Elucidating the Role of Attention and Emotion

on Subjective Time Perception

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INTRODUCTION

Time Perception

Timing is essential to almost every behavior we engage in; knowledge of elapsed time allows us to anticipate sensory events and to prepare appropriate actions. However, the common sense notion that there exists one “true” independent time, has given way to the idea that time is different for each and every one of us (Myers 2001). Therefore, there is a fundamental distinction between our universal and rational idea of time, referred to as objective time, and our primary experience of duration, referred to as subjective time. While objective time generally refers to the qualitative and quantitative description of time that remains unchanged under different conditions, subjective experience is based on personal interpretations and, therefore, is subject to change with respect to different conditions.

Over the years, civilization adopted and invented various methods and arbitrary devices that enable monitoring of objective time in a reliable manner. The development of reliable time marking devices, such as clocks and calendars, allowed for social organization, communication, navigation, and commercial purposes (Gorman & Wessman, 1977). On the other hand, human subjective estimation of time is a self-conscious awareness of duration, a mode of introspection based on intuitions and biological rhythms (e.g., attention cycles). In essence, subjective time estimates rarely match objective time, which progresses linearly and in constant units.

Subjective temporal judgments may be susceptible to contextual influences including, but not restricted to, the physical characteristics of the stimuli (Fraisse, 1984), their emotional valence (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Noulhiane et al., 2007), and the attentional load required with respect to the task at hand (Block & Zakay, 1997). Our subjective perspective of the amount of time that has passed, or the speed at which time is passing, can vary, leading to distortions from objective time. When we feel like less time has occurred (passed) than actually has (i.e., underestimation), time feels like it has speeded up. When we feel like more has occurred (passed) than actually has (i.e., overestimation), time feels like it has slowed down.

Psychophysical research attempts to study how subjective human timing matches the objective time of mechanical and electronic clocks (see Block et al., 2010 for review). Such studies illustrate how individuals might translate their judgment of events and personal experience into a more culturally uniform, standardized system of judging events.

In situations in which participants are asked to judge time explicitly, two distinct experimental methods are identified: prospective and retrospective time estimations. Prospective timing involves time judgments of participants who know in advance that duration is an important aspect of the experiment, while in retrospective timing participants receive no prior warning (see Brown & Stubbs, 1988; Eisler et al., 2004; Hicks et al., 1976; Predebon, 1996). Prospective temporal estimations are commonly explained using attentional models (Tse et al., 2004; Zakay & Block, 2004) as well as arousal influences (e.g., Zakay, Nitzan, & Glicksohn, 1983). In contrast, retrospective timing is mainly associated with memory processes (Block & Zakay, 1997; Zakay &

Block, 1997, 2004). Therefore, prospective judgment tasks are particularly well suited to the study of the interaction between attention and arousal in information processing.

Models of Time

There is no known perceptual system or sensory organ that is solely responsible for the encoding of time. Theorists, therefore, explain time in terms of cognitive processes or the combination of both cognitive and biological processes. Various cognitive models have been used to explain the perception of durations, particularly in the range of seconds to minutes (Gibbon & Church, 1984; Staddon 2005; Taatgen et al., 2007; Thomas & Weaver, 1975).

A popular and dominant contemporary model of prospective timing is *Scalar expectancy theory* (*SET*, also referred to as scalar timing theory). Originally developed by Gibbon (1977; Gibbon and Church 1984; Gibbon et al., 1984) for animals, and later modified and applied to humans (Allan & Gibbon, 1991; Wearden 1992; 2003), SET is composed of three processes: the perception of time (internal clock), memory examples of times of reinforcement, and decision making (see Figure 1). Time estimation, based on this model, is controlled by the ratio comparison between the current subjective time (accumulator reading) and the number of pulses (emitted from a pacemaker) from previously reinforced accumulator readings stored in reference memory (Buhusi & Meck, 2005). When, for example, a stimulus is presented, the number of pulses that accumulates in working memory during stimulus presentation is compared with a sample from reference memory. A comparison process, based on a proportional threshold, then determines if the samples are the same (respond ‘yes’) or different (respond ‘no’).

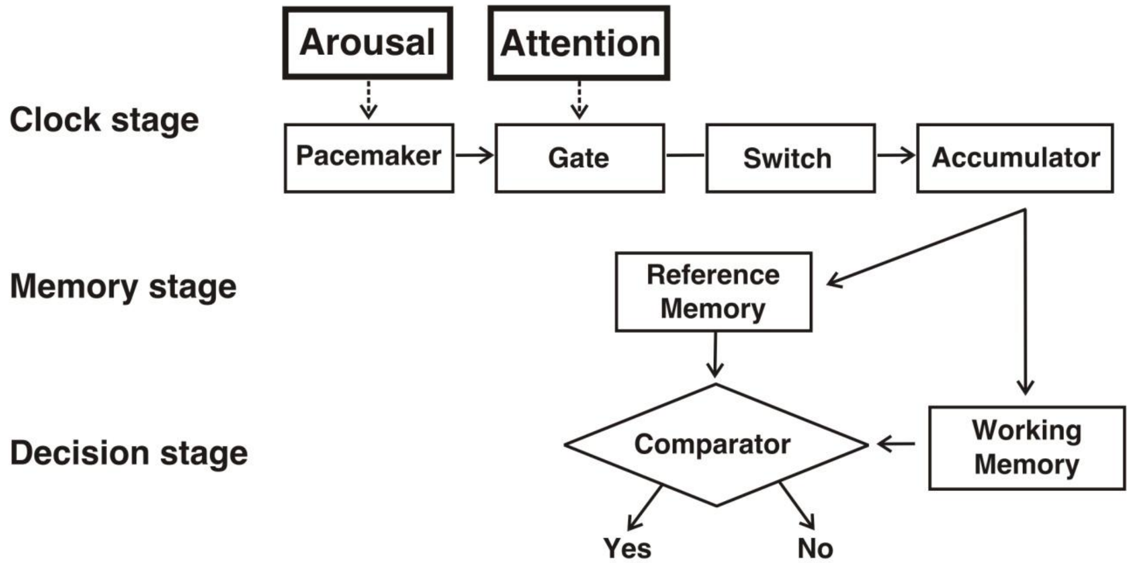

Figure 1. Scalar Expectancy Theory (SET; Gibbon & Church, 1984) with the additions of the Attentional gate model (Zakay & Block, 1997).

Understanding the inner-workings of the internal clock, whether involving chemical, neurological or physical processes (Marchetti, 2009; Triesman, 1963), is essential to the understanding of subjective time. The most prominent internal clock model, as described in SET, is the *pacemaker–accumulator model* in which the internal clock consists of a pacemaker and an accumulator. The pacemaker emits a series of pulses at a specific rate, and they accumulate and are counted in the accumulator. There is controversy among researchers as to the rate and distribution of these pulses. According to some theories the pacemaker has a constant rate and emits pulses on a linear fixed inter-pulse interval time scale. According to others, the pacemaker output is based on a logarithmic exponential inter-pulse interval time scale, in which pulses are emitted more and more slowly with time (Taatgen et al. 2007). Still others claim that the rate of the pulses is determined by the processing of the perceptual stimuli. For example, arousal inducing stimuli (e.g., trains of clicks with high intensity) are suggested to increase the rate of the pacemaker relative to non-arousing stimuli (Burle & Casini, 2001). The accumulator in the pacemaker–accumulator model, counts the pulses generated by a pacemaker and stores the number of pulses (subjective time units) accumulated during an event generating temporal information (Matell & Meck, 2000). The value of the accumulator is read at the end of the interval and stored in memory. A reset event sets the accumulator to zero, after which it starts counting pulses anew.

To account for attentional influences on timing, an attention-based system has been added to this model of time estimation. The attentional model includes a switch between the pacemaker and the accumulator, which can be opened to a greater or lesser extent in relation to the allocation of attention (Lejeune, 1998). In order for the pulses emitted from the pacemaker to be accumulated in the accumulator, the switch needs to be closed. Therefore, Gibbon et al. (1984), suggested that the closing of the switch indicates the start of the clock. Accordingly, when the switch opens the clock stops since the pulses emitted can no longer be accumulated (Gibbon et al., 1984). In addition to being a constant source of variability by closing and opening (Fortin, 2003), the switch's closing and opening can also be delayed, preventing from pulses to pass in the former and allowing the pulses to accumulate in the latter. The switch that creates the pacemaker-accumulator connection may be closed and opened repeatedly, a condition known as a 'flickering switch' (Gibbon & Church, 1984). The number of pulses stored in the accumulator at the end of the event to be timed is the basis for the subjective temporal judgment.

More recently, an Attentional Gate Model (AGM) in which an attentional gate was added to the inner clock metaphor, was developed (Zakay & Block, 1997). In this model there is a separation between the perceptual information processing system - the switch (which operates more or less automatically in accordance with stimulus onset and offset), and the attentional processing system - the gate (Zakay, 2000). Attention modulates the gate that allows pulses to be registered. If engaged in a non-temporal task that demands attention, the gate will open wider and fewer pulses will be accumulated in the accumulator. In contrast, more subjective time units can be accumulated if additional attentional resources are allocated to time (Zakay, 1989; Zakay & Block, 1997). Fewer time units are associated with shorter perceived durations, and more time units are associated with longer perceived durations (Macar et al., 1994). Thus, there is a trade off in allocation of attention between temporal and non-temporal processing, suggesting that attentional resources are essential to temporal processing.

In addition to the amount of attention allocated to time, the AGM suggests that prospective judgments also depend on arousal levels (see emotional arousal and time below). According to this model, increasing arousal levels leads the pacemaker to increase the number of pulses per unit of time, consequently, collecting more time units in the accumulator and thus increasing the perceived duration. Therefore, the AGM suggests that both the heightened awareness of the passage of time itself (i.e., attention to time) and an increase in arousal levels are associated with a lengthening of the experienced duration.

Attention

At any moment in time, we are bombarded with a variety of stimuli, only some of which are relevant to our current goals. Driving a car, for example, requires processing information related to road conditions, operating the machinery while sometimes performing concurrent tasks (e.g., monitoring the kids in the backseat), preparing to detect and identify emergencies, and estimating the distance in-between cars. The stimuli presented, therefore, will often require different actions, that may be compatible or incompatible with each other. The attentional system, separated into independent processes, allows for the coordination between the perceived stimuli and our actions.

One important model of attention construes it as three functionally disparate control networks: alerting, orienting, and executive control (Fan et al., 2002; Posner & Peterson, 1990; Raz & Buhle, 2006). These three attentional networks seem largely independent of one another other with each having its own functional anatomy, cytoarchitecture, and development. However, substantial functional overlap among these control networks suggests that they communicate and interact in subtle ways (Callejas et al., 2004). These networks carry out functions, such as achieving and maintaining the alert state, orienting to sensory events, and controlling thoughts and monitoring feelings (Posner, 2012).

The alerting system functions to achieve and maintain a state of high sensitivity to incoming stimuli. It refers to the changes of the internal state in preparation for perceiving a stimulus (Fan et al., 2005; Raz, 2004). The vigilance in the alert state is usually followed by rapid responding, but this decrease in reaction time (RT) is also usually accompanied by higher error rates (Posner & Petersen, 1990). Alertness involves a specific control network of attention that acts to support visual orienting and probably also influences other attentional networks.

Orienting refers to a process of selecting information from a sensory input. Orienting to a stimulus implies that the stimuli at a given location become amplified, which improves efficiency of processing. Orientation of attention can either be reflexive, as when triggered by a stimulus (e.g., a brief presentation that directs attention to its location), or shifted as a result of voluntary control, as when a person searches the visual field for a target. Therefore, orienting to a cue can be achieved either overtly by moving the eyes, or covertly without eye movement (Posner, 1980). The orienting system has been proposed to include three networks as well: shift, engagement, and disengagement of attention (Posner & Petersen, 1990). Shifting refers to the spatial relocation of attention. Engagement is evidence of shifting and refers to the facilitated processing of a given stimulus, while disengagement refers to the process in which, shifting to and engagement with, a stimuli is withdrawn or inhibited (Yiend, 2010).

The third attentional network is executive control, for which a critical component is the ability to suppress or override competing behavioral responses to resolve cognitive conflict (Casey et al., 2002). This executive (conflict) system involves complex mental operations both to monitor and resolve conflict between computations occurring in different brain areas. This network is mostly needed in situations such as planning, decision-making, error detection, novel responses and overcoming habitual actions. Therefore, executive attention is largely founded on the notion of cognitive load, or mental effort demanded by a primary task.

Different processes require different amounts of cognitive load (effort), and thereby, different executive attentional allocation. Efficient processes (e.g., reading) occur unintentionally, effortlessly, cannot be easily interrupted and may not give rise to awareness (Posner & Snyder 1975; Raz & Buhle, 2006). Since efficient processes require very little executive attention, they barely interfere with other processes. On the contrary, inefficient processes are effortful (e.g., saying the ink color in a Stroop task) and therefore require intention and awareness (attention). Most cognitive processes are located on the continuum between efficient and inefficient. Moreover, this location may change over time. Repeated practice can change an initially inefficient process to an efficient one, while an adverse condition can change an efficient process into an inefficient process (Posner & Snyder, 1975; Flaherty 1999). For example driving starts off as an inefficient process yet becomes efficient with repeated practice. However, in an approaching car accident situation, driving becomes an inefficient process that once again demands attention.

Attentional load is fundamental to the attentional capacity theory, which assumes a limited central pool of resources. According to the limited resources concept, our ability to perform simultaneous tasks depends on the amount of attentional capacity the task requires (Kahneman, 1973; cf 2011). The more mental effort an individual exerts toward completing a task, the more the task requires of a limited pool of available capacity. Accordingly, attention methodology has largely focused on employing dual task techniques, using tasks that presumably compete for the same attentional resources (Meyer & Kieras, 1997; Navon & Miller, 2002).

Attention and Time

The AGM is equipped to predict the influences of attentional load on timing. When attention is allocated away from timing, the closing of the gate is attenuated and fewer pulses are accumulated per time interval (Meck, 2003). Therefore, subjective time estimation of an interval will be shorter than the objective temporal interval when an additional task requires the processing of non-temporal information. “Time flies when you are having fun” because you attend to various experiences and are not attending to the dimension of time. In contrast, “a watched pot never boils” according to attentional theories because when you are bored, your attentional resources are focused on the time dimension and subjective time is therefore experienced as longer than objective time.

Dual task procedures provide the basis for numerous studies to depict an attentional influence on timing (e.g. Brown, 1985). A dual task procedure involves two tasks performed at the same time. Therefore, dual task timing procedures typically include a temporal task in addition to another non-temporal attention-demanding task. Since there are finite attentional resources, attention should theoretically be divided between the two tasks that demand similar cognitive resources (Kahneman, 1973).

An inefficient non-temporal task that requires attentional effort will shift attention away from the timing task, while an efficient non-temporal task will allocate attentional resources toward the timing task. Accordingly, prospective time estimates are said to be negatively related to the cognitive load of the non-temporal task (i.e., low, medium or high difficulty of non-temporal task). As the cognitive load increases, subjective time estimation becomes shorter (Block 1989, 1990, 1992; Khan, 2006; Zakay, 1989).

Attention, therefore, plays an important role in our judgment and perception of time. Though studies rarely make the distinction as to which attentional control network is manipulated, it is possible to infer the focus of attention by assessing the methods used. Dual task timing procedures with a non-temporal task that includes various levels of cognitive load (i.e., executive attention), spatial cues (i.e., engagement and disengagement processes related to orienting) and alerting demands (e.g., specific instructions), allow for the assessment of the different networks of attention on time perception.

Procedures that exemplify how orienting interacts with temporal processing can include an experiment conducted by Mattes & Ulrich (1998), in which participants are asked to judge a duration of a stimulus, with a pre-cue preceding the stimulus and directing attention either toward the temporal stimulus (valid cue) or away for the temporal stimulus (invalid cue). Assuming that an invalid pre-cue requires reorienting (and therefore additional attentional resources) to shift from the cued location to the correct stimulus location, less attention would be available for timing, the internal clock would accumulate fewer pulses, and accordingly subjective duration of a stimulus with an unexpected (invalid) source would appear shorter than the objective duration.

Meck (1984) presented another type of orienting procedure that involves modality mismatch (i.e., visual or auditory) between the cue and the signal to be timed. For example, trials on which an auditory cue (i.e., noise) preceded a visual stimulus (i.e., light), time estimations for the stimulus were shorter than when the cue and stimulus were of the same modality. The noise cue directs attention (i.e., orienting) toward the sound and away from the light. This causes a delay in the closing of the attentional gate which, in turn, allows for fewer pulses to accumulate in the accumulator and causes the light stimulus to be subjectively perceived as shorter.

Other procedures related to orienting involve different allocation of attention to the temporal versus the non-temporal task. For example, in a dual task neuroimaging experiment by Coull et al. (2004), the amount of attention allocated to the temporal versus the non-temporal tasks was manipulated. Participants were asked to direct their attention to either the duration of an event or to its color, using a five-condition parametric design for modeling both behavioral performance and the blood oxygen level–dependent (BOLD) fMRI signal as a function of increasing attention to either time or color. In accord with attentional models, participants were progressively slower and less accurate in providing a time estimate (underestimated durations) as they paid progressively less attention to the temporal attributes of a stimulus across the five conditions. However, they simultaneously became faster and more accurate in providing a color estimate. This experiment illustrates the tradeoff between attention allocated to timing and attention allocated to the non-temporal task.

Ono et al. (2007) showed that disengagement also has an influence on timing. They assessed subjective temporal estimation of a stimulus that had previously been ignored. The previously ignored stimuli seem to demand more attentional resources than the previously attended or novel stimuli and, therefore, divert attention away from time. Accordingly, previously ignored stimuli were perceived to have shorter durations.

Procedures that involve alerting interactions with temporal processing are typically associated with expectations and anticipations of an event. For example, Gaudreault et al. (2010) showed that the longer participants were waiting for a break (i.e., interruption) in an interval to be timed, the more attention was allocated to the arrival of the break. In other words, increased attentional allocation toward a stimulus (e.g., the break) is related to the increase in anticipation toward the stimulus itself (i.e., alerting).

Therefore as participants became more alert, less attention was allocated to time and resulted in shorter subjective time estimations.

The influence of executive attention on timing is the most prominent in the literature on timing and attention, and typically involves manipulations of cognitive load (i.e., task difficulty). A recent meta-analysis conducted by Block et al. (2010), concluded that there is a negative correlation between cognitive load and time estimations. As cognitive load for the non-temporal tasks increases, the subjective time estimations decrease (i.e., shorter estimates). Accordingly, responding to a stimulus, as opposed to passively viewing it, decreases the time perception for the duration of the stimulus.

These studies shed light on how attentional allocation influences our subjective perception of time. However, attention might not be the only factor influencing subjective timing. Before closing the book on perceived time manipulations, it is necessary to consider the, conceivably conflicting, influences of a different factor on subjective time – emotional arousal.

Emotional Arousal

Emotions play on central stage in our lives. They are what drive us and what drive us astray. Without emotions there are nothing but dull moments, reflex and routine. Typically, emotions are elicited by external events. For example, if you encounter a bear in the forest, you might respond by contemplating the danger of the situation; this is followed by a tide of strong physiological changes - arousal, consequently you open your eyes and mouth wide, have the urge to run and feel something that you label as ‘fear’.

Emotions, therefore, induce thoughts, bodily changes, action tendencies, modulations of mental processes such as attention, and conscious feelings.

Theories of emotions disagree on the causes and categorization of emotions. For example, William James (1884) and Karl Lange (1885) proposed that bodily changes precede our emotional experience and therefore, emotions are derived from changes in the body. Others claim that emotions are innate, hardwired, and functional; assisting in the management of human action, by guiding our attention and prompting action (Ekman, 1984). In general, however, it is assumed that emotions depend on two basic dimensions: valance (i.e., positive or negative affect) and arousal. In timing research (e.g., Effron et al., 2006, Stetson et al., 2007), the effects of arousal on subjective time perception is typically interpreted as emotional arousal (i.e., arousal that is generated by the emotional stimulus).

Emotional Arousal and Time

Throughout the past five decades, many studies have attempted to explore the relationship between emotional arousal and subjective time (Angrilli et al. 1997; Droit-Volet & Meck, 2007; Langer et al. 1961; Loftus et al. 1987; Stetson et al. 2007). Most scientific accounts, as well as personal accounts, rely on retrospective judgments of time (i.e., the person is unaware that an estimation of the duration of an event is needed) and perceive time as moving slowly in arousing situations. For example, a pilot's description of an emergency situation in which his plane was going down:

"…It seemed to be taking forever to come down……a half minute ordeal that seemed to take ten minutes was over.'' (Carson 1982, p.26)

Experiments with manipulations of emotional arousal are usually only faint reflections of actual life-threatening experiences and therefore present a significant challenge. To get a broad understanding of how arousal and time interact, different types of arousal have been examined using the prospective paradigm, in which participants are aware of the temporal component of the task. The wide range of experiments investigating arousal include studies with fear anticipation, actual threatening situations, videotaped affective scenes, facial expressions and affective pictures.

Langer et al. (1961) was one of the first to try and manipulate time estimation by presenting participants with a threatening situation and having them judge when five minutes had elapsed. They had participants walk blindfolded either toward a prospective danger (a hole in the ground) or away from danger, toward safety. Participants who walked toward danger made longer time estimates than participants who were safely moving away from the danger, covering the same distance. In addition, the more imminent danger became, the more time was overestimated. In other words, as the participants became more aroused from fear, their subjective time moved even more slowly, and their estimations increased. Other expectancy studies, using the ‘threat’ of an aversive stimulus at the end of an interval duration to manipulate arousal levels (e.g., threat of electric shock at the end of predetermined time intervals), judged time as longer than participants expecting a harmless or neutral event (Baddeley 1966; Hare, 1963; Falk & Bindra, 1954). More recently Gilbert et al. (1977) found that overestimation of fixed intervals also occurs following a stressful situation and not only in anticipation of a stressful situation.

Watts and Sharrock (1984) also presented participants with actual threats to manipulate emotional arousal. They recruited arachnophobic and non-arachnophobic individuals and presented them with spiders for different durations. The phobic individuals' estimates were longer and more variable compared with the non-phobics.

Other studies have induced arousal by having participants jump off a suspended catch air device diving tower (Stetson et al., 2007) or have novel skydivers retrospectively estimate the duration of their skydiving experience. The results have shown that participants with increased fear perceived time as passing slowly while participants with increased excitement perceived time as passing quickly (Campbell & Bryant, 2007). Thus, situations perceived to be threatening seem to lead to an increase in arousal that is associated with the appearance of subjective time passing more slowly, that is, the feeling that more time has passed than objectively has.

Some studies have incorporated videotaped recordings to facilitate arousal. Loftus et al. (1987) showed participants a videotape of a bank robbery at different arousal levels. In the 'low stress' version the robber is depicted entering the bank and calmly handing the teller a note. In the 'high stress' version the robber holds an automatic firearm and uses profanities and threatening language. Participants significantly overestimated the duration of the 'high stress' tape. Moreover, the higher the individuals' degree of anxiety, the longer the film seemed to be.

Facial expressions are utilized especially frequently in emotional and arousal studies. In Thayer and Schiff's (1975) experiment, participants were asked to estimate the duration of eye contact of a pleasant-positive (i.e., smiling) or an unpleasant-negative (i.e., angry) facial expression. Results indicated that unpleasant interactions produced an overestimation of interval duration relative to pleasant interactions. The authors suggested that the participants' subjective time may have been influenced by the high degree of discomfort the unpleasant-negative condition induced. Droit-Volet et al. (2004) used facial expressions of anger, happiness, or sadness, and a neutral-baseline facial expression to investigate how the perception of emotion influences the experience of time. Using a bisection task, participants were trained to discriminate between a short (400 ms) and a long (1600 ms) presentation of a pink oval. After training, participants were shown facial expressions for different durations between 400 and 1600 ms, and were instructed to classify the duration of facial expression presentation as being more similar to the short duration or the long duration. Results suggest that the perceived duration of emotional faces, particularly angry faces, was longer compared to neutral faces. This temporal bias with angry faces might be due to social adaptation, since it has been shown to occur as early as three years of age, and does not change across different stages of development (Gil et al., 2007).

Effron et al. (2006) also used facial expressions to influence the perceived timing of the stimulus presentations in a bisection task. Similarly, they found that participants overestimated the duration of an angry face compared to a neutral face. However, this overestimation was not observed when participants were incapable of imitating the facial expression (i.e., by holding a pen between their lips). This result suggests that it is the imitation of facial expressions that produces autonomic changes that are correlated with actual emotion.

The study of the influences of emotional arousal on timing, however, sometimes yields paradoxical effects in the way the emotional stimuli can cause over- as well as under-estimations of time. For example, Angrilli et al. (1997) used the International Affective Picture System (IAPS, Lang et al., 2005) to investigate the influences of valence (negative vs, positive emotions) and arousal (low vs, high) on time perception. Results showed that in the high-arousal condition, the durations of negative pictures (e.g., pictures of dead babies) were overestimated, whereas the durations of positive pictures (e.g., pictures of naked couples) were underestimated. In contrast, in the low-arousal condition, negative pictures (e.g., pictures of rats) were underestimated and positive pictures (e.g., pictures of babies) were overestimated. Similarly, Noulhiane et al. (2007) used the International Affective Digital Sound system (IADS, Bradley & Land, 1999) to examine the estimation of the duration of emotional arousing sounds compared with the duration of neutral sounds. They found that negative emotional sounds, regardless of arousal levels, were judged longer in duration than neutral or positive sounds, suggesting that negative stimuli produce a greater increase in arousal. However, when they used high-arousing (either positive or negative) stimuli, stimuli were perceived to be shorter than low-arousing stimuli.

The slowing down of perceived time established in the various experiments described above (e.g. Droit-Volet et al., 2004; Effron et al., 2006; Gil et al., 2007) can be explained using the AGM. The arousal level influences the speed of the pacemaker. The suggestion that arousal levels are related to the rate of the pacemaker stem from early attempts to manipulate the speed of the pacemaker using state change designs. In this type of design, the reference memory is created during one arousal state, and comparisons are tested in a different arousal state. Increasing or decreasing body temperature (Wearden & Penton-Voak 1995), using drugs that increase or decrease dopamine levels (Buhusi & Meck, 2002), and using click trains (repetitive clicks) prior to the presentation of the stimuli to be timed (Burle & Casini, 2001) are methods that have been used to manipulate the pacemaker speed when comparing interval durations to the internal reference clock.

Treisman et al. (1990) found that particular frequencies of repetitive stimulation (clicks or flashes) caused specific interference with the operation of the pacemaker of the internal clock. In addition, they found that these types of repetitive stimulation generally appeared to 'speed up' the pacemaker, probably by increasing participants' arousal. Speeding up the pacemaker results in more pulses collected in the accumulator, which, in turn, is associated with the perception of slower subjective time.

Accordingly, Wearden et al. (1999) measured arousal during a non-emotional experimental session. As the session proceeded, arousal levels declined systematically, and performance on a timing task changed in a manner consistent with the proposal that the 'internal clock' was running more and more slowly, accumulating fewer pulses. This result suggests that subjective time moved faster as the session progressed (i.e., longer stimuli tended to be estimated as shorter intervals as testing proceeded), a result consistent with the proposed link between arousal and subjective time.

However, the 'slowing' effect of subjective time during emotionally arousing scenarios can also be explained by attentional influences. An emotionally arousing situation, in addition to being very stressful, is also highly attention demanding. According to attentional theories, an arousing situation might increase attention to the duration of the threatening event. More attention is directed toward timing the specific duration of the threat, and less attention is directed toward timing of other non-emotional events occurring within the same context (Droit-Volet & Meck, 2007). Consistent with the AGM, when more attention is allocated to time, more pulses are accumulated in the accumulator and therefore subjective time moves more slowly.

The AGM, therefore, allows the interpretation of the estimations to be either related to arousal, and therefore influencing the pacemaker, or related to attention, and therefore influencing the gate latency. Slowing down subjective time can be construed as an increase in 'arousal' or as an increase in 'attention to time', while speeding up subjective time can be interpreted as a decrease in 'attention to time'. As a result, researchers studying the influences of arousal on time find it reasonable to explain their finding based on either arousal or attentional factors (e.g., Angrilli et al., 1997; Noulhiane et al., 2007). Specifically, if there is an underestimation of duration, results are typically interpreted as resulting from the attentional resources allocated away from timing due to the attentional demands of the stimuli. In contrast, when there is an overestimation of duration, results are typically interpreted as an increase in pacemaker speed due to the arousing nature of the stimuli. However, this differential interpretation, involving either an attention-driven mechanism or an arousal-driven mechanism, implies that attention and arousal can operate semi-independently of one another (Burle & Casini, 2001) while numerous studies exploring attentional networks and emotion have advocated their interaction.

Interaction Between Attention and Emotional Arousal

Western philosophy and science have long upheld the notion that emotion and cognition are separate systems that seldom interact. Blaise Pascal (1623-1662), the

French mathematician and philosopher, famously maintained that '*The heart has its reasons which reason knows not of*.' Though it is unclear how attentional and emotional processing might interact, different theories of attention and emotion arousal have addressed the crosstalk between the two (Eastwood et al., 2001; Hansen & Hansen, 1994; Mathews, 2003; Pessoa et al., 2002; Wells & Matthews, 1994). Attention has been linked to both emotional regulation and self-regulation, defined respectively as the reduction, increase or maintenance of an emotional response according to context, and the reduction, increase or maintenance of emotions, thoughts or actions in accord with the direction given by the self or others (Raz & Buhle, 2006).

