52
Low arousal, positive	4.59 (0.05)	4.01-5.00	7.15 (0.07)	6.53-8.20
Neutral	2.75 (0.07)	1.72-3.56	4.96 (0.05)	4.38-5.50

Note. Ratings for arousal and valence were given on a 9-point scale. A 9 on the arousal scale represents high arousal, and a 1 represents low arousal. A 9 on the valence scale represent high pleasure (positive valence) and a 1 represents low pleasure (negative valence). Values in parentheses represent the standard error of the mean.

Figure 7. Example images from the International Affective Picture System (Center for the study of emotion and attention; Lang et al., 2008).

Independent samples t-tests confirmed that all high arousal stimulus sets were indeed more arousing than low arousal sets, which in turn, were more arousing than the neutral set (see Table 4 for all t-tests). T-tests also confirmed that valence ratings were significantly higher (more positive) for each positive set than for the neutral set, which in turn received higher valence ratings than the negative sets. The neutral set was shown to significantly differ from every emotional set in the expected direction, for both arousal and valence.

As expected, arousal ratings for the low arousal negative stimulus set were not significantly different from that of the low arousal positive set. Valence ratings for the high arousal positive set did not significantly differ from that of the low arousal positive. It was found, however, that the high arousal negative set was rated as being even more negative than its low arousal counterpart. This was because only a small number of IAPS images fell within the high arousal range defined by Angrilli et al. (1997). In order to gather enough images for the temporal bisection task, the range had to be extended. Differences in the distribution of images for each emotional group thus rendered the high arousal negative set significantly more negative and higher in arousal than all other sets. This difference was also seen in the study by Smith and colleagues (2011) although the authors do not report it. Smith and colleagues used a smaller number of images for each arousal by valence combination (only 10 images/set) than the present study, yet valence ratings for high arousal negative images were still significantly lower than valence ratings for low arousal negative images, $t(18) = -3.152, p = .006$. This shows that even with a small number of stimuli, it is difficult to find high arousal negative and low arousal negative IAPS images of equal valence ratings.

Table 4

T-tests of Arousal and Valence Ratings

		Arousal		Valence	
		t(68)	p	t(68)	p
HANV	HAPV	3.192	.002	-36.636	<.001
	LANV	35.242	<.001	-4.350	<.001
	LAPV	35.370	<.001	-38.046	<.001
	Neutral	51.986	<.001	-22.795	<.001
HAPV	LANV	23.473	<.001	41.964	<.001
	LAPV	23.701	<.001	-0.978	.331
	Neutral	39.950	<.001	23.902	<.001
LANV	LAPV	0.436	.664	-44.217	<.001
	Neutral	22.425	<.001	-25.558	<.001
LAPV	Neutral	21.938	<.001	26.012	<.001

Note: HANV = high arousal negative valence, HAPV = high arousal positive valence, LANV= low arousal negative valence, LAPV = low arousal positive valence.

Procedure. Participants were tested alone or in small groups of 2-6. They were individually seated at computer stations separated by wooden dividers. A between-subjects design was used for task and emotion category. Participants performed one of the three time estimations tasks; analog scale estimation, reproduction or temporal bisection.

The testing phase consisted of one block of trials composed of 35 emotional IAPS images randomly mixed with 35 neutral IAPS images. A between-subjects design was used for emotion. Thus, the type of emotional pictures presented depended on the category to which the participant had been randomly assigned: high arousal positive, high arousal negative, low arousal positive or low arousal negative. Stimuli were randomly assigned to one of the seven durations, with 5 trials at each duration. Each picture was presented only once.

Temporal bisection task. The temporal bisection procedure required that participants decide if the duration of a stimulus was closer to a short or long anchor duration. It began with a training block (10 trials) in which participants learned to discriminate between the short (2000ms) and long (6000ms) anchors. For each practice trial, a grey rectangle appeared in the centre of the screen. On half of the trials, the rectangle was displayed for the short duration. In the other half, the rectangle was displayed for the long duration. After each presentation, participants indicated whether the stimulus appeared for the short or long interval. They were instructed to respond as accurately as possible and that reaction times were not being measured. Response was made using the index and middle fingers of the participant's dominant hand. For short durations, participants pressed the left arrow key while for long durations, they pressed the right arrow key. Participants received visual feedback (the word "correct" or "incorrect") following each practice trial. In the testing phase, the grey rectangle was replaced by an IAPS image. Each trial was preceded by the appearance of the word "Ready" for 1000ms. Next, a picture was presented for either one of the anchor durations or for one of five evenly-spaced intermediate durations; 2667, 3333, 4000, 4667, or 5333ms. The participant's response triggered the start of the next trial.

Analog scale task. Participants were asked to estimate the duration for which an image was displayed by clicking along a graduated scale that appeared on screen after the presentation of each test picture (Figure 3). In the practice phase (4 trials), participants judged the length of presentation of a grey rectangle that appeared in the centre of the screen. The rectangle was displayed for one of seven possible durations (2000, 2667, 3333, 4000, 4667, 5333, or 6000ms). Following its presentation, the graduated line representing 0-10 seconds appeared (170mm in length). Using the mouse, participants clicked on the point on the line they believed matched the duration of presentation. Participants were told they could click anywhere along the line, including between tick marks that represented seconds (e.g. participants could click halfway between the 2 and 3 second marks if they believed the image was presented for about 2.5 seconds). They were asked to respond as accurately as possible. In test trials, the grey rectangle was replaced by IAPS images, shown one at a time, and followed by the graduated scale.

Reproduction task. In this condition, participants were asked to reproduce the duration of presentation of a stimulus image. In the practice phase (4 trials), participants were first shown a stimulus image (grey rectangle) for one of seven possible durations (2000, 2667, 3333, 4000, 4667, 5333, or 6000ms). After the rectangle disappeared, the word "reproduce" was shown in the centre of the screen. Participants were instructed to try to reproduce the duration of the stimulus by pressing and holding the spacebar. While the spacebar was depressed, another grey rectangle appeared to serve as visual feedback. The rectangle disappeared when participants let go of the spacebar. In the test trials, the grey rectangle was replaced by IAPS images. When reproducing the duration, participants still received visual feedback in the form of a grey rectangle. Participants were instructed to respond as accurately as possible.

Results

The analyses were designed to make two key comparisons within each time estimation task. The first analysis compared time judgements across the four emotion categories (high arousal negative, high arousal positive, low

arousal negative and low arousal positive). The second compared duration judgements for emotional trials to duration judgements for neutral trials presented in the same block. Significant and theoretically meaningful effects are reported in the text and the full set of ANOVA results can be found in Appendix A.

For the classical timing tasks (analog scale and reproduction), it was also possible to test for proportional or absolute effects of emotion. As explained in the *Classical timing paradigms* section of the introduction (pages 27-33), proportional effects of emotion are indicative of increased pacemaker speed (if the duration of activating images is overestimated) or a narrowed attentional gate (if the duration of attention-capturing images is underestimated) whereas absolute effects indicate that emotional stimuli influenced the opening or closure of an all-or-nothing switch. Although the classical timing tasks allow one to determine whether temporal shifts are proportional or absolute, such an analysis is not possible with the temporal bisection task. This is because temporal bisection yields only one estimate (the PSE) that describes timing behaviour across the tested duration range. In order to test for proportionality, it is necessary to use several duration ranges, and compare PSEs across those ranges. The temporal bisection task in the present study used only one duration range (2000-6000ms), thus it can be used only to test for underestimation versus overestimation of emotional relative to neutral images. In studies 2-4, temporal bisection will be used across multiple duration ranges, to permit differentiation between absolute and proportional effects of emotion on the PSE.

Temporal bisection.

Point of subjective equality. Analyses of the temporal bisection task data began by calculating the proportion of “long” responses for emotional images at every stimulus duration. Proportions of long responses for emotional and neutral trials for each emotion (high arousal negative, high arousal positive, low arousal negative, and low arousal positive) are shown in Figure 8. Proportions of long responses were transformed to z-scores, and linear regression was used to fit a straight line to the five most central duration points (2667, 3333, 4000, 4667, & 5333ms). The slope and intercept of the regression line were then used to find the PSE, which is the duration corresponding to a proportion of long responses of 0.5 (Church & Deluty, 1977). Low PSE values signal an

overestimation (images are perceived to last longer), whereas higher PSEs are indicative of underestimation. PSE values for emotional and neutral trials were calculated for each participant.

Emotional and neutral PSEs were compared in a mixed ANOVA using arousal, valence, and sex as between-subject variables³ and trial type (emotional or neutral) as the within-subjects variable. Results of the ANOVA are shown in Table A1. There was no obvious shift of the response curve for emotional compared to neutral trials for any of the four emotions, suggesting that there was no difference between time estimation of emotional images and neutral images (see Figure 8). This was confirmed by the ANOVA, which showed that the effect of trial type did not approach significance, $F(1, 40) = .949, p = .336, \eta_p^2 = .023$, nor were there any interactions or trends involving trial type (see Table A1). Thus duration estimates for emotional images did not differ from those of neutral images in any of the emotion conditions.

However, the ANOVA showed a marginally significant effect of arousal, $F(1, 40) = 3.817, p = .058, \eta_p^2 = .087$, whereby durations of high arousal images were underestimated in comparison to durations of low arousal images. Figure 9, which shows the mean PSE for emotional and neutral trials of each emotion group, suggests that the effect of arousal may be driven by a difference in the mean PSE for images in the low arousal positive group. As can be seen, PSEs for the low arousal positive condition were lower than all other PSEs, indicating that the duration of low arousal positive images as well as the neutral images presented in the same block were judged as longer than emotional and neutral images of the three other groups (high arousal negative, high arousal positive, and low arousal negative). The interaction between arousal and valence, however, failed to reach conventional levels of significance in the omnibus ANOVA, $F(1, 40) = 2.880, p = .097, \eta_p^2 = .067$.

Given the lack of any difference between time estimation for emotional and neutral trials, PSEs were collapsed across trial type. A one-way between-subjects ANOVA was conducted to compare the effect of emotion group (high

³ Although neutral images did not of course vary in arousal or valence, they appeared in a block of emotional images that varied by arousal and valence between subjects.

arousal negative, high arousal positive, low arousal negative, and low arousal positive) on mean PSEs. The effect of emotion group was significant, $F(3, 12) = 3.572, p = .021$. Post-hoc Tukey pairwise comparisons revealed that PSEs from the low arousal positive group were lower than PSEs for images in the high arousal negative ($p = .056$), high arousal positive ($p = .049$), and low arousal negative groups ($p = .045$). This means that the duration of images from the high arousal negative, high arousal positive, and low arousal negative groups was judged as shorter than the duration of images from the low arousal positive group. There were no other significant pairwise comparisons (all $p > .999$). Importantly, these between subject differences were observed for both emotional and neutral trials mixed in the same block.

Figure 8. Study 1, temporal bisection task: proportions of long responses for emotional and neutral trials as a function of stimulus duration.

Figure 9. Study 1, temporal bisection task: mean point of subjective equality for emotional and neutral trials. Error bars represent standard errors.

Difference Limen. Sensitivity to time and proportional effects were assessed using DLs, which represent the smallest duration difference that can be discriminated for the range of durations used. DLs for both emotional and neutral trials for each participant were calculated from the same straight lines fitted to find the PSEs. The range of durations corresponding to 25-75% of long responses was found and then halved to reveal the DL. Steeper slopes, which are indicative of higher (better) sensitivity to time, yield lower DL values than shallow slopes, which signal poor temporal sensitivity. Means and standard errors of the DLs for emotional and neutral trials are shown in Table 5. DLs were compared in a mixed ANOVA using arousal, valence, and sex as the between-subject variables and trial type (emotional or neutral) as the within-subjects variable. Results are shown in Table A2. There were no significant main effects or interactions (all $p > .139$), indicating that sensitivity to time was constant across emotions and did not differ for emotional and neutral trials within a block.

Table 5

Temporal Bisection Task: Mean Difference Limens

	Emotional		Neutral	
	Mean	SEM	Mean	SEM
High arousal negative	766.179	62.202	746.165	62.717
High arousal positive	843.762	93.825	690.327	47.571
Low arousal negative	726.082	64.449	781.683	87.419
Low arousal positive	701.746	36.683	707.064	88.991

Note: SEM= Standard error of the mean.

Analog Scale. Participants assigned to the analog scale gave time estimates by clicking along a graduated scale presented on the computer screen. Estimates were recorded using the location of the mouse click along the scale. The horizontal distance between the click and the left edge of the scale (0 seconds) was converted from pixels to seconds, with each pixel corresponding to 1/64 of a second. Figure 10 shows mean time estimates for the emotional trials as a function of stimulus duration. As can be seen, time estimates increased with stimulus duration in a linear, monotonic fashion, which indicates that results conformed to the mean accuracy property of scalar timing.

Figure 10. Study 1, analog scale task: mean duration estimates for emotional trials as a function of stimulus duration.

Results were analysed using the method used by Angrilli et al. (1997) and Noulhiane et al. (2007). $T_{corrected}$ were computed as $(T_{estimated} - T_{target})/T_{target}$ (Angrilli et al., 1997; McConchie & Rutschmann, 1970; Treisman, 1963). $T_{corrected}$ values represent the amount by which durations were over-or underestimated, expressed as a proportion of the length of the stimulus. Negative $T_{corrected}$ values represent the proportion by which durations were underestimated and positive $T_{corrected}$ values represent the proportion by which durations were overestimated.

Figure 11 shows the mean $T_{corrected}$ values for emotional trials. All $T_{corrected}$ values were below zero, indicating that durations of all emotional images were

underestimated. The effect of emotion on time estimates for emotional images and neutral images presented in the same block was assessed by conducting a mixed ANOVA on the $T_{\text{corrected}}$ values. The between-subjects factors were arousal, valence, and sex. The two within-subjects factors were duration (2000, 2667, 3333, 4000, 4667, 5333, & 6000ms) and trial type (emotional or neutral). Results, shown in Table A3, revealed three significant two-way interactions. First, there was an interaction of duration and sex, $F(6, 144) = 3.787, p = .002, \eta_p^2 = .136$. Figure 12 shows mean $T_{\text{corrected}}$ values for male and female participants as a function of duration. Visual examination of Figure 12 reveals that men provided shorter time estimates than women for the short stimulus durations but there was no significant difference between men and women's estimates for the longer durations. Next, a significant interaction between trial type and duration suggests that the relative underestimation of emotional and neutral trials was not consistent across durations, $F(6, 144) = 2.626, p = .019, \eta_p^2 = .099$ (see Figure 13). Lastly, there was a Trial Type X Arousal interaction, $F(1, 144) = 5.035, p = .034, \eta_p^2 = .173$. In low arousal conditions, neutral images (mean $T_{\text{corrected}} = -0.136, \text{SEM} = 0.038$) were underestimated to a similar degree to emotional images (mean $T_{\text{corrected}} = -0.135, \text{SEM} = 0.038$), whereas in high arousal conditions, emotional images (mean $T_{\text{corrected}} = -0.165, \text{SEM} = 0.027$) were underestimated to a greater degree than neutral images (mean $T_{\text{corrected}} = -0.157, \text{SEM} = 0.029$).

Figure 11. Study 1, analog scale task: mean $T_{corrected}$ values for emotional trials as a function of stimulus duration. Error bars represent standard errors.

Figure 12. Study 1, analog scale task: mean $T_{corrected}$ values for male and female participants as a function of stimulus duration. Results are collapsed across trial type (emotional and neutral). Error bars represent standard errors.

Figure 13. Study 1, analog scale task mean $T_{corrected}$ values for emotional and neutral trials as a function of stimulus duration. Results are collapsed across all arousal/valence conditions. Error bars represent standard errors.

Reproduction. Figure 14 shows mean duration estimates for emotional trials of the reproduction task as a function of stimulus. Duration estimates increased linearly with stimulus duration, indicating that the mean accuracy property of scalar timing was met.

Figure 14. Study 1, reproduction task: mean duration estimates for emotional trials as a function of stimulus duration.

Next, duration estimates were converted to proportions of the target duration in the same way as they were computed for the analog scale task:

$$T_{\text{corrected}} = (T_{\text{estimated}} - T_{\text{target}}) / T_{\text{target}}$$

(Angrilli et al., 1997; McConchie & Rutschmann, 1970; Treisman, 1963). Figure 15 shows the mean $T_{\text{corrected}}$ values for emotional trials as a function of stimulus duration and results of the ANOVA are displayed in Table A4. All $T_{\text{corrected}}$ values were below zero, indicating that participants produced durations that were shorter than the length of presentation of the stimuli. The effect of emotion on reproductions was tested using a mixed ANOVA for arousal, valence and sex (between-subjects factors) as well as duration and trial type (within-subjects factors). There were no effects of arousal, valence, or any interactions involving emotional factors. The analysis revealed only a significant effect of duration, $F(6, 144) = 5.944, p = <.001, \eta_p^2 = .199$, which indicated that the extent of the underestimation varied non-systematically from duration to duration. Duration did not interact with trial type, $F(6, 144) = 0.342, p = .914, \eta_p^2 = .014$, indicating that there was no difference in the extent of underestimation for emotional and neutral trials within each duration.

Figure 15. Study 1, reproduction task: mean $T_{\text{corrected}}$ values for emotional trials as a function of stimulus duration. Error bars represent standard errors.

Discussion

The primary goal of Study 1 was to test the effect of emotional images on time perception using three different tasks; temporal bisection, estimation on an analog scale, and duration reproduction. This was done to replicate and extend the research of Angrilli and colleagues (1997) who used a small number of images from the IAPS database to test the effect emotion on time perception using the analog scale and reproduction methods in a 2000 to 6000ms duration range. Study 1 used a between-subjects design to eliminate potential carry-over between emotions.

Analog scale and reproduction. Participants underestimated the duration of all images in the analog scale and reproduction tasks, suggesting that all images (including neutrals) captured attention. Performance on the analog scale task showed a significant interaction between arousal and trial type. In low arousal conditions (low arousal negative and low arousal positive) there was no difference between time estimates for neutral images and for emotional images. In high arousal conditions (high arousal negative and high arousal positive) the underestimation appeared more pronounced for emotional images than for neutral images. This pattern, which is consistent with an attentional effect of emotion in high arousal conditions, is at odds with the findings of Angrilli et al. (1997) who found attentional effects when arousal was low but activation effects when arousal was high. In the present study, the analog scale task also revealed a significant interaction between trial type and duration, indicating that the relative underestimation of emotional and neutral trials varied across durations in a non-systematic way. The goal of Study 1 was to select a time estimation task to be used in subsequent experiments. On the one hand, these findings show that the analog scale task is sensitive to emotion effects (as seen in the arousal by trial type interaction). On the other hand, analog scale data also revealed a significant interaction between duration and sex, whereby men provided shorter duration estimates than women for short stimulus durations. The Duration X Sex interaction did not interact with arousal or valence, and therefore shows a difference in time perception for women and men. The reproduction task showed no effect of emotional factors.

In a recent study, Gil and Droit-Volet (2011) found activational effects of emotion on time perception for emotional faces when using an analog scale task or temporal bisection, but not when using duration reproduction. In the analog scale and bisection tasks, the duration of photographs of angry facial expressions was judged to be longer than the duration of photographs of neutral expressions. The authors posited that differences between tasks were found because the tasks call upon different cognitive processes. Unlike the analog scale and temporal bisection tasks, which rely mostly on the clock component of cognitive models of time perception, the reproduction task is believed to rely mostly on memory processes (Baudouin et al., 2006; Gibbon, 1977; Gil & Droit-Volet, 2011). Differences in the mental processes underlying time estimation tasks may explain the lack of emotion effects in the reproduction task of the present study, but it cannot easily explain the difference between temporal bisection and analog scale results, which are thought to rely on similar processes. Unlike with Angrilli et al. (1997), the interaction between arousal and valence was not significant. This may be because effects sizes for arousal and valence in the present study were particularly low (see Tables A3 and A4). Angrilli and colleagues, who found an Arousal X Valence interaction in both the analog scale and reproduction tasks, used a more powerful within-subjects design whereby participants were exposed to every type of emotional stimuli. This possibility will be explored by using a within-subjects design for emotion in a subsequent study (Study 3).

Temporal bisection. In the temporal bisection task, analyses on the PSE revealed that the duration of high arousal negative, high arousal positive, and low arousal negative images was underestimated in comparison to the duration of low arousal images. However, this effect was observed for both emotional and neutral trial types in each block. One interpretation of this effect is that it reflects a type 1 error, that is, participants in the low arousal positive condition are overestimators. However, an alternative explanation is that the presence of high arousal and negative emotions led to an underestimation of all trials in the block. These results are somewhat in line with Angrilli et al. (1997), who found an underestimation of high arousal images compared to low arousal images for the longer durations (4 and 6 seconds) but not for the 2 second duration, in which

they found that the duration of low arousal images was underestimated compared to high arousal images. Angrilli and colleagues posited that time estimates for the 2 second stimulus presentation were guided by activation mechanisms, that is, that the speed of the internal pacemaker was greater for high arousal than for low arousal images. For the 4 and 6 second presentations, however, Angrilli and colleagues suggested that activation had subsided and that attention mechanisms prevailed.