Emotional images require attentional resources in order to be processed (Pessoa et al., 2002). Irrelevant emotional stimuli have been shown not to interfere with the relevant task if the task demanded a high attentional load (i.e., executive attention), suggesting that the processing of emotional stimuli requires attentional allocation (Erthal et al., 2005; Pessoa et al., 2002). Furthermore, attention to emotional stimuli is typically guided by a combination of both stimulus driven (bottom-up) as well as goal-directed (top-down) influences (Ohman, 1993).

Processing negative emotional stimuli differs from processing positive or neutral emotional stimuli (Aronoff et al. 1988; Eastwood et al., 2001; Fox et al., 2000; Mathews, 2003). Studies report that the detection of stimuli that convey negative affect is faster and more efficient than the detection of stimuli that convey positive or neutral affect. These findings suggest that the detection of negative affect may have priority and guide attention, particularly orienting, more effectively (Fox et al., 2000). For example, in a crowd of faces, an angry or sad face is detected more easily and accurately than a happy face (Eastwood et al., 2001). In addition, search slopes (related to the time required to search for a target in a large crowd of distracters compared to a small crowd) for angry faces were significantly lower than for happy faces, suggesting that the search for an angry face is much faster than the search for a happy or neutral face (Hansen & Hansen, 1988). In a later study, Hansen and Hansen (1994) showed that there were faster saccadic eye movements in response to an unattended angry face than to an unattended happy face, whereas the disengagement away from a fixated face was slower from angry faces than from happy faces. Therefore, angry faces seem to have higher priority for attentional capture (i.e., orienting), but once attended (fixated), disengagement takes longer. Based on this pattern of fast attentional engagement and slow attentional disengagement toward angry faces, researchers argue that there is a difference between attention grabbing and attention holding (Fox et al. 2001; Georgiou et al., 2005; Hermans et al., 1999).

Accordingly, Chapman and Underwood (1998) showed how the presence of danger, as in an imminent car accident, increased the length of the fixation time while the length of saccadic eye movements decreased. This suggests individuals were sampling information from a smaller area. High emotional arousal, triggered by threatening situations, therefore, focuses attention in space and time. Intuitively, these findings make adaptive sense since it may be important to detect a potential threat quickly, but also to maintain attentive processing to the location of the threat once it has been detected. Having recognized the presence of a source of threat, less effort is directed to search for additional threats and more is devoted to evaluating the threat that has been recognized. Increased emotional arousal, related to threatening situations, leads to the narrowing of the focus of attention and the reduction of the range of cues an organism uses

(Easterbrook, 1959). Attention is therefore allocated to the most salient and important information.

How Attention, Emotional Arousal, and Time Interact

Human timing is influenced by experiences that are continually changing and can be more or less infused with affective content. Depending on the focus of attention to these experiences, time distortions are created. We have argued that, according to the AGM, attention resources allocated away from timing shortens the perceived duration, while negative emotional arousal lengthens the perceived duration of an event. However, we have also discussed an interaction between attention and emotional arousal as individuals allocate more attention to emotional stimuli than to neutral stimuli (Derakshan & Eysenck, 2009; Fox et al., 2001; Yiend & Mathews, 2001). In order to truly comprehend human timing, it is essential to uncover the effects of the three-way interaction between attention, emotional arousal and time. Understanding how these influences interact will help anticipate and predict subjective timing.

To illustrate the complexity of the combination of these three elements, let us consider a study by Tipples (2008). Tipples used a temporal bisection task to test whether or not individual differences in negative emotionality influenced time estimation of emotional stimuli. He found that, regardless of the participants' emotionality, the durations of angry faces were overestimated relative to the durations of happy faces, fearful faces and neutral faces. Moreover, self-reported negative emotionality further increased the overestimation of angry and fearful faces compared to neutral faces. These results are consistent with arousal theories of time estimation. However, if you consider this study from an attentional perspective, these results are considered controversial. According to the AGM, increased attention allocation to emotional stimuli should occur at the expense of attention to time and therefore lead to an underestimation of duration (Fox et al., 2000; Fox et al., 2001; Georgiou et al., 2005; Hermans et al., 1999). Participants orient faster, dwell longer, and disengage slower from angry and fearful stimuli compared to neutral or happy stimuli. Participants are, consequently, expected to attend more to the arousing stimuli, and less to the timing of the stimuli and, therefore, are anticipated to underestimate the stimulus duration. These contradicting predictions by the AGM for arousal and attention warrant a closer assessment of the model.

Figuring out the three-way interaction between arousal, attention and time proves not to be an easy feat. In order to truly understand the causes of the different subjective time distortions, it is important to manipulate the levels of attentional resources allocated away from time as well as the levels of emotional arousal in an experimental design.

Burle and Casini (2001), manipulated both attention devoted to time and arousal levels in an effort to understand these interactions. Attention was manipulated by asking participants to perform a choice reaction time task (i.e., indicating the location of a light) while simultaneously reproducing a 1100 ms duration, in the dual task procedure. In addition, arousal was manipulated by presenting participants with low intensity or high intensity (aversive) click trains (i.e., rapid repetitive tones of either 62 or 67 dBs). The results of the dual task procedure were later compared to the results obtained in a single task procedure (i.e., time estimation alone). According to the results of their experiment, participants underestimated duration when performing the dual task, and they estimated the elapsed duration as longer when arousal levels were higher compared to when they were lower. Furthermore, arousal's influence on time estimation was the same under the single and dual task conditions. Therefore, the authors concluded that attention and arousal are independent of one another and influence different processes as consistent with the AGM.

However, to date there has not been a study that includes the interaction between emotional arousal and attention to the arousing stimuli, such as a task that involves different levels of attentional processing of the arousing stimulus. Assessing time distortions while controlling for both arousal levels of the stimuli and the amount of attentional resources devoted to those stimuli, is likely to shed new light and a greater understanding on the currently conflicting and confusing study of human timing.

Terminological Conundrums

Within the community of time researchers (e.g., Zakay & Block, 1997), reference to the overarching term "attention" entails an appeal to a unitary term; moreover, the working nomenclature suggests that arousal is independent of attention and that emotion can potentially influence both. However, recent findings from the cognitive neuroscience of attention have demonstrated that often terms such as attention, arousal and emotion blur into an overlapping set (e.g., Bush, et al., 2000; Raz & Buhle, 2006).

The concept of arousal is typically referred to as intrinsic alertness, an increase in general excitability in unwarned situations. This concept is related to studies conducted on the role of the brain stem reticular system in maintaining alertness (Maruzzi & Magoun, 1949). In addition, Attentional alerting essentially implies preparedness or boosting of the participant's mental readiness. Therefore, these two concepts seem to have a conceptual overlap. Theoretical advances and functional typologies of attention change the way different researchers operationalize these terms of art (Posner, 2012). In this respect, the collective contribution of these elements and especially their interaction is sometimes more important than the individual contribution of each on its own (Kahneman, 1973; Raz & Buhle, 2006).

Research Focus

This research attempts to elucidate the influences of the interaction between attention and emotion on subjective duration. However, in contrast to the research (e.g., Burle and Casini, 2001) conducted thus far (e.g., an attention demanding non-emotional task presented in addition to an emotional stimulus) the goal of this study is to manipulate the attentional resources allocated to the emotional stimulus itself. Three main experiments (in addition to a set of preliminary experiments presented in Experiment 1), were designed to address this three-way interaction. These experiments incorporated a dual-task procedure in which both a timing task (i.e., a temporal bisection task) and a non-temporal task were performed simultaneously.

Experiment 2 was divided into two sections, the first (Experiment 2A) was designed to assess the effects of emotional arousal on time estimation. The goal was to replicate the findings of studies (e.g., Droit-Volet and Meck, 2007) what showed overestimation of subjective time while passively viewing angry facial expressions. However, instead of using facial expressions of different identities, a morphed continuum of facial expressions from angry to neutral of the same identity, was used. The second part of the experiment (Experiment 2B) manipulated attentional allocation to the facial expressions to assess the influences of executive attention to the emotionally arousing stimulus (i.e., angry faces) on subjective timing. The goal of Experiment 2B was to address the question whether the overestimation of subjective time due to angry faces might be influenced by the processing speed of the facial expressions.

In Experiment 3 the goal was to evaluate the effects of attention on subjective time estimation. Specifically, a visual search task, with an identity morph continuum of neutral facial expressions as the target and distractors, was used. Executive attention was manipulated by varying the difficulty of the search and thereby assessing its influences on subjective timing. In accordance with the AGM, an underestimation of subjective time was expected as attentional resources were allocated away from the temporal task (as difficulty of the task increases).

Experiment 4 was a combination of experiment 2 (i.e., using angry to neutral facial expression to assess the effect of arousal) with experiment 3 (i.e., a visual search task to assess the effect of attention). More specifically, the goal was to manipulate the different networks of attention (i.e., orienting, alerting and executive control) based on predictions of interaction between attention and emotional arousal. Particularly, executive attention was manipulated by varying the difficulty of the search task, orienting was manipulated by presenting participants with angry versus neutral distractors, and alerting was manipulated by specified instructions prior to the task (e.g., “search for an angry face”).

Experiment 3 and 4 were designed to be identical with the exception of the facial stimuli used (identity in Experiment 3 and emotion in experiment 4). Therefore, it was possible to compare the results from the non-emotionally arousing task with the emotionally arousing task to assess the differential effects related to the interaction between attention and emotion. More importantly, this comparison was designed to shed new light on the effects of the interaction, between emotional arousal and attention, on subjective time estimations.

GENERAL METHODS

For a glossary of key terms and abbreviations see appendix I.

Participants

A total of 67 participants took part in four sets of experiments. Participants in Experiments 1 and 2 were graduate students in the Cognitive, Linguistic, and Psychological Sciences department from Brown University, while participants from Experiments 3 and 4 were undergraduate students fulfilling course requirement for an introductory psychology or introductory statistics class at Brown University. Only individuals without vision or dexterity problems that would prevent them from performing the computerized trials were recruited for these experiments. Each participant signed an informed consent document before beginning research procedures and was tested one at a time at an individual computer station, allowing for privacy.

Each participant completed two sessions of approximately 40 minutes each. Following the completion of the first session, participants had one to five days to return for the second session. The first session provided the baseline data for the second session. Upon completion of the two experimental sessions, participants were thanked for their time and informed of the purpose of the research.

Apparatus

Two Pentium 4 PCs (1.6 to 2.5 GHz) running Windows XP Professional were used in the experiments. Computers were each equipped with a 14-inch flat screen computer monitor, with 1024x768 resolution. The monitors refresh rate (approximately 60 hertz) was taken into account and subtracted from the durations in the experiments. Matlab software (version R2010b), was used to automate the experiments, present the experimental stimuli, record responses, and analyze data. Matlab was supplemented with the psychophysics toolbox (version 3), which interfaced between Matlab and the computer hardware. Psychtoolbox (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007) is especially designed for trials with millisecond timing accuracies.

Stimuli

The pictures used in these experiments were adopted from the Karolinska face dataset (Lundqvist, et al., 1998; Oosterhof & Todorov, 2008) which consists of pictures of professional actors portraying different facial expressions. All faces were cropped at the hair line and fitted into an oval shape on a black background. This ensured that the shape of the face, hair structure and background were all similar. Faces exhibiting best identified facial expressions were selected. Considerations for selection of the faces can be found in experiment 1B (see below).

Abrosoft FantaMorph (a morphing software) was used to create an animated video transformation of one image (P1) into another (P2). Specific images along the transformation continuum were selected for the experiments. In particular, seven degrees of morphing was chosen for experiments 1B: 0%P1-100%P2, 25%P1-75%P2, 33%P1-67%P2, 50%P1-50%P2, 67%P1-33%P2, 75%P1-25%P2, 100%P1-0%P2 (referred to as 0%, 25%, 33%, 50%, 67%, 75% and 100% of P1). For following experiments, the continuums were reduced to five degrees of morphing: 0%, 33%, 50%, 67%, and 100% of P1. See figure 2 for an example of an emotional morphed continuum between angry and neutral expressions and figure 3 for an example of an identity morphed continuum between two females.

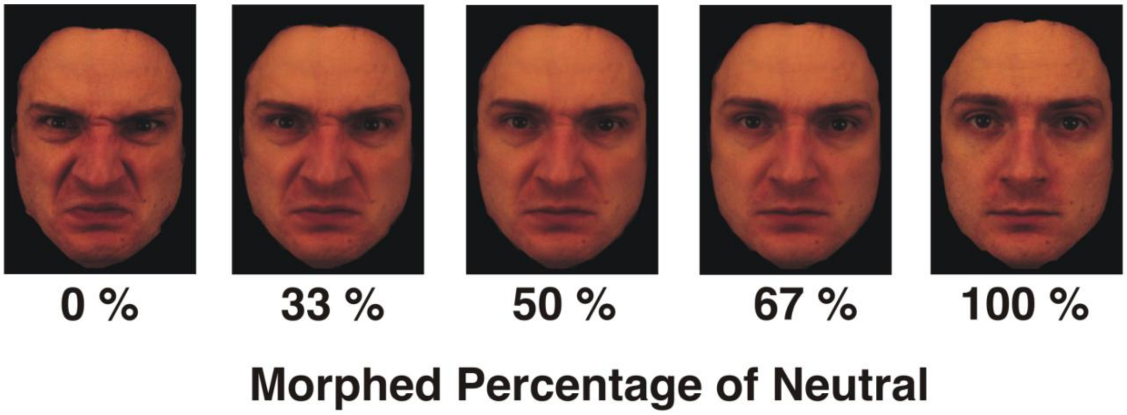

Figure 2. Example for a continuum of morphed stimuli ranging from an angry expression (i.e., morphed stimulus of 0% neutral) to a neutral expression (100% neutral). All faces belong to the same identity.

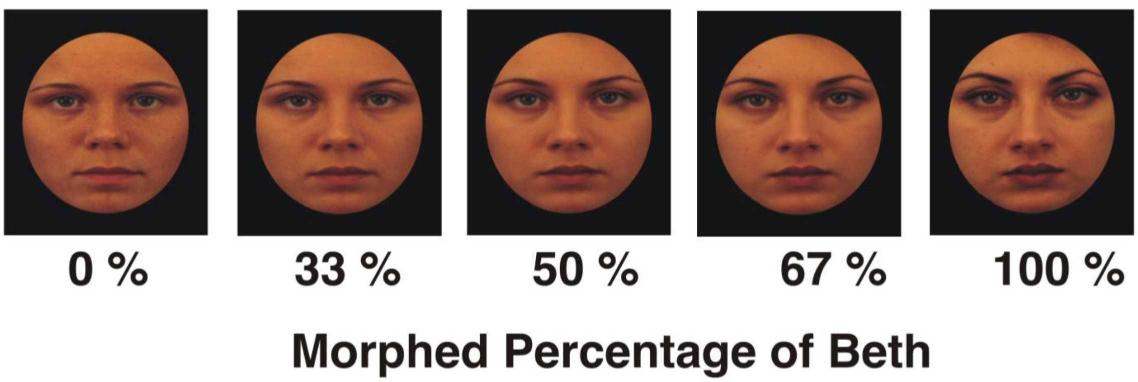

Figure 3. The continuum of morphed stimuli ranging from Jane (i.e., morphed stimulus of 0% Beth) to Beth (100% Beth). All faces present a neutral facial expression.

The morphing used involved the image processing techniques of warping (aligning two images) and cross dissolving (e.g. linear interpolation to fade from one image to another). Warping determines the way in which the pixels in one image are mapped to the pixels in the other image. Each picture was fitted with 67 reference points (see appendix II) centered on prominent and expressive features of the images, including points around the eyes, eyebrows, nose and mouth.

Procedure

For these experiments, participants were first introduced to the general nature of the experiments. Following the verbal instructions, participants were positioned at a distance of approximately 76 cm away from the computer monitor and asked to read the entire set of instructions as they appeared on the computer screen. The experimenter then proceeded to walk the participants through a set of practice trials that covered all or a subset of the possible types of conditions for each part of the task. During this time, the participant was observed and any misconception of the tasks was clarified. After the practice trials, participants proceeded to complete the experimental trials. Participants were allowed to take a break during the experiment when the screen indicated they should "Press the space bar to continue".

EXPERIMENT 1. PSYCHOPHYSICAL DESCRIPTIONS OF TEMPORAL INTERVALS AND FACIAL EXPRESSIONS

Experiment 1 is comprised of preliminary studies that provide the basis for future experiments presented in this thesis. The first part, Experiment 1A, introduced the background for the use of the temporal bisection task with the unique application of a gray frame image presented along the edges of the screen as the time marker. In the second part, Experiment 1B, eight different morphed continuums were evaluated and, based on the participants' assessments, three were selected to be used in the subsequent experiments.

Experiment 1A. Temporal Bisection Task With Frame

A bisection procedure trains participants to respond differentially (e.g. right and left lever or key presses) to the presentation of short and long stimulus durations. The short and long reference durations often follow a 1:4 ratio (Macinnis & Guilhardi, 2006) (e.g., 400 ms is the short duration and 1600 ms is the long duration). Once differential responding to the short and long reference durations has been trained, the stimulus is presented at intermediate durations intermixed with the reference durations. The intermediate durations are typically five logarithmically spaced intervals between the two extremes, in which the distances between successive durations become longer as the durations increase (Kopec & Brody, 2010). Upon being presented with an intermediate duration, the participants should indicate which reference duration, held in memory, they believe it is more similar to, short or long. While the responses for the training trials receive feedback in order for the participant to learn the reference durations (e.g., the word "correct" appears on the screen), the intermediate durations and the short and long durations on the testing trials are not reinforced. The response is a subjective decision and there is no correct or incorrect answer. Figure 1.1(A) illustrates the temporal bisection task, while Figure 1.1(B) represents the dependent variables associated with this procedure (e.g., proportion "long", bisection point and Weber's ratio), described below in detail.

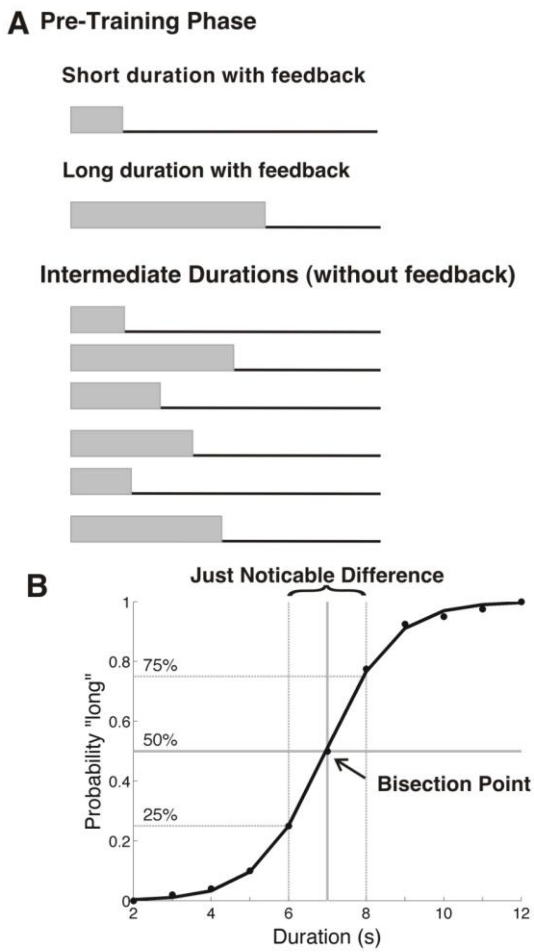

Fig. 1.1. The temporal bisection task. (A) Training is split into two phases. During feedback trials, participants learn the reference durations (short and long intervals) and receive feedback. During the no-feedback trials, intermediate durations are added and feedback is withheld. Subjects are instructed to indicate which reference duration they feel the intermediate stimulus duration is closest to. (B) Probability of a participant responding ‘‘long” as a function of duration. The bisection point is defined as the duration which produces 50% ‘‘long” responses. (Adapted from Kopec, C. D., & Brody, C. D., 2010)

This duration estimation task requires three cognitive functions related to timing. Specifically, the reference durations (i.e., short and long) must be stored in, and retrieved from, memory; the temporal stimulus presented must be estimated; and a comparison with the reference stimuli must be made (Kopec & Brody, 2010).

A similar task was first introduced by Stubbs in 1976, in which pigeons were presented with a series of key-illumination time periods. The pigeons timed the duration of the trial and responded with a peck to either a green light key when the duration was short or a red light key when the duration was long. In 1977, Church and Deluty trained rats to time the duration of a trial (either 2 sec or 8 sec), and respond using the left or right levers as to whether the duration was closer to the short or long reference durations. In 1991, the task was first applied to humans in two separate works by Wearden (1991) and Allan and Gibbon (1991). As common to most bisection tasks today, participants were presented with tones (filled auditory intervals) of different durations and were to respond whether the duration of the tone was closer to the short or long reference duration.

While the stimuli themselves are generally either a tone or a light presented for some length of time, some recent bisection experiments presented participants with innovative stimuli. Light blue squares of 14x14 cm (Wearden, 1995), blue circles 4.5 cm in diameter (Delgado & Droit-Volet, 2007), or a pink ovals (Gil, 2011), presented in the middle of the monitor screen for different durations, were used to train reference stimulus durations.

In the present task, participants were shown a gray image of a frame presented peripherally along the edges of a black computer monitor, lasting either for a long duration (1600 ms) a short duration (400 ms) or an intermediate duration. A key question to answer in the present experiment was whether or not the specified stimulus would yield a psychometric curve with the same characteristics typical of a traditional bisection task. Predominantly, if the proportion "long" responses would increase as a function of increased durations and if the bisection point would correspond to the geometric mean of the short and long reference intervals.

Methods of Experiment 1A.

Participants.

Six graduate students at Brown University participated in this experiment.

Apparatus.

See Apparatus section in General Methods.

Procedure.

Trials began with a white fixation cross in the center of an otherwise blank computer screen. Five hundred ms following the onset of the trial, a gray frame appeared along the edges of the screen in addition to the fixation cross. The width of the frame was constantly three centimeters allowing for 858 (33x26) squared centimeters inside the frame. The frame remained on the screen for one of seven different durations: 400 ms, 504ms, 635ms, 800 ms, 1000 ms, 1270 ms, or 1600 ms. Regardless of the duration of the frame on a given trial, a question about the duration ("what was the duration of the frame?") consistently appeared 2.3s following trial start. Therefore, following the frame, participants continued looking at the blank screen with a central fixation cross for an additional interval of time that corresponded to the difference between 1.8s and the frame duration presented. Following the question presentation, the participants replied either 'Short' or 'Long' by pressing the left arrow key or right arrow key on the keyboard, respectively. Participants were asked to respond with the index and ring fingers of their right hand. To continue to the next trial, participants were asked to press the 'space' bar key (see figure 1.2).

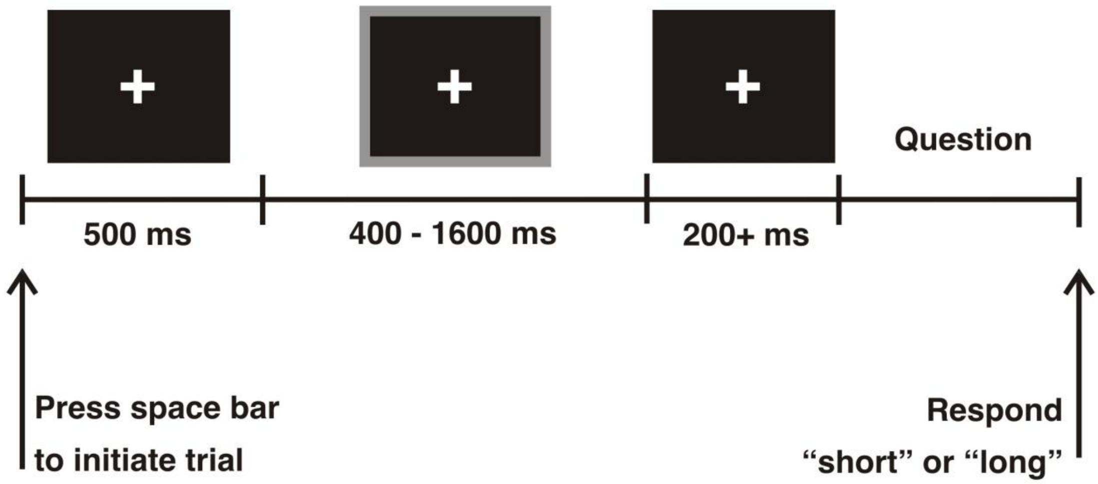

Figure 1.2. Procedural representation of experiment 1A.

The training included four short trials, four long trials and four intermixed trials (2 short/2 long), all including feedback. Testing included seven durations, 400 ms 504 ms 635 ms 800 ms 1000 ms 1270 ms and 1600 ms, with an equal probability for presentation for each participant. There were a total of 140 testing trials (20 trials per duration). The order of the duration presentation was determined based on random permutations. No feedback was given during the testing trials.

Measures.

Independent Measures.

Durations. The "short" reference duration of the frames in these experiments was 400 ms and the "long" reference duration was 1600 ms. During experimental trials, in addition to the two reference durations, five intermediate durations were introduced: 504ms, 635ms, 800 ms, 1000 ms, and 1270 ms. The spacing of the durations was based on a logarithmic scale with base 10. Therefore, the differences between duration intervals become larger as the durations increased. Using logarithmic spaces, the mid duration (800 ms), in between the short (400ms) and the long reference durations (1600 ms), is the geometric mean. In order to simplify the assessment and appreciate the symmetry of the data, the durations were later plotted on a linear scale (appendix III demonstrates the transformation between a logarithmic and a linear scale).

Dependent Measures:

Proportion "long". Commonly used in temporal bisection tasks, the proportion of the participants responding ''long" describes the participant's subjective time estimations. This probability was calculated by dividing the number of times the participant replied "long" to a given duration by the total number of responses to the same duration (i.e., number of times the participant replied "short" plus number of times the participant replied "long" to a given duration). A psychometric curve, in which the temporal stimuli were presented on the x-axis (between 400 ms and 1600 ms) and the proportion "long" on the y-axis (between 0 and 1), represents the participants' time estimation curve. This function typically shows a monotonic increase with duration as participants generally respond "short" to the shortest duration and "long" to the longest durations. See Figure 1.1(B) for illustration.

Bisection Point (BP)[*]. The point at which the psychometric curve, derived from plotting proportion "long" as a function of durations (see above), crosses the .5 point on the y-axis is referred to as the 'bisection point / point of indifference / point of subjective equality'. The bisection point represents the duration which produces 50% ''long" responses and therefore identifies the duration on the x-axis in which participants theoretically would reply "short" and "long" an equal amount of times. At this duration the decision-making process used to compare the duration to the reference values (i.e., “short” and “long”) stored in memory is equal for both options. The bisection point has been shown to fall close to the geometric mean (i.e.,$\sqrt{(400\times1600)}$=800 ms) of the two training durations(Allan & Gibbon, 1991; Church & Deluty, 1977; Siegel & Church, 1984; Wearden, 1991). See Figure 1.1(B) for illustration.

Weber’s Ratio (WR)[*]. The psychometric curve, derived from plotting proportion “long” as a function of duration (see above), also represents the participants’ ability to discriminate whether the given duration is closer to the “short” reference duration or the “long” reference duration. This degree of discriminability is referred to as the Weber Ratio (or Weber fraction). A low Weber Ratio corresponds to a high degree of discriminability (steep curve) while a high Weber Ratio corresponds to a poorer discriminability (shallow curve) (Brown, 1960; Gibbon, 1977).

Weber’s ratio is calculated by subtracting the duration at which a subject responded ‘‘long” with probability .75 with the duration at which a subject responded ‘‘long” with probability .25 and dividing the result by the bisection point (the duration at which a subject responded ‘‘long” with probability .5). The dividend in this equation is also referred to as the ‘‘just noticeable difference”, the smallest proportional change in the stimulus that could be detected by the participant. See Figure 1.1(B) for illustration.

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[*]To estimate the bisection points and Weber’s ratio, a Weibull probability distribution was fitted onto the data using the Psignifit toolbox version 2.5.6 for Matlab (see http://bootstrap-software.org/psignifit/) which implements the maximum-likelihood method described by Wichmann & Hill (2001). A curve was fitted for each participants per condition. When analyzing the bisection points the 400-1600 durations were linearly represented with values of 1-7. The geometric mean of the short (e.g. 1) and long (e.g., 7) linear representations of duration equals 4 (corresponding to 800 ms).

Results of Experiment 1A

As presented in figure 1.3, the longer the durations of the frames presented, the more likely the participants replied “long”. Descriptive statistics of the seven durations indicated that at 400 ms (the short duration) participants consistently estimated the duration of the frame as “short” (M = 0, 95% CI [-.12 .12]). The duration estimations at the geometric mean (800 ms), (M = .56, 95% CI [.44 .68]) were very close to the point of indifference (.5 Proportion “long”) and also showed the highest amount of variability. The longest frame duration (1600 ms) displayed the longest duration estimates (M = .99, 95% CI [.86 1]). Binomial expansion calculations indicate that the probability of getting a positive difference between the “Proportion Long” estimations for increasing duration is significant ($p<0.001$). In addition, upon fitting a Weibull curve to the data, it was apparent that the estimated bisection point (M=3.99, SD = .7) and the Weber’s ratio (M=.3, SD=.1) were in accordance with the results of a bisection curve.