The results of the temporal bisection tasks are consistent with attention theories of time perception, which propose that attention-capturing stimuli divert attention from the temporal aspect of a task, and thus lead to shorter time estimates than stimuli that fail to capture attention (Buhusi & Meck, 2006; Fortin, Chérif, & Neath, 2005; Thomas & Weaver, 1975). Study 1 results suggest that high arousal as well as negative images (e.g. mutilation, sexual scenes, and bugs) captured more attention than low arousal positive images (e.g. kittens). Attentional effects of emotion are also in line with a large literature showing behavioural and physiological evidence of increased attention toward emotional (e.g. threatening) stimuli (Lang et al., 1993; Lundqvist & Öhman, 2005; Schupp, Junghöfer, Weike, & Hamm, 2003; Schupp et al., 2004). While it is often argued that negative stimuli activate more attentional resources than positive or neutral stimuli, a recent study by Franken et al.(2008) showed that pleasant stimuli engage attention to the same degree as unpleasant ones when both are highly arousing.

Studies of the effect of emotion on temporal perception have used a myriad of time estimation tasks. Thus, the goal of the present study was to select a single time estimation task to be used in all subsequent studies. Unlike the analog scale, temporal bisection task data did not show effects or interactions of participant sex. Moreover, the temporal bisection task was shown to be sensitive the effect of emotion (contrary to the reproduction task, which showed no effect of arousal or valence). For these reasons, the temporal bisection task was selected for use in subsequent experiments.

Carry-over effects of emotion. Emotion was a between-subject variable, thus, individual participants were only shown images from one of four emotion categories: high arousal positive, high arousal negative, low arousal positive, or

low arousal negative. It was found that the emotional content depicted by the emotional pictures not only influenced time perception for these specific images, but also affected performance on the neutral trials presented in the same block. Specifically, participants who viewed images that were either highly arousing, negative, or both not only underestimated the duration of these images, but also underestimated the duration of neutral images presented in the same block.

It is easy to understand how activational effects might produce carry-over by increasing the speed of the pacemaker, but more difficult to propose a mechanism that would cause attentional effects of emotion to carry over. One possibility is that attention influences time perception for emotional images and that these perceived durations shift the criterion value for temporal bisection decisions in favour of underestimation of all images. Alternatively, carry-over might be explained by physiological evidence that attentional capture of emotional images continues well beyond image presentation (Hajcak & Olvet, 2008). Hajcak and Olvet (2008) examined attentional capture by measuring an ERP called the late positive potential (LPP) during and after image viewing, and found enhanced and prolonged LPP (indicating enhanced attention) for emotional as opposed to neutral IAPS images. The present study was not designed to test previous trial effects specifically: such a design would have necessitated yet another variable and more images so that previous trial effects could be assessed across all duration ranges.

One more possibility is that carry-over effects of emotion may have been linked to the strategy participants used to make the temporal bisection. Participants were not given specific instructions to avoid counting, nor was counting prevented through the use of a concurrent task. According to Grondin, Meilleur-Well, and Lachance (1999) it is not uncommon for participants to spontaneously use chronometric counting when performing a time estimation task. Moreover, Grondin et al. found that counting improved temporal sensitivity for durations of 1.2 seconds or longer, but not for shorter intervals. The present study used only one duration range; therefore, results could not be compared to time perception for sub-second durations. In the next study, however, participants performed the temporal bisection task in one of three duration

ranges: 400-1600ms, 1000-4000ms, or 2000-8000ms. See Study 2 for a discussion of chronometric counting in the temporal bisection task.

Findings that performance on any given trial may be influenced by the emotional content of previous trials has important implications for studies that use within-subject designs in which stimuli belonging to various emotional groups are presented together (Angrilli et al., 1997; Chambon et al., 2008; Droit-Volet et al., 2004; Effron et al., 2006; Grommet et al., 2011; Noulhiane et al., 2007; Smith et al., 2011; Tipples, 2008). It is common practice to include neutral trials, which are used as a baseline to allow for comparison between emotional groups (Chambon et al., 2008; Droit-Volet et al., 2004; Effron et al., 2006; Smith et al., 2011; Tipples, 2008). If a block of trials contains emotional stimuli from various emotion groups (e.g. high arousal positive and low arousal negative; anger and sadness) it may be hard to delineate the effect of each emotion onto neutral trials. Furthermore, there may be carry-over of one emotion onto the others. Such complex carry-over effects can be prevented by using emotion as a between-subjects variable, however, it is worth noting that the between-subjects design used in Study 1 yielded very low effect sizes for arousal, valence, as well as their interaction. For the analog and reproduction tasks, the results of Study 1 did not replicate those of Angrilli et al. (1997) who found a significant interaction between arousal and valence – both of which were within-subjects variables. In Study 1's temporal bisection task, the interaction between arousal and valence failed to reach significance ($p = .097$), perhaps because of the small effect size (Arousal X Valence $\eta_p^2 = .067$). The power for this experiment may be increased by using a larger group of participants or by increasing the number of trials. Unfortunately, the number of trials was limited by the number of IAPS images that fell within each emotional category. Images belonging to the high arousal positive group were in particularly short supply, with only 27 images falling within the range arousal and valence ratings defined by Angrilli et al. (1997). Thus, the ranges had to be expanded. Given that using standardized emotional material and avoiding image repetition were important features of Study 1, it was not possible to increase the number of trials beyond 35 images per emotion.

Scalar timing. According to the SET model of timing, the relative underestimation for high arousal negative, high arousal positive, and low arousal

negative images compared to low arousal positive images implies that fewer pulses reached the accumulator when viewing high arousal or negative images than when viewing low arousal positive images. There are two mechanisms through which attention-capturing stimuli may reduce the number of pulses that reach the accumulator. The first suggests that attention affects the closure or opening of an attentional switch located between the pacemaker and the accumulator (Lejeune, 1998). Effects on the switch are absolute, meaning that the magnitude of the underestimation of attention-capturing stimuli is independent of the duration of the stimulus being timed. The second mechanism proposes that attention causes underestimation by narrowing the opening of an attentional gate (Zakay, 2000, 2005). Attention effects on the gate are proportional with real time, meaning that the magnitude of the underestimation increases with stimulus duration. Therefore, it is possible to delineate between attentional gate and switch effects by testing whether or not the underestimation is proportional with real time. In a temporal bisection task, absolute effects lead to the violation of the scalar property of variance whereas proportional effects do not (see p.36). Thus, if attentional effects of emotion conform to the scalar properties, one can conclude that attention-capturing stimuli likely narrowed the opening of an attentional gate. However, if attentional effects are accompanied by a violation of scalar timing, attention-capturing stimuli likely affected the closure or opening of the switch. Testing the scalar property of variance in a temporal bisection task is usually done by comparing WRs across multiple duration ranges. In Study 1, the temporal bisection task was only conducted in a single duration range (2000 to 6000ms). Thus, it was not possible to use conformity to scalar variance as a test for proportional effects. To determine whether attentional effects seen in Study 1 were caused by the narrowing of the opening of an attentional gate (proportional effect) or the closure of an attentional switch (absolute effect) the experiment was repeated using multiple duration ranges (Study 2).

Study 2: The Effect of Duration Range

Study 1 compared the effect of emotional arousal and valence on time perception using three estimation tasks. The reproduction task was not sensitive to emotional effects. The analog scale task did show emotion effects (attentional effects of emotion in high arousal conditions) however, the results also showed that time estimates varied for male and female participants. The final task, temporal bisection, was sensitive to emotion effects without showing differences between duration judgements made by men and women. For these reasons, the temporal bisection task was selected to be used in subsequent experiments. Results for the temporal bisection of Study 1 and those of Angrilli et al. (1997) point to the presence of attentional effects of emotion whereby the duration of attention-capturing stimuli is underestimated compared to other stimuli. These results are in marked contrast to studies in which the duration of arousing images was overestimated, thus pointing to activational effects of emotion (e.g. Droit-Volet et al., 2004; Effron et al., 2006; Tipples, 2008). There are two important differences between these sets of studies. Firstly, most studies that found attentional effects of emotion used complex visual stimuli (scenes) standardized for arousal and valence (Bradley & Lang, 1999; Lang et al., 2008) whereas the majority of studies that found activational effects of emotion used photographs of emotional facial expressions (Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Tipples, 2008). These studies either used only one type of facial expression (e.g. angry) along with neutral faces, or used emotional facial expressions that were not fully crossed for both arousal and valence (e.g. anger, happiness, sadness). The second difference between studies that found activational effects of emotions and those that found attentional effects is stimulus duration. Studies that find support for attentional effects of emotion on time perception typically use longer stimulus durations than studies that support activation effects of emotion. Droit-Volet et al., Effron et al. and Tipples presented stimuli for 400 to 1600ms whereas images in Study 1 and the Angrilli et al. study were shown for 2000 to 6000ms. As proposed by Droit-Volet and her colleagues, the 2 to 6 second range may be too long to be sensitive to activational effects. It is possible that activational mechanisms triggered at stimulus onset subside as the duration of stimuli increases (see also Angrilli et

al., 1997). Thus, time estimation for a stimulus presented for up to 2 seconds may be influenced mainly by factors that affect the speed of the internal clock's pacemaker but attentional mechanisms may prevail at longer durations. Given this evidence for dynamic effects of emotion, the present study was designed to compare the effect of emotion on time perception across three duration ranges.

Absolute or Proportional Effects of Emotion

The use of multiple duration ranges can also allow testing for proportional effects of emotion on time perception for complex images. Testing for proportional effects requires that a certain pattern of under- or overestimation be observed in at least two separate duration ranges. Consider for example, two duration ranges, which will be referred as d_1 (the shortest range of the pair) and d_2 (the longer range). If, say, the duration of negative images is underestimated compared to the duration of neutral images in both d_1 and d_2 , the underestimation will be deemed proportional if two requirements are met. Firstly, the magnitude of the underestimation (as measured by the difference between the PSEs for negative and neutral images) needs to be larger in d_2 than d_1 . Secondly, WRs for neutral images need to be the same in d_1 and d_2 , as do the WRs for negative images. Differences in mean WRs for neutral and negative images are permitted so long as they do not interact with duration range. In other words, tests of the scalar property of variance are concerned with inter-range differences in WRs.

Figure 16 shows the predictions of attentional and activational effects of emotion when comparing results of a temporal bisection task across two ranges (the ranges of 400-1600ms and 1000-4000ms are used as examples). For simplicity, these graphs compare only emotional stimuli to neutral stimuli. It should be understood that the emotional stimuli most likely to be subject to attentional effects are stimuli that capture attention (e.g. high arousal and negative stimuli) whereas the emotional stimuli likely to be subject to activational effects are high arousal stimuli, followed by low arousal stimuli.

Attentional effects of emotion on an attentional gate. Attentional effects of emotion on the gate should produce a *proportional underestimation* of emotional stimuli. As shown in Figure 16 (top panel), this would be marked by a

higher PSE for emotional stimuli than for neutral stimuli. Moreover, the magnitude of the underestimation (marked by a rightward shift of the response function) would be larger for the long duration range than for the short one. Given that attentional gate effects are proportional with real time, WRs would remain constant across ranges.

Attentional effects of emotion on an attentional switch. Attentional effects of emotion on the closure/opening of an attentional switch would produce an *absolute underestimation* of emotional stimuli (Figure 16, middle panel). PSEs for emotional images should be larger for emotional than for neutral stimuli, but the magnitude of the rightward shift of the response functions for emotional stimuli will be constant across duration ranges. Absolute effects in a temporal bisection task violate the scalar property of variance. Because the switch acts in an all-or-none fashion, switch effects would have a more pronounced impact on temporal sensitivity for short duration ranges than for longer ones. Therefore, WRs of the shorter range should be higher (an indication of poor temporal discriminability) than WRs of the longer range.

Activational effects of emotion. Activational effects of emotion would cause a *proportional overestimation* of emotional stimuli compared to neutral stimuli (Figure 16, bottom panel). Activational effects of emotion would cause the pacemaker to emit pulses at a greater speed for emotional than for neutral stimuli. Thus, PSEs for emotional stimuli would be lower than PSEs for neutral stimuli. Furthermore, the magnitude of the overestimation (which can be seen in the leftward shift of the response function for emotional versus neutral stimuli) would be larger in the long duration range. Finally, given that pacemaker effects do not violate the scalar property of variance, WRs would remain constant across ranges.

Figure 16. Predictions of attentional effects of emotion on an attentional gate (top panel), attentional effects of emotion on the switch (middle panel), and activational effects of emotion on the pacemaker (bottom panel).

To date, only two temporal bisection studies have looked at the effect of emotion on time perception for complex emotional images across multiple duration ranges: Grommet et al. (2011) and Smith et al. (2011). Both studies used a 400-1600ms range as well as a shorter range, and both studies used duration range as a within-subjects variable (Grommet et al., 2011; Smith et al., 2011). Every participant in the study by Grommet et al. (2011) performed one block of the temporal bisection task in the 250-1000ms range and one block in the 400-1600ms range. Block order was counterbalanced across subjects. Analyses revealed problems associated with the use of duration range as a within-subjects variable: block order effects interacted with duration range. Duration estimates were influenced by previous exposure to another stimulus duration range. Nevertheless, results were averaged across block orders for all analyses of the effect of emotion. Block order effects on duration estimates may have also been present in the study by Smith et al. (2011), in which the order of 10 blocks of trials was randomized. Participants performed five blocks of the temporal bisection in the 100-300ms range and five blocks in the 400 to 1600ms range. Smith et al. did not test block order effects and simply collapsed the results across all blocks using the same duration range.

Block order effects aside, the study by Grommet and colleagues (2011) found that participants overestimated the duration of fear-inducing stimuli compared to the duration of neutral stimuli in both ranges (as expected according to an activation account). Although a measure of temporal sensitivity similar to the WR showed no effect of duration range, the magnitude of the difference between fearful and neutral PSEs for the 400-1600ms range was not greater than the magnitude of the difference between fearful and neutral PSEs for the 250-1000ms range. The absolute nature of the discrepancy across duration ranges was thus inconsistent with a pacemaker speed explanation. Grommet et al. suggested that the overestimation may have been the results of a shorter switch closure latency or longer switch opening latency for fear images than for neutral ones.

In the study by Smith and colleagues (2011) it was not possible to test for proportional effects given that the influence of emotion on time perception was not consistent across the two ranges used. Smith et al. found different patterns in

the short (100 to 300ms) and long (400 to 1600ms) ranges. In the short range, results were in line with attentional effect of emotion whereby the duration of negative images was underestimated compared to the duration of positive and neutral images. In the long range, however, results showed a complex pattern that could not be categorically ascribed to attentional or activational effects of emotional stimuli, although the authors mostly attributed the results to activational effects.

Study 2 Goals

The majority of temporal bisection studies on the effect of emotion are conducted in the 400 to 1600ms range using emotional facial expressions as stimuli (Chambon et al., 2008; Droit-Volet et al., 2004; Efron et al., 2006; Gil et al., 2009; Gil & Droit-Volet, 2011; Tipples, 2008). Two temporal bisection studies that used complex emotional images in this duration range found conflicting results, and more importantly, included features such as image repetition or multi-block designs that cloud the interpretation of their findings (Gil & Droit-Volet, 2011; Grommet et al., 2011). The first goal of Study 2 was thus to test the effect of complex emotional stimuli fully crossed for valence and arousal in the 400 to 1600ms range. To avoid block order effects such as those reported by Grommet et al., participants only completed one block of trials, with duration range manipulated between subjects. The second goal of Study 2 was to test the impact of emotional arousal and valence on time perception in three different duration ranges; 400 to 1600ms, 1000 to 4000ms, and 2000 to 8000ms. These specific duration ranges were chosen in order to achieve the third goal of Study 2, which was to test the effect of emotion on temporal sensitivity using WRs. WRs are absolute indices of temporal sensitivity that can be compared across duration ranges. There is evidence that WRs can vary as a function of the spread between the short and long anchor durations (Kopec & Brody, 2010) thus, using a proportional spread allows for the most direct comparisons across duration ranges. The short duration range (400 to 1600ms) has a spread of four, meaning that its long anchor duration is four times longer than its short anchor duration. The long duration range of 2000 to 8000ms was chosen because it was the range with a spread of 4 that most closely resembled the 2000 to 6000ms range used

by Angrilli et al. (1997) and in Study 1. A middle duration range of 1000 to 4000ms was also included. Finally, in the event that emotion effects are not dynamic (that is, if the same pattern of underestimation or overestimation is observed across duration ranges) Study 2 will allow for test of proportional/absolute effects that can point to which component of the internal clock are influenced by emotion.

Method

Participants. Four hundred sixty-two undergraduate psychology students (223 men, 237 women, and two who failed to report their sex) from the University of Washington received course credit for their participation. All had normal or corrected-to-normal vision. The study was approved by the Human Subjects Division of the University of Washington's Institutional Review Board.

Apparatus. Stimuli were presented using eMac computers running Matlab and the Psychophysics Toolbox extension (Brainard, 1997). Pictures (measuring 135.5 x 101.6 mm) were viewed on the computers' 17.0" CRT monitors, at a resolution of 1280 x 960 pixels.

Stimuli. Stimuli were the same coloured images from the IAPS database used in Study 1. See Table 3 for means and ranges of arousal and valence ratings of the IAPS images used.

Task. Participants made duration judgements using the temporal bisection task (see Temporal Bisection Task section of Study 1). Three different stimulus duration ranges were used; short, mid or long. In the short duration range, images were presented for 400, 600, 800, 1000, 1200, 1400 or 1600ms. In the mid duration range, images were presented for 1000, 1500, 2000, 2500, 3000, 3500, or 4000ms. In the long duration range, images were displayed for 2000, 3000, 4000, 5000, 6000, 7000 or 8000ms. Anchor durations were the shortest and longest duration of the range in question (e.g. anchor durations for the middle range were 1000 and 4000ms). The presentation of each image was preceded by the word "Ready". As Study 1 revealed the presence of carry-over effects of emotion, the presentation of the word "Ready" was changed from a fixed duration (1000ms) to a random duration between 1000 and 2000ms. Participants were instructed to respond as accurately as possible.

Procedure. Participants were tested alone or in small groups of 2-4. They were individually seated at computer stations separated by curtain dividers. A between-subjects design was used for task and emotion category; hence participants were randomly assigned to one of the four emotion categories and to one of the three duration ranges. The procedure was the same as the temporal bisection task used in Study 1 with the exception that the block consisting solely of neutral trials was excluded. Participants began with a training block (10 trials) in which they learned to discriminate between the short and long anchor durations. In the testing block, participants made short/long decisions for 70 trials (35 emotional IAPS images randomly mixed with 35 neutral IAPS images). Image durations depended on the duration range assigned to each participant. Images were shown for either one of the anchor durations or for one of five evenly-spaced intermediate durations. Stimuli were randomly assigned to one of the seven durations, with 5 trials per duration. Each picture was presented only once.

Results

Proportion of long responses, points of subjective equality, and DLs for emotional and neutral trials were calculated using the method described in Study 1 and used by Droit-Volet and her colleagues (2004). Data from 2 participants were excluded from analyses because the participants failed to identify their sex. Some participants produced psychometric functions that were so shallow that the regression line had a very small slope. Consequently, the duration corresponding to a proportion of long responses (PSE) for these participants was either lower than the short anchor duration or longer than the long anchor duration. Thus, data from 10 participants were excluded for having nonsensical PSE values that were lower than the short anchor or greater than the long anchor for that participant's duration range. Of the remaining 450 participants, 14 were excluded for having PSEs that were more than three standard deviations away from the mean for that duration range. Five more participants were excluded for having DLs that were more than three standard deviations away from the mean for that duration range. Finally, two participants were excluded for being age outliers; a 50 year old female, and a male who

entered his age as 15 years old despite the fact that the study was only open and visible for sign up to students who were 18 years of age or older. Sex and age descriptive statistics for the remaining participants in each duration range are reported in Table 6 and the number of male and female participants in each emotion group is shown in Table 7. Significant and meaningful effects for each duration range are reported in the text and Study 2 ANOVA tables can be found in Appendix B.

Table 6

Mean Age and Range of Study 2 Participants

	N	Min	Max	Mean	SEM
400-1600ms					
Men	76	18	31	19.46	0.21
Women	64	18	23	19.20	0.17
1000-4000ms					
Men	66	18	30	19.62	0.23
Women	87	18	31	19.29	0.18
2000-8000ms					
Men	68	18	25	19.38	0.19
Women	68	18	28	19.44	0.20

Note: SEM= Standard error of the mean

Table 7

Number of Male and Female Participants per Emotion Group for Study 2

	High arousal negative	High arousal positive	Low arousal negative	Low arousal positive
400-1600ms				
Male	22	17	20	17
Female	14	18	16	16
1000-4000ms				
Male	17	17	18	14
Female	21	21	23	22
2000-8000ms				
Male	18	16	18	16
Female	19	14	18	17

Short duration range

Point of subjective equality. Figure 17 shows the proportions of long responses for emotional and neutral trials for each of the four emotion conditions. PSEs for emotional and neutral trials were the dependent measure in a mixed ANOVA using arousal, valence, and sex as between-subjects factors, and trial type (emotional, neutral) as the within-subjects factor. There was a trend toward an effect of trial type, $F(1, 132) = 3.653, p = .058, \eta_p^2 = .027$, indicating that the duration of emotional images was underestimated (higher PSE values) compared to the duration of neutral images. Mean PSEs for emotional and neutral trials for each emotion group are shown in Figure 18. There were no other trends or significant effects involving arousal, valence, or sex. Notably there were no interactions between trial type and either emotional dimension, indicating that all emotional stimuli were similarly underestimated. All results of the ANOVA are displayed in Table B1.