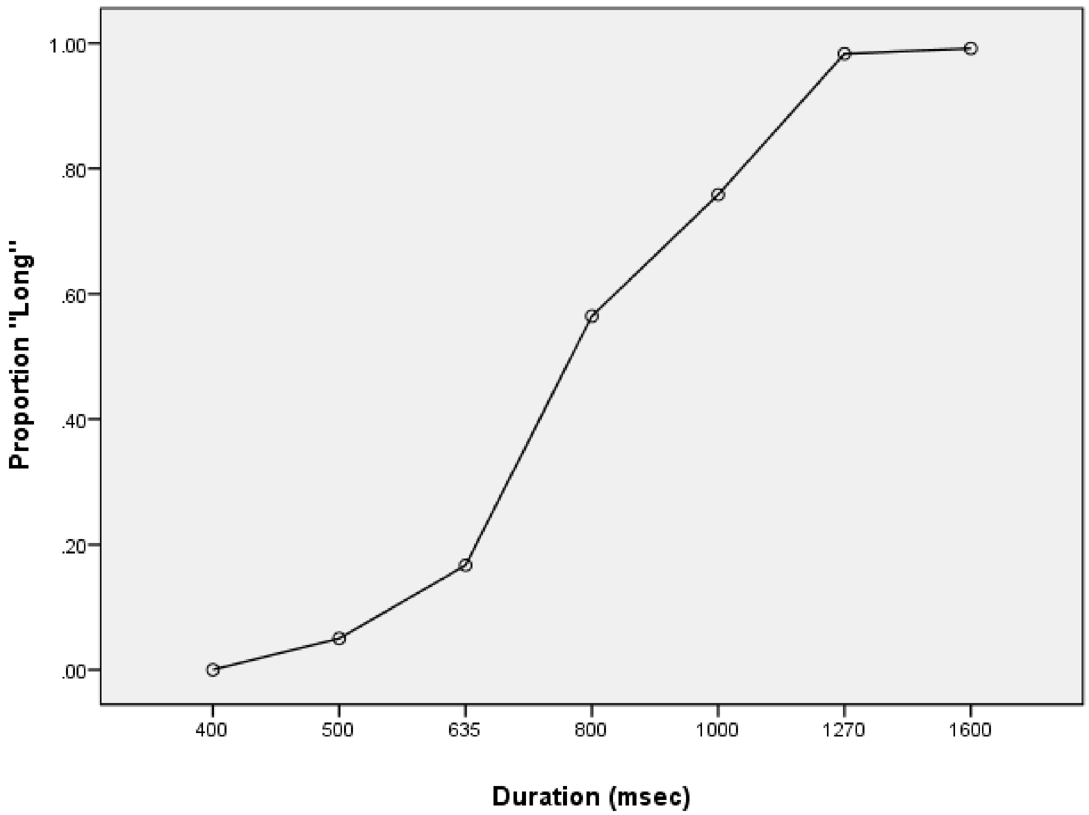

Figure 1.3. The relationship between frame durations (in msec) and proportion "long" estimates for the Temporal Bisection Task (Experiment 1A). Notice that as durations increase, so does the proportion "long" estimates. In addition, notice that the bisection point falls close to the 800 msec duration (the geometric mean).

Discussion of Experiment 1A

Results show that using a gray frame, presented at the edges of the screen for different durations, yielded comparable data to bisection tasks performed with other temporal stimuli. Specifically, proportion "long" increased as the duration of the frame increased. In addition, the bisection point was centered on approximately 800 ms, which is the geometric mean between the short (400 ms) and long (1600 ms) reference durations. This result indicates that the participants were able to correctly discriminate among the durations of the frame. This experiment, therefore, validates the use of gray frames as a temporal stimulus in bisection tasks.

Experiment 1B. Rating of Morphed Facial Expressions

Creating morphed images by warping and cross dissolving a neutral and an angry facial expression from the same person can generate a continuum of facial expressions from 0% to 100% (see general methods for more detail). In theory, a 50% morphed image would be equivalent to the 'point of indifference' or 'bisection point' on the bisection task of perceived emotion. This is the point at which participants rate the image as ''angry" as often as they would rate it as "neutral". However, not all morphed continuums are symmetrical and the 50% image might not necessarily fall midway between the reference neutral and angry facial expressions. To this end, a rating task was developed to evaluate the perceived subtle featural displacements of the morphed faces that contribute to the judgments of facial expressions.

Participants in this task were required to rank eight different morphed continuums of facial expressions. A psychometric curve similar to the one described in the bisection task was then created by plotting the morphed percentages of neutral on the x-axis and the proportion "neutral" on the y-axis. This proportion "neutral" was calculated by dividing the number of times the participant replied "neutral" to a given morphed image, by the total number of trials of the same morph. The goal of this preliminary experiment was to identify the continuums on which the participant's ratings produce a psychometric curve with a bisection point close to the 50% morphed face.

Methods of Experiment 1B.

Participants.

Same participants as in Experiment 1A (N=6).

Apparatus.

See Apparatus section in General Methods.

Procedure.

The setup was similar to the procedure of Experiment 1A, with the exception that instead of a frame appearing 500 ms following a fixation cross, a morphed image appeared. The dimensions of the morphed faces were 12.5x14cm and they appeared central to the screen. The face remained on the screen for a total of 1600 ms. Participants were asked to reply, as fast and as accurate as they could, during the presentation of the face, whether they thought the face was more similar to a neutral face (key ‘V’ on the keyboard) or to an angry face (key ‘B’ on the keyboard). Once the participants made a response, the face disappeared. To continue to the next trial, participants were asked to press the ‘space’ bar key (see figure 1.4. for a procedural illustration).

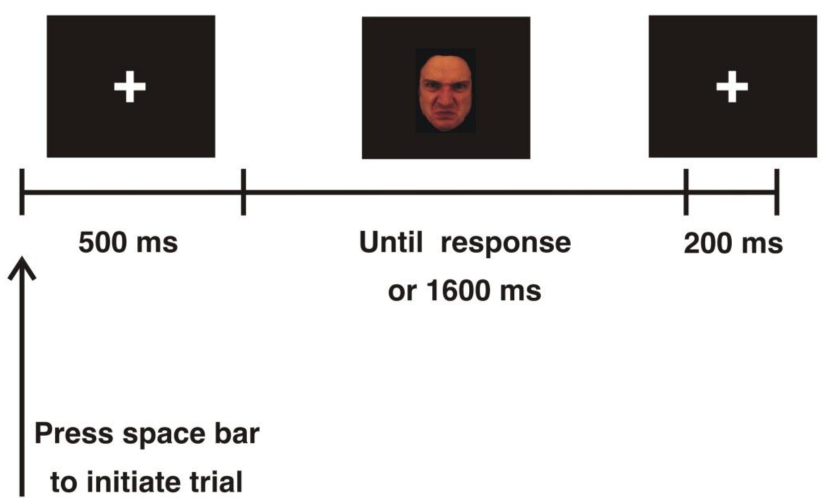

Figure 1.4. Procedural representation of Experiment 1B.

The experiment was divided into eight blocks, one for each identity in the neutral-angry continuum tested. For each block, the training included four trials with neutral expressions (100% of neutral), four trials with angry expressions (0% of neutral) and four intermixed trials (2 neutral/2 angry), all including feedback. There were a total of 96 (12x8 blocks) training trials in the experiment. Testing included seven morphed images, 0%, 25%, 33%, 50%, 67%, 75%, and 100% of neutral, with an equal probability for presentation. A total of 49 trials per block (seven trials per morphed image) testing trails were presented. The order of the morph presentation was determined based on random permutations. No feedback was given during the testing trials.

Measures.

Dependent Measures:

Proportion "neutral". The proportion of the participants responding ‘‘neutral" to the facial expression categorization. This probability was calculated by dividing the number of times the participant replied "neutral" to a given morphed face by the total number of responses to the same morph (i.e., number of times the participant replied "angry" plus number of times the participant replied "neutral" to a given morph). A psychometric curve, in which the morphed faces were presented on the x-axis (between 0% and 100% of neutral) and the proportion "neutral" on the y-axis (between 0 and 1), represents the participants' facial expression estimation curve.

Bisection Point (for proportion "neutral"). The point at which the psychometric curve, derived from plotting proportion "neutral" as a function of morphed faces (see above), crosses the .5 point on the y-axis is referred to as the 'bisection point'. The bisection point represents the morphed face which produces 50% ‘‘neutral" responses and therefore identifies the morphed percentage on the continuum that is midway between the angry and neutral facial expression.

Weber's Ratio (for proportion "neutral"). The psychometric curve, derived from plotting proportion "neutral" as a function of morphed face (see above), also represents the participants' ability to discriminate whether the given morph is closer to the "angry" reference expression or the "neutral" reference expression.

Results of Experiment 1B.

As seen in figure 1.5, an increase in percentage of the facial expressions from 0% to 100% of neutral, was significantly associated with an increase in "neutral" responses (binomial calculations, $p<0.01$). In addition, the mean bisection point ($M=4.21$, $SD=.32$) and mean Weber's ratio ($M=.22$, $SD=.1$) for all continuums yielded satisfactory psychometric curves.

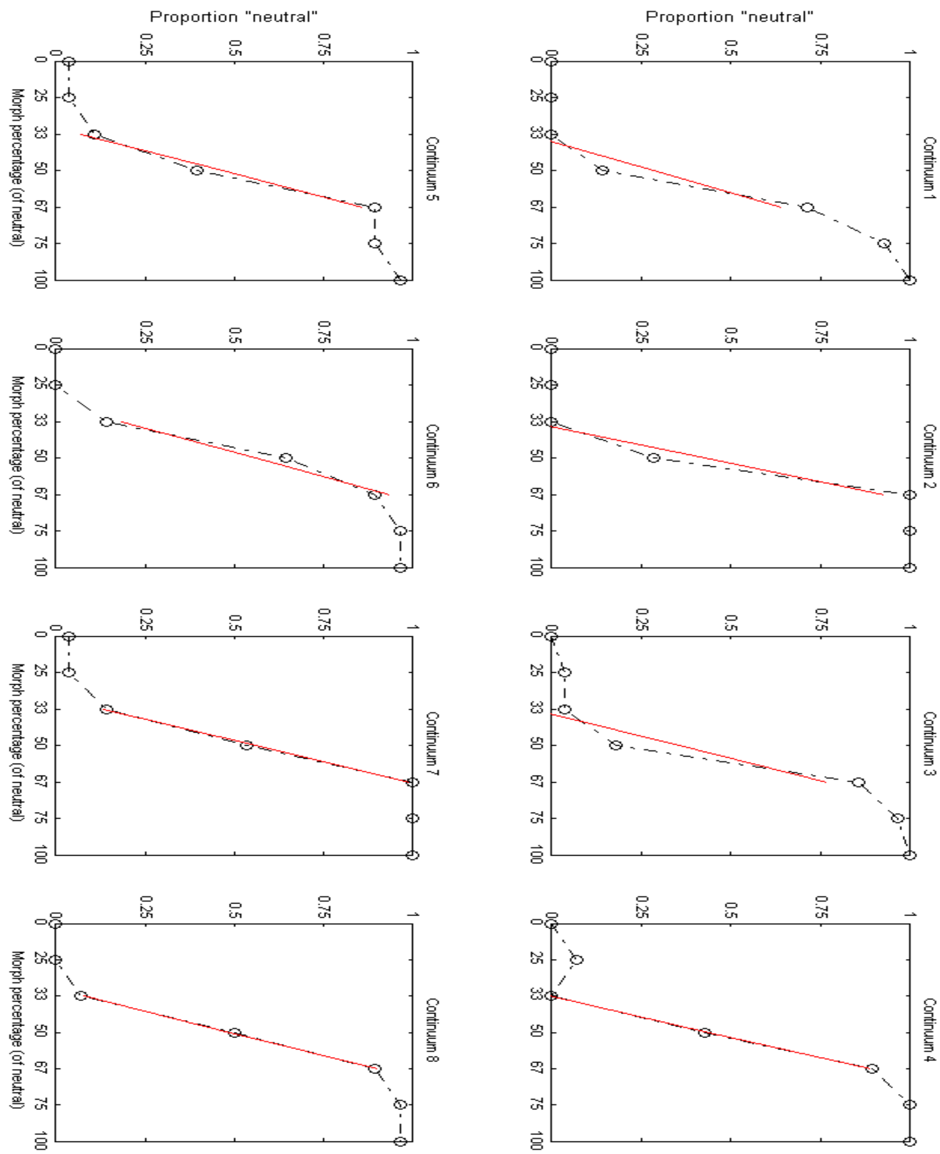

Figure 1.5. Relationship between the frame durations (in msec) and proportion “neutral” for eight different continuums (representing eight different identities morphed) between angry and neutral used in Experiment 2B. Red line represents a linear fit to the data between morphed face of 33% and 67% of neutral.

Discussion of Experiment 1B.

Theoretically, a bisection point for the proportion “neutral” (.5 on the y-axis, equal probability of responding neutral and angry) would correspond to the morphed face closest to the midpoint on the continuum (i.e., 50% neutral and 50% angry expression of the same identity). Results show that continuums 5, 7 and 8 produced the most adequate bisection points. It is apparent that, for these continuums, participants were able to discriminate between the facial expressions and that the 50% morph produced relatively equivalent probability of replying ‘angry’ or ‘neutral’. This experiment, therefore, validates the use of continuums 5, 7 and 8 as suitable morphed stimuli between neutral and angry. These three continuums were the ones used in the other emotion-related tasks in this thesis.

EXPERIMENT 2. TEMPORAL BISECTION TASK WITH FACIAL EXPRESSIONS

This experiment was designed to assess the influences of emotional arousal on time perception estimations. Particularly, this experiment was divided into two sessions. The first part, Experiment 2A, was designed to replicate the overestimation results prevalent in timing and emotional arousal studies (e.g., Droit-Volet & Meck, 2007). Specifically, these experiments claim that angry facial expressions influence the arousal component of the attentional gate model, thereby resulting in longer time estimations (Droit-Volet & Gil, 2009). Replicating the effects of emotional facial expressions on time estimations, allows for a baseline for further assessment of the influences of arousal on subjective time in the second part of the experiment. Specifically, Experiment 2B examined the effects of attentional allocation to the emotional facial expressions, on time estimations. Attentional allocation to the faces, particularly executive attention (involved in decision making), may influence the processing of the facial expressions and thereby, influence subjective timing. Therefore, this experiment examined the interaction between emotional arousal and attention, and their effects on time perception.

This experiment combined the methods of Experiments 1A and 1B and presented participants with morphed emotional facial expressions (from angry to neutral) displayed in the center of the screen while, in addition, a gray frame appears along the edges of the computer screen for different durations of time (i.e., the temporal bisections task). In Experiment 2A, participants passively observed the facial expressions while timing the duration of the frame surrounding the faces. Specifically, participants were asked to look at the faces presented, though no additional processing was required. Passive viewing of the faces was the method used in previous studies that resulted in overestimations due to angry facial expressions (e.g., Droit-Volet & Meck, 2007). In contrast, during Experiment 2B, participants actively observed the facial expressions while timing the duration of the frame surrounding the faces. Specifically, participants were asked to pay more attention to the faces by actively observing the faces and making decisions as to their expressions. Therefore, increasing the executive attention allocated to the facial expressions.

Experiment 2A. Passive Observation

As mentioned in the general introduction, facial expressions of anger have been shown to elicit a longer subjective estimation of duration compared to neutral expressions (Droit-Volet & Gil, 2009). Timing researchers have attributed these overestimation results to the effects of arousal on time estimations (e.g., Droit-Volet & Meck, 2007; Gil et al., 2007). These findings were typically observed in experiments that implemented a mixed design in which different expressions (happy, sad, angry, and neutral) of different identities were presented randomly, and participants were to observe the facial expression presented on the screen while estimating the duration of the face presentation, as in a bisection task.

In the present experiment participants were presented with mixed morphed facial expressions from one identity ranging from neutral to angry (see figure 2 for example). In addition to the faces, a gray frame was presented peripherally on the edges of the computer monitor that lasted for a long duration (1600 ms) a short duration (400 ms) or an intermediate duration (see Experiment 1A). As in previous experiments (Droit-Volet et al., 2004; Droit-Volet & Meck, 2007; Gil et al., 2007), participants were told to passively observe the facial expressions presented (i.e., no decision process was required) while assessing the durations of the frame surrounding the faces.

A key question to answer in the present experiment was whether or not passively viewing the morphed expressions, ranging from neutral to angry, would influence the subjective estimation of time. In particular, would an angry expression elicit longer time estimations than the other morphed images, as found in previous experiments with facial expressions (e.g., Droit-Volet & Meck, 2007).

Methods of Experiment 2A.

Participants.

Fourteen Undergraduate students at Brown University fulfilling course credits participated in this experiment.

Apparatus.

See Apparatus section in General Methods.

Procedure.

As in the previous experiment, trials began with a 500 ms fixation cross in the center of an otherwise blank computer screen. Following 500 ms, a face appeared in the center of the screen (as in Experiment 1B). Participants were instructed to passively observe the facial expressions. Specific faces selected for this experiment were from actor BF09 from the Karolinska face dataset. A gray frame along the edges of the screen appeared 400 ms following the face presentation onset. The frame remained on the screen for a given duration (in between 400 ms and 1600 ms) as in Experiment 1A. Regardless of the duration of the frame on a given trial, a question about the duration of the frame consistently appeared 2.9 sec from the onset of the trial. Therefore, following the frame, participants continued looking at the facial expression for an additional time that corresponded to the difference between two seconds and the frame duration presented (e.g., if a 1600 ms frame was presented, then the facial expression would remain on the screen for an additional 400 ms). Following the question presentation, the participants replied either ‘Short’ or ‘Long’ by pressing the left arrow key or right arrow key on the keyboard respectively. Participants were asked to respond with the index and ring fingers of their right hand. To continue to the next trial, participants were asked to press the ‘space’ bar key (see figure 2.1 for an illustration of the procedure).

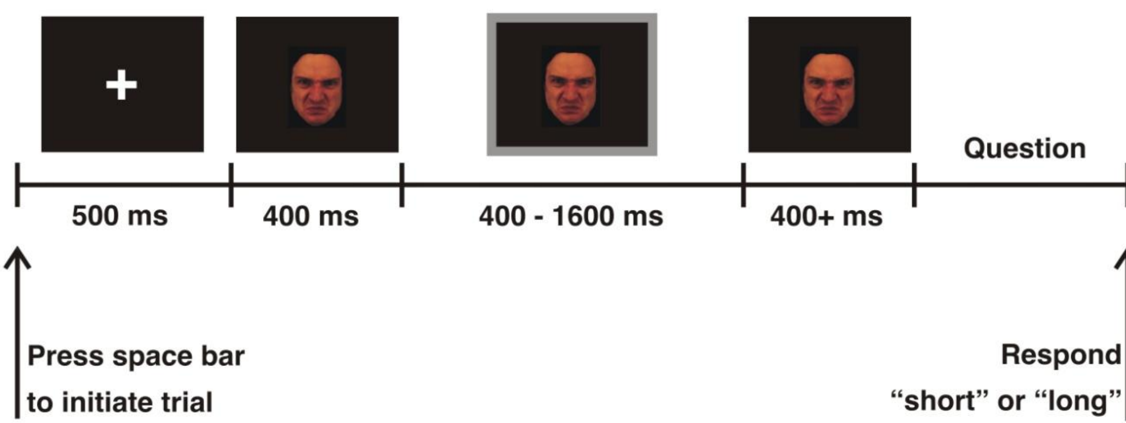

Figure 2.1. Procedural representation of Experiment 2A.

The training included 30 trials, 12 for the bisection task (as in Experiment 1A), 12 for the facial expressions (as in Experiment 1B, representing only the angry and neutral extremes for participants to recognize the reference facial expressions) and six for facial expressions with bisection frames, all including feedback. Testing included seven durations, 400 ms, 504 ms, 635 ms, 800 ms, 1000 ms, 1270 ms, and 1600 ms, each with an equal probability for presentation. In addition, there were five morphed images in between the angry and neutral facial expressions (0%, 33%, 50%, 67%, and 100% of neutral), presented intermixed. There were a total of 420 testing trials (12 trials per duration x morph combination). The order of the duration presentation was determined based on random permutations. Participants were to passively observe the facial expressions of the morphed faces and reply to the question about the duration of the frame. No feedback was given during the testing trials.

General methods for analysis.

Dependent Measures:

Proportion "long", bisection point, and weber's ratio (as in Experiment 1A). The differences between the bisection points and Weber's ratios of the morphed stimuli were analysed with a repeated measures ANOVA which included morph percentage (5 levels: 0% to 100%) as the within-subject factor.

Results of Experiment 2A.

Morphed percentages:

Descriptive statistics confirm that participants' probability of 'long' responses increased as the faces presented become angrier (closer to the 0% of neutral morphed percentage), with the exception that the 67% of neutral morph (not 0% of neutral) produced the shortest duration estimations. Duration estimations made while presented with the 0% of neutral (i.e., angry) morph (M=.52, 95% CI [.46 .58]) were longer than the duration estimations made while presented with the 50% (M=.48, 95% CI [.42 .55]) or the 67% of neutral (M=.47, 95% CI [.42 .53]) morphed stimuli. Figure 2.2 presents the Weibull curve fits to the data and confirms the longer time estimates associated with angrier facial expressions.

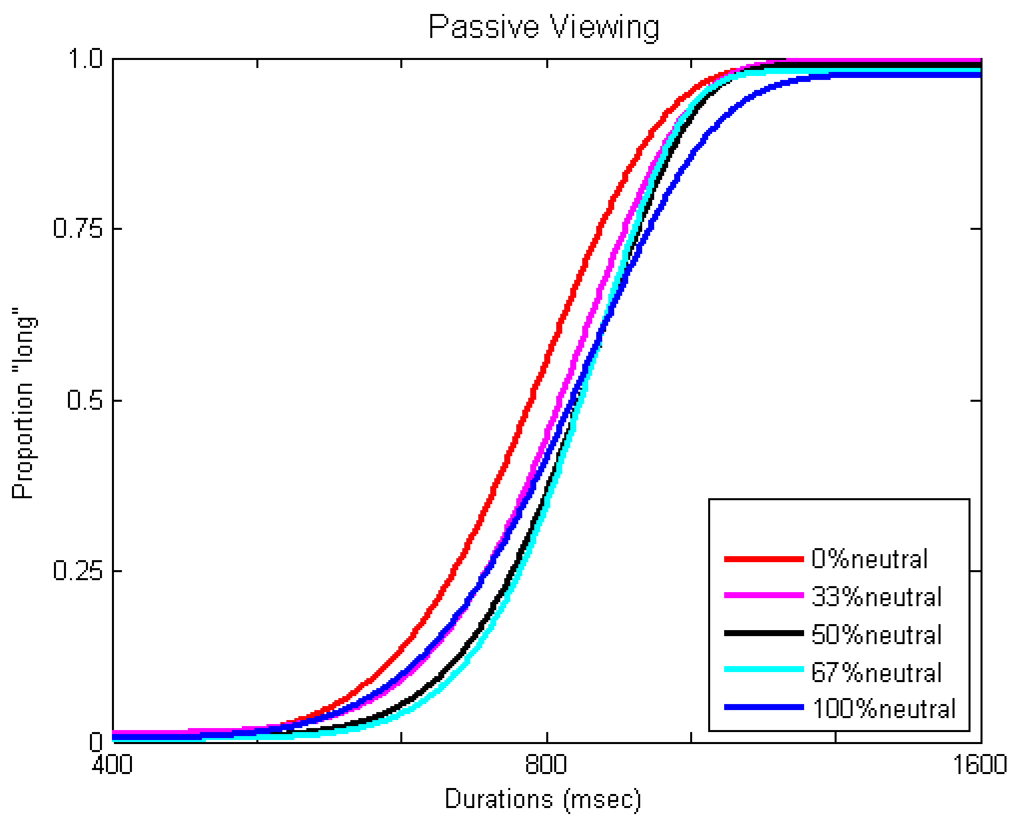

Figure 2.2. The relationship between frame durations (in msec) and proportion "long" for the five different morphed stimuli from 0% neutral to 100% neutral for the passive viewing condition. Notice that the red curve (representing angry faces) is shifted to the left of the other curves.

There was no significant difference between the bisection points of the different morphs $F(4,52)=1.7$, $p=.16$. The quadratic fit was also not significant $F(1,13)=2.7$, $p=0.12$ though there was a significant difference between the 0% neutral (M=3.84, 95% CI [3.4 4.3]) and the 67% neutral morph (M=4.13, 95% CI [3.8 4.5]). Similar to the

Proportion "long" data, this result shows a tendency for the bisection point to decrease (longer time estimations are associated with leftward shifts on the psychometric curve of Proportion "long") as the morphed image becomes angrier (see Figure 2.6, passive activity level). The slopes or Weber's ratios of the morphed stimuli were not found to be significantly different $F(4,52)=1.3$, $p=.28$.

Discussion of Experiment 2A.

The psychometric curve associated with the proportion "long" for angry facial expressions was shifted to the left of the other facial expressions. A leftward shift of the curve indicated that the time estimations for the frames were longer when participants passively observed an angry face. Though, bisection points were not significantly different, there appeared to be a tendency for bisection points to decrease as faces became more angry, a result that is in agreement with the longer time estimation when presented with angry faces.

These results are in keeping with the findings from studies that have shown longer subjective durations when presented with angry faces (Driot-Volet et al., 2004; Gil et al., 2007; Tipples, 2008, 2011). These finding are typically interpreted based on arousal influences. Specifically, increased arousal is thought to accelerate the rate of the pacemaker leading to a greater number of counted units of time and consequently, an overestimation of time.

However, this explanation does not take into account the possible interaction between attention on emotion. Accordingly, it is unclear whether the durations of the frames presented seemed longer when coupled with angry faces (as opposed to neutral faces) because of increased attentional processing of the faces. Angry faces may have increased orienting of attentional allocation to the faces, thus affecting the attentional gate of the AGM. Alternatively, efficient processing of the angry faces would theoretically allow greater allocation of attention to the temporal task and thus promote the closing of the attentional gate, causing more pulses to accumulate resulting in overestimation of subjective time. It is possible to assess this alternative processing explanation by varying the attention allocated to the facial expressions. Specifically, by asking participants to make decisions that require focus on the emotional expressions of the morphed faces (i.e., active observation).

Experiment 2B. Active Observation

Attention to a demanding task influences the subjective estimation of time (Block et al., 2010). According to the AGM, interference should occur between the non-temporal and the temporal task. As more resources are drawn from timekeeping functions to meet non-temporal task demands, timing performance becomes more unreliable because fewer temporal cues are processed and stored. Therefore, the more attention to a non-temporal task means less attention to time, causing shorter time estimations (e.g., Block et al., 2010; Fortin, 2003). However, it is unclear if this result holds true if attention is directed towards emotional stimuli (e.g., facial expressions).

In the following experiment, participants were presented with the same temporal task as in Experiment 2A, except this time they were required to actively observe the facial expressions. Specifically, participants were told to observe the morphed facial expressions presented and rate the facial expressions as either 'closer to the angry expression' or 'closer to the neutral expression' (as in Experiment 1B) in addition assessing the durations of the frame surrounding the face.

As in Experiment 1B, it is apparent that deciding whether the 50% morphed image is closer to a neutral or angry expression is the most demanding, while deciding whether or not 0% or 100% is closer to neutral or angry is straightforward. Therefore, in this experiment, active viewing both forces the participants to focus more on the nuances of the facial expressions and demands even more complex decision making in regards to the morphed images, while keeping the executive attention in 0% morph (neutral face) and 100% morph (angry face) equated.

A key question to answer in the present experiment is whether or not actively viewing the morphed expressions, ranging from angry to neutral, will influence the subjective estimation of time. In particular, will more attention towards the facial expression presented on screen strengthen the effects of the expressions on time estimation, or will the enhanced executive attention overpower the subjective lengthening effect found with angry expressions in Experiment 2A.

Methods for Experiment 2B.

Participants.

Same participants as in Experiment 2A.

Apparatus.

See Apparatus section in General Methods.

Procedure.

The procedure for this experiment is the same as Experiment 2A with the exception that participants rated the facial expressions presented during the face presentation. As in the previous experiment, trials began with a 500 ms fixation cross in the center of an otherwise blank computer screen. Following 500 ms, a face appeared in the center of the screen. During the facial presentation, participants were to reply, as fast as they could, whether they thought the face was closer to an angry or neutral expression. Responses were made with their left hand on keys 'V' for 'neutral' and 'B' for 'angry'. Four hundred ms following the face presentation, a gray frame along the edges of the screen appeared. The frame remained on the screen for a given duration (between 400 ms and 1600 ms) as in Experiment 2A. If participants replied to the facial ranking after the disappearance of the frame, the face immediately disappeared and a fixation cross appeared in its place. However, if participants replied to the facial ranking during the time the frame was still on the screen, the face would remain on the screen until the frames' disappearance, followed by a fixation cross. Regardless of the duration of the frame or the face on a given trial, a question about the duration of the frame consistently appeared 2.9 sec from the onset of the trial. Following the question presentation, the participants replied whether the duration of the frame was closer to 'Short' or 'Long' by pressing the left arrow key or right arrow key on the keyboard respectively. Participants were asked to respond with the index and ring fingers of their right hand. To continue to the next trial, participants were asked to press the 'space' bar key (see Figure 2.3 for a procedural illustration). See Experiment 2A for further details.