Figure 17. Study 2, 400 to 1600ms: proportions of long responses for emotional and neutral trials as a function of stimulus duration.

Figure 18. Study 2, 400 to 1600ms: mean point of subjective equality for emotional and neutral trials. Error bars represent standard errors.

Difference limen. To test the effect of emotion on temporal sensitivity, DLs for both trial types (emotional, neutral) were used as the dependent variable in a mixed ANOVA using arousal, valence, and sex as between-subjects variables and trial type as a within-subjects variable. Results of the ANOVA appear in Table B2. There was a marginally significant interaction of trial type, valence, and sex, $F(1, 132) = 3.832, p = .052, \eta_p^2 = .028$. Separating the data according to both sex and arousal revealed a Trial Type X Valence interaction for men who were assigned to the high arousal condition, $F(1, 37) = 6.238, p = .017, \eta_p^2 = .040$. As shown in Figure 19, the interaction was driven by male participants in the high arousal negative group who showed better temporal sensitivity for neutral images (mean DL = 181.450, SEM = 4.685) than for high arousal negative images (mean DL = 217.303, SEM = 12.307). There was no difference in temporal sensitivity for emotional and neutral trials in any other condition for men, or in any condition for women.

Figure 19. Study 2, 400 to 1600ms: mean difference limen for emotional and neutral trials for male (top panel) and female (bottom panel) participants. Error bars represent standard errors.

Middle duration range

Point of subjective equality. Figure 20 shows the proportions of long responses for emotional and neutral images of each emotion plotted as a function of stimulus duration. Emotional and neutral PSEs were dependent variables for a mixed ANOVA using arousal, valence, and sex as between-subjects factors, and trial type (emotional, neutral) as the within-subjects factor. Results of the ANOVA are shown in Table B3. Figure 21 shows mean emotional and neutral PSE values for each emotion group. There was no main effect of trial type, $F(1, 145) = 0.010, p = .922, \eta_p^2 < .001$ but the interaction between trial type, valence, and sex was significant, $F(1, 145) = 5.311, p = .023, \eta_p^2 = .035$. The interaction was explored by separating results according to sex. For male participants, the Trial Type X Valence interaction was significant, $F(1, 62) = 5.586, p = .021, \eta_p^2 = .083$. As can be seen in Panel A of Figure 22, men assigned to the negative conditions (low arousal negative and high arousal negative) underestimated the duration of emotional images compared to the duration of neutral images, $F(1, 33) = 4.786, p = .036, \eta_p^2 = .127$. Men assigned to the positive conditions (low arousal positive and high arousal positive) made similar time judgements for emotional and neutral trials, $F(1, 29) = 1.315, p = .261, \eta_p^2 = .043$. For female participants, trial type and valence did not interact, $F(1, 83) = 0.680, p = .412, \eta_p^2 = .008$, nor were there effects of valence, $F(1, 83) = 0.912, p = .342, \eta_p^2 = .011$, or trial type, $F(1, 83) = 1.150, p = .287, \eta_p^2 = .014$. The effect of arousal was not significant, $F(1, 145) = 0.070, p = .791, \eta_p^2 < .001$.

Figure 20. Study 2, 1000 to 4000ms: proportions of long responses for emotional and neutral trials as a function of stimulus duration.

Figure 21. Study 2, 1000 to 4000ms: mean point of subjective equality for emotional and neutral trials. Error bars represent standard errors.

Figure 22. Study 2, 1000 to 4000ms: mean point of subjective equality for emotional and neutral trials separated according to valence for male participants (left panel) and female participants (right panel). Error bars represent standard errors.

Difference limen. Temporal sensitivity for emotional and neutral trials was compared in a mixed ANOVA using arousal, valence, and sex as between-subjects variables and trial type (emotional, neutral) as the within-subjects factor. Results are shown in Table B4. There was a significant effect of trial type, $F(1, 145) = 8.615, p = .004, \eta_p^2 = .056$, whereby temporal sensitivity was better when making duration judgements for emotional images (mean DL = 494.015, SEM = 8.814) than for neutral images (mean DL = 529.188, SEM = 11.231). The effect of trial type did not interact with arousal, valence, or sex. There was also a nearly significant effect of valence, $F(1, 145) = 3.872, p = .051, \eta_p^2 = .026$, signalling better temporal sensitivity for participants who saw negative images (mean DL = 495.554, SEM = 9.567) than for participants who saw positive images (mean DL = 528.733, SEM = 13.787).

Long duration range

Point of subjective equality. Figure 23 shows the proportions of long responses for emotional and neutral trials of each emotion group as a function of stimulus duration. Points of subjective equality for emotional and neutral trials were compared in a mixed ANOVA using arousal, valence, and sex as between-subjects factors, and trial type (emotional, neutral) as the within-subjects factor (results of the analysis are shown in Table B5 and Figure 24 shows the mean PSE for emotional and neutral trials). There was a Valence X Sex interaction, $F(1, 128) = 6.078, p = .015, \eta_p^2 = .045$. Figure 25 shows mean emotional and neutral PSEs values for negative and positive conditions, separated by sex. The effect of valence did not reach significance for men, $F(1, 64) = 2.581, p = .113, \eta_p^2 = .039$, indicating that men assigned to positive and negative conditions made similar duration judgements. Women, however, underestimated the duration of images in the positive conditions compared to the duration of images shown in the negative condition, $F(1, 64) = 4.000, p = .050, \eta_p^2 = .059$. There was no effect of trial type, $F(1, 128) = 0.739, p = .392, \eta_p^2 = .006$, nor did trial type interact with arousal, valence, or sex, indicating that within each emotion group, participants provided similar time estimates for emotional and neutral images.

Figure 23. Study 2, 2000 to 8000ms: proportions of long responses for emotional and neutral trials as a function of stimulus duration.

Figure 24. Study 2, 2000 to 8000ms: mean point of subjective equality for emotional and neutral trials. Error bars represent standard errors.

Figure 25. Study 2, 2000 to 8000ms: mean point of subjective equality for emotional and neutral trials separated according to valence for male participants (left panel) and female participants (right panel). Error bars represent standard errors.

Difference limen. Temporal sensitivity was assessed by conducting a mixed ANOVA on DLs using arousal, valence, and sex as between-subjects factors and trial type as the within-subjects factor. Results are displayed in Table B6. The ANOVA revealed a main effect of trial type, $F(1, 128) = 12.908, p < .001, \eta_p^2 = .092$, indicating better temporal sensitivity for emotional trials (mean DL = 927.891, SEM = 14.448) than for neutral trials (mean DL = 992.799, SEM = 17.755). Trial type did not interact with any other factor, showing that the effect was robust across emotion groups. There was also a significant Valence X Sex interaction, $F(1, 128) = 6.494, p = .012, \eta_p^2 = .048$. DL values for male participants who saw negative and neutral images (mean DL = 1000.061, SEM = 30.220) were comparable to DL values for male participants who saw positive and neutral images, $F(1, 64) = 1.647, p = .204, \eta_p^2 = .025$. However, the effect of valence was significant for women, $F(1, 64) = 5.909, p = .018, \eta_p^2 = .085$. Female participants who saw negative and neutral images (mean DL = 901.967, SEM = 19.741) showed better temporal sensitivity than female participants who saw positive and neutral images (mean DL = 983.108, SEM = 28.736).

Weber ratios. For each participant, WRs were calculated by dividing the DL of each emotional category by its corresponding PSE. For instance, the WR for high arousal positive trials is calculated by dividing the DL of high arousal positive trials by the PSE of high arousal positive trials for that participant. DLs were calculated using the same regression line fitted to find the PSEs. Like DLs, lower WR values are indicative of higher (better) sensitivity to time, and higher WR values signal poor temporal sensitivity. Unlike the DL, which is an *absolute* measure of sensitivity, the WR is a *relative* measure of discriminability. The use of WRs thus allows for comparison across the three different duration ranges used in the present study (short, 400-1600ms; middle, 1000-4000ms; long, 2000-8000ms).

WRs for emotional trials and neutral trials of each duration range are shown in Figure 26. WRs were the dependent measure in a mixed ANOVA using duration range, arousal, valence, and sex as between-subjects factors and trial type (emotional, neutral) as a within-subjects factor. Results of the ANOVA are shown in Table B7. The effect of trial type was significant, $F(1, 405) = 16.304, p < .001, \eta_p^2 = .039$. WRs were lower for emotional trials than for neutral trials,

indicating steeper psychometric functions for emotional trials than for neutral ones. In other words, temporal sensitivity was better for emotional than for neutral trials. Trial type did not interact with duration range, $F(2, 405) = 0.888$, $p = .412$, $\eta_p^2 = .014$, or any other factor, which means that the effect was robust across duration range and seen for all emotions. There was also a main effect of duration range, $F(2, 405) = 4.635$, $p = .010$, $\eta_p^2 = .022$, showing that the scalar property of variance did not hold across all three ranges. Post hoc Tukey comparisons of ratios (see Table 8) revealed lower WR values in the long duration range compared to the short ($p = .051$) and middle ($p = .010$) duration ranges, which did not differ. There was also a Duration Range X Sex interaction, $F(2, 405) = 3.355$, $p = .036$, $\eta_p^2 = .016$. However, when analyses were repeated using the arithmetic mean rather than the PSE as the denominator in WR calculations, the Duration Range X Sex interaction was not significant. This shows that the interaction was driven by low PSE values for female participants in the long duration range and not by differences in temporal sensitivity.

Figure 26. Study 2: mean Weber ratio for emotional and neutral trials of each duration range. Error bars represent standard errors.

Table 8

Tukey HSD Comparisons for Weber Ratios of Study 2

Compared Ranges	Mean WR Difference	Standard Error	p	95% Confidence Interval	
				Lower Bound	Upper Bound
Short vs. Middle	-0.002	0.004	.851	-0.013	0.008
Short vs. Long	0.011	0.005	.051	0.000	0.021
Middle vs. Long	0.013	0.004	.010	0.003	0.024

Note: Mean square error = 0.001

Discussion

Emotion effects in the short duration range. The first goal of the present study was to test the effect of complex emotional images on time perception in the widely-used 400 to 1600ms range of a temporal bisection task. The study revealed that shorter duration estimates were provided for emotional compared to neutral images. The systematic underestimation of emotional images in this duration range is opposite to the results of numerous time perception studies that also used a temporal bisection task in the 400 to 1600ms range. For instance, studies by Droit-Volet and colleagues (2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Grommet et al., 2011) as well as Tipples (2008) all found a relative overestimation of the duration of emotional stimuli compared to neutral stimuli. In the case of Droit-Volet et al., Effron et al., Gil et al. (2007), and Tipples et al., the overestimation of emotional facial expressions compared to neutral expressions was attributed to changes in the speed of the internal clock's pacemaker. It was posited that viewing emotional faces increased the speed of the pacemaker, allowing a greater number of pulses to be accumulated than when viewing a neutral face. Conversely, Study 2 provides evidence of attentional effects of emotion in the 400 to 1600ms duration range, as reflected by the underestimation of emotional stimuli. Importantly, this demonstrates that

the inconsistencies between the findings for complex images and for faces are not because of duration range.

To date, only Smith et al. (2011) and the present thesis have used IAPS images fully crossed for arousal (low, high) and valence (negative, positive) in a temporal bisection task. The study by Smith and his colleagues included a 400 to 1600ms range identical to the short duration range used in the present study. Smith et al.'s PSE analyses showed that the duration of low arousal negative images was underestimated compared to the duration of low arousal positive, high arousal negative, and neutral images. Proportions of long responses showed the same pattern (underestimation of low arousal negative images) in the 1000ms duration, and post-hoc analyses also showed a relative overestimation of high arousal negative images only at the 800ms stimulus duration (Smith et al., 2011). The overestimation of high arousal negative images was not seen in PSE analyses, yet Smith and colleagues focus their discussion on this overestimation and fail to discuss why low arousal negative were underestimated compared to other emotional images and most importantly, compared to neutral images. Their findings are difficult to attribute to either attentional or activational effects of emotion.

Dynamic effects of emotion. Study 2 included three duration ranges. The short duration range of 400 to 1600ms was chosen because it is widely used in studies of time perception for emotional facial expressions. A long range of 2000 to 8000ms was included because it is similar to the duration range used in previous studies of the effect of complex emotional stimuli on time perception (2000 to 6000ms; Angrilli et al., 1997; Noulhiane et al., 2007) while maintaining the same spread (a 1:4 ratio between the short and long anchor durations) as the short duration range. A middle duration range of 1000 to 4000ms was also included.

Results varied across duration ranges. As previously discussed, PSEs in the 400 to 1600ms range showed attentional effects of emotion. Likewise, results of the middle duration range (1000-4000ms) were also in line with attentional effects. PSE analyses revealed an interaction between trial type, valence, and sex that stemmed from time judgements made by male participants assigned to negative conditions. Men in these groups underestimated the duration of

emotional images (either high arousal negative or low arousal negative images) compared to neutral images. There was no such effect for women or for any participants assigned to positive conditions. These results suggest that for men, negative images attracted more attention than neutral images.

The long duration range (2000 to 8000ms) revealed a different pattern. There was an effect of valence for women, but not for men. Women assigned to positive conditions provided shorter duration estimates than women assigned to negative conditions. There was no main effect or interaction involving trial type, meaning that the underestimation was for both positive and for neutral images that were presented in the same block. The effect therefore appears to have carried over to neutral trials, like the carry-over effects seen in Study 1. In contrast to findings for the short and middle duration ranges, results of the long duration range are not easily reconciled with attentional effects of emotion. ERP studies of the effect of arousal and valence on attention typically report greater attentional capture by negative stimuli than by positive ones (e.g. Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Carretié et al., 2004; Hajcak & Olvet, 2008; Ito et al., 1998). Some ERP studies have reported finding an attentional bias toward negative images even for high arousal stimuli whereas others report that high arousal positive and high arousal negative stimuli have similar effects on attention (Franken et al., 2008). They do not, however, find evidence of greater attentional capture by positive than by negative stimuli. Thus, the pattern of results from the long duration range of the present study cannot be explained by ERP research on attention. Nor can the underestimation of positive (and mixed neutral) images compared to negative (and mixed neutral) images be explained by activation effects of emotion, which predict a relative overestimation of arousing stimuli. Indeed, research on the effect of emotion on activation consistently find that activation increases with arousal, but is unrelated to valence (Greenwald et al., 1989; Lang et al., 1993). There is thus no clear explanation of the pattern of results seen in the long duration range.

Temporal sensitivity and scalar variance. Temporal sensitivity was measured within each duration range using DLs and compared across duration ranges using WRs. There was a significant effect of trial type on WRs, which was robust across all duration ranges. It revealed that WRs were lower for emotional

trials than for neutral trials, indicating that temporal sensitivity was better when viewing emotional images than when viewing neutral images.

WR analyses showed scalar variance when comparing the short range (400-1600ms) and the middle range (1000-4000ms). Had emotion effects in these two ranges been the same, scalar variance would have pointed to proportional effects of emotion on the attentional gate (if images that capture attention were underestimated compared to images that do not capture as much attention) or the pacemaker (if activating images were overestimated compared to images that produce less activation). However, the effect of emotional factors on time perception was not quite the same in short and middle ranges. In the short range, the duration of all emotional images was underestimated compared to neutral images, pointing to attentional effects of all emotional trials. The middle duration range also showed attentional effects of emotion, but only for men who were shown a mix of neutral and negative images. Thus, while it is possible to determine that results were incompatible with activational effects of emotion, Study 2's results cannot conclusively prove the presence of proportional effects of emotion, and so cannot distinguish between attentional switch and gate accounts. When comparing temporal sensitivity of the short and middle ranges to that of the long range, scalar variance no longer held. In other words, participants who completed the bisection task in the 2000 to 8000ms range showed better temporal sensitivity (lower WRs) than participant who bisected the 1000 to 4000ms interval.

It is easy to imagine that the categorizing durations as short or long was easier in the long duration range than in the short and middle ranges. Although the relative difference between the short and long anchor was consistent across duration ranges (the long anchor was four times longer than the short anchor) the *absolute difference* between anchor durations (i.e. the length that separates the two anchors) increased with duration range. In the short range (400 to 1600ms), the anchor durations were separated by 1200ms. In the middle range (1000 and 4000ms), the difference between anchors was 3000ms. In the long range of 2000 to 8000ms, the two anchors were separated by 6000ms. Unlike the spread, the effect of the absolute difference between anchor durations on the WRs has not been studied extensively (Kopeck & Brody, 2010). In their review of

the temporal bisection task for human subjects, Kopec and Brody identified the effect of absolute distance between anchor durations on WRs as a topic that requires further study.

Alternatively, lower WRs in the longest range could be because participants used a counting strategy to make duration judgements. Concerns about the use of counting strategies have been raised by reports that chronometric counting leads to violations of the scalar property of time estimation (Grondin et al., 1999; Hinton & Rao, 2004; Wearden, 1991) which is why some studies of time estimation in the seconds range typically use a concurrent task to prevent the use of chronometric counting (e.g. Wearden, Rogers, & Thomas, 1997). Participants in the present study were not given specific instructions as to which timing strategy to use or not to use. The inclusion of a secondary task would not have been appropriate given that it would be impossible to delineate between attentional effects of emotion and attentional effects of the secondary task.

In a recent study, Rattat and Droit-Volet (2012) compared the effect of counting and not counting on temporal bisection of the 1000-4000ms interval as well as the 2000-8000ms interval (an exact match to the middle and long duration ranges of Study 2, respectively). They found no effect of condition (counting or not counting) on PSEs, indicating that counting strategies did not influence duration judgements. However, counting significantly impacted upon WRs. The use of a counting strategy was shown to produce violations of the scalar property of variance by lowering WRs in the long duration range. This provides strong evidence that improved temporal discriminability in the long duration range of the present study was due to chronometric counting. Researchers have favoured durations below 2 seconds because such short durations may prevent the use of counting (Droit-Volet et al., 2004).

While the effect of emotion on counting has not been explicitly studied, it is worth noting that arousal, which increases the speed of the pacemaker, may also lead one to count faster. Many studies have reported that counting speed increases when body temperature is above normal and decreases with below-normal temperatures (for a review see Wearden & Penton-Voak, 1995). This suggests that chronometric counting is susceptible to activation effects and thus,

the use of a counting strategy might not change the impact of emotional arousal on time estimates. Still, evidence that chronometric counting leads to violation of the scalar property of variance can be particularly problematic in establishing whether emotions affect time perception through the pacemaker or gate (proportional effects) or the switch (absolute effects). The durations used in the long duration range of the present study may have been particularly easy to count given that stimulus durations were separated by exactly one second: 2000, 3000, 4000, 5000, 6000, 7000, and 8000ms. For this reason, the long duration range in the next study will be changed to 2000 to 6000ms (interval durations: 2667, 3333, 4000, 4667, and 5333ms).

Sex effects. Study 2 revealed the presence of sex effects on time perception in the middle and long ranges. It is possible that men and women rate emotional pictures differently on the arousal and valence scales. Imagine for example, that women found high arousal negative images more arousing than men did. If this were true, time perception for women viewing high arousal negative images would be more susceptible to activational mechanisms whereas time judgements made by men would be more susceptible to attentional mechanisms. Differences in the ratings provided by men and women would thus produce time perception differences that are not inherent to sex. Complex images were selected based on mean arousal and valence ratings, which were provided by male and female participants. The IAPS instructional manual states that participants were “members of both sexes taking an Introductory Psychology class and who participated as part of a course requirement. Approximately 100 participants (half female) rated each picture.” (Lang et al., 2008, p.4). However, it is possible that arousal and valence ratings differed for men and women.

Few studies have examined the role of sex in a temporal bisection task, although sex congruency effects have previously been reported in experiments using face stimuli. For instance, a temporal bisection study conducted by Tipples (2008) included a footnote reporting sex congruency effects on the proportions of long responses, but statistical analyses of sex effects were not reported. Chambon et al. (2008) found that the duration of photographs of elderly faces were underestimated in comparison to the duration of photographs of young

faces, but only when the participant's sex was the same as the sex of the stimulus face. Men underestimated the duration of elderly male faces compared to that of young male faces, but reported no difference in the duration of old and young female faces. Conversely, women underestimated the duration of photographs showing elderly female faces compared to young female faces, but made similar duration judgements for faces of young and old men. It is because of sex congruency effects that some studies included only female participants and used stimuli consisting solely of female faces (e.g. Effron et al., 2006).

Given that sex congruency effects were only ever tested and reported in studies using faces as stimuli, there was no empirical reason for restricting participation in Study 2 to students of one sex. Previous time perception research using complex emotional images from the IAPS database either omitted participants' sex from statistical analyses (Grommet et al., 2011; Smith et al., 2011) or failed to report participant sex altogether (Angrilli et al., 1997). Whether differences between time perception by male and female participants were inherent to sex or not, Study 2 shows the importance of reporting participants' sex, and of including sex in statistical analyses. It also suggests that the findings of studies conducted using only male or only female participants may not be generalized to the other sex.