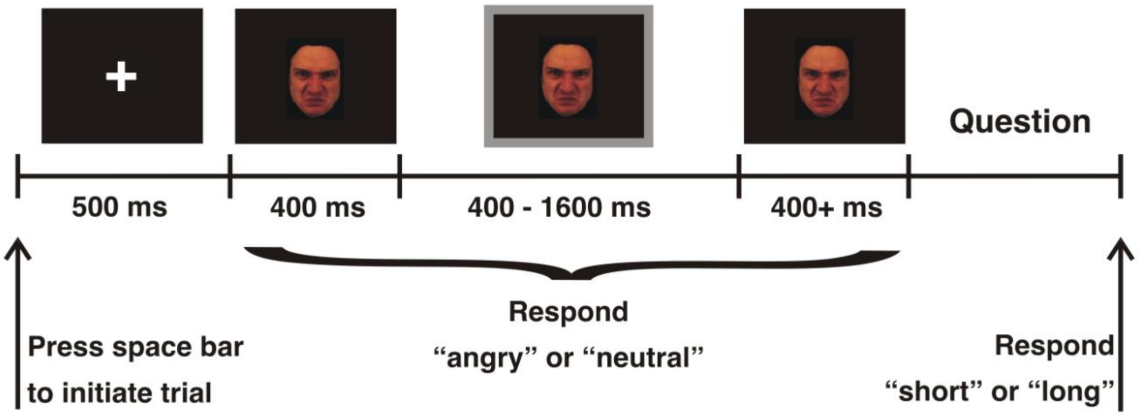

Figure 2.3. Procedural representation of Experiment 2B.

General Methods of Analysis.

Dependent Measures:

Reaction Time (RT). Reaction time was used as a measure for processing speed in the non-temporal tasks. Reaction time was defined in these experiments as the time in seconds from the onset of the face on the screen to the time the participants responded to the faces by pressing a key on the keyboard.

Proportion "angry" (similar to proportion "neutral" used in Experiment 1B)

Proportion "long", Bisection Point, *Weber's Ratio**. Measures for the temporal task (as in Experiment 2A)

*The bisection points produced by the distributions were required to have a value in-between the minimum value of 1 and the maximum value of 6.5 (values outside this range indicate that the participants were unable to discriminate between the reference durations).Bisection point values that did not meet this criterion, as well as their corresponding values for Weber's ratio, were considered outliers as this indicated a poor curve fit to the data. These values were consequently replaced by the mean value of the condition in question (in accordance with the task) across participants. This substitution had to be made on 4% of the trials in this experiment.

In addition to the general methods in Experiment 2A, reaction times to the facial expression were analysed using an ANOVA with morphed percentage (5 levels: 0%-100% of neutral) and duration (7 levels: 400-1600 ms) as within-subject factors. Also, the proportion of trials, in which the participants replied that the stimulus was "angry" per facial expression, was analysed with a binomial calculation with morphed percentage (5 levels: 0%-100% of neutral) and duration (7 levels: 400-1600 ms).

Results of Experiment 2B.

Morphed percentage:

The judgments made to classify the facial expressions of the morphed stimuli, as seen in figure 2.4, showed a reduced probability in responding "angry" as the percentage of the facial expressions from 0% of neutral (angry face) to 100% of neutral increased (binomial calculations, $p<0.01$). As expected, descriptive statistics showed that the 100% morph yields a Proportion "angry" estimate of close to zero (almost no 'angry' replies) ($M=.01$, 95% CI [0 .04]), and the 0% yield a Proportion "angry" estimate of close to 1 (almost all 'angry' replies) ($M=.98$, 95% CI [.95 1.01]). The 50% morphed stimulus yields an estimate close to the bisection point, though with a small bias for replying 'neutral' ($M=.42$, 95% CI [.39 .45]); this proves to be an appropriate midpoint for the continuum of neutral-angry facial expressions because it is the point at which the categorical decision of 'angry' or 'neutral' is ambivalent.

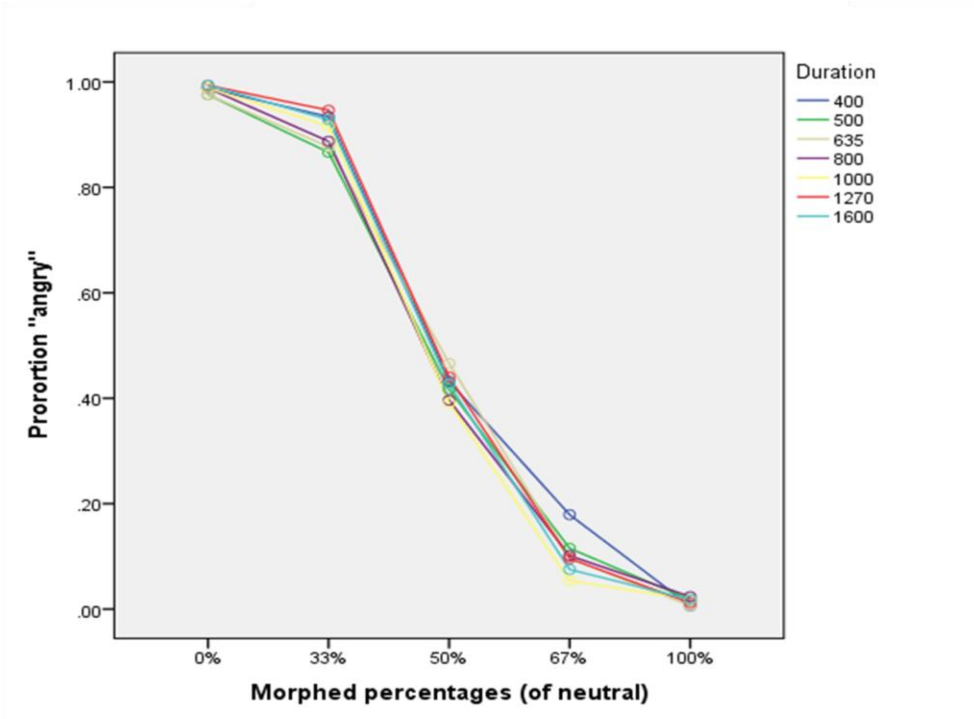

Figure 2.4. The relationship between the morphed percentages of neutral (i.e., five stimuli on the continuum between angry and neutral) and proprtion "angry" for the seven different frame durations (in msec). Notice that as the facial expression become angrier (closer to 0% of neutral), the proportion of 'angry' responses increases.

In contrast to Experiment 2A, when looking at the proportion "long" responses and fitting the Weibull distributions, it is apparent that the psychometric curves associated with the morphed facial expressions have shifted. Figure 2.5, presents the psychometric curves in this experiment. These shifts were confirmed by the significant differences between the bisection points of the morphed stimuli, $F(4,52)=2.81$, $p<.05$. A quadratic fit showed a significant effect $F(1,13)=19.14$, $p<0.001$. Pairwise comparisons show that responses to the 50% morphed stimuli (M=4.58, 95% CI [4.16 5]) were significantly larger (indicating a leftward shift of the psychometric function) than the responses to 100% (neutral) (M=4.24, 95% CI [3.9 4.58]) and the 0% (angry) morphed stimuli (M=4.2, 95% CI [3.7 4.6]), $p<.05$. Therefore, as shown in Figure 2.6 (Active

Viewing), it is apparent that at bisection point, when presented with the 50% morphed stimulus, participants have a higher probability of replying 'short' to the duration of the frame, compared to the other morphed stimuli. There was no significant difference between the Weber's ratio's or slopes of the different morphs, $F(4,52)=.78$, $p=.54$, though slopes appear steeper for the 0% and 100% morph and shallower for intermediate morphs. The quadratic fit $F(1,13)=2.75$, $p=0.12$ was also not significant.

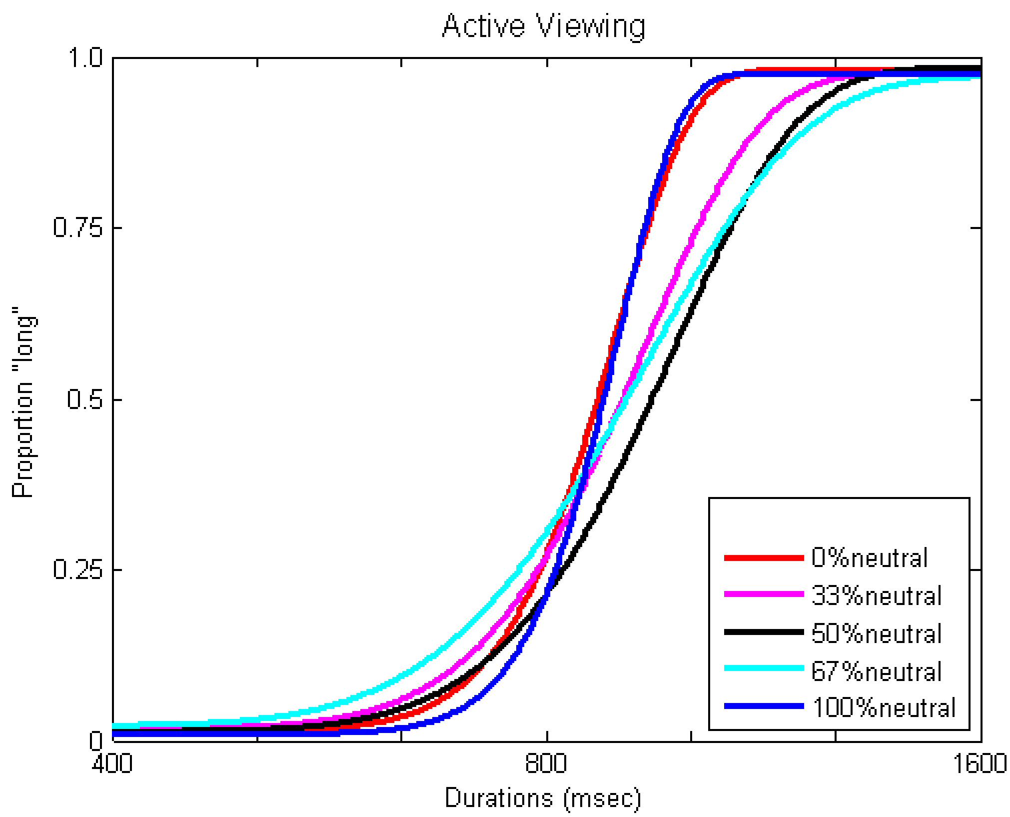

Figure 2.5 The relationship between frame durations (in msec) and proportion "long" for the five different morphed stimuli from 0% neutral to 100% neutral for the active viewing condition. Notice that the red and blue curves (angry and neutral faces) overlap and the black curve (50% morph) is shifted the most to the right.

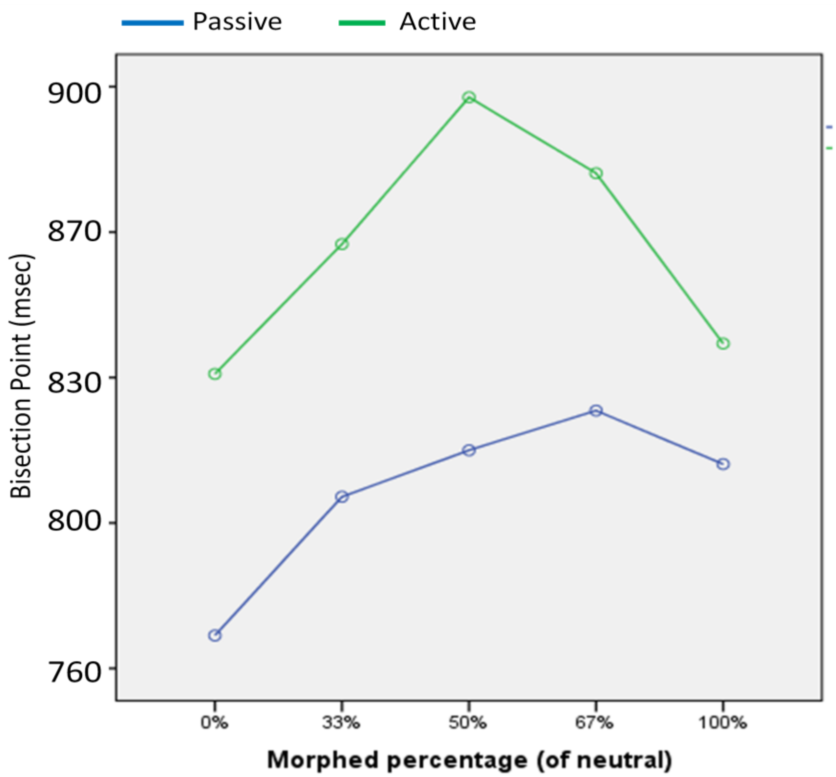

Figure 2.6. Mean bisection points (in msec)* for the five morphed stimuli on the angry to neutral continuum, between 0% neutral and 100% of neutral for the passive viewing (Experiment 2A in blue) and active viewing (Experiment 2B in green) conditions. Notice that during passive viewing, there appears to be an overestimation due to angry face (0% morph) presentation. However, when equating the executive attention required to process the reference (0% and 100%) facial expressions in the active condition, the subjective time estimation becomes similar (no more overestimation of time due to angry faces). Also notice the effects of attention on time estimation: subjective time is underestimated in the active condition compared with the passive condition, and as face discrimination becomes more difficult (closer to 50%) participants have a higher probability of replying 'short' to the duration of the frame.
*Bisection points (in msec) converted into the 1-7 linear scale: 760=3.8, 800=4, 830=4.2, 870=4.4, 900=4.6.

Figure 2.7 shows that reaction time was also significantly influenced by morph percentage, $F(4,52)=17.48$, $p<.0001$. The quadratic fit was also significant $F(1,13)=41.5$, $p<0.0001$. The more ambivalent the morph, the longer the reaction times required for making the response to the face (i.e., the reaction times increased when replying to a 50% morph compared with a 0% or 100% morph). Post hoc comparisons showed that the reaction times for the 0% of neutral (i.e., angry) morph (M=.9, 95% CI [.67 1.13]), was significantly different than the reaction times for all the other morphed percentages;

100%(M=.95, 95% CI [.73 1.17]), 67%(M=1.03, 95% CI [.82 1.24]), 50%(M=1.1, 95% CI [.9 1.3]), 33%(M=1, 95% CI [.79 1.22]), $p<.05$. The reaction times for 100% of neutral and the 50% (midpoint on the neutral-angry continuum) were also significantly different than the reaction times for all other morphed images, $p<.05$, with the exception of the 67% of neutral morphed image.

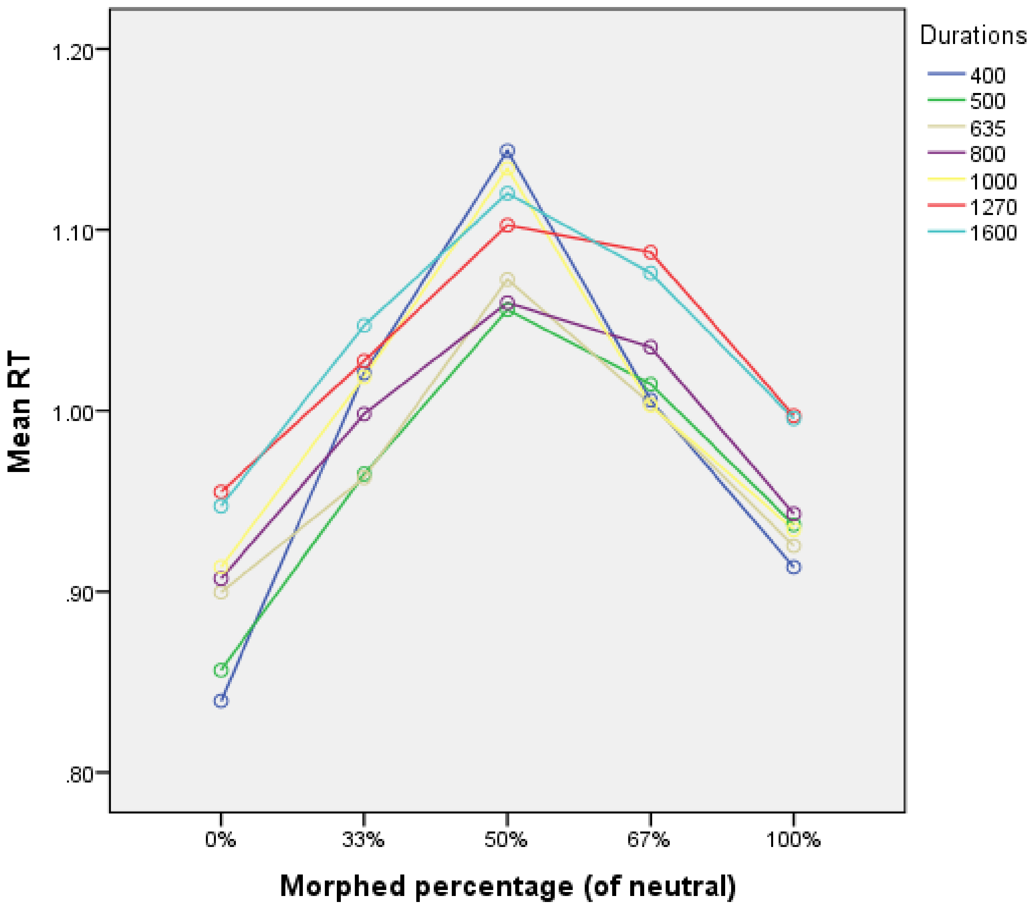

Figure 2.7. Mean reaction time results (RT; in sec) for the morphed percentages of neutral (0% to 100% from angry to neutral facial expression) for the seven different frame durations (in msec). Notice that as the morph becomes more ambivalent (closer to 50% morph), it requires greater processing speed (the reaction times required for making the decision about the facial expression increases) for all frame durations.

Discussion of Experiment 2B.

In accordance with preliminary experiments 1A and 1B, results show that both the time estimates of the durations and the expression estimates of the morphed continuum, present reliable psychometric curves. Specifically, as durations increase so did the proportion “long” estimates, and as the morphed face became angrier so did the proportion “angry” estimates. Also, in accordance with Experiment 2A (passive viewing), when presented with angry faces participants increased their proportion “long” estimates.

However, it is clear by looking at the results from the bisection point analysis (see Figure 2.6) that the decision-making task (deciding whether the facial expression presented was closer to a neutral or closer to an angry facial expression) considerably influenced the participants’ time estimations. As the morphed face became more ambivalent (i.e., closer to the middle of the continuum) and therefore more difficult to differentiate, more executive attention was allocated toward the decision-making task and less towards the timing task. In accordance with the attentional effects on subjective time perception (depicted in the attentional gate model), more attention allocated toward the non-temporal task was associated with a decrease in proportion “long” estimates (i.e., participants responded ‘short’ more often).

As expected, the reaction times (Figure 2.7), from the onset of the face stimulus to the time it took the participants to make a decision regarding the facial expression, were also influenced by the difficulty of the task. The reaction times along the edges of the continuum (angry and neutral faces) were shorter compared with reaction times closer to the midpoint of the continuum (50% morph). Interestingly, when comparing the reaction time results with the bisection point results, there appeared to be a very straightforward association, as the curves were very similar (Figures 2.6 and 2.7). The more time participants needed to process the facial expressions and reach a decision regarding its expression, was associated with shorter subjective time estimations. Therefore, the 50% morphed face both resulted in longer reaction times for the non-temporal task and in shorter time estimations for the temporal task. Moreover, since processing of the angry face and the neutral face (at the continuum's extremes), occupied the least attentional resources (easy task due to simple distinction), the reaction times for the two extremes were similar. Therefore, results indicated that asking the participants to attend to the facial expression of the faces did not produce longer time estimations (smaller bisection points) for the angry faces relative to the neutral faces (as in the passive condition, Experiment 2A), but rather the bisection points become more similar.

These results are consistent with the notion of attentional influences on the internal clock (Zakay & Block, 1997). Attention is divided between the two tasks in the dual-task procedure: temporal estimation and facial expression rankings. As more attention was allocated towards the facial expression (increased reaction time), less attention is allocated towards the timing task (frame duration estimations), resulting in shorter time estimations (increased bisection points) (e.g., Coull et al., 2004). Therefore, as reaction times increase based on the difficulty of the task (i.e., increased executive attention to the non-temporal task), the probability of responding "long" to the temporal stimulus decreased.

This experiment shows that increased attention to the facial expression influences the perception of time, in accordance with the time required to process the faces. The expressions on the faces may influence the processing of time differently, yet relatively equating the executive attentional loads for the two reference expressions (in the active condition), showed no differential effects of facial expression on proportion “long” time estimations (Figure 2.6). The effects of overestimation of time due to the presentation of angry faces compared with neutral faces (as shown in Experiment 2A) was no longer observed when equating the executive attention required to process the facial expressions of neutral (100%) and angry (0%). Therefore, it is possible to assume that the influences of the facial expressions on subjective time estimations, previously attributed to independent arousal effects (e.g., Droit-Volet & Gil, 2009), is mediated by the attentional requirements necessary in order to process these facial expressions. The comparison between Experiment 2A and 2B was performed to further investigate the effects of the interaction between attention and emotion on subjective time estimations.

Comparison between Experiment 2A and Experiment 2B

General Methods of Analysis.

To compare the psychometric curves of duration estimation during passive viewing and active viewing, Proportion “long”, bisection points, and Weber’s ratios were calculated. A repeated measures ANOVA with morph percentage (5 levels: 0% to 100%) and activity level (active, passive) as the within-subject factor was used to analyse the differences between the bisection points and Weber’s ratios.

Results of comparison (2A vs. 2B).

Proportion “long” of passive viewing (Experiment 2A) compared to active viewing (Experiment 2B), showed that during passive viewing of the stimuli (M=.49, 95% CI [.44 .55]), the estimation of the duration of the frame was more accurate (closer to .5) relative to active viewing (M=.43, 95% CI [.38 .49]). Moreover, as shown in figure 2.8, for each morphed face separately, active viewing of the face stimuli was associated with shorter time estimates compared to passive viewing of the stimuli (i.e., psychometric curves of duration estimations were shifted to the right for active viewing). Bisection point analysis confirmed this result as the bisection points of passive vs. active viewing differed significantly, $F(1,13)=6.24$, $p<.05$. During passive viewing, the 800 ms duration (geometric mean of durations) was identified to be the point of indifference (bisection point), and therefore considered very accurate (i.e., consistent with timing performance without a non-temporal task distraction, fig. 1.3) (M=4, 95% CI [3.6 4.4]) while the bisection point for the active viewing condition was larger and therefore suggests shorter duration estimates (i.e., rightward shift of the psychometric curve) (M=4.48, 95% CI [4 4.8]) $p<.05$. In addition, there was no significant difference between the average slopes of the passive and active conditions $F(1,13)=2.46$, $p=.14$.

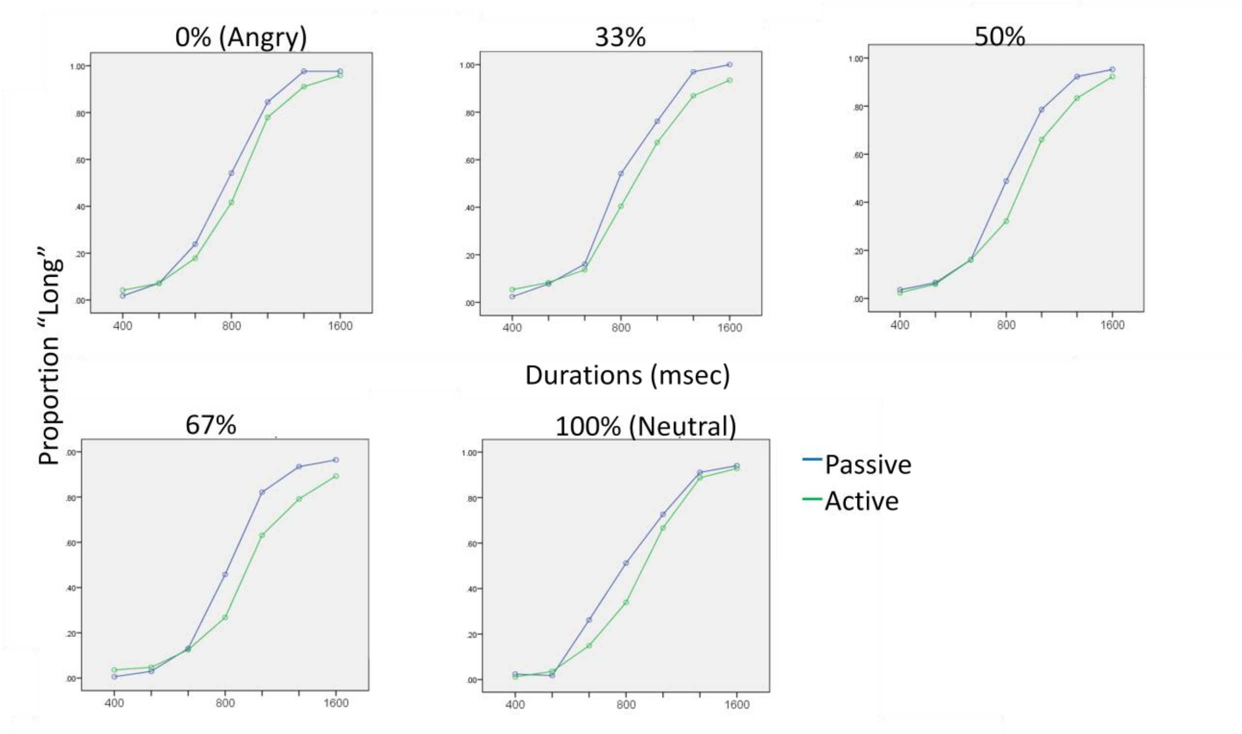

Figure 2.8. A comparison between passive and active viewing conditions for the relationship between frame duration (in msec) and proportion "long" during the presentation of all facial expressions from 0% (of neutral) to 100% (of neutral) morphed stimuli. Notice that for all morphed faces, time estimations on the active condition was shifted to the right compared with the passive condition.

Discussion of comparison (2A vs. 2B).

Passively viewing different facial expressions has been shown to be associated with differential time estimations. Specifically, angry faces are associated with longer time estimates compared with neutral faces (e.g., Droit-Volet & Gil, 2009). However, these changes might be due to the processing speed of the faces and therefore to the attention necessary to process the faces, rather than due to the emotional arousal they stimulate. Consequently, the active viewing paradigm was developed to address this issue by creating conditions with varied task difficulty levels in addition to varied facial expressions. The comparison between the passive and active viewing tasks highlighted the influences of the attentional manipulation on temporal processing.

During passive viewing of the faces (Experiment 2A), participants were asked to look at the faces with no accompanying task. However, during active viewing of the faces (Experiment 2B), participants were asked to intensively observe the facial expressions of the faces presented and make decisions as to their expressions. This forced participants to pay more attention to the faces. A comparison of the results showed that increased attention to the faces was associated with shorter estimates of time. For all facial expressions, there was a rightward shift in the psychometric curves for Proportion "long" during active viewing. In addition, bisection points confirmed this difference between tasks as the bisection point for the active viewing state was also consistently larger than for the passive viewing state. These results support the proposal that the allocation of attention is central to time perception. Specifically, it seems that during the passive viewing state, less attention was allocated to the faces and therefore time estimations were more accurate (i.e., the mean bisection point was closer to the 800 ms geometric mean, as in Experiment 1A) than in the active viewing experiment. During the active state, attention was allocated to the faces rather than to the timing of the frame, and therefore time estimations were shorter (Figure 2.8).

As addressed in the Discussion of Experiment 2B, the speed with which the faces were processed strongly influenced the participants' time estimations. Once more, faces that required more attentional resources to process were associated with shorter time estimations. This result was supported by the comparing the participants' reaction times in the non-temporal task when presented with different morphed expressions, with the bisection points related to the temporal task when presented with different morphed expressions.

Experiment 2A does not allow for a direct comparison between processing speed and time estimation because participants passively viewed the faces and no reaction time was recorded. However, previous research on the interaction between attention and emotion suggests that there is an evolutionary advantage to processing emotional facial expressions faster and more efficiently (e.g., Eastwood et al., 2001; Lebue & Deloache, 2008; Ledoux, 2000; Ohman et al., 2001). Therefore, it is probable that in Experiment 2A, the longer time estimations that were observed on trials with angry faces were also related to more efficient orienting, and consequently faster processing of the facial expressions. Moreover, increasing executive attention to the facial expression by manipulating difficulty, as in Experiment 2B, attenuated the initial differences in attentional allocation among the facial expressions.

In summation, the results presented in this experiment, both introduced the influences of emotional arousal and attention on subjective time estimations. Specifically, subjective time was overestimated due to the presentation of angry facial expressions, and attentional allocation away from the temporal task was associated with an underestimation of subjective time. Moreover, by manipulating the amount of attention necessary to process the facial expressions, it became apparent that the interaction between emotional arousal and attention was associated with differential time estimations. Particularly, the more executive attention allocated towards the facial expressions was related to shorter time estimates. However, in order to fully understand the effect of the interaction between emotional arousal and attention on timing, an experiment that incorporates all three attentional networks (i.e., executive attention, orienting and alerting) was necessary. Toward that end, a visual search task with neutral facial expressions (Experiment 3) and emotional facial expressions (Experiment 4) was designed.

EXPERIMENT 3. TEMPORAL BISECTION WITH IDENTITY SEARCH TASK

This task was designed to assess the effects of attention on time perception. According to the AGM, in a dual task procedure, as more resources are drawn from the temporal task, fewer temporal cues are processed and stored, causing shorter time estimations (Zakay & Block, 1997). Block et al., (2010) have shown that a demanding (high cognitive load) non-temporal task is associated with decreased subjective time estimation (i.e., shorter estimates). However, timing studies have not clearly made the connection between the processing speed required to perform the non-temporal task (measures of cognitive load) and time perception estimations.

This experiment manipulated the amount of attentional allocation towards the non-temporal task by varying the difficulty levels of the task, in order to assess the influences of increased attentional load on timing estimations. In addition, reaction times for the different cognitive load conditions were measured in order to evaluate the effects of processing speed (in the non-temporal task) on perceived timing.

The non-temporal attentional task used in this experiment is a variation of the visual search task. Visual search tasks have been extensively used to assess attentional priority (see Mu¨ller & Krummenacher, 2006, for a recent review). In the standard paradigm, the observer is presented with a display that can contain a target stimulus amongst distractor stimuli. The number of distractor stimuli may vary and is determined by the crowd size (i.e., total number of stimuli on screen). The target can either be present or absent and the task is to make a ‘present/absent’ decision as quickly and as accurately as possible (e.g., Treisman & Gelade, 1980; Wolfe, 1998, 2001).

Visual search tasks have been used to assess processing efficiency because they test detection latency. Detection latency is the time between the onset of the stimulus and the participant’s response. This reaction time can be plotted as a function of crowd size. The slope of this function is the ‘slope rate’ or ‘efficiency of search’. The two modes of visual search that have been proposed are parallel search and serial search (Treisman & Gelade, 1980).

Parallel search is an efficient search method in which all items in the crowd are explored simultaneously. In contrast, serial search refers to an inefficient search method in which a linear increase in reaction time as crowd size increases is observed because individual items are searched in succession. Efficient processes are associated with the earliest stages of the visual system and are executed rapidly, while inefficient processes involve more complex computations. Therefore, the detection latency in efficient search is independent of crowd size (similar reaction time regardless of number of distractors), while the detection latency in inefficient search is positively related to crowd size (increase in reaction times relative to increase in distractors).

Common theories of visual search include the feature integration theory (FIT, Treisman & Gelade, 1980), the parallel, competitive model of visual search (Duncan & Humphreys, 1989), and guided search (Wolfe, 1994). FIT suggests a specialized map for representations of specific features defining the target (e.g., color, threat), which enables the speedy detection of such targets among distractors. The parallel, competitive model of visual search (Duncan & Humphreys, 1989) is based on findings that indicate a target is detected faster the more it differs from the distractors, and the more similar the distractors are to each other. According to this theory, information is hierarchically structured into units that combine information of lower levels (according to Gestalt grouping and similarity). The activation of a unit is determined by its similarity to an internal description of the target (saved in memory) and by the amount of grouping with other units.

Guided search (Wolfe, 1994) suggests that there is both serial and parallel processing involved in visual search (not just parallel as in the parallel, competitive model) that is not determined by the number of features defining the target (as proposed by the FIT model). According to guided search, visual search entails parallel processing that is both stimulus driven (bottom-up) as well as goal-directed (top-down). Ultimately, search models have converged on the notion that search performance results from the interaction of goal-directed top-down and stimulus-driven bottom-up mechanisms (e.g., Bundesen, 1990; Cave & Wolfe, 1990; Itti & Koch, 2000; Treisman & Sato, 1990; Wolfe, 1994).

The stimulus-driven or bottom-up allocation of attention is achieved by detecting simple features (e.g., luminance, color, orientation, and motion direction) that differ from the surrounding features in a significant manner (e.g., Nothdurft, 1991; Treisman & Sato, 1990)). Therefore, detection latencies depend on the dissimilarity between the target and the distractors (Wolfe, 2003; Wolfe et al., 2011). Moreover, it has been established that search performance deteriorates as target-distractor similarity increases (Cheal & Lyon, 1992; Duncan & Humphreys, 1989; Eriksen & Yeh, 1985; Pashler, 1987; Wolfe, 1994). In order to discriminate between highly similar targets and distractors, participants need to extract detailed information on the distinctive features of the stimuli. Therefore, it is possible to manipulate attention load by manipulating target-distractor similarity. The attentional manipulation associated with this detailed analysis involves the executive control network of attention. The greater the similarity levels between target and distractor, the more executive attentional resources are required for detecting the target.

Visual search is, therefore, a perceptual task that is closely associated with attentional processes. It requires more or less processing resources, and this demand can be manipulated experimentally. More specifically, it is possible to vary difficulty by varying the number of faces on the screen (distractors) and by varying the similarity levels between target and distractors. These manipulations involve cognitive load and consequently influence the executive attention resources required for the task. By incorporating a visual search task with a temporal bisection task, it was possible to assess the influences of executive attention on subjective time estimations.

The following experiment incorporated a visual search task with morphed faces as the target and distractors. The images of morphed faces were extracted from an identity continuum between two female identities, both displaying neutral facial expressions. Each identity had distinct facial features, which allowed for the discrimination between the identities. However, since the facial expressions were neutral, the effects of these differences were expected to have an insignificant effect on time estimations. The reason for using faces in the visual search task stemmed from a future comparison between the visual search task conducted with neutral expressions (this experiment) with a visual search task conducted with emotional expressions (see Experiment 4 for more detail).

This experiment was divided into two sessions, starting with a single visual search task and concluding with a dual visual search task with a temporal component. Specifically, in Experiment 3A, participants were presented with the visual-search task with the identity continuum (between Beth and Jane, both presenting a neutral expression). This allows the assessment of whether or not the differences in attentional allocation have a significant effect on participants' reaction time and accuracy levels, as well as providing an introduction and practice for the subsequent experiment. Difficulty was manipulated by varying the similarity levels between the distractors and target, and by increasing the crowd size (i.e., number of distractors on the screen). Differences in similarity and/or crowd size would theoretically be associated with differential attentional resources (e.g., Wolfe, 1994).

Experiment 3B included the same identity search task as presented in Experiment 3A; however, in 3B the visual search task was accompanied with the temporal bisection task (as in Experiment 1A). Adding the temporal bisection task allows the evaluation of the effects of attention on time estimation. The different similarity levels between the distractors and the target face, in addition to a range of crowd sizes, allowed for varied difficulty of search trials, as in Experiment 3A. This dual task situation will allow an investigation on the association between executive attention (measured by reaction time) and time estimations (measured by Proportion "long" and bisection points).

Methods of Experiment 3

Participants.

Twenty three undergraduates at Brown University fulfilling course credits participated in this experiment (Experiment 3A and Experiment 3B).

Apparatus.

See Apparatus section in General Methods.

Procedure for Experiment 3A.

The procedural setup was similar to the one in Experiment 2B, however, in this experiment, there were several faces on the screen and the task is to identify the absence or presence of a target face. In particular, this experiment was divided into two blocks (counterbalanced), in which the participants were to search for a target face. In the first block, the faces on the screen that distracted from the target face (i.e., distractors) were all of a female named Jane (0% of Beth morph), while in the second block the distractors were all of a female named Beth (100% of Beth morph). Specific faces selected were from actors BF19 and BF23 from the Karolinska face dataset. The target face was a morphed face of: 0%, 33%, 50%, 67% or 100% of Beth, on the morphed continuum between Jane and Beth, two distinct female identities with a neutral expression. The crowd size consisting of distractor faces plus one target face, was four, eight or 12, presented with equal probability. Since the distractors were either 0% of Beth or 100% of Beth, and the target faces ranged from 0%-100% of Beth, the combinations between distractor and target ranged from 0% similarity, in which the distractors and the target are on opposite sides of the continuum (e.g., the distractor is 0% of Beth and the target is 100% of Beth), to 100% similarity, in which the distractor and target are of the same morph (e.g. the distractor is 0% of Beth and the target is 0% of Beth). Therefore, in each block there were five levels of similarity between distractor and target: 0%, 33%, 50%, 67% or 100%. Figure 3.1 illustrates 0% and 67% similarity levels in the Jane distractor block.

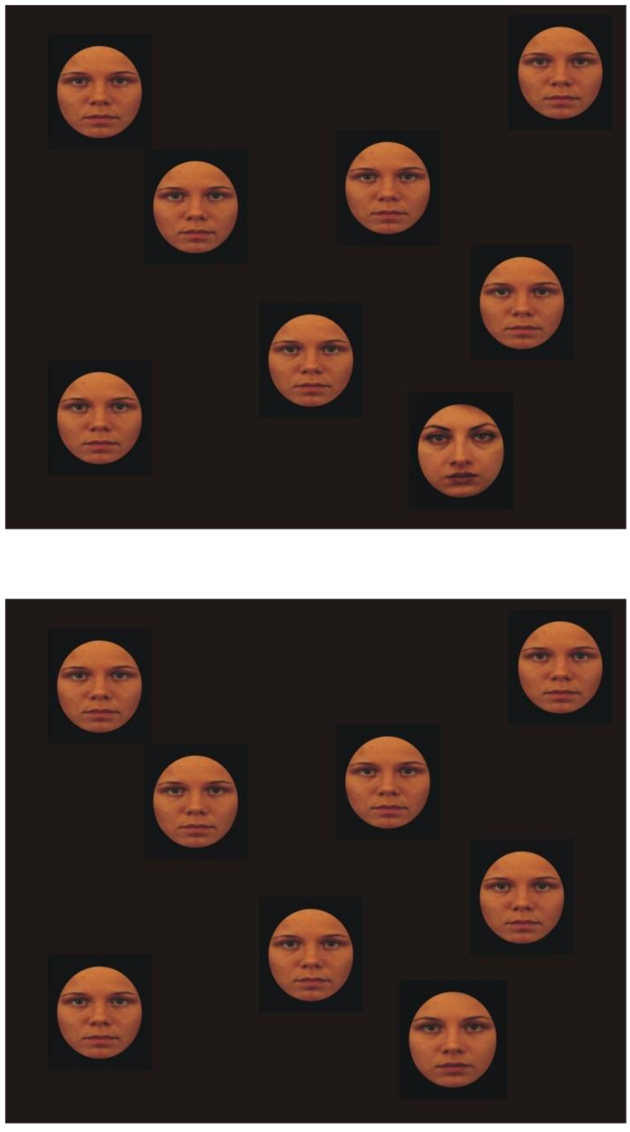

Figure 3.1. Illustration of faces presented on screen during the Jane distractor block. Top figure represents 0% similarity (distracters are 0% of Beth and target is 100% of Beth). Bottom figure represents 67% similarity (distracters are 0% of Beth and target is 33% of Beth). Both figures depict crowd size of eight faces. {Target face is on the bottom right}

As illustrated in Figure 3.2, in a typical trial, a fixation cross appears for 500 ms, followed by several faces 3x3cm each in random locations on the screen. The locations were assigned with the stipulation that they may not overlap each other or the gray frame (in case of overlap, another randomly assigned position would be assigned prior to the presentation on screen). Participants were to respond as fast as they could during the face presentation, to indicate whether the target face was absent or present. A target face was defined as a face that is "more 'Beth-like among the Jane distractors" or "more 'Jane-like' among the Beth distractors". Participants were advised that some of the differences might be very small and therefore they should focus on the features of the faces. Faces remained on the screen until the response had been made, or for a maximum duration of 2.7 sec. Participants were asked to respond by pressing keys 'V' if 'target is absent 'or 'B' if 'target is present' on the keyboard, with their left hand. The probability of absent trials was equal to the probability of present trials. This means that on 50% of the trials, there was a 100% similarity condition, in which the target image face was the same as the distractors (i.e., 0% Beth distractor - 0% Beth target or 100% Beth distractor -100% Beth target). After the participant responded, the trial would end, and a 500 ms delay would begin prior to the next trial start. Every ten trials, participants were asked to press the 'space bar' key to continue to the next trial, thus giving them the opportunity to take a break if needed.

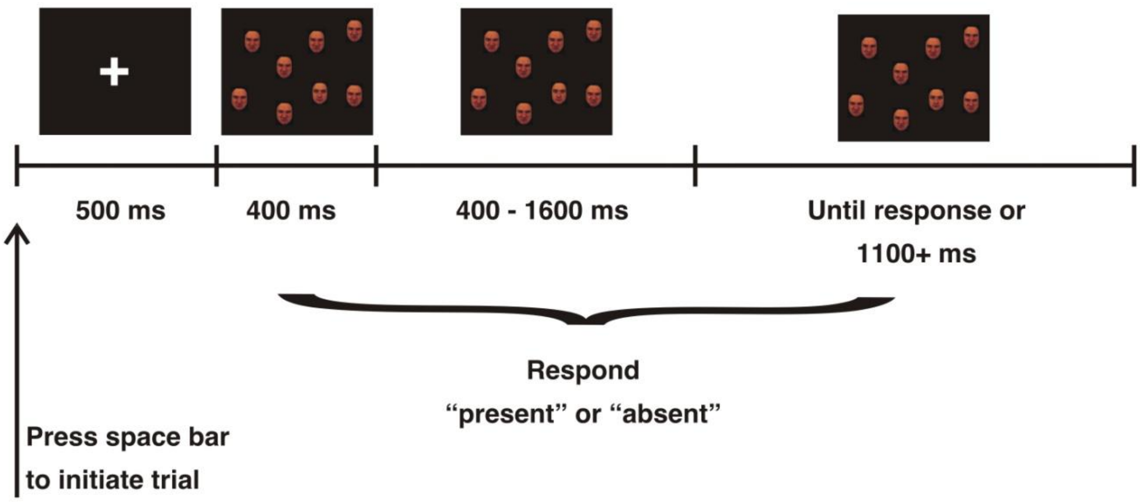

Figure 3.2. Procedural representation of Experiment 3A(this procedure has the same structure as Experiment 3B with the exception of the temporal bisection task).

The training included 30 trials (15 trials per block), incorporating the three crowd sizes (four, eight, or 12), and the five different distractor-target similarity combinations (0%, 33%, 50%, 67% or 100%), all of which included feedback. Testing consisted of 168 experimental trials per block which consisted of seven repetitions of the three crowd sizes with four types of distractor-target similarity (0%, 33%, 50%, 67%), representing the 'target present' conditions (84 trials) and 28 repetitions of the three crowd sizes with one type of distractor target similarity (100%), representing the 'target absent' condition (84 trials). Within a block, the target images were presented intermixed. The order of the presentation was determined based on random permutations. No feedback was given during the testing trials.

Procedure for Experiment 3B.

The procedure for this experiment was the same as Experiment 3A, with the addition of the bisection task. In this experiment, 400 ms following the presentation of the faces, a gray frame appeared around the outside edge of the screen. The frame remained on the screen for a given duration (ranging from 400 to 1600 ms), as in Experiment 2A. If participants replied to the faces (target absent or present) after the disappearance of the frame, the face would immediately disappear and a fixation cross would appear in its place. The disappearance of the face is meant to encourage the participants to reply as fast as they can. However, if participants replied to the faces during the time the frame was still on the screen, the faces would remain on the screen until the frame disappeared, followed by the presentation of a fixation cross. This is because the duration estimation may be influenced by the faces on the screen. Participants were asked to respond to the faces as fast as they could during the faces presentation by pressing keys ‘V’ or ‘B’ with their left hand. Participants were then asked to respond to the duration following the appearance of the question on screen. Regardless of the duration of the frame or the faces on a given trial, the question about the duration of the frame consistently appeared 3.6 sec after the onset of the trial. Following the question presentation, the participants replied whether the duration of the frame was closer to the ‘short’ or ‘long’ standard duration by pressing the left arrow key or right arrow key on the keyboard ,respectively, with their right hand. Upon response the trial ended, a 500 ms delay began, followed by the start of the next trial. Every 10 trials, participants were asked to press the ‘space bar’ key to continue to the next trial. See figure 3.3 for a procedural illustration.

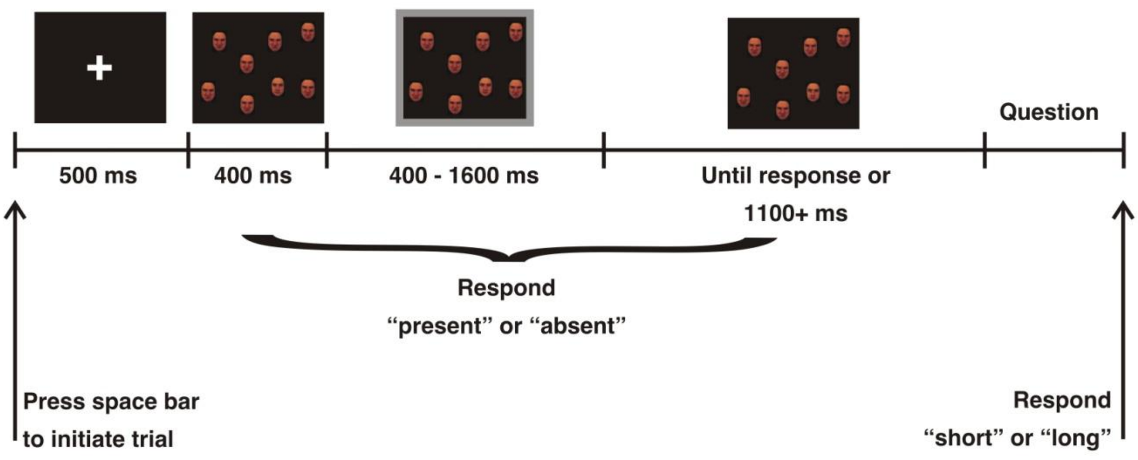

Figure 3.3. With Frame. Procedural representation of Experiment 3B.

The training included 78 trials (39 trials per block) with feedback, separated into three sections per block: 12 training trials for the bisection task (as in Experiment 1A), 15 training trials for the facial search task (as in Experiment 3A), and 12 training trials combining bisection with the facial search task. Testing included 168 experimental trials per block, which consisted of one repetition of the three crowd sizes, four 'target present' conditions, and seven durations (84 trials), and four repetitions of the three crowd sizes, one 'target absent' condition, and seven durations (84 trials). Within a block, the target images were presented intermixed with each other. The order of the presentation was determined based on random permutations. No feedback was given during the testing trials.

General method for analysis.

Measures for Experiment 3A.

Independent Measures.

Target faces. The morphed faces used in the experiments were the different faces developed with the morphing software (see Stimuli for details). The morph was created on the Jane-Beth identity continuum.

Distractor type. Distractors were the faces on the screen in addition to the target face which the participant was in search of. Distractors were either 0% of Beth (Jane faces) or 100% of P1 (Beth faces) separated into two blocks (one distractor type per block). The order of the blocks was counterbalanced across participants.

Similarity. In the visual search task, a similarity measure is the referred to as the similarity between the facial expression of the distractor faces and the facial expression of the target face. The similarity ranged between 0% similarity (100% morphed difference between the face and distractors) and 100% similarity (no difference between the face and distractors). There were five different levels of similarity: 0%, 33%, 50%, 67%, and 100% corresponding to difficulty of the trial from low difficulty to high difficulty respectively. For example, angry distractors with a neutral target face or neutral distractors with an angry target face, was 0% similarity and therefore the easier task.

Crowd size. The target face that the participants were in search of was accompanied on the screen by either 3, 7 or 11 distractor faces. The total number of faces on the screen on a given trial was four, eight, or 12 faces.

Dependent Measures.

Reaction Time (RT). Reaction time was used as a measure for processing speed in the visual search task. Reaction time was defined in these experiments as the time in seconds from the onset of the faces on the screen to the time the participants responded ("absent" or "present") to the faces by pressing a key on the keyboard.

Accuracy. Accuracy was a measure for assessing the precision (percent correct) with which the participants identified the faces. Accuracy was calculated for the visual-search task to ensure adequate performance and determine speed / accuracy tradeoffs.

Measures for Experiment 3B.

Independent Measures.

Durations (as in Experiment 1A), Target faces, Distractor type, Similarity, Crowd size (as in Experiment 3A).

Dependent Measures.

Reaction Time (RT), Accuracy. (as in Experiment 3A) Proportion "long", Bisection Point (BP), Weber's Ratio (as in Experiment 1A).

Results were analysed with a general linear model (GLM) repeated measures ANOVA. Reaction time and accuracy were analysed with an ANOVA running distractor type (Jane or Beth), similarity of target to distractor (5 levels: 0%-100% of Beth) and crowd size (four, eight, or 12), as within-subject factors.

In Experiment 3B, mean proportion "long" was analysed with an ANOVA running crowd size (three levels including four, eight, or 12 faces in the crowd), distractor type (Jane or Beth), similarity of target to distractor (five levels from 0%-100% of Beth) as within-subject factors. Further, an ANOVA with distractor type (Jane vs. Beth) and similarity between target and distractor (five levels from 0% to 100%) as the within-subject factor was used to analyse the differences between the bisection points and

Weber's ratios. There were six outlier bisection points and Weber's ratios that did not meet criteria. These values (~2% of the data) were excluded and replaced with the mean value for distractor x similarity values across participants.

To compare the reaction time/accuracy results found in Experiment 3A with those found in 3B, a general linear model (GLM) repeated measures ANOVA with distractor type (Jane or Beth), similarity of target to distractor (5 levels: 0%-100% of Beth), crowd size (four, eight, or 12), and experimental session (3A vs. 3B) as within-subject factors was used.

Results of Experiment 3A.

Crowd size.

There was a significant difference in reaction time among the different crowd sizes, $F(1.5, 32.5)=301.95$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=9.2$, $p<.05$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.7$). Pairwise comparisons showed that the reaction times for crowd size was significantly different among all sizes. In particular, the larger the crowd size, the slower the reaction times (in sec) ; crowd size 4 (M=1.36, 95% CI [1.3 1.4]), crowd size 8 (M=1.67, 95% CI [1.6 1.74]), crowd size 12 (M=1.84, 95% CI [1.76 1.93]). In addition, there was an accuracy main effect of crowd size $F(2,44)=55.8$, $p<.0001$. Pairwise comparisons showed that the accuracy for crowd size was significantly different between all sizes. Specifically, the larger the crowd size, the lower the accuracy (proportion correct); crowd size 4 (M=.86, 95% CI [.82 .91), crowd size 8 (M=.80, 95% CI [.76 .84]), crowd size 12 (M=.73, 95% CI [.69 .77]).

Therefore, results indicated that an increase in crowd sized was associated with an increase in reaction times and a decrease in accuracy.

Similarity.

There was a main effect of similarity on reaction time, $F(2.3,5.8)=167$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=26$, $p<.005$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.57$). Pairwise comparisons showed that the similarity between target and distractor significantly influenced the reaction time to the faces. Particularly, as trials increased in similarity (increased in difficulty), they also increased in RT, $p<.001$. There was also a main effect of similarity on accuracy $F(2,44)=33$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=45.2$, $p<.005$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.5$). Pairwise comparisons showed that there were significant differences in accuracy between each similarity level ($p<.01$) except between 0% and 33% and between 100% and 67%. As the trials increased in difficulty, the less accurate the responses became. However, a similarity level of 67% showed the lowest accuracy levels ($M=.61$, 95% CI [.55 .67]).Results indicate that increasing the similarity levels between target and distractor both increases the reaction times and decreases the accuracy levels (though 67% similarity is the least accurate).

Crowd size x similarity.

Results showed a significant interaction effect between crowd size and similarity on reaction time $F(8,176)=3.64$, $p<.001$. As depicted in Figure 3.4, reaction times increased as similarity (i.e., difficulty) increased for all crowd sizes, though the increase was smaller for the low similarity (i.e., easy trials) and more pronounced as the trials increased in similarity (i.e., more difficult). In addition, there was a significant interaction effect on accuracy $F(4.8, 107.2)=3.14$, $p<.05$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=58.6$, $p<.005$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.6$). Figure 3.5 illustrates how accuracy decreased as similarity increased for all crowd sizes, though this decrease was very small in low similarity (easier) trials and much more pronounced as similarity increased (trials became more difficult).

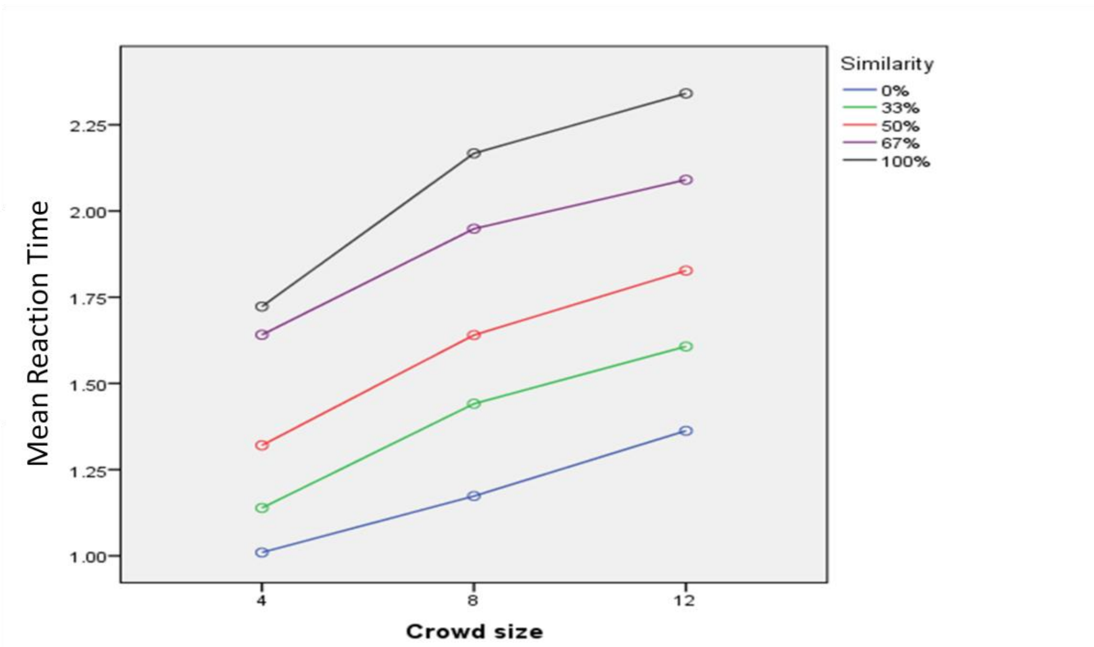

Figure 3.4. The relationship between crowd size and mean reaction time (in sec) for the different similarity levels between target and distractor (ranging from 0% to 100%). Reaction time increased with increasing similarity and with increasing crowd size. In addition, an interaction between similarity and crowd size shows that low similarity trials (e.g., 0% similarity - blue curve) have a shallower slope than higher similarity levels (e.g., 100% similarity - black curve).

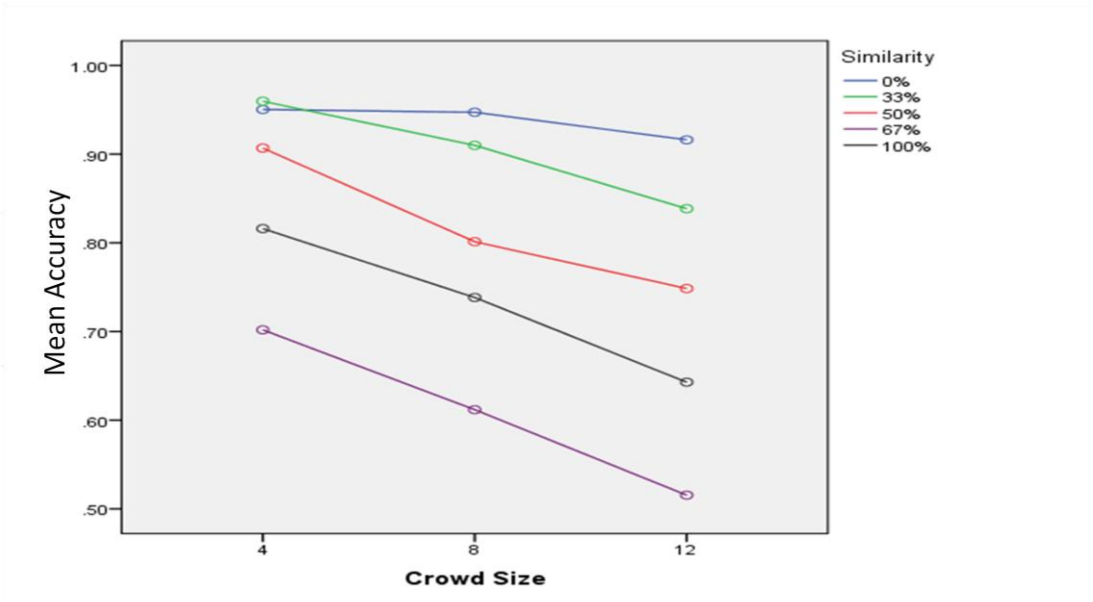

Figure 3.5. The relationship between crowd size and mean accuracy levels (in percentages) for the different similarity levels between target and distractor (ranging from 0% to 100%). Accuracy decreased with increasing similarity and with increasing crowd size. In addition, an interaction between similarity and crowd size shows that low similarity trials (e.g., 0% similarity - blue curve) have a shallower slope than higher similarity levels (e.g., 100% similarity - black curve).