Effect sizes and the between-subjects design. The temporal bisection task used in study 1 (2000-6000ms) as well as in the long duration of the present study (2000-8000ms) showed carry-over effects of emotional trials onto neutral trials presented in the same block. Thus, it can be argued that emotional dimensions should be manipulated between-subjects. However, it is worth noting that both studies showed dramatically small effect sizes and a number of marginally significant results. For instance, the Arousal X Valence interaction in Study one had a η_p^2 of only .067. In the present study, this same interaction showed a η_p^2 of .013, .023, and .007, for the short, middle, and long ranges, respectively. Study 2 η_p^2 for main effects of arousal and valence were all under .003, and .016, respectively. Such low effect sizes highlight the need to increase statistical power by increasing the number of trials, participants, or by changing the design of the experiment. Avoiding image repetition is a crucial feature of all experiments in the present thesis (for a discussion, see p.50). To build a set of

unique stimuli, images were thus selected from the largest database of emotional images standardized for arousal and valence (the IAPS). Unfortunately, as explained in the discussion of Study 1, the number of available high arousal positive IAPS images limits the number of trials that can be completed without having to repeat images. Thus, although the presence of carry-over effects of emotion in the long duration range can be used to argue for a between-subjects design for emotion, low effect sizes warrant the need for the use of a within-subjects design. By using emotion as a within-subjects variable, it may be possible to increase statistical power for tests of the effect of emotional variables on time perception. The next study will thus use a within-subjects design for emotional arousal and valence.

Study 3: Arousal and Valence as Within-subjects Variables

Study 1 found that the effect of viewing emotional images can carry over and influence time perception for neutral images presented in the same block. For this reason, a between-subjects design whereby participants were only shown emotional stimuli belonging to one emotion category (high arousal negative, high arousal positive, low arousal negative, or low arousal positive) was also adopted in Study 2 rather than presenting emotional images that differ in arousal and valence within the same block. This was done to prevent carry-over effects of one or more types of emotional images onto the others.

In an effort to prevent carry-over effects of emotion onto neutral trials, the response-stimulus interval for Study 2 was increased to a randomly varying duration between 1000 and 2000ms. There were no carry-over effects in the short and middle duration ranges. Emotional trials were underestimated relative to neutral trials, which were unaffected by emotion condition. The long duration range, however, showed a significant interaction between sex and valence that did not interact with trial type. This suggests that emotion effects carried over to neutral trials. Finding carry-over effects of emotion in long ranges (Study 1, 2000-6000ms and Study 2, 2000-8000ms) but not in the short and middle ranges suggests that carry-over was linked to stimulus duration rather than the response-stimulus interval. It was posited that participants use a different timing strategy (i.e. chronometric counting) in longer ranges, which changes the criterion to which all trials of the bisection task (emotional and neutral) are compared.

Results of Study 1 (temporal bisection task), as well as Study 2's short and middle duration ranges all found that the duration of emotional images (sometimes all, sometimes only a certain subset such as negative images) was underestimated compared to neutral images. This suggests that emotional images divert attention away from the passage of time. Results of Study 2's long duration range could not be as easily described by attentional effects of emotion, nor could they be easily explained by an activation account. Attentional effects of emotion have been found in other studies that used complex images (Gil et al., 2009; as well as in the 100-300ms range of Smith et al., 2011), while others found support for activation effects of emotion (e.g.

Grommet et al., 2011). Moreover, attentional effects on the perceived duration of complex emotional images are in stark contrast to studies of the effect of emotion on time perception for emotional facial expressions, which all report activational effects of emotion (Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Tipples, 2008).

There are two important differences in the experimental design of studies 1 and 2 and the design of previously published temporal bisection studies of emotion. The first is that previous studies manipulated emotion within-subjects (Droit-Volet et al., 2004; Effron et al., 2006; Smith et al., 2011; Tipples, 2008). Having now established that arousal and valence effect have particularly small effect sizes (see Study 2 discussion), it is possible that using a within-subjects design is simply a more powerful way to test emotion effects. Thus, opposite findings of attentional effects of complex emotional images and activational effects of emotional facial expressions may be the results of different designs. This possibility is explored in the present study. The second difference is that all previous research on the effect of emotion on time perception repeated the presentation of stimuli over the course of the experiment (Droit-Volet et al., 2011; Effron et al., 2006; Gil et al., 2009; Gil & Droit-Volet, 2011; Grommet et al., 2011; Smith et al., 2011; Tipples, 2008). As discussed in the introduction of this thesis, image repetition differentially affects stimuli belonging to different arousal or valence categories. Thus, avoiding repetition was an important requirement for the systematic assessment of emotion effects on time perception undertaken in the present thesis. The possibility that differences between the findings of Studies 1 and 2 and the findings of previous studies of emotion was due to image repetition will be explored in Study 4.

Study 3 Goals

The purpose of Study 3 was to determine if using a within-subjects design for arousal and valence would have a different effect on time perception for complex images than using a between-subjects design (Studies 1 and 2). With that difference in mind, the goals of the present study are therefore the same as those of Study 2: to test the effect of complex emotional stimuli that vary according to arousal and valence on time perception and temporal sensitivity,

and to compare results across three duration ranges. In the present study, participants will perform the temporal bisection task in a short (400 to 1600ms), middle (1000 to 4000ms), or long duration range (2000 to 6000ms). The short and middle ranges for Study 3 are identical to the short and middle ranges of Study 2. The long range of 2000 to 6000ms was chosen for two reasons: because it is the same duration range used in Study 1's temporal bisection task (which matches the range of durations used by Angrilli et al., 1997), and because its intermediate durations may not be as easily counted as durations in Study 2's 2000 to 8000ms range (see Study 2 for a discussion). Just like in Studies 1 and 2, IAPS images will not be repeated, meaning that participants will see each specific image only once over the course of the experiment.

Method

Participants. Three hundred and seventeen undergraduate psychology students (165 men and 152 women) from the University of Washington received course credit for their participation. All had normal or corrected-to-normal vision. The study was approved by the Human Subjects Division of the University of Washington's Institutional Review Board.

Apparatus. Stimuli were presented using Dell PCs running Matlab and the Psychophysics Toolbox extensions (Brainard, 1997). Pictures (512 x 384 pixels, measuring 135.5 x 101.6 mm) were viewed on the computers' 23" flat LCD monitors, at a resolution of 1280 x 1024 pixels.

Stimuli. The same coloured images from the IAPS database used in Studies 1 and 2 were used in the present study. See Table 3 for means and ranges for arousal and valence ratings of the IAPS images used.

Task. Participants performed a temporal bisection task (see Temporal Bisection Task section of Study 1). Three different stimulus duration ranges were used; short, mid or long. In the short duration range, images were presented for 400, 600, 800, 1000, 1200, 1400 or 1600ms. In the mid duration range, images were presented for 1000, 1500, 2000, 2500, 3000, 3500, or 4000ms. In the long duration range, images were displayed for 2000, 2667, 3333, 4000, 4667, 5333 or 6000ms. Anchor durations were the shortest and longest duration of the range in question (e.g. anchor durations for the middle range were 1000 and

4000ms). Each trial was preceded by the appearance of the word “Ready” for a random interval between 3000 and 4000ms. The participant’s response triggered the start of the next trial. Participants were instructed to respond as accurately as possible.

Procedure. Participants were tested alone or in small groups of 2-5. They were individually seated at computer stations. A within-subject design was used for emotion, thus participants were shown all four types of emotional stimuli as well as neutral stimuli, randomly mixed. Participants performed one block of 175 trials (35 images of each emotion category; high arousal negative, high arousal positive, low arousal negative, low arousal positive and 35 neutral images). Examples of the images used are shown in Figure 7. The experiment began with a short training phase (10 trials) followed by one block of test trials (175 trials). Stimuli were randomly assigned to one of the seven durations, with 5 trials per duration. Each picture was presented only once.

Results

Proportions of long responses, points of subjective equality (PSEs) and DLs were calculated using the method described in the temporal bisection section of Study 1, which was also used in Study 2 and by Droit-Volet et al. (2004). Data from 15 participants were excluded for having nonsensical PSE values (i.e. PSEs that were lower than the short anchor or greater than the long anchor for that participant’s duration range). Of the remaining 302 participants, 15 were excluded for having PSEs that were more than three standard deviations away from the mean for that duration range and 24 more were omitted for having DLs that were more than three standard deviations away from the mean for that duration range. Two participants were excluded for being age outliers (47 and 50 years old). Sex and age descriptive statistics for the remaining participants in each duration range are reported in Table 9. Mean PSEs, DLs, and WRs for all duration ranges are shown in Table 10.

Table 9

Mean Age and Range of Study 3 Participants

	N	Min	Max	Mean	SEM
400-1600ms					
Men	49	18	25	19.37	0.21
Women	49	18	23	19.37	0.15
1000-4000ms					
Men	53	18	24	19.49	0.18
Women	39	18	27	19.54	0.27
2000-6000ms					
Men	50	18	27	19.28	0.23
Women	45	18	29	19.62	0.29

Note: SEM= Standard error of the mean

Table 10

Mean Point of Subjective Equality, Difference Limen, and Weber Ratio for Study 3

	Point of subjective equality	SEM	Difference limen	SEM	Weber ratio	SEM
400-1600ms						
HANV	979.029	16.655	204.441	5.129	0.216	0.008
HAPV	981.058	12.943	199.429	4.179	0.208	0.006
LANV	998.347	12.361	197.820	4.187	0.200	0.005
LAPV	977.054	11.795	192.431	2.913	0.200	0.005
Neutral	976.929	11.494	190.202	3.057	0.197	0.004
1000-4000ms						
HANV	2517.760	36.535	497.756	12.745	0.203	0.008
HAPV	2520.648	29.148	490.108	11.167	0.196	0.005
LANV	2482.360	24.503	479.913	10.795	0.196	0.005
LAPV	2486.353	24.899	452.243	7.075	0.183	0.003
Neutral	2498.112	28.628	467.205	8.499	0.190	0.005
2000-6000ms						
HANV	4054.421	47.714	672.298	14.166	0.167	0.004
HAPV	4074.967	45.669	652.183	13.922	0.161	0.004
LANV	3989.424	45.510	642.435	14.644	0.164	0.005
LAPV	3971.199	42.331	639.004	11.678	0.163	0.004
Neutral	3954.399	45.095	671.264	17.556	0.172	0.005

Note: HANV = high arousal negative valence, HAPV = high arousal positive valence, LANV= low arousal negative valence, LAPV = low arousal positive valence, SEM= Standard error of the mean.

Unlike Studies 1 and 2, however, arousal and valence in the present study were manipulated within subjects. In the between-subjects design (Studies 1 and 2) it was possible to directly compare the results of both trial types: emotional and neutral. In the present study, participants performed the temporal bisection task for five different trial types: high arousal positive, high arousal negative, low arousal positive, low arousal negative, and neutral. For this reason, statistical analyses of the PSEs and DLs were carried out in a slightly different way. The comparison of emotional trials to neutral trials was conducted using two types of difference scores: dPSEs and dDL.

A difference score between emotional PSEs and the neutral PSE was obtained for each emotion by subtracting the emotional PSE from the neutral PSE (e.g. dPSE for high arousal negative = neutral PSE – high arousal negative PSE). Although this difference score has not been used in previous time perception literature, dPSEs offer a more intuitive measure of the bisection point than raw PSE values: higher dPSEs are reflective of longer duration estimate whereas lower dPSEs are indicative of shorter time estimates. Moreover, the sign of the dPSE indicates whether emotional trials were under- or overestimated compared to the duration of neutral trials. Negative scores indicate that the duration of emotional images was underestimated compared to that of neutral trials; whereas positive scores are indicative of a relative overestimation of emotional images compared to neutral images.

One-sample t-tests were conducted to compare the dPSE of each emotion to zero. These tests are equivalent to the one-sample t-tests conducted on the d' (the difference between the z-score of the proportion for long responses to emotional faces and the z-score of the proportion of long responses to neutral faces) in previous studies of the effect of emotional images on time perception (e.g. Droit-Volet et al. 2004). A significant result indicates that the duration of emotional trials for that particular emotion (e.g. high arousal negative) was either underestimated (if the dPSE is negative) or overestimated (if the dPSE is positive) compared to the duration of neutral trials. The effect of arousal and valence on time perception was tested in a mixed ANOVA on the dPSEs. It should be noted that because dPSEs represent the difference between the PSE for neutral trials and the PSE for each emotion group, the results of the ANOVA on

dPSEs will yield the same results (same F and p values) as would an ANOVA on raw PSE values for emotional trials. The effect of emotional trials as a whole (i.e. whether emotional trials were systematically under- or overestimated compared to neutral trials) was tested using the intercept term of the ANOVA. The test of the intercept term is thus equivalent to testing the effect of “trial type” in Studies 1 and 2.

As with the PSEs, difference scores were also used to test the effect of emotion on temporal sensitivity. For each of the four emotions, a difference score (dDL) was obtained by subtracting the emotional DL from the neutral DL (e.g. dDL for high arousal negative = neutral DL – high arousal negative DL). The dDL of each emotion (e.g. dDL for high arousal negative stimuli) represents the difference between temporal sensitivity of that specific emotion and temporal sensitivity of neutral images, expressed in milliseconds. Compared to raw DL values reported in Studies 1 and 2, dDLs have two advantages. Firstly, dDLs values are more intuitive, with higher scores representing better temporal discrimination than lower scores. Secondly, the sign of the dDL for a given emotion (e.g. high arousal negative) shows whether temporal sensitivity for these trials was better (positive dDL) or worse (negative dDLs) temporal sensitivity for neutral trials.

The effect of arousal and valence on temporal sensitivity was tested in a mixed ANOVA on the dDLs, which is statistically equivalent to conducting an ANOVA on raw DL values. The effect of emotional trials as a whole (i.e. whether emotional trials have better or worse temporal sensitivity than neutral trials) was tested using the intercept term of the ANOVA on dDLs. Tests of the intercept term in the present study are thus equivalent to tests for effects of “trial type” in Studies 1 and 2.

In order to compare temporal sensitivity across duration range and test for scalar variance, WRs were calculated by dividing the DL of emotional or neutral trials by the corresponding PSE. For instance, the WR for high arousal negative images was obtained by dividing the DL for high arousal negative images by the PSE for high arousal negative images. Just like for PSEs and DLs, a difference score (dWR) for each emotion was obtained by subtracting the emotional WR from the neutral WR. Just like for dDLs, lower dWRs correspond

to poor temporal discrimination whereas higher dWRs correspond to better temporal discrimination.

Statistically significant and theoretically meaningful effects are reported directly in the text. Full ANOVA tables for Study 3 can be found in Appendix C.

Short duration range

Point of subjective equality. Figure 27 shows the proportion of long responses for all trials as a function of stimulus duration. Arousal and valence were manipulated within-subjects, meaning that participants were shown images belonging to all four emotional categories as well as neutral images in one single block. For clarity, however, the proportions of long responses of each category are shown separately. Proportions of long responses for neutral (baseline) trials are also shown in each panel.

Mean dPSEs are shown in Figure 28. All mean dPSE values were negative, indicating that the duration of emotional images was underestimated compared to the duration of neutral images. One-sample t-tests on the dPSEs showed that time estimates for high arousal negative, $t(89) = -0.154$, $p = .878$, high arousal positive, $t(89) = -0.380$, $p = .705$, and low arousal positive images, $t(89) = -0.013$, $p = .990$, were not significantly different from time estimates for neutral images. Only the dPSE for low arousal negative images was significantly different from zero, $t(89) = -2.221$, $p = .029$, indicating that the duration of low arousal negative images was underestimated compared to the duration of neutral images. The effect of arousal, valence, and sex on time perception was tested in a mixed ANOVA on the dPSEs. Results of the ANOVA are displayed in Table C1. The intercept term showed that the duration of emotional stimuli as a whole was not significantly under- or overestimated compared to the duration of neutral trials, $F(1, 88) = 0.702$, $p = .405$, $\eta_p^2 = .008$. There was no significant effect of arousal, $F(1, 88) = 0.966$, $p = .328$, $\eta_p^2 = .011$, of valence, $F(1, 88) = 1.042$, $p = .310$, $\eta_p^2 = .012$, or of sex, $F(1, 88) = 1.961$, $p = .165$, $\eta_p^2 = .022$, nor were there any significant interactions.

Figure 27. Study 3, 400 to 1600ms: proportions of long responses for emotional trials as a function of stimulus duration. The proportions of long responses for neutral trials (baseline) are also shown in each panel.

Figure 28. Study 3, 400 to 1600ms: mean dPSEs. Error bars represent standard errors.

Difference limens. Mean dDLs values are shown in Figure 29. To compare temporal sensitivity across emotion groups, a mixed ANOVA on the dDLs was conducted using arousal and valence as within-subjects variables, and sex as a between-subjects variable (Table C2). All dDL values were negative, indicating worse temporal sensitivity for emotional trials than for neutral trials. The grand mean of dDLs for emotional trials was tested against zero using the intercept of the ANOVA. The effect was significant, $F(1, 88) = 6.044$, $p = .016$, $\eta_p^2 = .064$, confirming that temporal sensitivity was worse for emotional than for neutral trials. The ANOVA showed no significant main effects [arousal, $F(1, 88) = 2.722$, $p = .103$, $\eta_p^2 = .030$, valence, $F(1, 88) = 2.334$, $p = .130$, $\eta_p^2 = .026$, sex, $F(1, 88) = 0.364$, $p = .548$, $\eta_p^2 = .004$]. There were no significant interactions.

Figure 29. Study 3, 400 to 1600ms: mean dDLs. Error bars represent standard errors.

Middle duration range

Point of subjective equality. Figure 30 shows the proportions of long responses for neutral trials and for high arousal negative (Panel A), high arousal positive (Panel B), low arousal negative (Panel C), and low arousal positive images (Panel D) as a function of stimulus duration. Mean dPSE values are shown in Figure 31. As can be seen, dPSEs for high arousal images were negative whereas mean dPSE values for low arousal images were positive. One-sample *t*-tests comparing dPSEs to zero showed no significant difference between time estimates for neutral images and for high arousal negative, $t(84) = -0.703$, $p = .484$, high arousal positive, $t(84) = -0.875$, $p = .384$, low arousal negative, $t(84) = 0.650$, $p = .517$, or low arousal positive images, $t(84) = 0.497$, $p = .621$. A mixed ANOVA was conducted on the dPSEs using arousal and valence as within-subjects variables and sex as a between-subject variable. Results of the ANOVA are displayed in Table C3. The intercept showed no difference between PSEs for emotional trials as a whole and PSEs for neutral trials, $F(1, 83) = 0.001$, $p = .979$, $\eta_p^2 < .001$. The ANOVA showed no effect of valence, $F(1, 83) = 0.047$, $p = .828$, $\eta_p^2 = .001$, or sex, $F(1, 83) = 1.542$, $p = .218$, $\eta_p^2 = .018$, nor did valence or sex interact with each other or with arousal. There was only a trend toward an effect of arousal, $F(1, 83) = 3.003$, $p = .087$, $\eta_p^2 = .035$. As can be seen in Figure 31, the trend suggests that the duration of high arousal images was underestimated compared to the duration of low arousal images.

Figure 30. Study 3, 1000 to 4000ms: proportions of long responses for emotional trials as a function of stimulus duration. The proportions of long responses for neutral trials (baseline) are also shown in each panel.

Figure 31. Study 3, 1000 to 4000ms: mean dPSEs. Error bars represent standard errors.

Difference limens. Mean dDL values are shown in Figure 32. Temporal sensitivity was compared across emotion groups in a mixed ANOVA using arousal and valence as the within-subjects factors, and sex as the between-subject factor. Results are shown in Table C4. The intercept term showed no significant difference between DLs for emotional trials and DLs for neutral trials, $F(1, 83) = 1.986, p = .163, \eta_p^2 = .023$. There was a significant effect of arousal, $F(1, 83) = 9.845, p = .002, \eta_p^2 = .106$, showing that temporal sensitivity for low arousal images was better than temporal sensitivity for high arousal images. There was also a significant effect of valence, $F(1, 83) = 5.251, p = .024, \eta_p^2 = .060$, whereby temporal sensitivity for positive trials was better than sensitivity for negative trials. There was no effect of sex, $F(1, 83) = 0.608, p = .438, \eta_p^2 = .007$.

Figure 32. Study 3, 1000 to 4000ms: mean dDLs. Error bars represent standard errors.

Long duration range

Point of subjective equality. Figure 33 shows the proportion of long responses for neutral images plotted alongside proportions of long responses for high arousal negative (Panel A), high arousal positive (Panel B), low arousal negative (Panel C), and low arousal positive images (Panel D) as a function of stimulus duration.

Mean dPSEs are shown in Figure 34. One sample t-tests comparing each dPSE to zero revealed that the duration of high arousal negative, $t(85) = -2.785, p = .007$, as well as high arousal positive images, $t(85) = -3.482, p = .001$, was underestimated compared to the duration of neutral images. There was no difference between duration estimates for low arousal negative and neutral images, $t(85) = -1.074, p = .286$, nor between estimates for low arousal positive and neutral images, $t(85) = -0.554, p = .581$. A mixed ANOVA was conducted on the dPSEs using arousal and valence as within-subjects variables and sex as a between-subject variable. Results of the ANOVA are displayed in Table C5. As can be seen in Figure 34, all dPSEs were negative, indicating underestimation of emotional trials compared to neutral trials. This effect was shown to be significant by testing the intercept term of the ANOVA against zero, $F(1, 84) = 6.365, p = .014, \eta_p^2 = .070$.

Comparing across emotions, the ANOVA showed a significant effect of arousal, $F(1, 84) = 9.271, p = .003, \eta_p^2 = .099$, whereby high arousal images were underestimated compared to low arousal images. The ANOVA also showed a significant interaction of valence and sex, $F(1, 84) = 8.961, p = .004, \eta_p^2 = .096$, which can be seen in Figure 35. Follow up analyses revealed that men underestimated the duration of negative images compared to the duration of positive images, $t(45) = 2.031, p = .048$, whereas women underestimated the duration of positive images compared to the duration of negative images, $t(39) = 2.191, p = .034$.