Distractor type.

There was a main effect of distractor type on reaction time, $F(1,22)=4.77$, $p<.05$. Pairwise comparisons showed that the reaction times (in sec) while presented with Jane distractors (M=1.65, 95% CI [1.57 1.73]) was significantly larger than reaction times while presented with Beth distractors (M=1.6, 95% CI [1.53 1.67]). There was no significant difference in accuracy between Jane and Beth distracters, $F(1,22)=3.35$, $p=.08$.

Distractor x Similarity.

A closer look at the differences in reaction times between the distractor types, revealed an interaction effect between distractor and similarity $F(3,66.4)=13.36$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=19.6$, $p<.05$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=.75). As shown in Figure 3.6, the reaction times when presented with Beth distractors was faster than when presented with Jane distractors for all similarity levels apart from 0% similarity. Once again, there was no interaction effect between distractor and similarity on accuracy levels F(2,44)=2.9, p=.06. Figure 3.7 shows that accuracy decreased in the same way for both distractor types, as similarity levels increased.

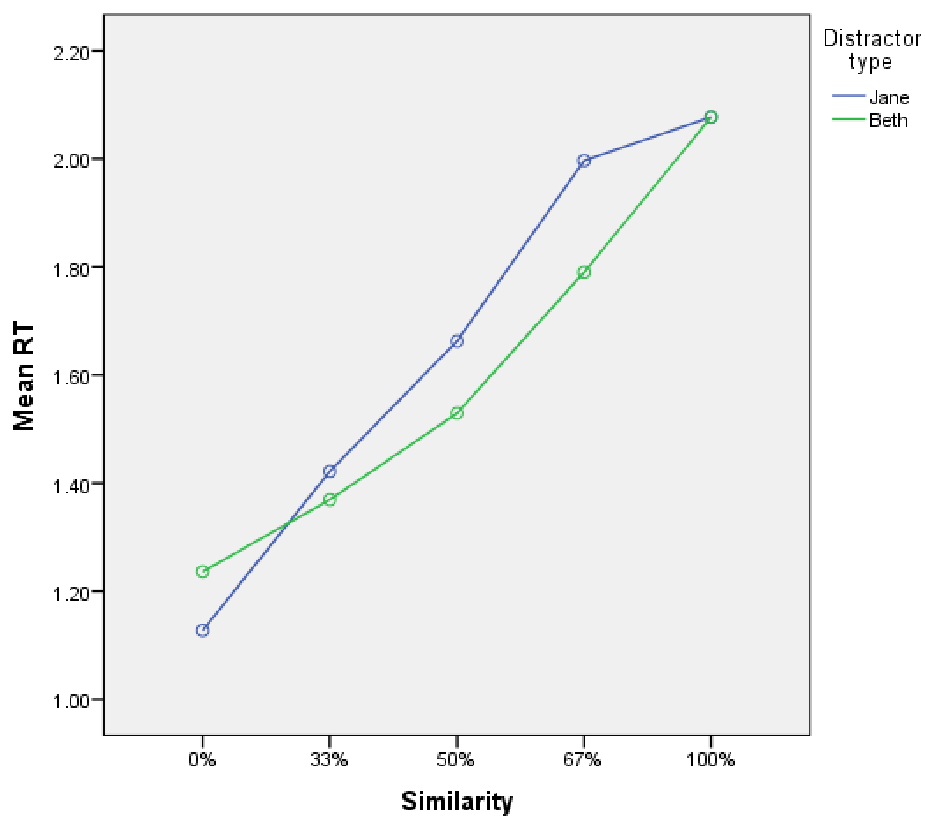

Figure 3.6. The relationship between similarity levels and mean reaction times (in sec) for the different types of distractors in each block. Notice that the reaction times when presented with Beth distractors was faster than when presented with Jane distractors for all similarity levels apart from 0% similarity.

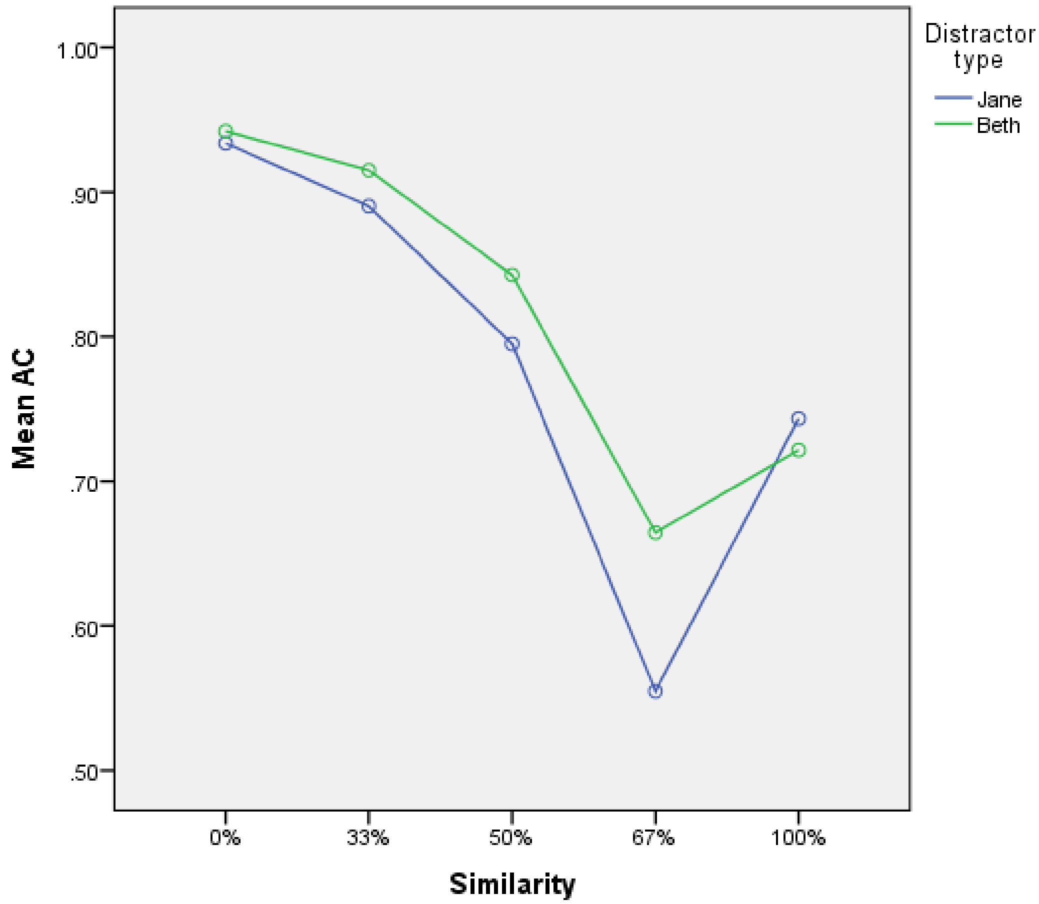

Figure 3.7. The relationship between similarity levels and mean accuracy (proportion correct for the different types of distractors in each block. Notice that accuracy decreased in the same way for both distractor types, as similarity levels increased.

Results of Experiment 3B.

Crowd Size.

As shown in figure 3.8, there was a main effect of crowd size on reaction time, $F(1.5,32.9)=144.2$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=8.6$, $p<.05$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.75$). Pairwise comparisons showed that the reaction time for crowd size was significantly different among all sizes. In particular, the larger the crowd size, the slower the reaction times (in sec); crowd size 4 (M=1.4, 95% CI [1.3 1.5]), crowd size 8 (M=1.64, 95% CI [1.53 1.74]), and crowd size 12 (M=1.76, 95% CI [1.65 1.87]).

There was also a main effect of crowd size on accuracy, $F(2,44)=33.56$, $p<.0001$. Pairwise comparisons showed that the accuracy was significantly different among all crowd sizes. In particular, the larger the crowd size, the lower the accuracy; 4 (M=.88, 95% CI [.86 .9]), 8 (M=.84, 95% CI [.82 .87]), and 12 (M=.78, 95% CI [.75 .81]). As shown in Figure 3.9, crowd size also had a significant main effect on Proportion "long", $F(2,44)=6.4$, $p<.005$. The larger the crowd size, the smaller the probability of responding 'long' (this corresponds to a right shift on the psychometric curve); 4 (M=.47, 95% CI [.31 .51]), 8 (M=.44, 95% CI [.41 .48]), and 12 (M=.43, 95% CI [.4 .46]). Post hoc comparisons showed that the crowd size of four faces was significantly different (i.e., the duration estimations were significantly longer) than the larger crowd sizes of eight and 12, $p<.05$. However, there was no significant difference between the crowd sizes of eight and 12.

In summation, results indicate that an increase in crowd size was related to both an increase in reaction times (slower response rate) and a decrease in accuracy (fewer accurate responses). Furthermore, larger crowd sizes were also associated with a smaller probability of responding 'long' and, consequently, shorter time estimations.

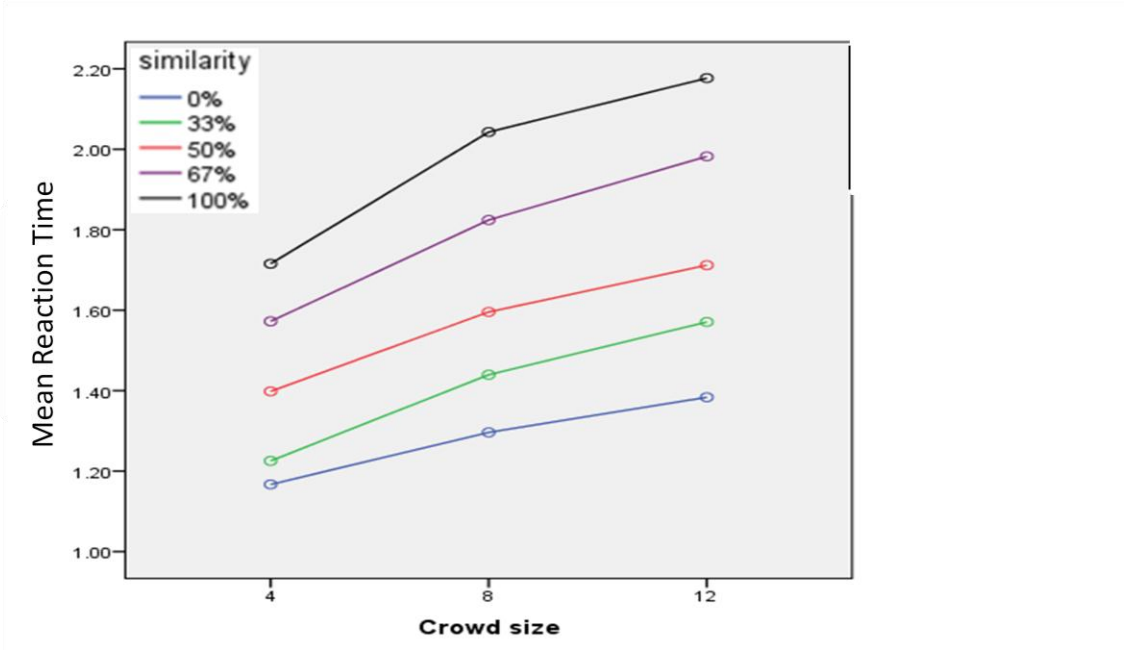

Figure 3.8. The relationship between crowd size and similarity levels on mean reaction time (in sec). Notice that an increase in crowd size as well as in similarity levels is associated with an increase in the processing speed for the visual search task . In addition, an interaction between similarity and crowd size shows that low similarity trials (e.g., 0% similarity - blue curve) have a shallower slope than higher similarity levels (e.g., 100% similarity - black curve).

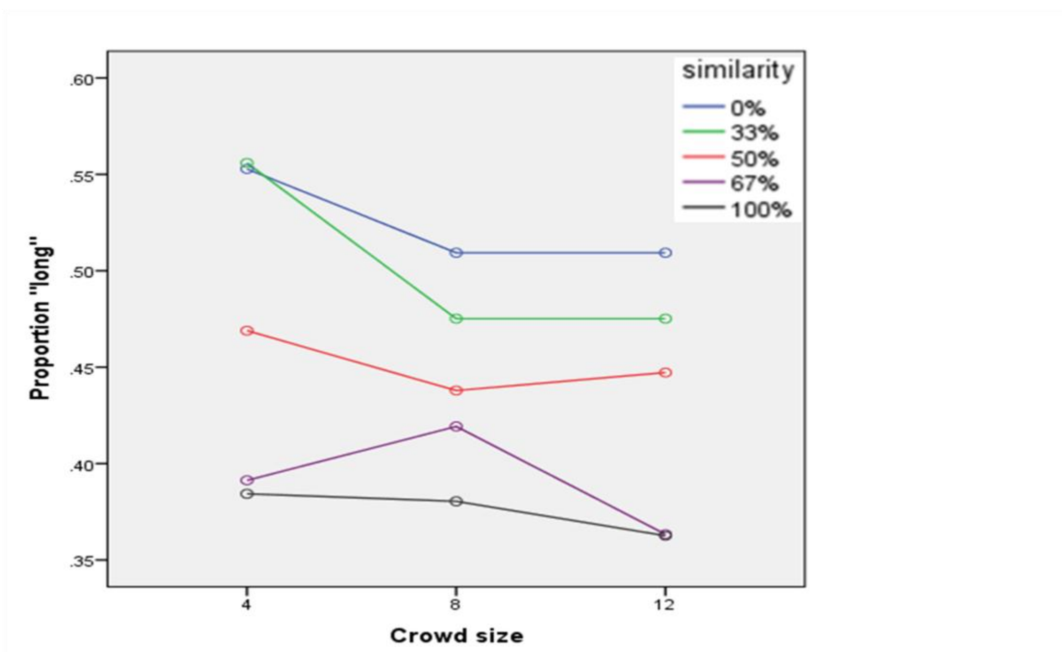

Figure 3.9. The relationship between crowd size and similarity levels on mean proportion “long”. Notice that an increase in crowd size as well as in similarity levels is associated with a decrease in the proportion “long” estimates for the timing task .

Similarity.

There was a main effect of similarity on reaction times, $F(1.9,42.3)=12.4$, $p<.0001$ (see figure 3.8). Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=51.1$, $p<.001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.48$). Pairwise comparisons showed that the similarity between target and distractor significantly influenced the reaction times. As similarity increased, the task became more difficult, and the longer the processing time required to reply to the faces, $p<.001$.

There was also a main effect of similarity on accuracy, $F(1.6,36)=45.8$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=74.3$, $p<.001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.4$). Pairwise comparisons showed that there were significant differences in accuracy between each similarity level ($p<.05$) except between 50% and 100% similarity. Results indicate that as the task increased in similarity (i.e., difficulty), the less accurate the responses became. However, the 67% similarity level showed the lowest accuracy levels (M=.6, 95% CI [.54 .67]). Furthermore, figure 3.9 shows that an increase in similarity levels is associated with the decrease in probability of responding 'long'. Figure 3.10 and 3.11 illustrates this decrease in proportion "long" responses as similarity levels increase for Jane and Beth distractors respectively. In particular, as depicted in Figure 3.12, the 800 ms and the 1000 ms durations showed the largest decrease in 'long' responses as the similarity increased. When fitting a curve to the data, it was apparent that the bisection point analysis confirmed this result, as there was main effect of similarity on bisection point, $F(2.7,60)=19.5$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated (χ^2=19, p<.05), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=.68). As the similarity between the target and the distractor increased, the bisection point increased (the curve shifted to the right). Pairwise comparisons show that all nonconsecutive similarity levels showed significantly different bisection points, p<.05. The most accurate bisection points (closest to 4 (on a 1-7 linear scale, 4 corresponds to the 800 msec duration)) were obtained on trials with the least amount of similarity 0% (M=3.87, 95% CI [3.5 4.2]), and 33% (M=4, 95% CI [3.8 4.3]).

There was also a significant main effect of similarity on Weber's ratio, F(4,88)=4.3, p<.005. Specifically, as with the bisection point, the Weber's ratios increased (indicating less discriminability) as similarity levels increased. Pairwise comparisons showed that there were significant differences among the Weber's ratios for the highest similarity level 100% (M=.5, 95% CI [.42 .61]) and the lowest similarity level 0% (M=.3, 95% CI [.2 .39]), as well as similarity level 33% (M=.37, 95% CI [.25 .48]), p<.05.

In conclusion, the results indicate that an increase in similarity between target and distractor was associated with an increase in reaction times, a decrease in accuracy (though the 67% similarity level showed the lower accuracy levels), a decreased probability of responding 'long' (particularly in trials with 800 ms and 1000 ms frame duration), an increase in bisection point, and an increase in Weber's ratio.

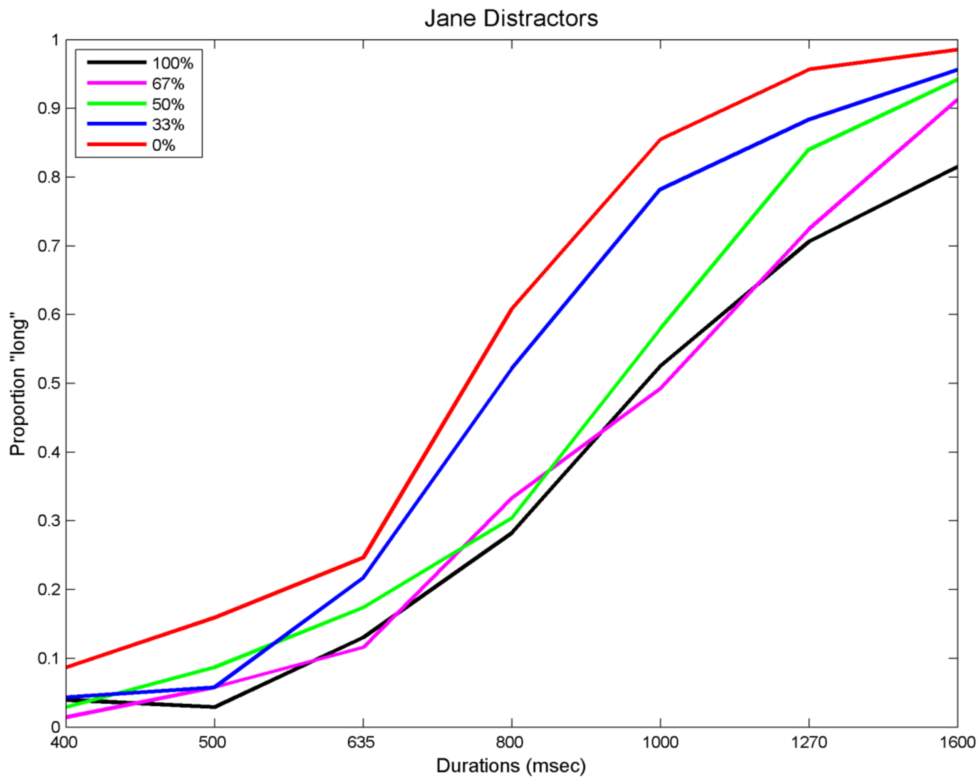

Figure 3.10. The relationship between durations (in msec) and proportion “long” estimates for the different similarity levels (ranging from 0% to 100%) for Jane distractor block. Notice that an increase in similarity levels is associated with rightward shifts in the curves (shorter time estimations).

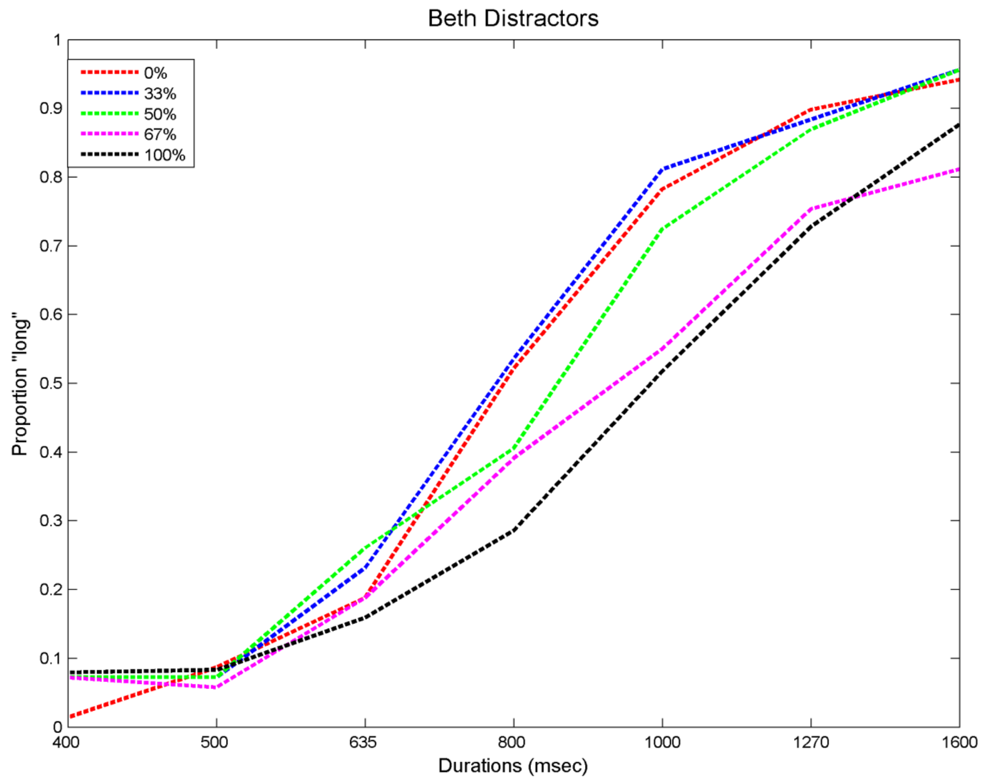

Figure 3.11. The relationship between durations (in msec) and proportion "long" estimates for the different similarity levels (ranging from 0% to 100%) for Beth distractor block. Notice that an increase in similarity levels is associated with rightward shifts in the curves (shorter time estimations).

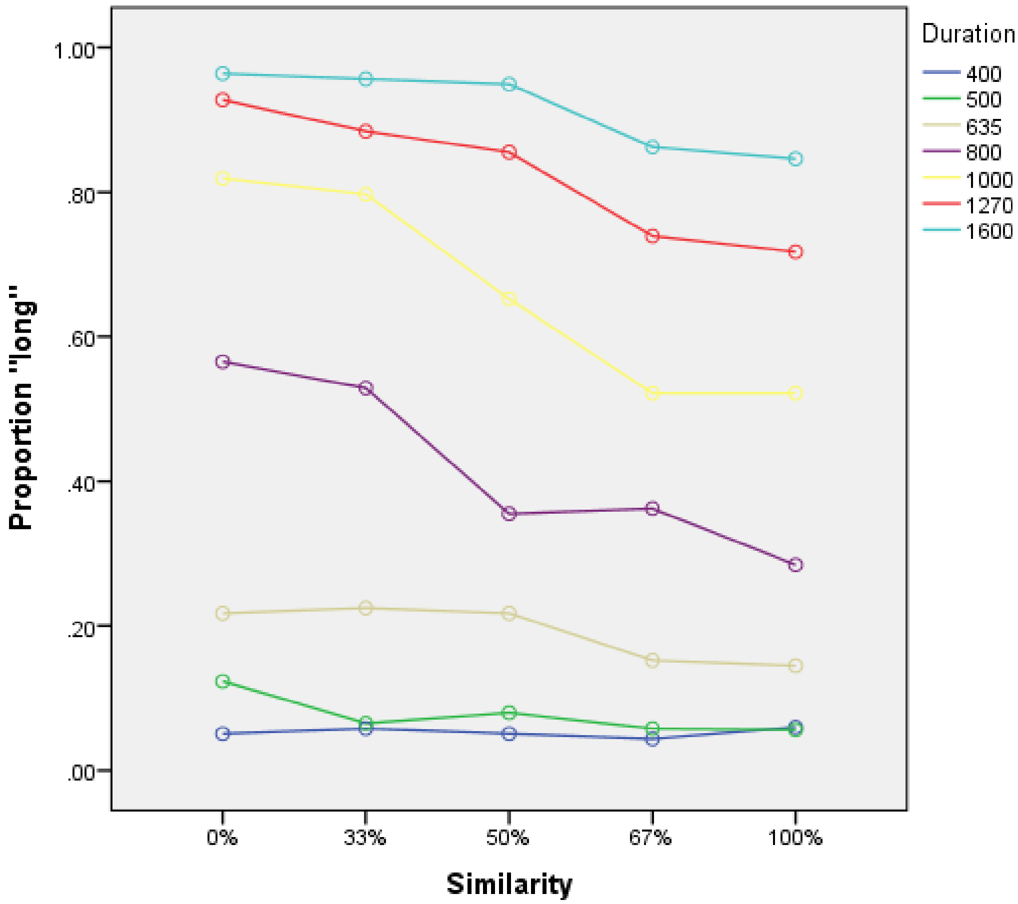

Figure 3.12. The relationship between similarity levels and proportion "long" estimates for the different frame durations (in msec). Notice that the 800 ms and the 1000 ms durations showed the largest decrease in 'long' responses as the similarity levels increased.

Crowd Size x Similarity.

There was a significant interaction effect between crowd size and similarity on reaction times, $F(8,176)=4.87$, $p<.001$. Reaction times increased as difficulty increased for all crowd sizes, though the increase was smaller for the trials with low similarities between target and distractor (easy task) and more pronounced as the similarity levels increased (more difficult). This interaction was also significant for accuracy, $F(5, 109)=3.46$, $p<.01$. Mauchly's test indicated that the assumption of sphericity had been violated (χ^2=72.2, p<.001), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=.62). Accuracy levels decreased as similarity increased for all crowd sizes, though this increase was very small on low similarity (easier) trials and much more pronounced on the higher similarity (harder) trials.

Distractor Type.

The differences between the Jane and Beth distractors on reaction times were not significant, F(1,22)=5.47, p=.46. In addition, there was no significant difference in accuracy between the Jane and Beth distractors, F(1,22)=.83, p=.37. Furthermore, following the curve fitting analysis, using Weibull fits, it was evident that there was no significant difference between the bisection points of the two distractor types F(1,22)=.86, p=.7, nor was there a significant difference between the Weber's ratios (i.e. slopes of the psychometric curve), F(1,22)=2.34, p=.14.

Distractor x Similarity.

Interestingly, there was an interaction between distractor type and similarity levels on reaction times, F(4,88)=12, p<.0001. Results indicate, as shown in Figure 3.13, that when presented with Beth distractors, the reaction times were faster for all similarity levels apart from 0% similarity. The accuracy Results of this interaction were not significantly different F(2.4, 53)=2.96, p=.05. Accuracy levels for Jane and Beth distractors across similarity levels are summarized in Figure 3.14, indicating that the participants were able to perform the visual-search task in the time constrains of the task while still achieving a high degree of accuracy.

This interaction also significantly affected mean proportion “long”, $F(4,88)=3.46$, $p<.05$. As depicted in Figure 3.15, when the distractor was Beth, the probability of responding ‘long’ was greater than when Jane was the distractor across all similarity levels, except for 0% similarity. When assessing the bisection points, the interaction between bisection points of distractor type and similarity levels was also significant, $F(4,88)=2.52$, $p<.05$. The bisection points, when presented with Jane distractors, were larger than when presented with Beth distractors, for all similarity levels apart from the 0% similarity level, as presented in figure 3.16. The Weber’s ratios were not significantly different across similarity levels, $F(4,88)=1.05$, $p=.38$.

In summary, the interaction between distractor type and similarity levels emphasized the association between reaction times and Proportion “long” as both were larger for Beth distractors for all similarity levels apart from 0% similarity. Bisection point analysis strengthens this association by revealing smaller bisection points for Beth distractors for all similarity levels with the exception of 0% similarity. The association between the proportion “long” and reaction times is apparent in Figure 3.17, for the different distractor types, for each similarity level, as a function of durations.

For a closer comparison between the speed of processing required of the participants to perform the visual search task (i.e., reaction time) and the proportion of ‘long’ responses in the timing task, a correlation was preformed. The correlation between reaction time (on x-axis) for the non-temporal task and Proportion “long” (on y-axis) for the temporal task was made by plotting 25 data points consisting of the five similarity levels by five durations points (intermediate durations without reference durations) for each participant independently. Each data point (either for reaction time or for Proportion “long”) was a difference score between the Jane and Beth distractors in the identity experiment. Data showed a negative correlation between reaction times and Proportion “long”. This indicates that an increase in the difference between the reaction times of the distractors is associated with a decrease in the difference between the Proportion “long” of the distractors and vice versa (r= -.22, SD=.25). Group data using the difference between the distractors for the five similarity levels, three crowd sizes, and five durations (total of seventy-five data points) were plotted to illustrate these differences (see Figure 3.18). Notably, the intercept for the correlation (M= -.01, SD=.086) was approximately centered at the axis origin (x-axis=y-axis). The figure shows that most data points fall either on the second quadrant (−,+) or the fourth quadrant (+,−), indicating that when the Jane block showed an increase in reaction times compared to the Beth block, it typically also showed a decrease in proportion “long” compare to the Beth block (per condition), and vice versa.