Figure 33. Study 3, 2000 to 6000ms: proportions of long responses for emotional trials as a function of stimulus duration. The proportions of long responses for neutral trials (baseline) are also shown in each panel.

Figure 34. Study 3, 2000 to 6000ms: mean dPSEs. Error bars represent standard errors.

Figure 35. Study 3, 2000 to 6000ms: mean dPSEs for male (top panel) and female participants (bottom panel). Error bars represent standard errors.

Difference limens. Mean dDLs for the long duration range are shown in Figure 36. The effect of emotion on temporal sensitivity was tested statically in a mixed ANOVA using arousal and valence (within-subjects) as well as sex (between-subjects). Results of the ANOVA are shown in Table C6. The intercept term showed no significant difference between dDLs for emotional trials as whole compared to neutral trials, $F(1, 84) = 1.756, p = .189, \eta_p^2 = .020$. There was a trend toward an effect of arousal which did not reach significance, $F(1, 84) = 3.053, p = .084, \eta_p^2 = .035$. As can be seen in Figure 36, the trend suggests better temporal sensitivity for low arousal than for high arousal images. There was also a significant interaction between valence and sex, $F(1, 84) = 4.603, p = .035, \eta_p^2 = .052$. Figure 37 shows the mean dDLs for men and women. Follow up analyses showed that for men, there was no effect of valence on temporal sensitivity, $t(45) = 0.741, p = .462$. For women, temporal sensitivity for positive trials was better than temporal sensitivity for negative trials, $t(39) = 2.267, p = .029$.

Figure 36. Study 3, 2000 to 6000ms: mean dDLs. Error bars represent standard errors.

Figure 37. Study 3, 2000 to 6000ms: mean dDLs for male (top panel) and female participants (bottom panel). Error bars represent standard errors.

Weber ratios. Figure 38 shows mean dWRs for each duration range. The effect of range on temporal sensitivity was tested using a mixed ANOVA on the dWRs, using duration range and sex as between-subjects variables. Results are shown in Table C7. The intercept term showed that the grand mean for dWRs was no different from zero, which shows that temporal sensitivity for emotional trials was not systematically better or worse than temporal sensitivity for neutral trials, $F(1, 255) = 0.539, p = .464, \eta_p^2 = .002$. There was a significant effect of arousal, $F(1, 255) = 8.031, p = .005, \eta_p^2 = .031$, whereby the temporal sensitivity for low arousal images (mean dWR = 0.001, SEM = 0.002) was better

than temporal sensitivity for high arousal images (mean dWR = -0.007, SEM = 0.002). Finally, the ANOVA also revealed a significant interaction between valence, duration range, and sex, $F(1, 255) = 3.221, p = .042, \eta_p^2 = .025$, which is indicative that the effect of valence and sex on temporal sensitivity varied according to duration range, thereby violating the scalar property of variance. As seen in the DL analyses conducted at each duration range, there was a significant Valence X Sex interaction in the long range: there was no effect of valence on temporal sensitivity for men, but women showed better temporal sensitivity for positive trials than for negative trials. Valence and sex did not affect temporal sensitivity in the short and middle ranges.

Figure 38. Study 3: mean dWRs for all duration ranges. Error bars represent standard errors.

Discussion

The aim of Study 3 was to test the impact of complex emotional images on time perception in a within-subjects design while also avoiding image repetition. Unlike Study 2, in which arousal and valence were between-subjects variables, the within-subjects design of the present study more closely matched previous temporal bisection studies of emotion (Droit-Volet et al., 2004; Effron et al., 2006; Gil et al., 2007; Gil & Droit-Volet, 2011; Grommet et al., 2011; Smith et al.,

2011) that have almost exclusively studied the perceived duration of emotional faces. Participants were shown four types of emotional images (high arousal negative, high arousal positive, low arousal negative, and low arousal positive) as well as neutral images within a single block of trials. In addition to allowing for the comparison of between-subjects (Study 2) and within-subjects designs, Study 3 had two goals: to test the effect of arousal and valence on time perception and temporal sensitivity for complex images, and to compare effects across three duration ranges. All images were presented in random order within a single block, and participants were randomly assigned to one of the three duration ranges.

Dynamic effects of emotion

Study 3 showed dynamic effects of affective variables, that is, the effect of emotional arousal and valence varied across the three duration ranges used. In the short duration range, images were displayed from 400 to 1600ms. All dPSEs were negative, suggesting that the duration of emotional images was systematically underestimated compared to the duration of neutral images. This result, which would have mirrored the findings of Study 2, was not found to be statistically significant. When comparing across the four emotional groups, PSE analyses revealed no significant effects of arousal or valence on time perception.

Participants assigned to the middle duration range were shown images for 1000 to 4000ms. There was no effect of image valence on the PSEs, but there was a trend toward an effect of arousal (i.e. a relative underestimation of the duration of high arousal images compared to low arousal images). Activational accounts of emotion predict an overestimation of the duration of highly arousing images. The results of the 1000-4000ms range of the present study are thus at odds with activational effects of emotion. When PSEs for emotional images were compared to the PSEs for neutral images, there was no significant difference. Duration estimates for neutral images were in the middle of estimates for all emotional trials, which is what Angrilli et al. also reported, although they did not include neutral trials in statistical analyses (Angrilli et al., 1997).

The present study's middle duration range results were different from what was found in Study 2, in which emotion was manipulated between subjects

as opposed to within. Indeed, Study 2's middle range showed that men who were shown a mix of negative and neutral trials underestimated the duration of the negative images compared to the neutral ones. There was no effect of trial type for male participants in the positive conditions or for any female participants. Although the two studies showed different patterns, it should be noted that both the underestimation of negative images compared to neutral images (male participants only; Study 2) and the underestimation of high arousal images compared to low arousal images (Study 3) are in line with attentional rather than activational effects of emotion. Given the 1000 to 4000ms range has not been used in previous studies of time perception for emotional stimuli and therefore, there is no literature to which the present results can be compared.

The task that participants performed in the long duration range, bisection of images presented between 2000 and 6000ms, was an extension of the task performed by participants in the temporal bisection condition of Study 1. The difference was that Study 1 participants saw only a mix of one type of emotional pictures and neutral pictures, whereas participants in the present study were shown all emotional images as well as neutrals. In the present study, participants underestimated the duration of high arousal images compared to low arousal images. The underestimation of high arousal images (which are known to capture attention) compared to low arousal images shows attentional effects of emotion (Droit-Volet & Meck, 2007; Schirmer, 2011). Likewise, Study 1 also showed attentional effects of emotion: the duration of high arousal negative, high arousal positive, and low arousal negative images was underestimated in comparison to the duration of low arousal positive and neutral images. Thus, the results of the 2000 to 6000ms range in both the within- and between-subjects experiments show support for attentional effects of emotion. Taken together, results from the three duration ranges of the present study suggest that attentional effects of arousal on time perception built up over time. Analyses for the shortest duration range showed no effects of arousal. The middle duration range showed a trend toward an effect of arousal whereby the duration of highly arousing images was underestimated in comparison to the duration of low arousal images, and the long duration range showed a significant effect of

arousal (in the same direction as the trend observed in the middle duration range).

The long duration range of the present study also showed a significant interaction between sex and valence. Men underestimated the duration of negative images compared to positive images, whereas women underestimated the duration of positive images compared to the duration of negative images. A nearly identical interaction between sex and valence was also found in Study 2's long duration range (2000-8000ms). The differences are that for Study 2, the effect of valence failed to reach significance for male participants and emotion effects carried over to neutral trials. Although sex effects were not expected to interact with emotion, nor were studies designed to test sex effects, it is now clear that sex can modulate emotion effects on time perception. The implications of sex effects on time perception for emotional stimuli will be addressed in the general discussion.

Temporal sensitivity and scalar timing

WRs were used to compare temporal sensitivity across the three duration ranges. Temporal sensitivity for low arousal images was found to be significantly better than that of high arousal images. The arousal effect was robust across all three ranges. WRs also varied according to duration range, indicating that the scalar property of variance was violated. What is more, the effect of duration range interacted with both valence and participant sex, indicating that temporal sensitivity needed to be assessed separately for each duration range.

In-range analyses of temporal sensitivity were conducted using DLs, which reflect the slope of the psychometric functions. In the 400 to 1600ms range, temporal sensitivity for emotional images was found to be systematically worse than temporal sensitivity for neutral images. Temporal discriminability effects did not vary according to valence or arousal. In the 1000 to 4000ms range, temporal sensitivity was worse for high arousal images than for low arousal ones. The 2000 to 6000ms showed yet another pattern: a significant interaction between valence and sex. Given that this interaction was only observed in the long duration range, it is believed to be responsible for the

Valence X Duration range X Sex interaction for WRs. For male participants, there was no difference in temporal sensitivity for negative and positive images. For female participants however, temporal sensitivity was better for positive images than for negative images. Temporal sensitivity findings in the short, middle, and long ranges of the present study were quite different from that of Study 2, which showed conformity to the scalar property of variance in the short and middle ranges.

It is difficult to contrast these results to temporal sensitivity effects of emotion in the literature. This is because although temporal bisection studies of emotion often report temporal sensitivity using either DLs or WRs, few have found significant effects of emotion on time discrimination. Moreover, many of these studies used only a single duration range. In the 400-1600ms range, for instance, Gil and Droit-Volet (2011) found no difference in the WRs for neutral and angry faces. Tipples (2008) found no difference between WRs for angry, fearful, happy, and neutral facial expressions. Finally, Grommet and colleagues (2011), who used fear-inducing and neutral complex emotional images from the IAPS database, failed to find temporal sensitivity differences between neutral and emotional images in the 250-1000ms and 400-1600ms duration ranges.

Lastly, the only published temporal bisection study that used IAPS images crossed for arousal and valence in the 400 to 1600ms range found that the WRs for low arousal negative images were significantly lower (better temporal sensitivity) than WRs for neutral and high arousal positive images (Smith et al., 2011). They also found that WRs for low arousal images were nearly significantly lower than WRs for high arousal images. Smith and colleagues did not speculate on the cause of this effect because the WRs they obtained were abnormally large, indicating that participants showed very poor temporal sensitivity in all conditions. WR values for temporal bisection tasks with anchor durations similar to those used by Smith et al. often revolved around 0.20. In the case of Smith et al., however, mean WRs were between 0.35 and 0.38 with standard deviations from 0.21 to 0.40.

The authors posited that large WR values were obtained because the study used a large number of stimuli (50 images) compared to other temporal bisection studies that typically use only a handful of stimuli. According to Smith

et al., “A small number of stimuli allows the participant to pay more attention to the timing of the item and less attention to the identity of the item, as frequent presentations of the stimulus leads to less effortful processing.” In the present study, an even larger stimulus set was used (175 images) and yet WRs were in the normally found range (see Table 10).

Complex stimuli vs. facial expressions

Study 1 found attentional effects of complex images on time perception, whereby the duration of attention-capturing images is underestimated compared to the duration of images that do not capture as much attention. However, previous studies have consistently found activational effects of emotional facial expressions, in which emotional stimuli are posited to have increased the speed of the internal clock’s pacemaker. Study 2 demonstrated that the difference was not due to the use of different duration ranges in studies of complex images and faces. The present study showed that the difference between attentional effects of complex images and activational effects of faces was not due to the use of a between-subjects design.

On the one hand, these results indicate that the effect of emotion on time perception depends on the type of stimuli used. On the other hand, however, there is one more important difference between experiments of the present thesis and emotion studies that used facial expressions as stimuli. In the present thesis, the images shown to participants were not repeated over the course of an experiment. This was done to make sure that any emotion effects on time perception were not enhanced, diminished, or modulated in any way by image repetition, which is known to have different effects on the processing of stimuli belonging to different arousal or valence categories. Because there are no published studies of the effect of emotional facial expression on time perception that avoid repeating images, the next study was designed to test if activational effects of emotional facial expression on time perception also occur when stimuli are not repeated.

Study 4: Time Perception for Emotional Facial Expressions

Study 4 Goals

The experiments in the thesis so far point to attentional effects of emotion on time perception, which is contrary to the findings of many studies conducted using the same task (temporal bisection) and duration range (e.g. 400-1600ms). In studies 1-3, emotional stimuli consisted of complex images that varied according to arousal (high, low) and valence (negative, positive), as well as neutral images. Studies that report activational effects of emotion, on the other hand, generally used photographs of men or women showing various facial expressions (e.g. anger, sadness, fear, neutrality; Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Tipples, 2008). Taken together, these results suggest that complex images and faces have opposite effects on time perception. According to the SET model of cognitive timing (Church, 1984), complex emotional stimuli are posited to shorten duration estimates by limiting the number of pulses that can reach the accumulator by either narrowing the opening of an attentional gate, or by delaying the closure of the switch (Lejeune, 1998; Zakay, 2000). The overestimation of emotional facial expressions compared to neutral expressions, however, is consistent with the explanation that emotional faces increase the speed of the pacemaker, thereby increasing the number of pulses that reach the accumulator (Church, 1984; Gibbon, 1977).

Before it can be concluded that these two types of emotional stimuli (complex images and faces) have different effects on the internal clock, one key difference between studies that used images and those that used faces as stimuli must be addressed. That is, experiments conducted using face stimuli repeated the presentation of individual photographs over the course of the experiment, whereas Studies 1, 2, and 3 did not. Stimulus repetition is a design feature that may impact the results of time perception research for emotional stimuli. Indeed, Morel et al. (Morel et al., 2009) found that image repetition has different effects on brain activity following the presentation of fearful, happy, and neutral faces. There are no published studies of the effect of emotional facial expression on time perception without stimulus repetition. Therefore, because there are no face studies to which the results of the thesis can be directly compared, Study 4

will replicate Study 3 using photographs of facial expression as stimuli. The goal of the current study is to determine if activational effects of emotional facial expression are also observed when stimuli are not repeated.

Sex Congruency Effects

Previous time perception research has shown sex congruency effects for face stimuli. Chambon et al. (2008) compared men and women's performance on a temporal bisection task using photographs of young and elderly male and female faces. When a participant's sex matched the sex of the actor in the stimuli, the duration of elderly faces was underestimated compared to the duration of young faces but when participant and actor sex were mismatched, there was no difference between time estimates for young and for old faces. Sex effects have also been shown in research on time perception for emotional facial expressions. Tipples, who tested male and female participants in a temporal bisection task with angry, happy, fearful, and neutral faces, found sex congruency for angry facial expressions. Women had higher proportions of long responses for female angry faces than for male angry faces, and conversely, men had higher proportions of long responses for male angry faces than for female angry faces. Sex of the participants or actors depicted in the stimuli was not included in statistical analyses, nor did Tipples comment on sex congruency effects for facial expressions other than angry. Given these sex congruency effects, the study by Effron et al. (2006) used only female participants and stimuli consisting solely of female faces showing angry, happy, or neutral expressions. The study by Droit-Volet et al. (2004) was also limited to female participants who were shown photographs of female faces with angry, happy, sad, or neutral expressions. Therefore, to be consistent with most studies of time perception for emotional expressions, Study 4 was also conducted with female participants, and only used stimuli showing women actors. Stimuli for the present study were taken from a database of colour photographs of actors displaying emotional or neutral facial expressions; the Karolinska Directed Emotional Faces set (KDEF; Lundqvist et al., 1989). All photographs in the KDEF database have been evaluated to confirm that they depict the intended emotional expression, and were found to be a valid set of affective stimuli (Goeleven, De Raedt, Leyman, & Verschuere, 2008).

To prevent differences in training or fatigue effects between the present study and the previous one (using complex emotional images), the number of trials in the present study was kept the same as in Study 3. Study 3 participants saw four sets of emotional images (high arousal negative, high arousal positive, low arousal negative, low arousal positive) as well as neutral images, for a total of 175 trials (35 images per set). Images were presented in random order within a single block of trials.

Method

Participants. Three hundred twenty eight undergraduate psychology students (women only) from the University of Washington received course credit for their participation. All had normal or corrected-to-normal vision. The study was approved by the Human Subjects Division of the University of Washington's Institutional Review Board.

Apparatus. Stimuli were presented using Dell PCs running Matlab and the Psychophysics Toolbox extensions (Brainard, 1997). Pictures (562 x 762 pixels, measuring 148.7 x 201.6 mm) were viewed on the computers' 23" flat LCD monitors, at a resolution of 1280 x 1024 pixels.

Stimuli. Coloured photographs were taken from the KDEF database (Lundqvist et al., 1989). This set contains pictures of individuals ranging from 20 to 30 years of age displaying various emotional facial expressions, taken at various viewing angles. The present study used images of 35 females facing the camera straight on and depicting anger (35 images), happiness (35 images), fear (35 images), sadness (35 images), or a neutral expression (35 images).

Task. Participants performed a temporal bisection task (see Temporal Bisection Task section of Study 1). Three different stimulus duration ranges were used; short, mid or long. In the short duration range, images were presented for 400, 600, 800, 1000, 1200, 1400 or 1600ms. In the mid duration range, images were presented for 1000, 1500, 2000, 2500, 3000, 3500, or 4000ms. In the long duration range, images were displayed for 2000, 2667, 3333, 4000, 4667, 5333 or 6000ms. Anchor durations were the shortest and longest duration of the range in question (e.g. anchor durations for the middle range were 1000 and 4000ms). Each trial began by the appearance of the word "Ready" for a random

interval between 3000 and 4000ms. The participant's response triggered the start of the next trial. Participants were instructed to respond as accurately as possible.

Procedure. The procedure was identical to that of Study 3. Participants were tested alone or in small groups of 2-5. They were individually seated at computer stations. A within-subjects design was used for emotion thus participants were shown all four types of emotional stimuli as well as neutral stimuli, randomly mixed. Participants performed one block of 175 trials (35 images of each emotion category; anger, fear, happiness, sadness, and 35 neutral images). Examples of the images used are shown in Figure 39. The experiment began with a short training phase (10 trials) followed by one block of test trials (175 trials). Stimuli of each facial expression were randomly assigned to one of the seven durations, with 5 trials per duration. Each picture was presented only once.

Figure 39. Example images from the Karolinska Directed Emotional Faces (Lundqvist, Flykt, & Ohman, 1998) dataset used in Study 4.

Results

Results were analysed using the same method as Study 3. For each participant, the proportions of long responses, the points of subjective equality (PSE) and the DL of each trial type (angry, fearful, happy, sad, and neutral) were calculated. Data from 19 participants were excluded for having nonsensical PSE values (i.e., PSEs that were lower than the short anchor or greater than the long anchor for that participant's duration range). Of the remaining 309 participants, 15 were excluded for having PSEs that were more than three standard deviations away from the mean for that duration range and 26 more were omitted for having DLs that were more than three standard deviations away from the mean for that duration range. Two participants were excluded for being age outliers (35 and 39 years old). Despite the fact that the study was only open and visible for sign up to female students who were 17 years of age or older, two participants reported being younger (3 and 15 years old) and two more failed to report their sex. Data from these four participants were also excluded. Age descriptive statistics for the remaining participants in each duration range (262 participants in total) are reported in Table 11. Mean PSEs, DLs, and WRs are shown in Table 12.

Table 11

Mean Age and Range of Study 4 Participants (All Female)

Duration range	N	Min	Max	Mean	SEM
400-1600ms	82	17	22	18.80	0.120
1000-4000ms	87	17	26	19.03	0.184
2000-6000ms	93	17	29	19.25	0.188

Note: SEM= Standard error of the mean

Table 12

Mean Point of Subjective Equality, Difference Limen, and Weber Ratio for Study 4

	Point of subjective equality	SEM	Difference limen	SEM	Weber ratio	SEM
400-1600ms						
Angry	975.036	12.932	205.376	4.997	0.213	0.006
Happy	956.043	14.453	203.942	5.095	0.221	0.009
Sad	981.611	11.358	197.562	4.306	0.203	0.005
Fearful	983.077	12.768	198.056	3.534	0.205	0.005
Neutral	979.666	12.758	200.250	4.137	0.208	0.006
1000-4000ms						
Angry	2501.712	34.568	486.055	11.342	0.197	0.005
Happy	2517.308	25.326	464.070	8.672	0.185	0.003
Sad	2520.655	27.069	463.158	9.991	0.185	0.005
Fearful	2466.585	24.940	452.482	7.267	0.186	0.004
Neutral	2514.651	29.020	482.464	12.538	0.193	0.005
2000-6000ms						
Angry	3969.172	42.985	688.269	15.640	0.175	0.004
Happy	3937.675	42.411	670.148	15.928	0.172	0.005
Sad	3965.775	41.105	649.683	12.767	0.166	0.004
Fearful	3965.219	41.919	678.181	16.536	0.174	0.005
Neutral	3944.054	44.982	669.165	12.894	0.172	0.004

Note: SEM= Standard error of the mean

Statistical analyses were performed on difference scores using the method described in Study 3. A difference score between each emotional PSE and the neutral PSE was calculated by subtracting the emotional PSE from the neutral PSE (e.g. dPSE for angry = neutral PSE – angry PSE). Negative dPSEs indicate that the duration of emotional images was underestimated compared to that of neutral trials, whereas positive dPSEs indicate a relative overestimation of emotional images.

For each duration range, one-sample t-tests were used to compare the dPSE of each emotion (angry, fearful, happy, and sad) to zero. A significant result on the one-sample t-test signals that the duration of emotional images in that category (e.g. anger) was either underestimated (negative dPSE) or overestimated (positive dPSE) compared to the duration of neutral images. Next, the effect of facial expression on time perception was tested using repeated-measures ANOVA on the dPSEs and planned pairwise comparisons. The effect of emotional trials as a whole (i.e. whether emotional faces were systematically under- or overestimated compared to neutral faces) was tested using the intercept term of the ANOVA.

Difference scores were also used to test the effect of facial expression on temporal sensitivity. For each emotion (anger, fear, happiness, and sadness) a difference score (dDL) was obtained by subtracting the emotional DL from the neutral DL (e.g. dDL for angry = neutral DL – angry DL). Higher dDL values indicate better temporal sensitivity than lower dDL values. Furthermore, negative scores show that the slope of the psychometric function was steeper for neutral faces than for emotional ones, meaning that temporal sensitivity was better for neutral than for emotional faces. Conversely, positive dDL values indicate better temporal sensitivity for emotional than for neutral faces.

The effect of emotion on temporal sensitivity was tested in a repeated-measures ANOVA on the dDLs. The effect of emotional facial expressions as a whole (i.e. whether emotional trials showed better or worse temporal sensitivity than neutral trials) was tested using the intercept term of the ANOVA.

WRs were calculated by dividing the DL of emotional or neutral trials by the corresponding PSE (e.g. WR for angry faces = DL for angry faces divided by the PSE for angry faces). Just like for PSEs and DLs, a difference score (dWR) for

each emotion was obtained by subtracting the emotional WR from the neutral WR. Like for dDLs, lower dWRs correspond to poor temporal discrimination whereas higher dWRs correspond to better temporal discrimination.

Short duration range

Point of subjective equality. Figure 40 shows the proportion of long responses as a function of stimulus duration. Participants saw images belonging to all five trial types within a single block but for clarity, proportions of long responses for each emotion (anger, fear, happiness, sadness) are presented in separate panels. The proportions of long responses for neutral trials are also shown in every panel. Mean dPSEs are shown in Figure 41. As can be seen, the mean dPSE for happy facial expressions was positive, whereas dPSEs for angry, sad, and fearful faces were close to zero. One-sample t-tests on the dPSEs confirmed that the duration of happy faces was overestimated compared to neutral images, $t(81) = 2.253, p = .027$. One-sample t-tests on the dPSE for angry, $t(81) = 0.411, p = .682$, sad, $t(81) = -0.192, p = .849$, and fearful faces, $t(81) = -0.312, p = .756$, were not significant.

The effect of emotion on time perception for facial expressions was tested in a repeated-measures ANOVA on the dPSEs. The intercept term showed that the grand mean of dPSEs was not significantly different from zero, indicating that there was no systematic under- or overestimation of emotional facial expressions as a whole, $F(1, 81) = 0.496, p = .483, \eta_p^2 = .006$. The effect of emotion neared significance, $F(3, 243) = 2.375, p = .071, \eta_p^2 = .028$. Planned comparisons showed that the duration of happy faces was overestimated in comparison to fearful, $t(81) = 2.347, p = .021$, and sad faces, $t(81) = 2.099, p = .039$, but the difference between happy and angry faces did not reach significance, $t(81) = 1.735, p = .086$. There was no difference between time estimates for any other pairs (all $p > .484$).

Figure 40. Study 4, 400 to 1600ms: proportions of long responses for emotional trials as a function of stimulus duration. The proportions of long responses for neutral trials (baseline) are also shown in each panel.

Figure 41. Study 4, 400 to 1600ms: mean dPSEs. Error bars represent standard errors.

Difference limen. Mean dDLs values for the short duration range are shown in Figure 42. The effect of emotion on temporal sensitivity was tested in a repeated-measures ANOVA on dDLs for angry, fearful, happy, and sad faces. Temporal sensitivity for emotional facial expressions as a whole was compared to temporal sensitivity for neutral faces using the intercept term. There were no significant difference between temporal sensitivity for emotional and neutral facial expressions, $F(1, 81) = 0.065, p = .799, \eta_p^2 = .001$. The effect of emotion was not significant, showing that temporal sensitivity did not vary according to the emotion depicted in the stimuli, $F(3, 243) = 1.120, p = .342, \eta_p^2 = .014$.

Figure 42. Study 4, 400 to 1600ms: mean dDLs. Error bars represent standard errors.

Middle duration range

Point of subjective equality. Figure 43 shows the proportion of long responses to angry (Panel A), happy (Panel B), Sad (Panel C), and fearful (Panel D) facial expressions along with neutral facial expression, as a function of stimulus duration. Mean dPSEs are shown in Figure 44. One-sample t-tests on the dPSEs revealed that the duration of fearful stimuli was significantly overestimated in comparison to the duration of neutral stimuli, $t(86) = 2.223, p = .029$, whereas duration estimates for angry, $t(86) = 0.429, p = .669$, happy, $t(86) = -0.109, p = .914$, and sad faces $t(86) = -0.254, p = .800$, were no different from duration estimates for neutral faces.

A repeated-measures ANOVA was conducted on the dPSEs. The intercept term showed no difference between emotional faces as a whole and neutral faces, $F(1, 86) = 0.394, p = .532, \eta_p^2 = .005$, indicating that the duration of emotional faces were not systematically under- or overestimated. The ANOVA showed a trend toward an effect of emotion, $F(3, 258) = 2.313, p = .076, \eta_p^2 = .026$. As can be seen, the dPSE for fearful faces was higher (indicating a relative overestimation) than all other dPSEs. Planned comparisons revealed that fearful faces were overestimated in comparison to happy, $t(86) = 2.494, p = .015$, and sad faces, $t(86) = 2.924, p = .004$. The difference between fearful and angry faces did not reach significance, $t(86) = 1.381, p = .171$. There was no difference between time estimates for any other pairs (all $p > .434$).

Figure 43. Study 4, 1000 to 4000ms: proportions of long responses for emotional trials as a function of stimulus duration. The proportions of long responses for neutral trials (baseline) are also shown in each panel.

Figure 44. Study 4, 1000 to 4000ms: mean dPSEs. Error bars represent standard errors.

Difference limen. Mean dDL values are shown in Figure 45. It shows that mean dDLs for happy, sad, and fearful faces were higher than the dDL for angry faces. Temporal sensitivity for images depicting emotional facial expressions was compared to temporal sensitivity for neutral facial expressions using the intercept term of a repeated-measures ANOVA on the dDLs. The result was significant, indicating that temporal sensitivity for emotional faces was systematically better than that of neutral faces, $F(1, 86) = 8.610, p = .004, \eta_p^2 = .091$. The ANOVA also showed a significant effect of emotion, $F(3, 258) = 3.499, p = .016, \eta_p^2 = .039$. Planned comparisons revealed that temporal sensitivity was significantly poorer (lower dDL value) for angry faces than for sad $t(86) = 2.227, p = .029$, and fearful faces $t(86) = 2.973, p = .004$. The difference between temporal sensitivity for angry and happy faces was only marginally significant, $t(86) = 1.859, p = .066$. There were no significant differences between temporal sensitivity for happy, sad, and fearful faces (all $p > .261$).

Figure 45. Study 4, 1000 to 4000ms: mean dDLs. Error bars represent standard errors.

Long duration range

Point of subjective equality. The proportion of long responses as a function of duration for angry (Panel A), happy (Panel B), sad (Panel C), and fearful (Panel D) expressions as well as neutral expression are shown in Figure 46 and mean dPSE values can be seen in Figure 47. One-sample t-tests showed no difference between time estimates for neutral faces and time estimates for angry, $t(92) = -0.637, p = .526$, happy, $t(92) = 0.150, p = .881$, sad, $t(92) = -0.604, p = .547$, or fearful faces $t(92) = -0.519, p = .605$. The intercept term of a repeated-measures ANOVA on the dPSEs showed that the grand mean of dPSEs was not significantly different from zero, $F(1, 92) = 0.212, p = .646, \eta_p^2 = .002$. The ANOVA showed no effect of emotion, $F(3, 276) = 0.346, p = .792, \eta_p^2 = .004$.

Figure 46. Study 4, 2000 to 6000ms: proportions of long responses for emotional trials as a function of stimulus duration. The proportions of long responses for neutral trials (baseline) are also shown in each panel.

Figure 47. Study 4, 2000 to 6000ms: mean dPSEs. Error bars represent standard errors.

Difference limen. Mean dDL values are shown in Figure 48. The effect of emotion on temporal sensitivity was tested in a repeated-measures ANOVA on the dDLs. The intercept term showed no difference between temporal sensitivity for neutral faces and temporal sensitivity for emotional faces, $F(1, 92) = 0.033$, $p = .856$, $\eta_p^2 < .001$. Although the effect of emotion did not reach significance, $F(3, 276) = 1.600$, $p = .190$, $\eta_p^2 = .017$, planned comparisons suggested that temporal sensitivity for sad faces was better than temporal sensitivity for angry faces, $t(92) = 2.101$, $p = .038$. There were no other significant differences (all $p > .111$).

Figure 48. Study 4, 2000 to 6000ms: mean dDLs. Error bars represent standard errors.

Weber ratios. Mean dWRs for each duration range are shown in Figure 49. The effect of duration range on temporal sensitivity was tested using a mixed ANOVA on the dWRs, using duration range as a between-subjects variable. Results are shown in Table D1. The duration range effect was not significant, $F(2, 259) = 0.659$, $p = .518$, $\eta_p^2 = .005$, nor did duration range interact with emotion. This shows that the scalar property of variance held across the three duration ranges for all facial expressions. The intercept term showed that the grand mean for dWRs was no different from zero, indicating that temporal sensitivity for emotional faces was not systematically better or worse than temporal sensitivity for neutral faces, $F(1, 259) = 0.129$, $p = .720$, $\eta_p^2 < .001$.

Figure 49. Study 4: mean dWRs for all duration ranges. Error bars represent standard errors.

Discussion

The present study replicated study 3 using facial expression stimuli rather than complex images that vary according to arousal and valence. The goal was to determine whether emotional facial expressions have activational effects on time perception when stimuli are not repeated over the course of the experiment. The stimuli were photos of women showing angry, happy, fearful, sad, or neutral expressions. Duration ranges used in the present study were the same as Study 3: short (400 to 1600ms), middle (1000 to 4000ms), and long (2000 to 6000ms).

Time perception for facial expression in the short range

In the short range, the duration of happy faces was overestimated compared to the duration of neutral images. The duration of happy faces was also significantly overestimated compared to sad and fearful faces, and marginally overestimated compared to angry faces. There were no other differences in time estimation for facial expressions in this duration range. Emotional faces have been shown to capture more attention than neutral faces (for a review, see Frischen, Eastwood, & Smilek, 2008). For example, Lundqvist and Öhman (2005) found an attentional bias for emotional facial expressions compared to neutral expressions in a visual search task. The SET model thus predicts that attentional effects of emotion will lead to an *underestimation* of the duration of emotional faces compared to neutral faces. Therefore, the overestimation of happy faces compared to neutral faces is contrary to attentional effects of emotion. Instead, the overestimation of happy compared to neutral faces can be explained by activational effects of emotion on the pacemaker. According to SET, activation increases the speed of the pacemaker, which in turn leads to overestimation of durations. Given that emotional facial expressions are more arousing than neutral expressions (Goeleven et al., 2008), activational effects of emotion should lead to a relative overestimation of the duration of emotional faces compared to neutral faces.

The present study's findings for the short duration are in line with a number of studies that have also found activational effect of facial expressions presented for 400 to 1600ms (Droit-Volet et al., 2004; Effron et al., 2006; Gil &

Droit-Volet, 2011; Tipples, 2008). Indeed, this rich literature on the temporal perception of facial expressions has consistently reported findings of overestimation of arousing (emotional) facial expressions compared to neutral faces. In that regard, the results of the short range of study 4 are in line with previous facial expression research. It is noteworthy that the present study failed to show overestimation of angry faces - a result that has been seen in most temporal bisection studies using facial expression stimuli that included angry faces. When Droit-Volet et al. (2004) compared time perception for angry, happy, and sad faces, they found that the duration of emotional faces was systematically underestimated compared to the duration of neutral faces. Although PSEs for angry and sad faces were lower (indicating a relative overestimation) than the PSE for sad faces, only the angry-to-sad comparison reached significance. Likewise, Effron et al. (2006) found that participants overestimated the duration of both types of emotional faces (angry and happy) presented compared to neutral images. Tipples (2008) found that participants overestimated the angry faces compared to all other facial expressions included in the experiment (happy, fearful, and neutral).

One possible explanation as to why the duration of angry faces was not overestimated in the short range of the present study is that angry facial expressions may have both activational and attentional effects on time perception. In a study of the effect of angry and neutral facial expressions on time perception, Gil and Droit-Volet (2011) found no effects using the temporal generalization and reproduction tasks. However, results from the verbal estimation, time production, and temporal bisection tasks showed an overestimation of the duration of angry faces compared to neutral ones. Given that verbal estimation and temporal production tasks are classical timing procedures that can be compared to real time duration, it is possible to distinguish whether durations were systematically over- or underestimated. While Gil and Droit-Volet (2011) found that the duration of emotional facial expressions was overestimated in comparison to the duration of neutral expressions, durations of all stimuli were systematically *underestimated*. The underestimation is in line with attentional effects of emotion and suggests that all stimuli (emotional and neutral) diverted attention away from the passage of

time (Zakay & Block, 1997). Thus, it is likely that both activational and attentional effects of emotion were present (Gil & Droit-Volet, 2011). The systematic underestimation shown in the verbal estimation and production tasks suggests that all stimuli (angry and neutral faces) diverted attention from the passage of time (attentional effects of face stimuli) whereas the relative overestimation of angry faces compared to neutral faces may have been caused by increase in the speed of the pacemaker when viewing angry faces (activational effects of emotion).

Another possibility is that the angry facial expressions used in the present study may not have been as arousing as angry expressions used in previous work. In the study by Tipples (2008) angry and fearful faces were rated higher on the arousal scale than happy and neutral faces (Russell, Weiss, & Mendelsohn, 1989). Stimuli for Study 4 were taken from the KDEF (Lundqvist et al., 1989) set, which contains coloured photographs of male and female actors displaying angry, fearful, disgusted, sad, happy, surprised, and neutral facial expressions. The present study only used photographs of female actors showing angry, fearful, happy, sad and neutral expressions. In a previous study by Goeleven et al. (2008) female participants were asked to rate arousal and intensity of all KDEF images. The results showed significantly higher arousal rating for emotional compared to neutral expressions, but no difference in arousal ratings when comparing emotions to one another. Happy faces were judged to be significantly more intense than all other expressions used in Study 4 (including neutral). Thus, it is possible that stimulus intensity contributed to the activational effects of happy faces on time perception. Facial expression stimuli used by Droit-Volet and colleagues (2004; Effron et al., 2006) were not rated for arousal or intensity (Neidenthal, Brauer, Halberstadt, & Innes-Ker, 2001).

The third possible explanation for the lack of activational effects of angry faces in the present study is the lack of repetition. Indeed, EEG and MEG research has shown that repetition can modulate brain response to the presentation of emotional and neutral stimuli, and that repetition effects vary according to the specific emotion (Codispoti et al., 2007; Ishai et al., 2004; Ishai et al., 2006; Morel et al., 2009). Three of these studies were conducted using emotional facial expression stimuli; however, none of them included angry faces (Ishai et al.,

2004; Ishai et al., 2006; Morel et al., 2009). There is thus no data on repetition effects for angry stimuli, but the contrast between the present study and previous research on time perception for faces suggests that repetition may enhance activational effects of angry faces.

Dynamic effects of emotion on time perception for facial expressions

The present study also included two more duration ranges. Results in the middle duration range (1000-4000ms) were different from the results of the short range. In the middle range, the duration of fearful faces was overestimated compared to the duration of neutral images as well as other happy and sad faces. The difference between duration estimates for fearful and angry faces did not reach significance. As with the short duration range, results cannot be explained by an attention account of emotion, which predicts the underestimation of emotional faces compared to neutral faces. Instead, the overestimation of fearful stimuli compared to neutral ones suggests that viewing fearful stimuli increased the speed of the pacemaker (activational effect of emotion).

There are no previous studies on the effect of time perception in the 1000-4000ms range, so a direct comparison to the literature cannot be made. However, in the 400-1600ms range, Tipples (2008) found no difference between time estimates for fearful, happy, and neutral faces. Only angry images were overestimated compared to all other facial expressions. Using MEG recordings, Morel et al. (2009) found that photographs of fearful facial expressions caused a larger increase in brain activity (corresponding to the arousing nature of the stimuli) than happy or neutral faces on the first presentation, but that the effect levelled off on subsequent presentations. Similarly, Ishai and colleagues (2004; 2006) found a more dramatic decrease in cortical activation following repeated exposure to fearful faces (i.e. the exact same stimulus) than to neutral faces. This suggests that the overestimation of fearful faces seen in the present study would likely not occur if stimuli are repeated.

It is unclear why overestimation of fearful faces was only seen in the middle range, whereas overestimation of happy faces was only seen in the short range. The long duration range (2000-6000ms) showed no effects of emotion on time perception for facial expressions. In all, the present study indicates that

emotion has different effects on time perception for faces at different stages of perception. Studies 2 and 3 showed that emotion effects for complex images also vary as a function of duration. What is clear, however, is that emotion effects on time perception for the duration of complex images are in line with attentional effects, whereas emotion effects for facial expressions are in line with activational effects – even when image repetition is avoided. Study 4 established that the different effects of complex emotional images and emotional facial expressions on time perception are likely reflections in differences in how people process faces and complex images. The general discussion will explore possible reasons as to why emotion effects are stimulus-dependent.

Temporal sensitivity

WRs were constant across all three duration ranges, indicating that results conformed to the scalar property of variance. However, because of the lack of parallel effects across ranges, this cannot be used to test whether effects of emotion on time perception for faces are proportional with real time. Although DL analyses *within* each range hinted at worse temporal sensitivity for angry faces than for other emotional faces in the middle and long ranges, the WR analysis showed no effect of emotion, nor an interaction between emotion and duration range. This means that temporal discrimination was constant across all emotions and all ranges.

General Discussion

The effect of emotion on our sense of subjective time has received a growing amount of attention; however the literature shows many inconsistent findings. Some point to attentional effects of emotion whereby emotional stimuli are underestimated because emotions attract attention (e.g. Gil et al., 2009). Others have found activational effects of emotion whereby the duration of emotional stimuli is overestimated because emotion increases activation (e.g. Droit-Volet et al., 2004; Tipples, 2008). It was suggested that inconsistencies in the published data were due to the use of a myriad of time estimation tasks, emotional stimuli, and duration ranges. The goal of this thesis was to thus conduct a systematic evaluation of the effect of emotion on time perception. Studies 1 through 3 used standardized visual stimuli fully crossed for arousal and valence to manipulate emotion. For comparison, Study 4 was conducted using facial expression stimuli belonging to discrete emotional categories. Finally, given that repetition has been shown to have differential effects on the processing of visual stimuli depicting different emotions (Codispoti et al., 2007; Ishai et al., 2004; Ishai et al., 2006; Morel et al., 2009), each stimulus picture was presented only once over the course of an experiment.

In the first series of experiments, Study 1, three time estimation tasks were compared: analog scale, reproduction, and temporal bisection. Emotional arousal and valence were manipulated between-subjects. Temporal bisection has been the task of choice in recent time perception and emotion research. It is easy to learn and because it is not attentionally taxing, it is unlikely to mask attentional effects of emotion. The temporal bisection task also yields easy-to-use metrics of different aspects of performance. Unlike results from classical timing tasks, temporal bisection performance normally conforms to the scalar properties of variance. In the analog and reproduction tasks, time judgements can show violations of the scalar properties of timing that have yet to be explained. However, duration judgements made using a classical timing paradigm such as analog scale estimation or reproduction can be directly compared to real durations (i.e. it is easy to see whether durations were underestimated or overestimated compared to real time). Given that time perception research conducted using the analog scale and reproduction tasks

(e.g. Angrilli et al., 1997) has shown different effects of emotion than research using a temporal bisection task (e.g. Smith et al., 2011), the goal of the first study was to select a task which was sensitive to emotion effects, which would then be used in all subsequent experiments.

All durations in the analog scale and reproduction tasks were underestimated compared to real time. There was no effect of arousal or valence on duration judgements made using the reproduction task, but the analog scale task was sensitive to emotion. When shown low arousal images mixed with neutral ones, there was no difference between participants' duration judgements for emotional and neutral trials. However, in the high arousal conditions the duration of emotional trials was underestimated compared to the duration of neutral trials. These results point to attentional effects of emotion in high arousal conditions. The analog scale task also showed an interaction between the sex of participants and stimulus duration, which did not interact with emotional factors. Time perception was thus different for male and female participants, regardless of the emotional content of the stimuli. Finally, there were no effects of sex in the temporal bisection task but this task did prove to be sensitive to emotion effects. The duration of high arousal and negative images (i.e. high arousal negative, high arousal positive, and low arousal negative) was underestimated compared to the duration of low arousal positive images. These findings, which are in line with attentional effects, suggest that the duration of high arousal and negative images was underestimated because these stimuli capture more attention than their low arousal positive counterparts. Given that it was sensitive to emotion effects and that it showed no difference in time estimates for male and female participants, the temporal bisection task was selected to be used in all other experiments of the present thesis.