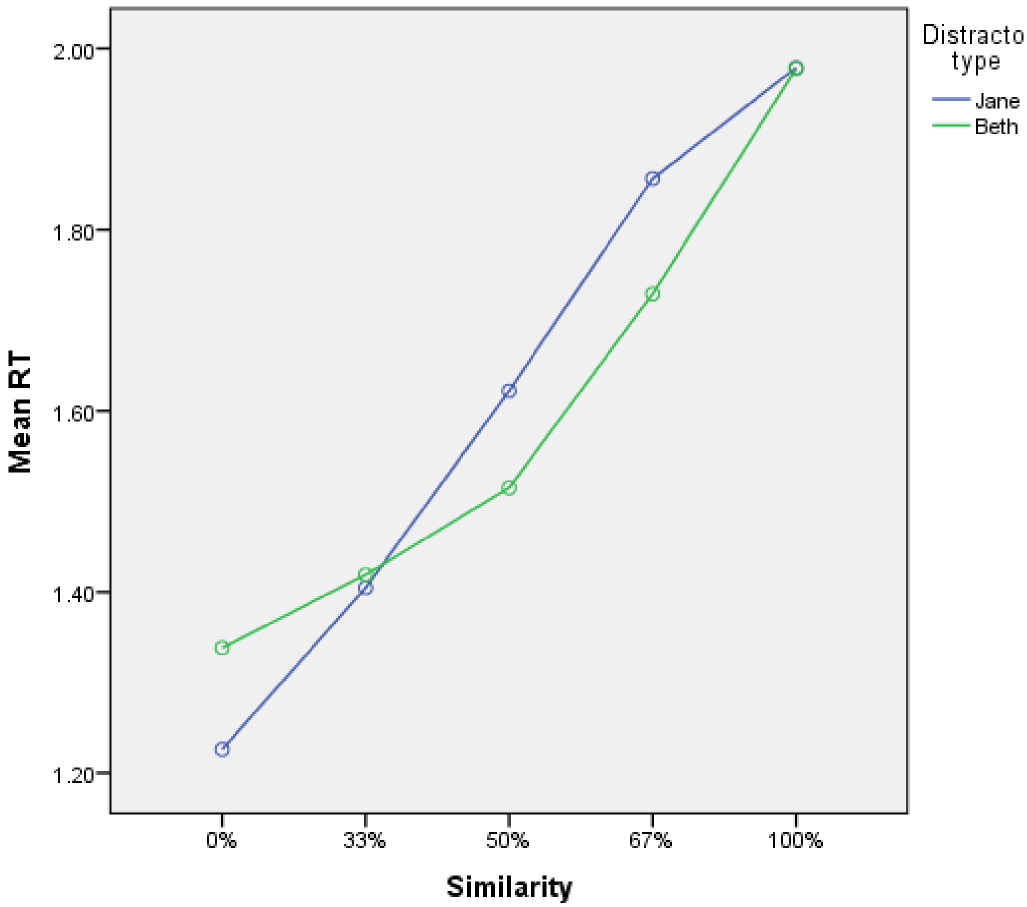

Figure 3.13. Mean reaction times (in sec) obtained for the different similarity levels for the two types of distractors. Notice that when presented with Beth distractors, the reaction times were faster for all similarity levels apart from 0% similarity.

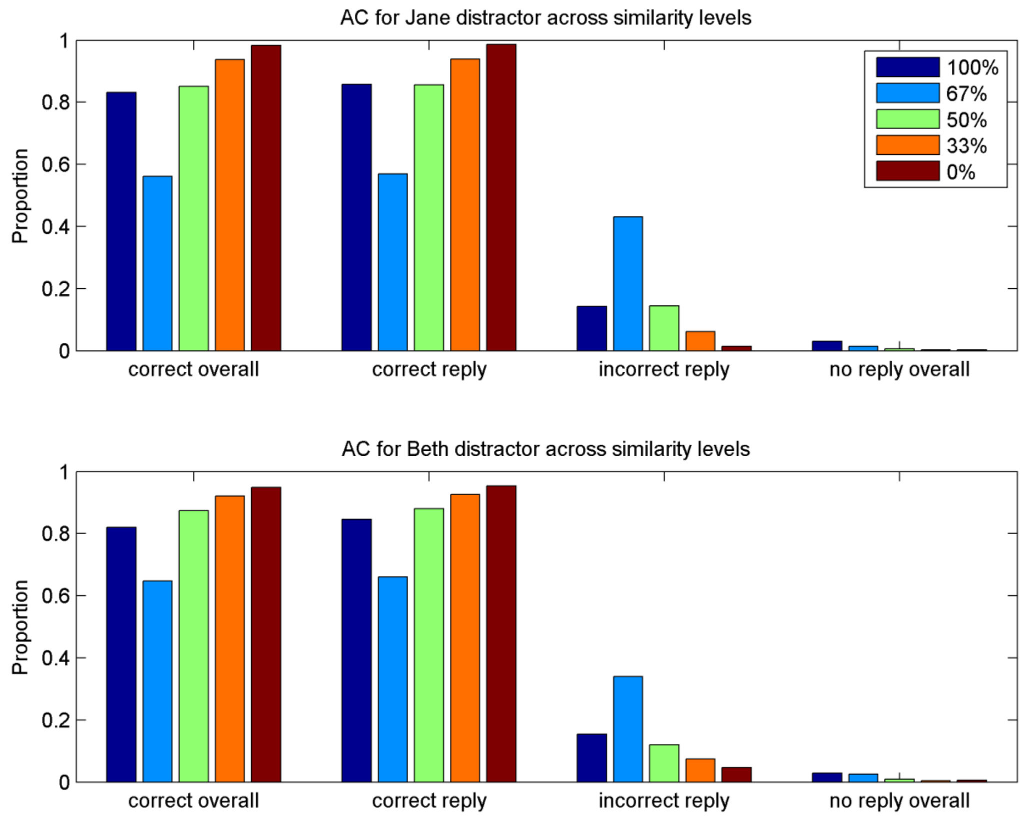

Figure 3.14. Accuracy levels for Jane (top figure) and Beth (bottom figure) distractor types for the different similarity levels (ranging form 0% to 100%). This figure shows that the participants were able to perform the visual-search task in the time constrains of the task while still achieving a high degree of accuracy, for both distractor types.
*Proportion correct overall – correct replies out of all trails.
*Porportion correct reply - correct replies out of all trials with responses.
*Proportion incorrect reply – incorrect reply out of all trails with responses.
*Proportion no reply overall – proportion of trials with no reply.

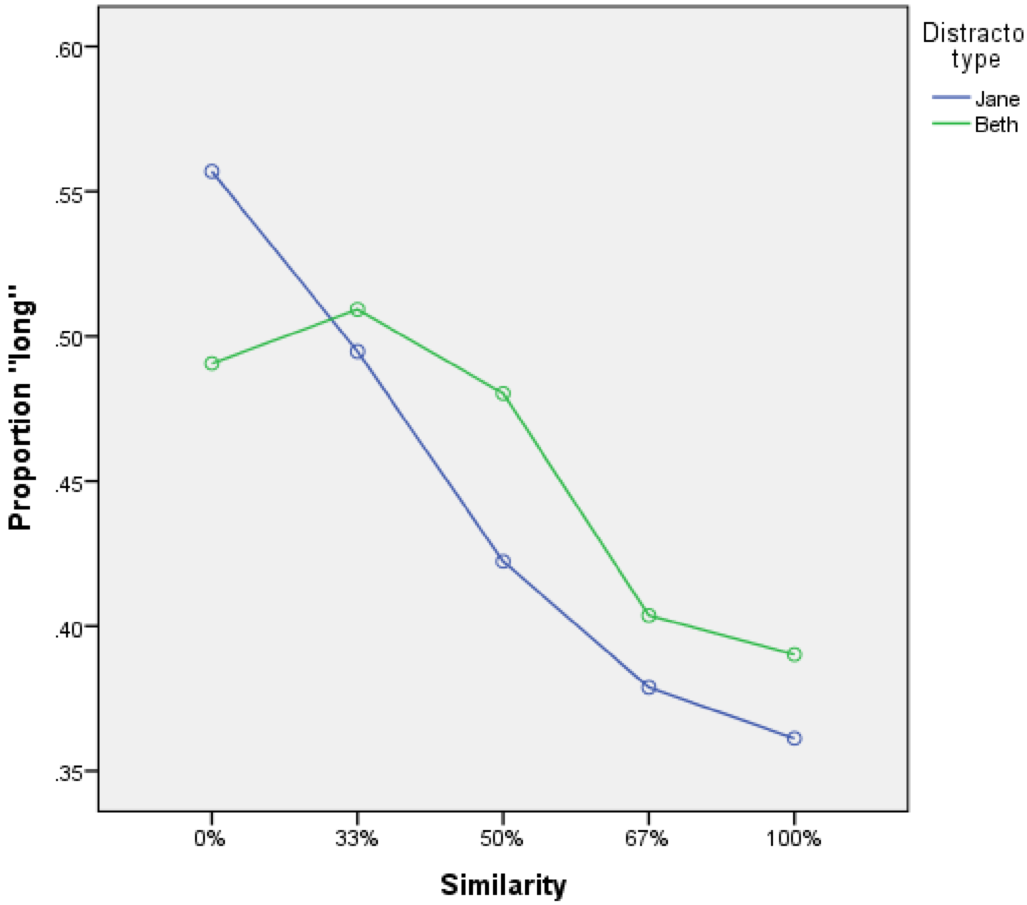

Figure 3.15. Proportion “long” responses for different similarity levels for the two types of distractors. Proportion “long” responses are higher for trials with Beth distractors compared with Jane distractors for all target-distractor similarity levels except for 0%.

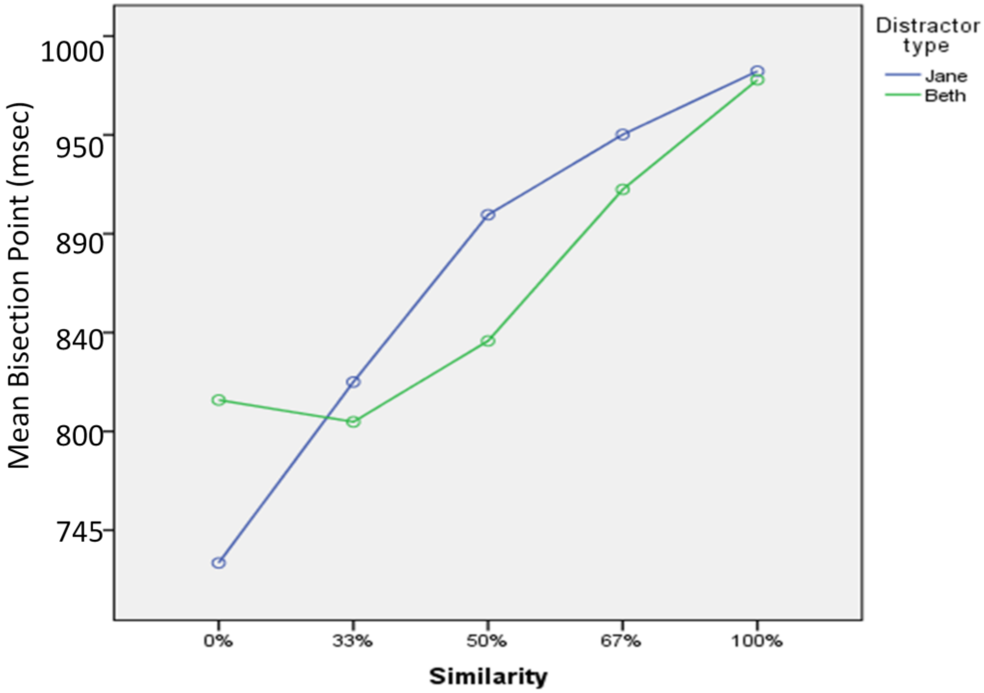

Figure 3.16. Mean bisection point (in msec)* estimates for different similarity levels for the two types of distractors. The bisection points, when presented with Jane distractors, were larger than when presented with Beth distractors, for all similarity levels apart from the 0% similarity level.
* Bisection points (in msec) converted into the 1-7 linear scale: 745=3.75, 800=4, 840=4.25, 890=4.5, 950=4.75, 1000=5.

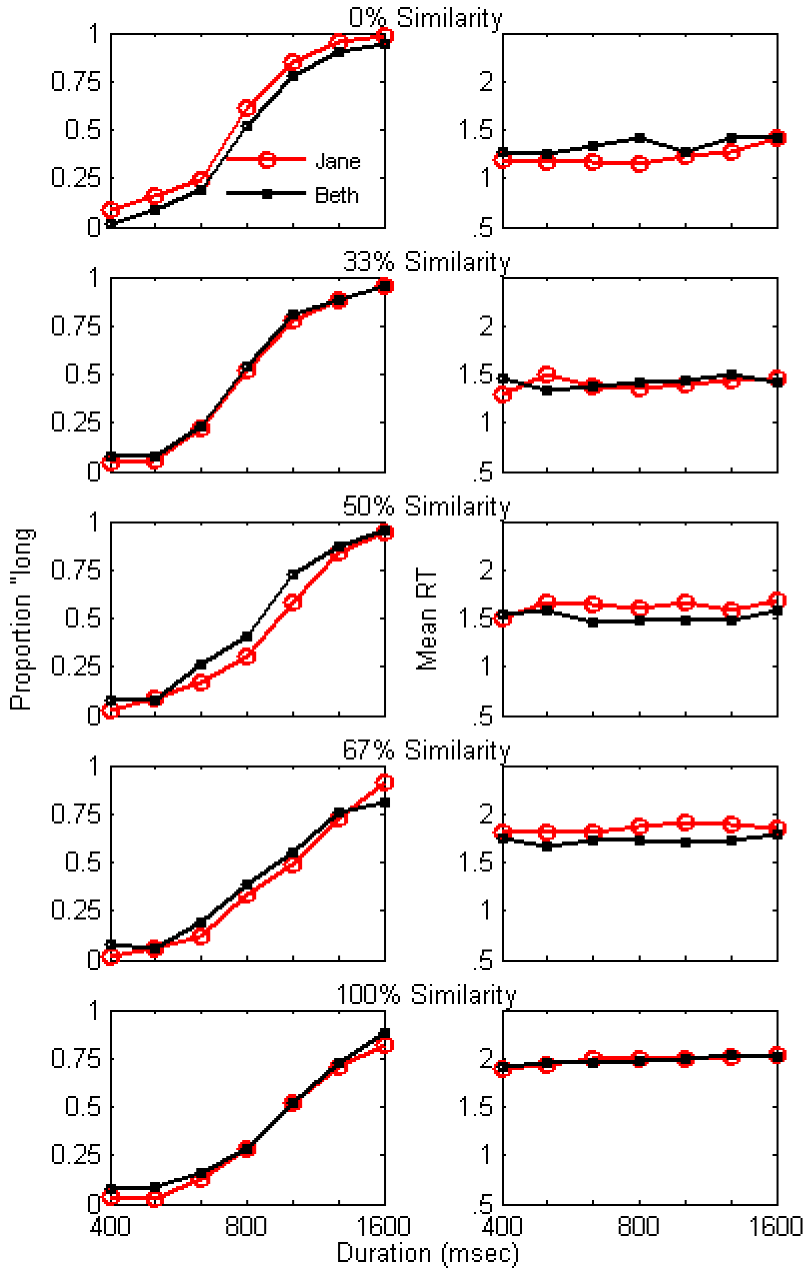

Figure 3.17. The relationship between durations (in msec) and proportion "long" (right) and mean reaction times (in sec) (left) for the different similarity levels (ranging from 0% on top to 100% on the bottom) for Jane (red) and Beth (black) distractor types.

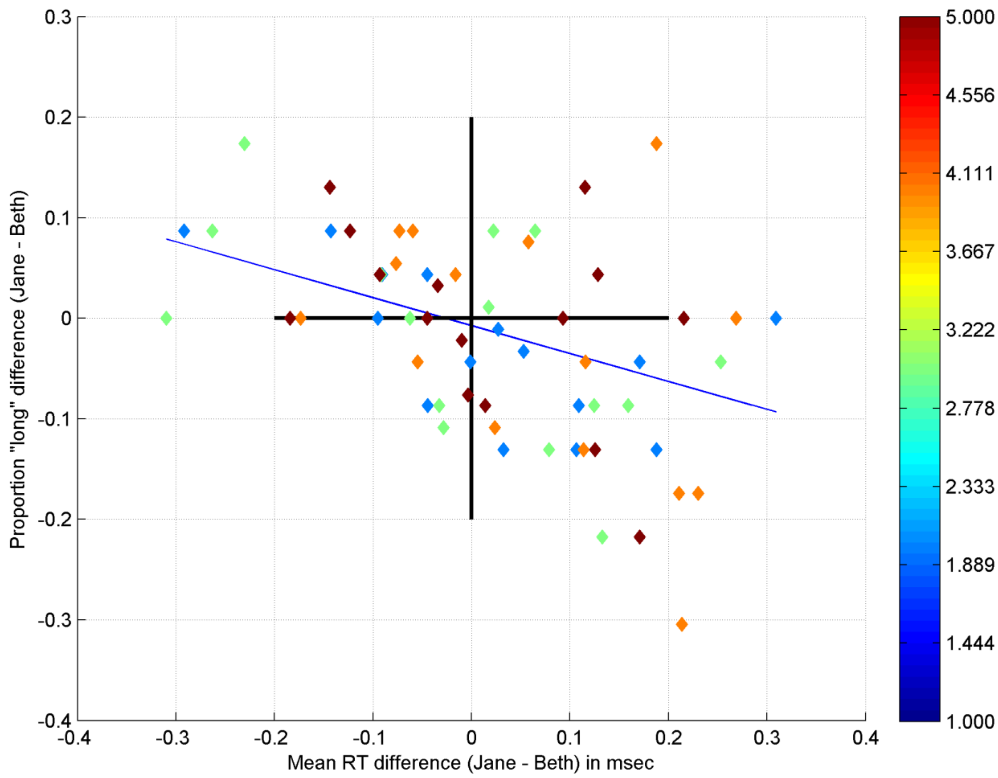

Figure 3.18. Relationship between the mean reaction times difference*[1] between Jane and Beth distractors (in sec), and the proportion "long" difference*[2] between Jane and Beth, per five similarity levels, three crowd sizes, and five durations (total of seventy-five data points). Colors represent the five frame durations (on a scale from 1 to 5 representing durations ranging from 500 to 1270 msec). Notice a strong correlation between the processing speed of the visual search task and the proportion "long" estimates of the timing task when comparing the differences between the Jane and Beth blocks.

*[1]Reaction times difference was calculated by subtracting mean RT during the Jane block by mean reaction times during the Beth block (per condition).

*[2]Proportion "long" differnce was calculated by subtracting proportion "long" during the Jane block by proportion "long" during the Beth block (per condition).

Results of comparison (3A vs. 3B).

The comparison demonstrated no significant difference in reaction time between Experiment 3B with the time estimation task and Experiment 3A without, $F(1,22)=.42$, $p=.5$. However, the response accuracy increased due to practice effects in Experiment 3B as compared to 3A, as shown in Figure 3.19, $F(1,22)=5.76$, $p<.05$. This increase was most pronounced in the 100% similarity differences, where participants were to reply “target absent” as indicated by the significant interaction between session and similarity, $F(3,68)=3.17, p<.05$. Mauchly’s test indicated that the assumption of sphericity had been violated ($\chi^2=25.6$, $p<.005$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.77$). Interestingly, the interaction effect between session and crowd size was also significant $F(2,44)=23.45$, $p<.001$. Both of the larger crowd sizes (eight and 12 faces) showed improved reaction time (faster reaction time) between Experiment 3A and 3B, however, the small crowd size (four faces) increased reaction time in Experiment 3B (see figure 3.19). The accuracy differences for this interaction effect was not significant, $F(2,44)=1.65$, $p=.2$.

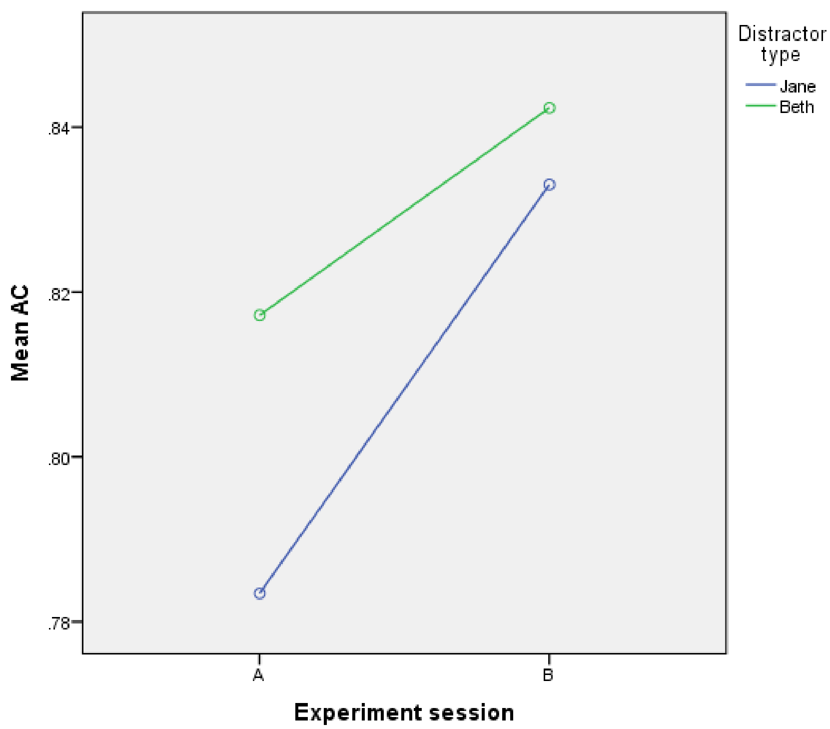

Figure 3.19. Effects of experimental session (A – single task vs. B – dual task) on Mean Accuracy (AC; in proportions correct) for the two types of distractors. Notice that accuracy was better with Beth distractors than Jane, and participants were more accurate when performing the visual search task the second time.

Discussion of Experiment 3

The results showed that the attentional manipulation in this experiment significantly influenced the reaction times and accuracy levels of the participants. Specifically, results indicated that both the increase in crowd size and the increase in similarity levels were associated with an increase in reaction times and a decrease in accuracy levels. These results were presented in both Experiment 3A and 3B and therefore strengthened the interpretation that the visual search task was a reliable and consistent means for manipulating attention.

As the visual search became more difficult, the trials demanded more attentional resources which affected the participants' reaction time. In addition, since participants were asked to respond during the presentation of the faces on the screen (i.e., a limited window of time), their accuracy levels were also reduced due to the increase in difficulty. Interestingly, accuracy levels were higher when replying "absent" at 100% similarity than replying "present" at 67% similarity. This difference in accuracy was likely due to the very small differences at 67% similarity, which stimulated the participants to reply "absent" even though the target was present.

As with standard visual search paradigms (Treisman & Gelade, 1980), the interaction effects are of most importance. Evaluating the interaction between crowd size and similarity on reaction time and accuracy levels emphasized the effects of the different similarity levels on search rates. Specifically, when it was easy to find the target within the distractors (i.e., trials with low similarity levels) there was only a small increase in reaction time and decrease in accuracy as the crowd size increased. However, when it was hard to find the target face (i.e., high similarity levels) the increase in reaction time and the decrease in accuracy were much greater. This result implies that when the target face is easy to detect, the crowd size has little effect on the search speed and accuracy. However, when the target is difficult to detect, the increase in crowd size notably influences search speed. This result is in accordance with claims of parallel search for low similarity levels and serial search for high similarity levels (Wolfe, 1994).

The comparison between Experiment 3A and 3B provides an indication for the differences between performing the visual search task with and without the temporal bisection task, in addition to straightforward practice effects. An increase in accuracy (fig. 3.19) in Experiment 3B was likely due to the practice effects. However, the interaction effect on reaction time between session and crowd size, which showed faster reaction times in Experiment 3B when participants were presented with many distractors on the screen (eight or 12), though slower reaction time when presented with few distractors, was likely due to the dual-task procedural difference. Particularly, when presented with four distractors, the reaction times were fast, thus, they occurred early on in the trial. It is likely that by adding a frame to be timed close to the beginning of the trial, participants were forced to respond to the visual search task during the frame's presentation on the screen (as opposed to later responses made after the frame's disappearance, for the trials with larger crowd sizes). Therefore, the dual task procedure (visual search and bisection timing task) influenced the reaction time for the trials with small crowd size, increasing their reaction times.

By performing a dual task that involved both visual search and time estimation, it was possible to study the association between the reaction time results and the time estimations reported. Executive attentional load, manipulated by difficulty of the task, and measured by the processing speed (i.e., participants' reaction time in the visual search task) influenced the proportion "long" estimates, and bisection points of the psychometric curves. Specifically, results indicate that when crowd size and/or similarity levels increase, reaction times also increase (slower reaction times), and the probability of responding 'long' decreases (shorter time estimations and larger bisection points). This association is consistent with the results found in Experiment 2B and with the idea that time perception is determined by the amount of attention allocated to time (Block et al., 2010). Longer processing speeds required for the non-temporal task shifts attention away from the timing task, therefore, according to the AGM, less pulses are accumulated in the accumulator and subjective time estimates become shorter.

As expected by the experimental design, there were no significant differences between reaction times, accuracy levels, proportion "long", bisection points, or Weber's ratios between the distractor types (i.e., Jane and Beth). However, a significant interaction effect between distractor type (i.e., morphed stimuli of 0% or 100% of Beth) and similarity on reaction times was observed. These differences might be attributed to the different features of the identities. Though the design of the task did not intend for a significant difference between distractors (i.e., no difference in accuracy levels), a difference in reaction times was observed between distractors. Moreover, this interaction effect on reaction time was consistent between experimental sessions (see figures 3.6 and 3.13 for comparison). Interestingly, when comparing the reaction time Results of this interaction (figure 3.13) with the interaction found for proportion "long" estimates and bisection points (figures 3.15 and 3.16 respectively), the figures present the same interaction. Particularly, as shown in Figure 3.15, for Beth distractors the probability of responding ‘long’ was greater than for Jane distractors across all similarity levels, except for 0% similarity, in comparison of figure 3.13, for which reaction time was faster for Beth distractors across all similarity levels, except for 0% similarity. Moreover, when comparing the bisection point results with the reaction time results (compare Figure 3.16 with Figure 3.13), these measures appear interrelated. This implies that the process which influenced the participants’ reaction times also influenced the participants’ time estimations in a compatible manner. Specifically, a demanding non-temporal task was associated with an increase in the participants’ reaction times and a decrease in the participants’ time estimations.

The correlation between the distractor differences for reaction time and Proportion “long” highlights the way in which these processes interact. Specifically, Figures 3.17 and 3.18 illustrates how an increase in reaction time for Jane distractors is associated with a decrease in Proportion “long” estimates for that distractor in comparison to Beth distractos, and vice versa.

This experiment, therefore, strengthens the proposition that time perception estimations are related to, and influenced by, the attention allocated to temporal processing (i.e., executive attention). An increased in difficulty of a non-temporal task systematically increases reaction time allocated to processing the face stimuli, thus allowing fewer resources for the timing of the duration of the task. Fewer resources allocated towards timing results in shorter subjective time estimations.

For both sessions of Experiment 3, all morphed stimuli (i.e., target and distractors) presented a neutral facial expression. In each block, the task was to find a target with facial features related to a different identity. However, the target presented the same facial expression as the distractors, therefore there was no theoretical advantage for finding Beth or Jane in a crowd of distractors. By modifying the task to include emotional facial expressions (i.e. angry faces), an additional element of attention could be addressed - specifically, the effects of orienting and alerting.

EXPERIMENT 4. TEMPORAL BISECTION WITH EMOTIONAL EXPRESSIONS SEARCH TASK

This experiment was designed to assess the effects of emotional arousal on attention, by studying the effects of the three control networks of attention: executive control, orienting, and alerting as influenced by the emotional component. Specifically, this experiment combined the facial expression continuum, between angry and neutral, that manipulated emotional arousal (as used in Experiment 2) with the visual search task that manipulated attentional load (as used in Experiment 3). The combination of emotional arousal and attentional load in one procedure enabled the investigation of their interaction. Furthermore, the addition of the temporal bisection task (in Experiment 4B) allowed for the assessment of how the interaction between attention and emotional arousal, influenced subjective time estimations.

The use of emotional facial expressions in the visual search task has probably been the most prevalent method used to study the effects of emotion on attention (e.g., Calvo et al., 2006; Eastwood et al., 2001; Hahn & Gronlund, 2007; Horstmann & Becker, 2008; Juth et al., 2005; Lamy et al., 2008; Schubo et al., 2006; Williams et al., 2005). If an emotional expression can draw attention (i.e., orient the participant) to a face more readily than a neutral expression, then search efficiency (measured by reaction time differences in response to crowd sizes) for the emotional face target should be fairly unaffected by the number of distractors. In addition, if attention is more readily available (i.e., increased alerting) to an emotional expression as compared to a neutral expression, then there is a search asymmetry.