Attentional effects of emotion found in the first study were at odds with activational effects of emotion that have been found in a number of previous temporal bisection task studies (Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Grommet et al., 2011). Thus, Study 1 showed that the discrepancy between emotion effects on complex images and faces was not, as previously proposed, due to the use of different time estimation tasks (temporal

bisection for face studies, e.g. Gil & Droit-Volet, 2011; Tipples, 2008, and analog scale/reproduction for complex images, e.g. Angrilli et al., 1997).

Having confirmed that the difference between the results of Study 1 and those of studies of emotional facial expressions was not due to different time estimation tasks, it was suggested that attentional effects may be due to the use of a longer duration range. Study 1 used stimulus durations ranging from 2000 to 6000ms, which are the same durations as those used by Angrilli et al. (1997) to test the effect of complex images (IAPS) on time perception. Studies using pictures of emotional facial expressions, however, typically show images for much shorter durations (400 to 1600ms). Therefore, in the next series of experiments, the temporal bisection task was used to test the effect of emotional arousal and valence on time perception in three different duration ranges; 400-1600ms, 1000-4000ms, and 2000-8000ms.

Emotion had different effects on time perception in different duration ranges. Results of the short and middle duration ranges were consistent with attentional effects of emotion on the perception of time. In the short range, the duration of all emotional images was underestimated compared to the duration of neutral images but there were no differences between emotions. In the middle range, male participants underestimated the duration of negative images compared to neutral images. In the long duration range, time estimates showed a complex pattern involving sex and valence effects that carried over to neutral trials. Although the results of the long duration range are not easily explained by an attentional account, they are still at odds with an activation explanation of emotion effects. Taken together, these data suggest that the time course of emotion effects varied according to the specific combination of arousal and valence depicted in the stimuli. The implication of this finding is that emotion effects in a particular range (e.g. 400 to 1600ms) cannot be assumed to hold in other ranges. Emotion effects are dynamic, and thus the duration of emotional stimuli is, in and of itself, an important factor to time perception. Although the specific pattern of how emotion effects change over time was not evident in Study 2, the next series of experiments helped establish the dynamic effects of arousal and valence on time perception.

The third study replicated Study 2 using a within-subjects design for arousal and valence rather than a between-subjects design. Study 3 showed that complex emotional images still have attentional effects on time perception when emotion is manipulated within-subjects. In the short range of Study 3, duration judgements for all emotional images were shorter than duration judgements for neutral images, but the effect was only significant for low arousal negative images. In the middle duration range, the duration of high arousal images was underestimated compared to the duration of low arousal images. This pattern was observed in the long duration range too, but the data also showed effects of valence and sex on duration judgements that complicated the comparison of WRs across the three ranges. Taken together, these three ranges reveal how emotion effects progress as duration increases; for short stimulus presentations, emotional stimuli direct attention away from the passage of time and are thus judged as lasting for shorter durations than neutral stimuli (although this effect failed to reach significance in Study 3, it was significant in the short range of Study 2). In the middle duration range, time estimates are subject to attentional effects of arousal whereby the duration of highly arousing stimuli is underestimated compared to the duration of low arousal stimuli. Attentional effects of emotional arousal persist in the long duration range, but time estimates for images presented for long durations are also subject to valence effects that differ for male and female participants.

According to SET, complex emotional images can divert attention away from the passage of time in two ways: by affecting the closure of an attentional switch, or by narrowing the opening of an attentional gate (Lejeune, 1998; Zakay, 2000). Attention effects on the switch and gate both lead to a relative underestimation of attention-capturing stimuli compared to other stimuli. To ascribe the underestimation to the gate or switch, it is necessary to test whether or not the effect is proportional with real time. For this purpose, Studies 2 and 3 included multiple duration ranges across which effects could be compared. However, the pattern of emotion effects needed to remain constant across at least two duration ranges in order to decide whether effects are proportional or absolute. Although the results of Studies 2 and 3 all pointed to attentional effects, the specific group of emotional stimuli that was underestimated varied across

duration range. Thus, it was not possible to test whether attentional effects were proportional (which would suggest that attention acts upon the gate) or absolute (which would suggest that attention acts upon the switch).

It may be possible to test for proportional effects in future studies by using shorter, overlapping duration ranges. Thus, it is suggested that Study 3 (within-subjects design for arousal and valence using IAPS images) be repeated using duration ranges that are more closely overlapped. Moreover, the ratio between the short and long anchor durations could be shortened to further increase the probability of finding two consecutive durations ranges showing the same pattern of emotion effects. For instance, the effect of arousal and valence could be tested in the following ranges: 1000-3000ms, 1100-3300ms, 1200-3600ms, and 1300-3900ms. If two ranges show similar effects of emotion (e.g. underestimation of high arousal negative images compared to neutral images), WRs and magnitude of the shift in PSEs can be used to test for proportional effects. The use of shorter, overlapping duration ranges may also help map out the time course of the effect of different emotions on the perception of time.

Studies 2 and 3 showed better temporal sensitivity in the long duration range (2000-6000ms and 2000-8000ms, respectively) than in the short and middle ranges (400-1600ms and 1000-4000ms). This shows that the scalar property of variance held for the short and middle duration ranges, but was violated in the long duration range. It was proposed that participants may have been using a different timing strategy in the long duration ranges than in the short and middle ones. This is consistent with findings that the use of a counting strategy can increase temporal sensitivity (lower WRs) thereby violating the scalar property of variance (Grondin et al., 1999; Hinton & Rao, 2004; Wearden, 1991). A very recent study showed that chronometric counting in a temporal bisection task does not affect the bisection point (Rattat & Droit-Volet, 2012). Therefore, there is reason to believe that the use of a counting strategy may not affect the impact of emotion on time perception (as measured by the PSE). However, the study by Rattat and Droit-Volet (2012) did confirm that counting strategies produce violations of the scalar property of variance by lowering WRs in the longer duration ranges of a temporal bisection task (e.g. 2000-8000ms). For this reason, future studies for which the authors want to compare temporal

sensitivity across duration ranges should try to prevent participants from counting. Rattat and Droit-Volet compared three methods that can be used to prevent participants from resorting to a counting strategy: articulatory suppression (continuously repeating “blablabla” during stimulus presentation), an interference task (reading digits presented onscreen), and explicit instructions not to count. The experiment also included a condition in which participants were told to use a counting strategy. They found that the PSE in a temporal bisection task did not change as a function of the counting or no-counting condition used. Moreover, all three methods used to stop participants from counting effectively prevented violations of scalar timing that stem from using chronometric counting. Of the three no-counting conditions, results from the temporal bisection task as well as other time estimation tasks revealed that simply asking participants not to count is the best way to prevent counting while also avoiding introducing extra noise into duration judgements. Given these recent findings, it is advised that researchers should explicitly instruct participants not to count durations.

Although studies in this thesis were not intended to test for sex differences in temporal perception, Studies 2 and 3 showed sex effects that interacted with emotional variables. Stimuli were selected from the IAPS based on ratings provided by a group of male and female participants (Lang et al., 2008), however, it is possible that emotional images did not carry the same arousal and valence properties for men and women. Another possibility is that arousal and valence ratings did not differ for men and women, but that the content of individual images elicited different discrete emotions for male and female participants. For instance, Mikels et al. (2005) found that 10% of IAPS images (39 out of 390 images tested) received different categorical ratings (e.g. anger, fear, contentment) from men and women. Although there are no published reports of sex effects on time perception for complex emotional images, sex-congruency effects have been found in studies using face stimuli. Previous research has shown that activational effects of emotional facial expressions on time perception are greater when male participants judge the duration of male faces than female faces (Tipples, 2008). Conversely, activational effects of emotion are more pronounced when female participants judge the

duration of female faces rather than male faces. For this reason, the effect of emotion on the temporal perception for facial expressions is often conducted using participants of only one sex, and using only facial stimuli depicting actors of the same sex (e.g. female participants and female faces, Effron et al., 2006). The present thesis shows that it is also important to consider sex differences when designing and carrying out experiments on the effect of emotion on duration judgements for complex stimuli. Because arousal and valence properties may differ for men and women, separate arousal and valence ratings should be collected for male and female participants. Studies should either analyse sex separately or in the least, include sex in statistical analyses. Further research is needed to determine whether sex differences in time perception for complex images are due to different arousal and valence ratings for male and female participants, or to inherent sex differences in temporal perception.

A limitation of the present thesis is that effect sizes for tests of the impact of emotion on time perception were found to be very small, which may be due to the small number of trials in each emotion category (i.e. 35). Two important objectives of this thesis were to systematically vary the arousal and valence levels of emotional stimuli and to avoid repeating images over the course of the experiments. Therefore, the number of trials for each arousal/valence combination was limited by the number of standardized IAPS images belonging to these groups. Pictures belonging to the high arousal positive group were particularly scarce, with only 27 images falling within the range of arousal and valence ratings that were defined by Angrilli and colleagues (1997). To allow for an even number of images at each duration range (5 stimuli per duration, per emotion) the ranges defined by Angrilli et al. were slightly expanded.

To guarantee high statistical power, experiments were conducted with a large number of participants. There were 30 to 41 participants in each emotion condition of Study 2, after having removed outliers. For Study 3, in which emotional arousal and valence were manipulated within-subjects, the number of participants in the short, middle, and long duration ranges after outlier removal was 98, 92, and 95, respectively. Still, the results of some tests showed only marginally significant results when compared to conventional levels of significance. Small effects may be of theoretical importance (that is, they allow

for the distinction between attentional and activational accounts) but they may be of little practical importance in the real world. Hence, the effect of emotional arousal and valence studied in the present thesis may not be able to account for large phenomena such as the feeling that “time flies” or the feeling that events are happening in slow motion. These effects may not be suited to understanding distortions in our subjective sense of time that involve complex cognitive processes, and may not be strictly prospective in nature. They may, however, be useful in testing models of emotion on time perception. To address this limitation, studies should be repeated with a larger number of stimuli. To increase the number of trials without having to repeat images, this would require that new images be added to the IAPS database, or that a new set of stimuli be built and rated for arousal and valence.

Unlike attentional effects of complex emotional images observed in Studies 1-3, numerous published studies that used face stimuli report that the duration of arousing emotional facial expressions is overestimated compared to the duration of less arousing emotional expressions or of a neutral expression (Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Tipples, 2008). According to the SET model (Church, 1984), the overestimation is consistent with activational effects of emotion whereby viewing arousing facial expressions increases the speed of the pacemaker. Study 4 replicated these studies without repeating stimuli over the course of the experiment. Stimuli were photographs of women showing angry, happy, sad, fearful, and neutral facial expressions taken from the KDEF set (Lundqvist et al., 1989). The results revealed that even in the absence of image repetition, the effect of emotion on time perception for facial expression stimuli remains in line with an activation explanation. For the short duration range of 400 to 1600ms, the duration of happy faces was overestimated compared to the duration of neutral, sad, and fearful faces, and marginally overestimated compared to angry faces. In the middle duration range of 1000 to 4000ms, the duration of fearful faces was overestimated compared to the duration of happy, sad, and neutral faces. There was no effect of emotion in the 2000 to 6000ms range. Although the results of Study 4 also revealed that emotion effects can change as stimulus durations increase, the take home message of face experiments is that emotional facial

expressions can increase the speed of the pacemaker and consequently lead to overestimation of duration.

A key finding of this thesis is that emotion effects on time perception are different for complex images and faces. For complex images, emotion effects were in line with an attentional explanation whereby the duration of attention-capturing stimuli was underestimated compared to other stimuli. For faces, however, emotion had activational effects whereby the duration of arousing facial expressions was overestimated compared to other expressions. Two possibilities will be discussed; whether the difference is due to differential processing for these two types of images, or whether it stems from the fact that one uses discrete emotional categories (faces) while the other uses dimensional approach (complex images).

Studies 3 and 4 showed different time frames for the effect of emotion on time perception for faces and for complex images. Activational effects of expressive faces on time perception were observed in the short (400 to 1600ms) and middle (1000 to 4000ms) duration ranges, but there were no effects of facial expression on time perception in the long range (2000 to 6000ms). In contrast, complex images showed attentional effects of emotion in the middle and long ranges, but emotion effects in the short range were not significant. Taken together, these suggest that facial expressions are processed quickly, and thereby shift time perception for short stimulus durations. This is in line with the suggestion of Droit-violet and Meck (Droit-Volet & Meck, 2007) that activational mechanisms are triggered quickly after stimulus onset whereas attentional mechanisms prevail in longer durations. Evidence for short-lived activational effects was also found by Angrilli and colleagues (1997), who reported that the duration of high arousal images was overestimated when images were displayed for 2 seconds, but not when they were shown for 4 or 6 seconds. The results of Study 4 suggest that activational mechanisms are particularly sensitive to emotion effects of facial expressions because expression is processed rapidly (Eimer & Holmes, 2002).

As shown in Study 3, complex images were not conducive to activational effects of emotion as was the case for expressive faces. Grommet and colleagues (2011), who also used complex images from the IAPS database, put forth that

activational mechanisms may require that a threshold level of activation be reached in order to increase the speed of the pacemaker. Because Studies 1 through 3 showed no activational effects following the presentation of IAPS images, it is possible that this threshold was not reached. Alternatively, attention effects of complex images on the gate or switch may simply have masked the presence of any increase in the speed of the pacemaker. Although it is well-established that emotional facial expressions attract more attention than neutral facial expressions (Lundqvist & Öhman, 2005), it is possible that the difference in attentional capture between emotional and neutral faces is simply not as large as the difference in attentional capture between emotional and neutral complex scenes. This would mean that attentional effects of emotional facial expressions can be masked by activational effects, but that the opposite may be true of complex images. Furthermore, processing complex emotional images is more cognitively demanding than processing the emotion depicted in an expressive face (Britton, Taylor, Sudheimer, & Liberzon, 2005). Each and every day, we read the expression on people's faces in order to assess their moods or feelings. Thus, humans are experts at identifying emotional facial expressions. It can be proposed that because facial expressions are processed rapidly, in an automatic or pre-attentive fashion (Eimer & Holmes, 2002; Ekman, 1992), emotional faces quickly trigger activation mechanisms. In contrast, more attention may be necessary to identify the emotion depicted in a complex scene. For instance, details in the picture need to be processed in order to understand the valence of the scene (e.g. the presence of a weapon, blood, or nudity). Unlike for faces, it may not always be immediately apparent which features in the image convey information about the emotional content of the scene. This difference may be at the heart of the differences in the time course of emotion effects for faces and scenes, whereby faces have activational effects that can be seen in short durations and complex scenes have protracted attentional effects that manifest in later stages of processing.

It may be possible to define the time course of activational and attentional effects of emotion for complex images and for faces using physiological measures such as skin conductance, heart rate, or pupil dilation. Increased skin conductance and pupil dilation are physiological markers of increased activation,

whereas heart rate deceleration is an index of attention that reflects the orienting response to a stimulus (Bradley et al., 1990; Bradley et al., 1991). It is proposed that future research record heart rate, and skin conductance/pupillary response while participants perform the temporal bisection task in various duration ranges. Physiological recordings could help address an important limitation of this thesis and of previous time perception studies, which is that they only test for net effects of emotion. That is, emotion effects are implied solely based on behavioural measures of over- or underestimation. Thus, if activational effects (marked by overestimation of arousing stimuli) and attentional effects (marked by underestimation of attention-capturing stimuli) are both present, only the effect causing the largest change in time estimation can be seen. Activation and attention are independent (Burle & Casini, 2001), so it is possible for an emotional stimulus to both increase the speed of the pacemaker and to draw attention away from the temporal aspect of the task. Although behavioural measures used in the present study (i.e. proportions of long responses, PSE) show whether emotion ultimately lengthens or shortens duration judgements, they do not show whether activational and attentional effects were simultaneously present. Mapping out the time course of physiological activation and attentional effects that arise from viewing complex images and facial expressions may help explain inconsistencies in the present thesis and in the literature. For example, in Study 4, the duration of angry faces was not overestimated compared to the duration of any other facial expressions. However, the literature shows many instances in which the duration angry faces – thought to be the most arousing of all expressions tested – is judged as longer than the duration of other expressions (Droit-Volet et al., 2004; Effron et al., 2006; Tipples, 2008). Physiological measures could help determine whether the lack of overestimation of the duration of angry faces was strictly due to a lack of activational effects or rather, if activational effects of angry faces were present but masked by attentional effects. Finally, physiological measures may also prove useful in ascribing activational and attentional effects of emotion to specific structures in the brain. Indeed, recent studies have been aimed at uncovering the neural bases of time perception and the internal clock mechanism. Although outside of the scope of the current thesis, a review of neurobiological models of

interval timing, including the prominent striatal beat frequency model, can be found in Cordes, Williams, and Meck (2007). For a review of the neural structures involved in temporal processing, see Grondin (2010).

Finding activational effects of emotion for faces and attentional effects of emotion for complex images also raises the question of whether this difference is due to different emotion categorization for faces and scenes. Complex images from the IAPS database were systematically manipulated according to two emotional dimensions: arousal (high, low) and valence (negative, positive). These particular dimensions were selected because they have been shown to account for the majority of the variance in emotional categorization (Greenwald et al., 1989; Lang et al., 1993). It was posited that manipulating emotions using a dimensional approach would offer a higher scientific value than a discrete approach because findings could be generalized to other emotions based on how they rate on the arousal and valence scales. However, the effect of arousal and valence on time perception could not be described simply. For instance, some experiments showed attentional effects of emotion involving only arousal (e.g. Study 3, middle range), only valence (e.g. Study 2, middle range), or both arousal and valence (e.g. Studies 1 and 3, long range). This suggests that categorization based on arousal and valence may be too wide to fully describe the effect of emotion on time perception. A particular arousal/valence combination can contain images belonging to different discrete emotion categories. For example, images in the high arousal positive category for Studies 1, 2, and 3 were a mix of erotic scenes (17 images) and adventure scenes (18 images). Images in the high arousal negative category included pictures of threat (e.g. weapons, snakes) as well as pictures of bloody flesh wounds, accident victims, and mutilated bodies. Moreover, a study by Mikels et al., 2005 revealed that a large number of IAPS images (263 out of 390 images tested) can elicit more than one emotion. Therefore, the diversity within an emotion group defined using dimensional scales may explain why the pattern of arousal and valence effects on time perception is so complex. Support for this proposal comes from recent research showing that even within the context of high arousal stimuli, the magnitude of the skin conductance response may vary according to the specific contents of a given picture (Costa & Esteves, 2008). For example, Bernat, Patrick, Benning, and

Tellegen (2006) found that the intensity and magnitude of the skin conductance response following the presentation of images with threatening or erotic content was greater than the response that followed the presentation of adventure or wound images. Discrete emotion categories may better capture motivational significance that taps into behavioural responses (e.g. approach or withdrawal) that rely heavily on timing mechanisms.

To date, only one study has attempted to delineate the effect of an emotional dimension (arousal) on time perception from that of discrete emotion categories. In a very recently published article, Gil and Droit-Volet (2012) systematically varied the level of arousal (high, low) of complex IAPS images belonging to different discrete emotional categories (i.e. disgust and sadness; Mikels et al., 2005). The study also included neutral images. Participants performed a verbal estimation task for two duration ranges: 200-800ms and 400-1600ms. Like the analog scale and reproduction tasks in Study 1, the duration of all images was underestimated compared to real time. When comparing across emotion groups, however, the results were in line with activational effects commonly reported when stimuli are arranged according to discrete emotion categories (Droit-Volet et al., 2004; Gil & Droit-Volet, 2011). For both disgust and sadness stimuli, results of the 200-800ms range revealed that the duration of high arousal images was overestimated compared to the duration of low arousal images, which in turn were overestimated compared to neutral images. Gil and Droit-Volet (2012) also asked participants to estimate the duration of IAPS images that were matched for arousal but that belonged to different discrete emotion categories (i.e. high arousal disgust and high arousal fear). In the 200-800ms range, the duration of high arousal disgust images was overestimated compared to the duration of high arousal fear images, which were overestimated compared to the duration of neutral images. The overestimation of disgust compared to fear, and fear compared to neutral images was proportional with real time, which is indicative of activational effects of emotion. Taken together, these results show that although arousal has a marked impact on time perception in the 200-800ms range, emotion effects also depend on the discrete emotion of the stimuli.

Results of the 400-1600ms were not as conclusive as those from the 200-800ms range (Gil & Droit-Volet, 2012). In many instances, the overestimations that were seen in the short range failed to reach significance in the long range. Therefore, the findings of Gil and Droit-Volet (2012) also show that the activational effects of high arousal stimuli are short-lived. Study 3 of the present thesis showed no significant effects of emotion on time perception for complex images in the 400-1600ms range, but did show attentional effects of emotion in longer ranges (1000-4000ms and 2000-6000ms). Hence, it is possible that Gil and Droit-Volet (2012) would have also found attentional effects of emotion if their study included a third, longer duration range. Finally, Gil and Droit-Volet (2012) only used three emotional images per emotion/arousal combination, and repeated the presentation of each image 21 times over the course of the experiment. Image repetition may have affected attention without affecting activation, allowing activational effects to emerge. Thus, for a more direct comparison to the findings of this thesis, it is proposed that the study be repeated with a larger set of stimuli to avoid repeating images, and that the manipulation of arousal for discrete emotion stimuli also be tested in longer stimulus durations.

In conclusion, the present thesis makes a significant contribution to the study of emotion effects on time perception by presenting the first, systematic review of the impact of two key emotional dimensions on duration judgements. To date, this collection of experiments is the first to assess the effect of emotion using unique stimuli that are not repeated over the course of an experiment. Temporal bisection was used to test for emotion effects in three different ranges. Complex emotional stimuli fully crossed for arousal and valence were presented in both between-subjects and within-subjects designs. Although dynamic effects make it difficult to draw precise conclusions about the mechanisms through which arousal and valence influence time perception, results pointed to attentional effects of complex emotional stimuli on time perception. Conversely, a series of experiments using photographs of facial expressions showed short-lived activational effects of emotional facial expressions on duration judgements.

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Appendix A

Table A1.

Study 1, Temporal Bisection Task: Mixed Analysis of Variance on the Points of Subjective Equality for Emotional and Neutral Trials

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	3.817	.087	.058
Valence	1	2.737	.064	.106
Sex	1	2.902	.068	.096
Arousal * Valence	1	2.880	.067	.097
Arousal * Sex	1	1.125	.027	.295
Valence * Sex	1	0.048	.001	.827
Arousal * Valence * Sex	1	1.612	.039	.212
Error	40	(281457.768)		
Within subjects				
Trial Type	1	0.949	.023	.336
Trial Type * Arousal	1	1.078	.026	.305
Trial Type * Valence	1	0.365	.009	.549
Trial Type * Sex	1	0.148	.004	.702
Trial Type * Arousal * Valence	1	0.194	.005	.662
Trial Type * Arousal * Sex	1	1.683	.040	.202
Trial Type * Valence * Sex	1	0.261	.006	.612
Trial Type * Arousal * Valence * Sex	1	0.051	.001	.823
Error	40	(137823.348)		

Note. Values in parentheses represent mean square errors.

Table A2

Study 1, Temporal Bisection Task: Mixed Analysis of Variance on Difference Limens for Emotional and Neutral Trials

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	0.383	.009	.539
Valence	1	0.168	.004	.684
Sex	1	0.514	.013	.477
Arousal * Valence	1	0.290	.007	.593
Arousal * Sex	1	0.076	.002	.784
Valence * Sex	1	0.009	<.001	.923
Arousal * Valence * Sex	1	0.001	<.001	.982
Error	40	(78155.281)		
Within subjects				
Trial Type	1	0.388	.010	.537
Trial Type * Arousal	1	2.270	.054	.140
Trial Type * Valence	1	1.087	.026	.303
Trial Type * Sex	1	<.001	<.001	.990
Trial Type * Arousal * Valence	1	0.126	.003	.724
Trial Type * Arousal * Sex	1	1.711	.041	.198
Trial Type * Valence * Sex	1	0.069	.002	.794
Trial Type * Arousal * Valence * Sex	1	0.611	.015	.439
Error	40	(49380.141)		

Note. Values in parentheses represent mean square errors.

Table A3

Study 1, Analog Scale Task: Mixed Analysis of Variance on $T_{corrected}$ values for Emotional and Neutral Trials

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	1.889	.073	.182
Valence	1	1.263	.050	.272
Sex	1	0.693	.028	.413
Arousal * Valence	1	0.113	.005	.739
Arousal * Sex	1	0.600	.024	.446
Valence * Sex	1	1.059	.042	.314
Arousal * Valence * Sex	1	0.424	.017	.521
Error	24	(0.431)		
Within subjects				
Trial Type	1	0.102	.004	.752
Trial Type * Arousal	1	5.035	.173	.034
Trial Type * Valence	1	1.089	.043	.307
Trial Type * Sex	1	0.003	<.001	.954
Trial Type * Arousal * Valence	1	1.188	.047	.287
Trial Type * Arousal * Sex	1	3.250	.119	.084
Trial Type * Valence * Sex	1	0.253	.010	.619
Trial Type * Arousal * Valence * Sex	1	0.776	.031	.387
Duration	6	1.696	.066	.126
Duration * Arousal	6	0.561	.023	.761
Duration * Valence	6	0.349	.014	.910
Duration * Sex	6	3.787	.136	.002
Duration * Arousal * Valence	6	0.560	.023	.761

Duration * Arousal * Sex	6	0.890	.036	.504
Duration * Valence * Sex	6	1.064	.042	.387
Duration * Arousal * Valence * Sex	6	0.334	.014	.918
Trial Type * Duration	6	2.626	.099	.019
Trial Type * Duration * Arousal	6	1.134	.045	.345
Trial Type * Duration * Valence	6	0.481	.020	.822
Trial Type * Duration * Sex	6	0.553	.023	.767
Trial Type * Duration * Arousal * Valence	6	1.252	.050	.284
Trial Type * Duration * Arousal * Sex	6	1.251	.050	.284
Trial Type * Duration * Valence * Sex	6	0.317	.013	.927
Trial Type * Duration * Arousal * Valence * Sex	6	1.199	.048	.310
Error	144	(0.005)		

Note. Values in parentheses represent mean square errors.

Table A4

Study 1, Reproduction Task: Mixed Analysis of Variance on $T_{corrected}$ values for Emotional and Neutral Trials

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	0.181	.007	.674
Valence	1	0.112	.005	.741
Sex	1	1.958	.075	.175
Arousal * Valence	1	1.400	.055	.248
Arousal * Sex	1	2.042	.078	.166
Valence * Sex	1	0.991	.040	.329
Arousal * Valence * Sex	1	1.077	.043	.310
Error	24	(0.11)		
Within subjects				
Trial Type	1	0.714	.029	.406
Trial Type * Arousal	1	0.946	.038	.340
Trial Type * Valence	1	1.719	.067	.202
Trial Type * Sex	1	0.794	.032	.382
Trial Type * Arousal * Valence	1	1.362	.054	.255
Trial Type * Arousal * Sex	1	0.117	.005	.735
Trial Type * Valence * Sex	1	0.170	.007	.684
Trial Type * Arousal * Valence * Sex	1	0.105	.004	.749
Duration	6	5.944	.199	<.001
Duration * Arousal	6	0.597	.024	.732
Duration * Valence	6	0.537	.022	.780
Duration * Sex	6	1.248	.049	.286
Duration * Arousal * Valence	6	1.726	.067	.119

Duration * Arousal * Sex	6	1.745	.068	.115
Duration * Valence * Sex	6	0.853	.034	.531
Duration * Arousal * Valence * Sex	6	0.533	.022	.782
Trial Type * Duration	6	0.342	.014	.914
Trial Type * Duration * Arousal	6	0.387	.016	.886
Trial Type * Duration * Valence	6	0.716	.029	.638
Trial Type * Duration * Sex	6	1.252	.050	.284
Trial Type * Duration * Arousal * Valence	6	0.394	.016	.882
Trial Type * Duration * Arousal * Sex	6	0.346	.014	.911
Trial Type * Duration * Valence * Sex	6	0.229	.009	.967
Trial Type * Duration * Arousal * Valence * Sex	6	0.692	.028	.656
Error	144	(0.004)		

Note. Values in parentheses represent mean square errors.

Appendix B

Table B1

Study 2: Mixed Analysis of Variance on the Point of Subjective Equality for Emotional and Neutral Trials of the 400 to 1600ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	0.002	<.001	.967
Valence	1	0.316	.002	.575
Sex	1	0.581	.004	.447
Arousal * Valence	1	1.685	.013	.197
Arousal * Sex	1	2.079	.016	.152
Valence * Sex	1	0.165	.001	.686
Arousal * Valence * Sex	1	1.203	.009	.275
Error	132	(20906.152)		
Within subjects				
TrialType	1	3.653	.027	.058
TrialType * Arousal	1	0.251	.002	.617
TrialType * Valence	1	0.836	.006	.362
TrialType * Sex	1	0.072	.001	.789
TrialType * Arousal * Valence	1	0.357	.003	.551
TrialType * Arousal * Sex	1	0.631	.005	.428
TrialType * Valence * Sex	1	1.621	.012	.205
TrialType * Arousal * Valence * Sex	1	0.265	.002	.607
Error	132	(5255.404)		

Note. Values in parentheses represent mean square errors.

Table B2

Study 2: Mixed Analysis of Variance on the Difference Limens for Emotional and Neutral Trials of the 400 to 1600ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	0.027	<.001	.870
Valence	1	0.723	.005	.397
Sex	1	0.316	.002	.575
Arousal * Valence	1	0.052	<.001	.820
Arousal * Sex	1	0.215	.002	.644
Valence * Sex	1	0.170	.001	.681
Arousal * Valence * Sex	1	0.073	.001	.788
Error	132	(2118.858)		
Within subjects				
TrialType	1	0.446	.003	.505
TrialType * Arousal	1	0.897	.007	.345
TrialType * Valence	1	2.372	.018	.126
TrialType * Sex	1	1.946	.015	.165
TrialType * Arousal * Valence	1	0.005	<.001	.943
TrialType * Arousal * Sex	1	0.828	.006	.365
TrialType * Valence * Sex	1	3.832	.028	.052
TrialType * Arousal * Valence * Sex	1	3.161	.023	.078
Error	132	(1454.505)		

Note. Values in parentheses represent mean square errors.

Table B3

Study 2: Mixed Analysis of Variance on the Point of Subjective Equality for Emotional and Neutral Trials of the 1000 to 4000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	0.070	<.001	.791
Valence	1	2.217	.015	.139
Sex	1	0.023	<.001	.880
Arousal * Valence	1	3.408	.023	.067
Arousal * Sex	1	0.040	<.001	.842
Valence * Sex	1	2.216	.015	.139
Arousal * Valence * Sex	1	0.358	.002	.551
Error	145	(185618.293)		
Within subjects				
TrialType	1	0.010	<.001	.922
TrialType * Arousal	1	0.188	.001	.665
TrialType * Valence	1	1.467	.010	.228
TrialType * Sex	1	1.751	.012	.188
TrialType * Arousal * Valence	1	0.987	.007	.322
TrialType * Arousal * Sex	1	0.153	.001	.696
TrialType * Valence * Sex	1	5.311	.035	.023
TrialType * Arousal * Valence * Sex	1	0.007	<.001	.933
Error	145	(40280.040)		

Note. Values in parentheses represent mean square errors.

Table B4

Study 2: Mixed Analysis of Variance on the Difference Limens for Emotional and Neutral Trials of the 1000 to 4000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	0.004	<.001	.948
Valence	1	3.872	.026	.051
Sex	1	0.000	<.001	.995
Arousal * Valence	1	1.499	.010	.223
Arousal * Sex	1	0.175	.001	.676
Valence * Sex	1	0.046	<.001	.830
Arousal * Valence * Sex	1	0.021	<.001	.884
Error	145	(21680.858)		
Within subjects				
TrialType	1	8.615	.056	.004
TrialType * Arousal	1	0.161	.001	.689
TrialType * Valence	1	0.003	<.001	.959
TrialType * Sex	1	1.242	.008	.267
TrialType * Arousal * Valence	1	0.034	<.001	.854
TrialType * Arousal * Sex	1	0.030	<.001	.862
TrialType * Valence * Sex	1	0.991	.007	.321
TrialType * Arousal * Valence * Sex	1	0.257	.002	.613
Error	145	(9973.501)		

Note. Values in parentheses represent mean square errors.

Table B5

Study 2: Mixed Analysis of Variance on the Point of Subjective Equality for Emotional and Neutral Trials of the 2000 to 8000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	0.315	.002	.576
Valence	1	0.023	<.001	.879
Sex	1	4.305	.033	.040
Arousal * Valence	1	0.882	.007	.350
Arousal * Sex	1	0.226	.002	.635
Valence * Sex	1	6.078	.045	.015
Arousal * Valence * Sex	1	0.142	.001	.707
Error	128	(550554.173)		
Within subjects				
TrialType	1	0.739	.006	.392
TrialType * Arousal	1	0.289	.002	.592
TrialType * Valence	1	0.154	.001	.695
TrialType * Sex	1	1.688	.013	.196
TrialType * Arousal * Valence	1	0.127	.001	.722
TrialType * Arousal * Sex	1	1.378	.011	.243
TrialType * Valence * Sex	1	0.021	<.001	.884
TrialType * Arousal * Valence * Sex	1	0.333	.003	.565
Error	128	(106400.768)		

Note. Values in parentheses represent mean square errors.

Table B6

Study 2: Mixed Analysis of Variance on the Difference Limens for Emotional and Neutral Trials of the 2000 to 8000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Arousal	1	2.105	.016	.149
Valence	1	0.346	.003	.557
Sex	1	2.076	.016	.152
Arousal * Valence	1	0.047	<.001	.828
Arousal * Sex	1	0.015	<.001	.902
Valence * Sex	1	6.494	.048	.012
Arousal * Valence * Sex	1	0.791	.006	.376
Error	128	(46764.415)		
Within subjects				
TrialType	1	12.908	.092	<.001
TrialType * Arousal	1	0.930	.007	.337
TrialType * Valence	1	0.181	.001	.671
TrialType * Sex	1	0.152	.001	.697
TrialType * Arousal * Valence	1	2.885	.022	.092
TrialType * Arousal * Sex	1	0.071	.001	.790
TrialType * Valence * Sex	1	0.379	.003	.539
TrialType * Arousal * Valence * Sex	1	1.561	.012	.214
Error	128	(22813.451)		

Note. Values in parentheses represent mean square errors.

Table B7

Study 2: Mixed Analysis of Variance on the Weber Fractions for Emotional and Neutral Trials

Source	df	F	η_p^2	p
Between subjects				
Duration Range	2	4.635	.022	.010
Arousal	1	1.781	.004	.183
Valence	1	0.407	.001	.524
Sex	1	1.102	.003	.294
Duration Range * Arousal	2	0.674	.003	.510
Duration Range * Valence	2	0.636	.003	.530
Duration Range * Sex	2	3.355	.016	.036 ⁴
Arousal * Valence	1	0.320	.001	.572
Arousal * Sex	1	2.596	.006	.108
Valence * Sex	1	0.597	.001	.440
Duration Range * Arousal * Valence	2	0.769	.004	.464
Duration Range * Arousal * Sex	2	0.243	.001	.784
Duration Range * Valence * Sex	2	0.230	.001	.795
Arousal * Valence * Sex	1	1.078	.003	.300
Duration Range * Arousal * Valence * Sex	2	0.235	.001	.790
Error	405	(0.003)		
Within subjects				
TrialType	1	16.304	.039	<.001
TrialType * Duration Range	2	0.888	.004	.412

⁴ When Weber ratios were calculated using the arithmetic mean rather than the point of subjective equality, the Duration X Sex interaction was not significant, $F(2, 405) = 0.821$, $p = .441$, $\eta_p^2 = .004$.

TrialType * Arousal	1	0.330	.001	.566
TrialType * Valence	1	0.338	.001	.561
TrialType * Sex	1	0.690	.002	.407
TrialType * Duration Range * Arousal	2	1.377	.007	.254
TrialType * Duration Range * Valence	2	1.187	.006	.306
TrialType * Duration Range * Sex	2	1.260	.006	.285
TrialType * Arousal * Valence	1	1.439	.004	.231
TrialType * Arousal * Sex	1	0.003	<.001	.953
TrialType * Valence * Sex	1	0.237	.001	.627
TrialType * Duration Range * Arousal * Valence	2	0.870	.004	.420
TrialType * Duration Range * Arousal * Sex	2	0.928	.005	.396
TrialType * Duration Range * Valence * Sex	2	0.682	.003	.506
TrialType * Arousal * Valence * Sex	1	1.164	.003	.281
TrialType * Duration Range * Arousal * Valence * Sex	2	2.402	.012	.092
Error	405	(0.002)		

Note. Values in parentheses represent mean square errors.

Appendix C

Table C1

Study 3: Mixed Analysis of Variance on the dPSEs of the 400 to 1600ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Sex	1	1.961	.022	.165
Error	88	(22984.633)		
Within subjects				
Arousal	1	0.966	.011	.328
Arousal * Sex	1	0.781	.009	.379
Valence	1	1.042	.012	.310
Valence * Sex	1	2.183	.024	.143
Arousal * Valence	1	1.561	.017	.215
Arousal * Valence * Sex	1	0.322	.004	.572
Error	88	(7680.934)		

Note. dPSEs represent the difference between the point of subjective equality for neutral trials and the point of subjective equality for emotional images. Values in parentheses represent mean square errors.

Table C2

Study 3: Mixed Analysis of Variance on the dDLs of the 400 to 1600ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Sex	1	0.364	.004	.548
Error	88	(4085.116)		
Within subjects				
Arousal	1	2.722	.030	.103
Arousal * Sex	1	0.247	.003	.620
Valence	1	2.334	.026	.130
Valence * Sex	1	2.259	.025	.136
Arousal * Valence	1	0.004	.000	.948
Arousal * Valence * Sex	1	0.513	.006	.476
Error	88	(1309.103)		

Note. dDLs represent the difference between the difference limen for neutral images and the difference limen for emotional images. Values in parentheses represent mean square errors.

Table C3

Study 3: Mixed Analysis of Variance on the dPSEs of the 1000 to 4000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Sex	1	1.542	.018	.218
Error	83	(198688.996)		
Within subjects				
Arousal	1	3.003	.035	.087
Arousal * Sex	1	1.203	.014	.276
Valence	1	0.047	.001	.828
Valence * Sex	1	0.125	.002	.725
Arousal * Valence	1	0.009	<.001	.923
Arousal * Valence * Sex	1	0.968	.012	.328
Error	83	(27419.218)		

Note. dPSEs represent the difference between the point of subjective equality for neutral trials and the point of subjective equality for emotional trials. Values in parentheses represent mean square errors.

Table C4

Study 3: Mixed Analysis of Variance on the dDLs of the 1000 to 4000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Sex	1	0.608	.007	.438
Error	83	(24017.772)		
Within subjects				
Arousal	1	9.845	.106	.002
Arousal * Sex	1	0.155	.002	.695
Valence	1	5.251	.060	.024
Valence * Sex	1	0.244	.003	.622
Arousal * Valence	1	1.290	.015	.259
Arousal * Valence * Sex	1	0.166	.002	.684
Error	83	(5927.244)		

Note. dDLs represent the difference between the difference limen for neutral trials and the difference limen for emotional trials. Values in parentheses represent mean square errors.

Table C5

Study 3: Mixed Analysis of Variance on the dPSEs of the 2000 to 6000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Sex	1	0.046	.001	.830
Error	84	(246497.357)		
Within subjects				
Arousal	1	9.271	.099	.003
Arousal * Sex	1	0.137	.002	.713
Valence	1	0.067	.001	.796
Valence * Sex	1	8.961	.096	.004
Arousal * Valence	1	1.078	.013	.302
Arousal * Valence * Sex	1	0.115	.001	.735
Error	84	(28519.704)		

Note. dPSEs represent the difference between the point of subjective equality for neutral trials and the point of subjective equality for emotional trials. Values in parentheses represent mean square errors.

Table C6

Study 3: Mixed Analysis of Variance on the dDLs of the 2000 to 6000ms Duration Range

Source	df	F	η_p^2	p
Between subjects				
Sex	1	4.635	.052	.034
Error	84	(97025.454)		
Within subjects				
Arousal	1	3.053	.035	.084
Arousal * Sex	1	0.499	.006	.482
Valence	1	1.258	.015	.265
Valence * Sex	1	4.603	.052	.035
Arousal * Valence	1	0.795	.009	.375
Arousal * Valence * Sex	1	0.246	.003	.622
Error	84	(8103.515)		

Note. dDLs represent the difference between the difference limen for neutral trials and the difference limen for emotional trials. Values in parentheses represent mean square errors.

Table C7

Study 3: Mixed Analysis of Variance on the dWRs

Source	df	F	η_p^2	p
Between subjects				
Duration Range	2	4.814	.036	.009
Sex	1	1.335	.005	.249 ⁵
Duration Range * Sex	2	1.851	.014	.159
Error	255	(0.002)		
Within subjects				
Arousal	1	8.031	.031	.005
Arousal * Duration Range	2	1.661	.013	.192
Arousal * Sex	1	0.153	.001	.696
Arousal * Duration Range * Sex	2	0.274	.002	.761
Valence	1	6.240	.024	.013
Valence * Duration Range	2	0.462	.004	.630
Valence * Sex	1	0.639	.003	.425
Valence * Duration Range * Sex	2	3.221	.025	.042
Arousal * Valence	1	0.278	.004	.599
Arousal * Valence * Duration Range	2	0.640	.005	.528
Arousal * Valence * Sex	1	0.102	<.001	.750
Arousal * Valence * Duration Range * Sex	2	1.128	.009	.325
Error	255	(0.002)		

Note. dWRs represent the difference between the Weber ratio for neutral trials and the Weber ratio for emotional trials. Values in parentheses represent mean square errors.

⁵ When Weber ratios were calculated using the arithmetic mean rather than the point of subjective equality, the effect of sex was significant, $F(1, 255) = 4.663$, $p = .032$, $\eta_p^2 = .018$. Temporal sensitivity was better for women (mean dWR = 0.002, SEM = 0.004) than for men (mean dWR = -0.007, SEM = 0.003)

Appendix D

Table D1

Study 4: Mixed Analysis of Variance on the dWRs

Source	df	F	η_p^2	p
Between subjects				
Duration Range	2	0.659	.005	.518
Error	258	(0.006)		
Within subjects				
Emotion	3	4.051	.015	.007
Emotion* Duration Range	6	1.545	.012	.160
Error	765	(0.001)		

Note. dWRs represent the difference between the Weber ratio for neutral trials and the Weber ratio for emotional trials. Values in parentheses represent mean square errors.