A search asymmetry occurs when two conditions require different attentional resources; for example, when it is easier to find a target within the distractors in one condition and difficult to find the target within the distractors in the second condition. More specifically, an efficient search occurs when the target spontaneously captures attention because it differs from its background along a simple dimension (e.g., the target "Q" is detected efficiently within "O" distractors), and an inefficient search occurs when the search requires attention to be shifted serially across the entire display to recognize the target (e.g., the target "O" is detected inefficiently within "Q" distractors) (Treisman & Gormican, 1988; Treisman & Souther, 1985; Wolfe, 2001;Wolfe, 2003; Wolfe et al., 2011).

Hansen and Hansen (1988) were the first who reported a classical search asymmetry for an angry face target among happy face distractors. They found that angry faces were detected faster than happy faces because of an early, stimulus-driven analysis of threat-related properties. This was later referred to as the threat-advantage hypothesis, which describes an evolutionary advantage to detect threatening stimuli more promptly and efficiently than non-threatening stimuli. Many subsequent experiments, using either photographic images or schematic illustrations of facial expressions, attempted to address this asymmetry (e.g., Eastwood et al., 2001; Fenske & Eastwood, 2003; Fox et al., 2000; Horstmann, 2007; Horstmann et al., 2006b; Ohman et al., 2001; White, 1995; Gerritsen et al., 2008; Pinkham et al., 2010). Overall, the findings suggest that emotional facial expressions, particularly angry expressions, typically attract attention (i.e., attentional orienting) relative to neutral faces, and the search for them is little affected by the number of the neutral distractors.

In addition to the attentional allocation to a target stimulus, reaction time in visual search tasks may also be related to the ability of the participant to suppress the irrelevant distractors (Weissman et al., 2009). Angry distractors, for example, may capture attentional resources, the disengagement from the angry faces would be slower, and consequently reaction times for target detection would increase.

This experiment incorporated a visual search task with morphed faces as the target and distractors, as in Experiment 3. However, the images of morphed faces came from an emotional continuum between a neutral and an angry expression of the same identity (as in Experiment 2). Therefore, search asymmetries are expected in this experiment, as different attentional processes are expected to be activated. The visual search task allowed us to vary the difficulty levels, by having different similarity levels and crowd sizes. Manipulation of difficulty levels influences the executive attentional resources and processing speed required for the task. However, adding emotional facial expressions to the visual search task allowed us to examine yet another subcomponent of attention and its interaction with emotion, namely orienting and alerting.

As mentioned, this procedure involves an asymmetry of search; the angry distractor block and in the neutral distractor block require different attentional resources related to orienting. Participants would theoretically allocate attentional resources to the angry facial expressions faster than to the neutral facial expressions (i.e., engagement) (e.g., Pinkham et al., 2010). In addition, angry facial expressions theoretically capture attentional resources (i.e., slower disengagement when presented with angry faces)

(Weissman et al., 2009). Therefore, angry distractors likely demand more attentional allocation than neutral distractors.

The asymmetry of search in the two blocks (i.e., neutral vs. angry distractors) also stemed from different attentional alerting resources to the different blocks. Particularly, participants were instructed to search for “a more angry face among the neutral distractors” or “a more neutral face among the angry distractors”. Theoretically, searching for an angry face would require more alerting resources (i.e., vigilance) than when looking for a neutral face. However, as opposed to executive attention and orienting, in which the increased (slower) reaction times are associated with greater attentional allocation to the task; in alerting the relationship between resources and reaction time is positive. Namely, increased alerting is associated with faster reaction time (e.g., Raz & Buhle, 2006).

This experiment was divided into two sessions, starting with a single visual search task and concluding with a dual visual search task with a temporal component. Specifically, in Experiment 4A, participants were presented solely with the emotional visual search task. This allows the assessment of whether or not the differences in attentional allocation have a significant effect on participants’ reaction time and accuracy levels, as well as providing an introduction and practice for the subsequent experiment. Difficulty was manipulated by varying the similarity levels between the distractors and target, and by increasing the crowd size (i.e., number of distractors on the screen). Differences in similarity and/or crowd size would theoretically be associated with differential attentional resources (e.g., Wolfe, 1994) as in Experiment 3.

Experiment 4B included the same emotional search task as presented in Experiment 4A; however, in 4B the visual search task was accompanied with the temporal bisection task (as in Experiment 1A). This dual task situation allowed for an investigation of the association between emotion, attention and time estimations. The goal of this experiment was to study the effects of executive attention, alerting and orienting (as related to emotional arousal) on time perception estimations. The different similarity levels between the distractors and the target face, in addition to the range of crowd sizes, allowed for varied difficulty of search trials, as in Experiment 4A. Moreover, the different instructions per block (i.e., the target face category) and the orienting process (due to angry vs. neutral distractors), also influenced the attentional allocation to search trials. Therefore, the networks and the amount of attention allocated to the emotionally arousing faces presented in the search task were manipulated, and the effects of this interaction on time perception were studied in this task.

A key question to answer in the present experiment is whether or not increased attentional allocation (executive attention, orienting or alerting) towards the facial expression presented on screen, will strengthen the effects of the expressions on time estimation and result in an overestimation of subjective time or will the enhanced executive attention overpower the subjective lengthening effect found with angry expressions and result in an underestimation of subjective time.

Methods of Experiment 4

Participants.

Twenty-four undergraduates at Brown University fulfilling course credits participated in both sessions of this experiment (Experiment 4A and 4B).

Apparatus.

See the Apparatus section in General Methods.

Procedure for Experiment 4A.

The procedural setup was identical to the one in Experiment 3A (see Figure 3.1), however, in this experiment, the morphed continuum was between a neutral and an angry facial expression, of one identity (e.g., Matt). This experiment was divided into two blocks (order counterbalanced), in which the participants were to search for a target face that varied from the distractors on the dimension of facial expression. In the first block, the faces on the screen that distracted from the target face (i.e., distractors) were all angry faces (0% of neutral), while in the second block the distractors were all neutral faces (100% of neutral). The target face was a morphed facial expression of: 0%, 33%, 50%, 67% or 100% of the neutral face, on the morphed continuum between angry and neutral (tested in Experiment 1B). Figure 4.1 illustrates 0% and 67% similarity levels in the angry distractor block.

Participants were to respond whether the target face was present or absent as fast as they could during the face presentation. A target face was defined as a facial expression that is “more angry among the neutral distractors” or “more neutral among the angry distractors”. Participants were advised that some of the differences may be very small and therefore they should focus carefully on the expressions of the faces.

See Experiment 3A for additional procedural details.

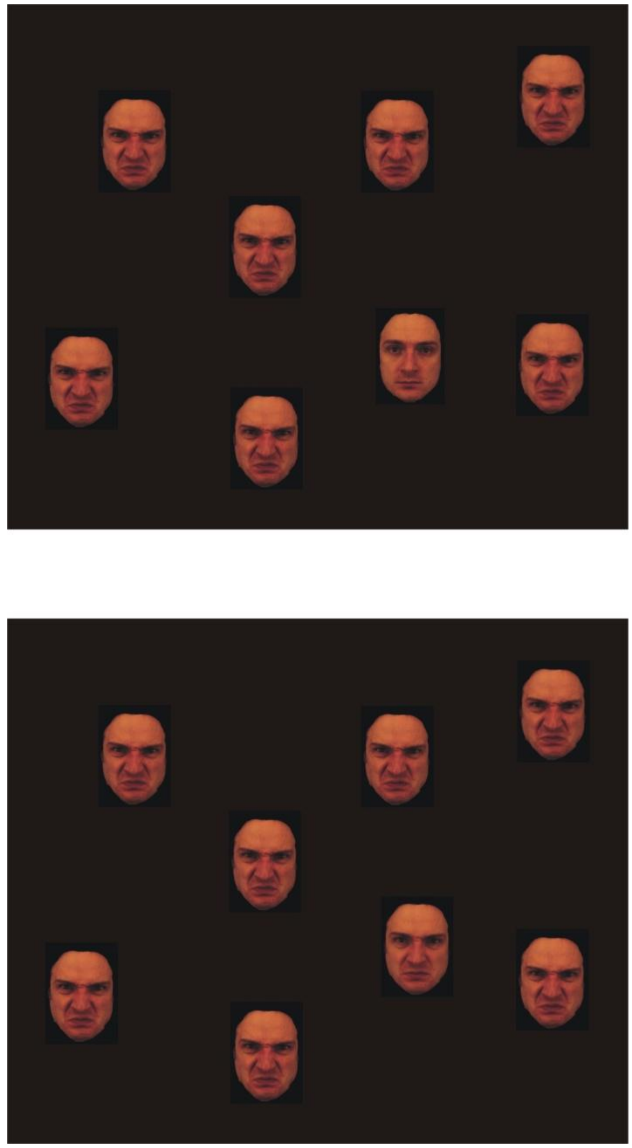

Figure 4.1. Illustration of faces presented on screen during the angry distractor block. Top screen represents 0% similarity (distracters are 0% of neutral and target is 100% of neutral). Bottom screen represents 67% similarity (distracters are 0% of neutral and target is 33% of neutral). Both screens depict crowd size of eight faces. {Target face is on the bottom, second from right}

Procedure for Experiment 4B.

The procedure for this experiment is identical to the procedure for Experiment 3B. However, for the present experiment the morphed continuum is between a neutral and an angry facial expression, of one identity (e.g., Matt).

General Methods of Analysis.

Measures for Experiment 4A are as in Experiment 3A, and for Experiment 4B are as in Experiment 3B, with the exception that the morph continuum is between angry and neutral facial expressions.

Results were analysed with a general linear model (GLM) repeated measures ANOVA. Reaction time and accuracy were analysed with an ANOVA with distractor type (angry vs. neutral), similarity of target to distractor (5 levels: 0%-100% of neutral) and crowd size (four, eight, or 12), as within-subject factors.

For Experiment 4B, in addition to the general Methods of analysis in Experiment 4A, mean proportion "long" was analysed with an ANOVA with crowd size (four, eight, or 12), distractor type (angry or neutral), and similarity of target to distractor (5 levels: 0%-100% of neutral) as within-subject factors. Further, an ANOVA with distractor type (angry or neutral) and similarity between target and distractor (5 levels from 0 to 100%) as the within-subject factor was used to analyse the differences between the bisection points and Weber's ratios. There were nine outlier bisection points and Weber's ratios that did not meet criteria. These values (~4% of the data) were excluded and replaced with the mean value for distractor x similarity values across participants.

To compare the reaction time and accuracy results found in Experiment 4A with those found in 4B, a general linear model (GLM) repeated measures ANOVA with distractor type (angry or neutral), similarity of target to distractor (5 levels ranging from 0-100%), crowd size (4, 8, or 12), and experimental session (4A vs. 4B) as within-subject factors was used.

Results of Experiment 4A

Crowd size.

There was a main effect of crowd size on reaction time, $F(2,46)=379.3$, $p<.0001$. Pairwise comparisons showed that the reaction time for crowd size was significantly different among all sizes. In particular, as crowd size increased, so did the reaction time (in sec); crowd size 4 (M=1.26, 95% CI [1.2 1.3]), 8 (M=1.6, 95% CI [1.55 1.67]), 12 (M=1.8, 95% CI [1.75 1.85]).

There was also a main effect of crowd size on accuracy, $F(2,46)=81$, $p<.0001$. Pairwise comparisons showed that the accuracy for crowd size was significantly different among all sizes. In particular, the larger the crowd size, the lower the accuracy (in proportion); 4 (M=.94, 95% CI [.92 .95), 8 (M=.89, 95% CI [.88 .92]), 12 (M=.79, 95% CI [.77 .82]). Therefore, results indicated that an increase in crowd size was associated with an increase in reaction time and a decrease in accuracy.

Similarity.

There was a main effect of similarity on reaction time, $F(2.4,56.1)=404.9$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=24.4$, $p<.005$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.6$). Pairwise comparisons showed that the similarity between target and distractor significantly influenced the reaction times to the faces. Particularly, the more similar, and therefore the more difficult the task, the longer the reaction time, $p<.001$.

Accuracy levels were also significantly effected by similarity, $F(2.5,58.6)=64.3$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=35$, $p<.001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.6$). Results indicate that as the task increased in similarity, and consequently in difficulty, the less accurate the responses became. However, the similarity level of 67% showed the lowest accuracy levels (M=.69, 95% CI [.65 .74]). Pairwise comparisons showed the accuracy at 0% and 67% similarity levels were significantly different than all other levels of similarity, $p<.05$. When the similarity was 0%, responses were the most accurate (M=.97, 95% CI [.96 .98]) while at 67% similarity responses were the least accurate. In conclusion, results indicate that increasing the similarity levels between target and distractor both increases the reaction times and decreases the accuracy levels (though the 67% similarity level was the least accurate).

Crowd size x similarity.

There was a significant interaction between crowd size and similarity level for reaction time, $F(8,184)=13.3$, $p<.0001$. Reaction time increased as difficulty increased for all crowd sizes, though the increase was smaller for the low similarity level trials (easy trials) and more pronounced as the trials increased in similarity (increased difficulty), as shown in Figure 4.2.

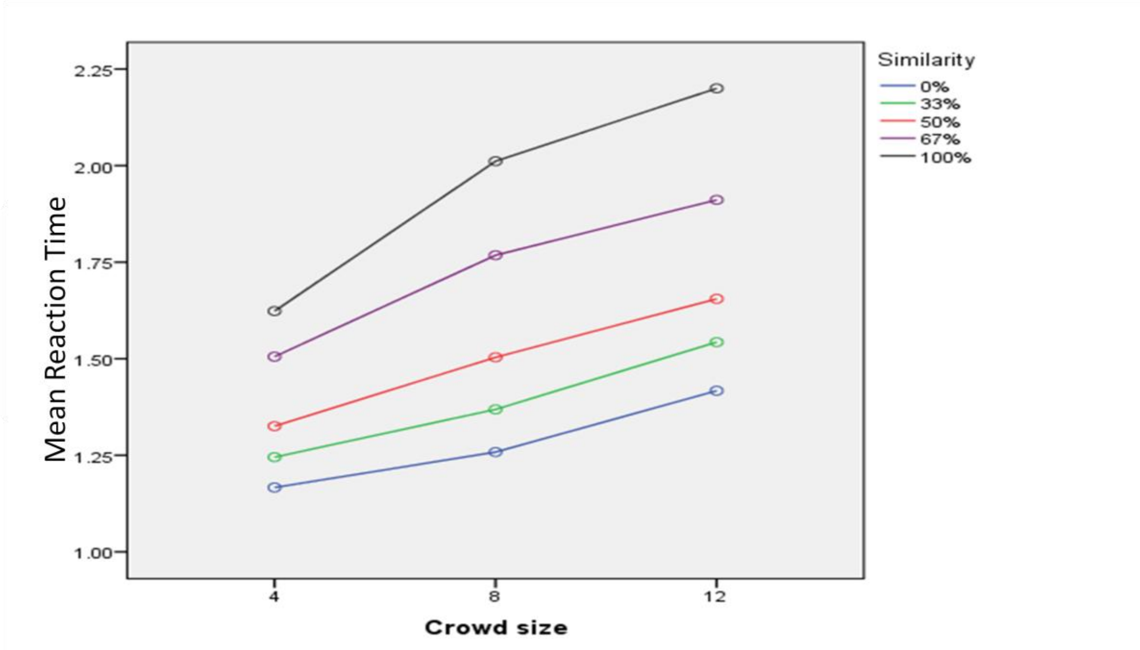

Figure 4.2. Mean reaction time (in sec) for the different crowd sizes, for different similarity levels (ranging from 0% to 100%). %). Reaction time increased with increasing similarity and with increasing crowd size. In addition, an interaction between similarity and crowd size shows that low similarity trials (e.g., 0% similarity - blue curve) have a shallower slope than higher similarity levels (e.g., 100% similarity - black curve).

There was also a significant interaction between crowd size and similarity for accuracy, $F(4.8, 112.6)=9.5$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=67$, $p<.001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.6$). As presented in Figure 4.3, accuracy decreased as similarity increased for all crowd sizes, though this decrease was very small for low similarity trials and much more pronounced as similarity increased, particularly for the 67% similarity level trials.

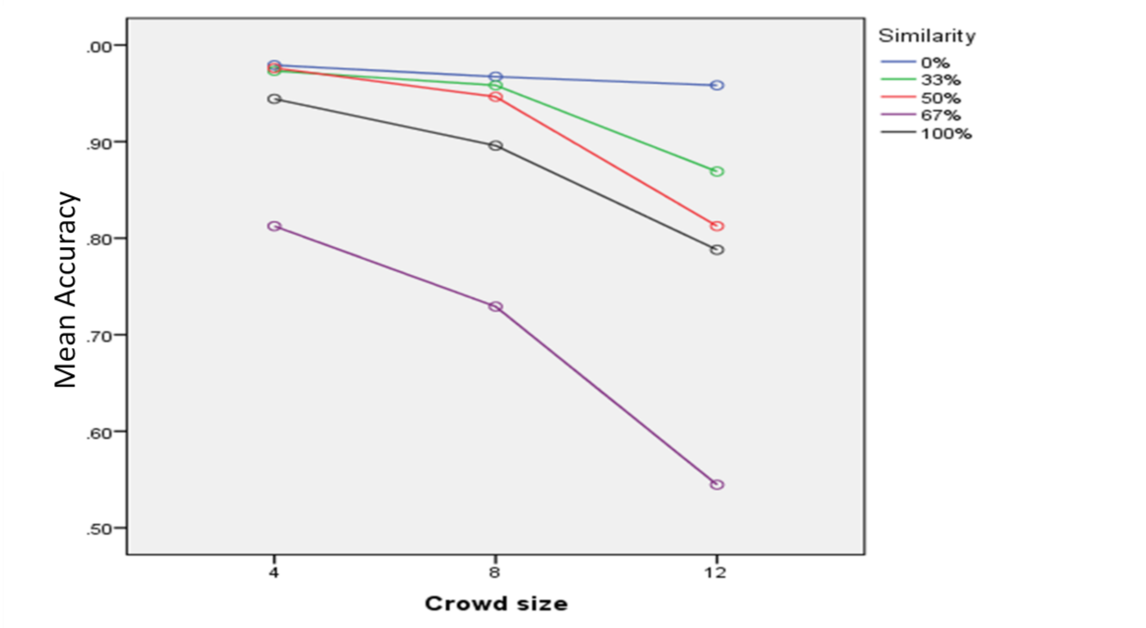

Figure 4.3. Mean accuracy (in percentages) for the different similarity levels, of different crowd sizes. Accuracy decreased with increasing similarity and with increasing crowd size. In addition, an interaction between similarity and crowd size shows that low similarity trials (e.g., 0% similarity - blue curve) have a shallower slope than higher similarity levels (e.g., 100% similarity - black curve).

Distractor type.

There was a main effect of distractor type on reaction time, $F(1,23)=54.7$, $p<.0001$. Pairwise comparisons showed that the reaction times for trials with angry distractors (M=1.66, 95% CI [1.6 1.7]) was significantly slower than reaction times when presented with neutral distractors, as depicted in Figure 4.4 (M=1.4, 95% CI [1.4 1.5]).

There was also a significant difference in accuracy between angry and neutral distractors, $F(1,23)=35.9$, $p<.0001$. Participants were less accurate on trials with angry distractors (M=.84, 95% CI [.82 .86]) compared with neutral distractors (M=.9, 95% CI [.89 .92]). Therefore, compared to neutral distractors, angry distractors were associated with both increased reaction times and decreased accuracy.

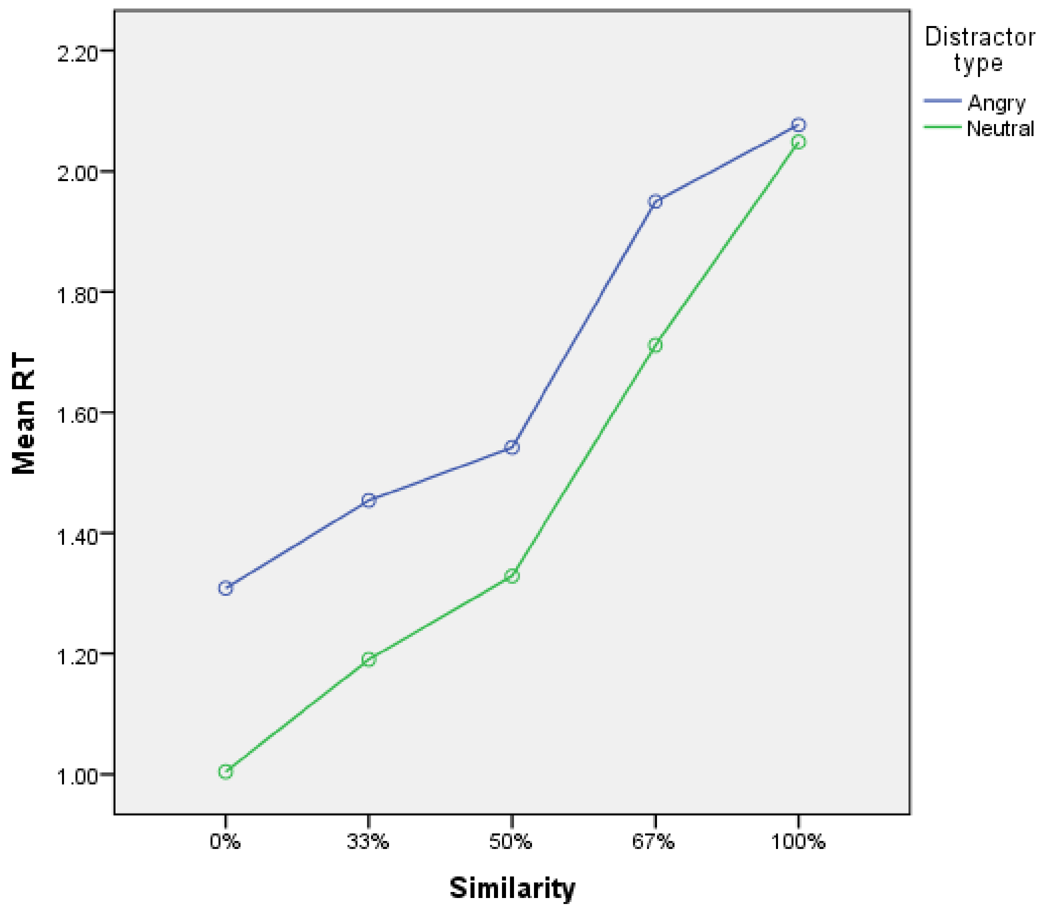

Figure 4.4. Mean reaction times (RT; in sec) for the different similarity levels, of the two different distractor types. Notice that when the distractors were angry faces (blue curve) that reaction times were slower than for neutral distractors(green curve).

Distractor x Similarity.

A closer look at the distractor type influences revealed a significant interaction between distractor and similarity on reaction times, $F(4,92)=12.5$, $p<.0001$. When presented with angry distractors, the reaction times were always slower than when presented with neutral distractors, for all similarity levels, though less so for the 100% similarity level (no target). There was also an interaction between distractor and similarity for accuracy levels, $F(2.8,65)=6.1$, $p<.0001$. Angry distractors were associated with decreased accuracy for all similarity levels, though more so for the 67% similarity level.

Results of Experiment 4B

Crowd Size.

There was a main effect of crowd size on reaction time, $F(1.2, 28.3)=17.5$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=21.6$, $p<.001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.6$). Pairwise comparisons showed that the reaction times for crowd size was significantly different among all sizes. In particular, as shown in figure 4.5, the larger the crowd size, the slower the reaction times; 4 (M=1.4, 95% CI [1.24 1.5]), 8 (M=1.58, 95% CI [1.46 1.69]), and 12 (M=1.74, 95% CI [1.63 1.85]).

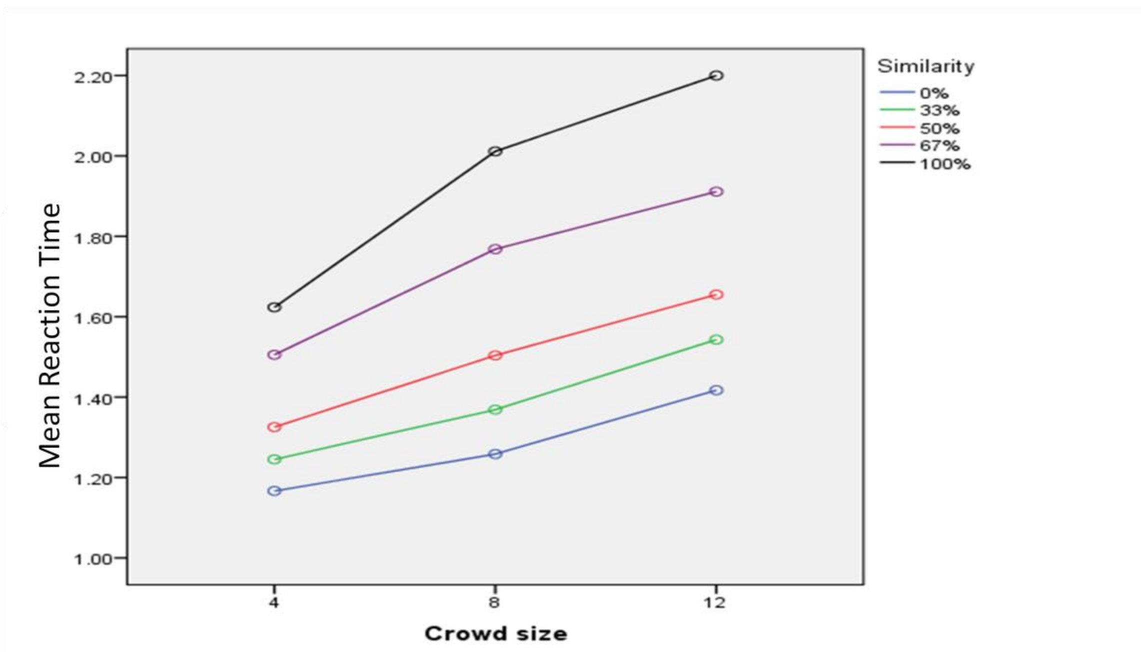

Figure 4.5. Mean reaction times (in sec) for the different crowd sizes, for the two different types of distractors in each block. Reaction time increased with increasing similarity and with increasing crowd size. In addition, an interaction between similarity and crowd size shows that low similarity trials (e.g., 0% similarity - blue curve) have a shallower slope than higher similarity levels (e.g., 100% similarity - black curve).

There was also a main effect of crowd size on accuracy, $F(2,46)=53.25$, $p<.0001$. Pairwise comparisons showed that the accuracy for crowd size was significantly different among all sizes. In particular, as shown in Figure 4.6, the larger the crowd size, the lower the accuracy; 4 (M=.92, 95% CI [.9 .94), 8 (M=.87, 95% CI [.85 .9]), and 12 (M=.81, 95% CI [.79 .83]). Moreover, there was a main effect of crowd size on mean proportion "long", $F(2,46)=4.7$, $p<.05$. As depicted in Figure 4.7, the larger the crowd size, the smaller the probability of responding 'long' (this equates to a right shift on the psychometric curve); 4 (M=.45, 95% CI [.41 .48]), 8 (M=.41, 95% CI [.38 .44]), and 12 (M=.4, 95% CI [.38 .43]). Post hoc comparisons showed that for crowd size of four faces, the duration estimations were significantly longer than the larger crowd sizes, $p<.05$. However, there was no significant difference between the eight and 12 crowd sizes.

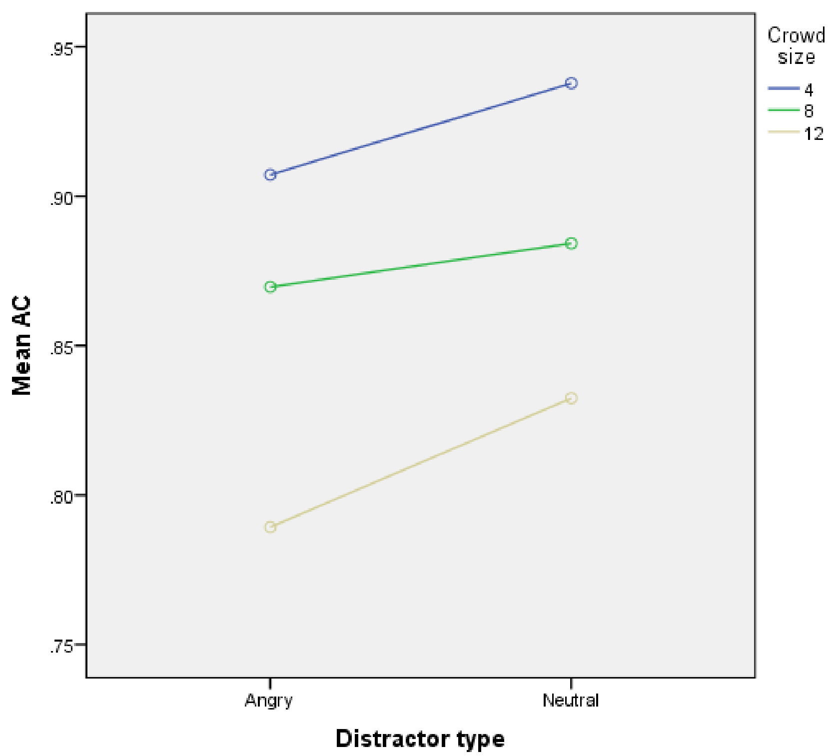

Figure 4.6. Mean accuracy (in percentages) for each distractor type, for the different crowd sizes. Notice that as crowd size increases, the mean accuracy decreases.

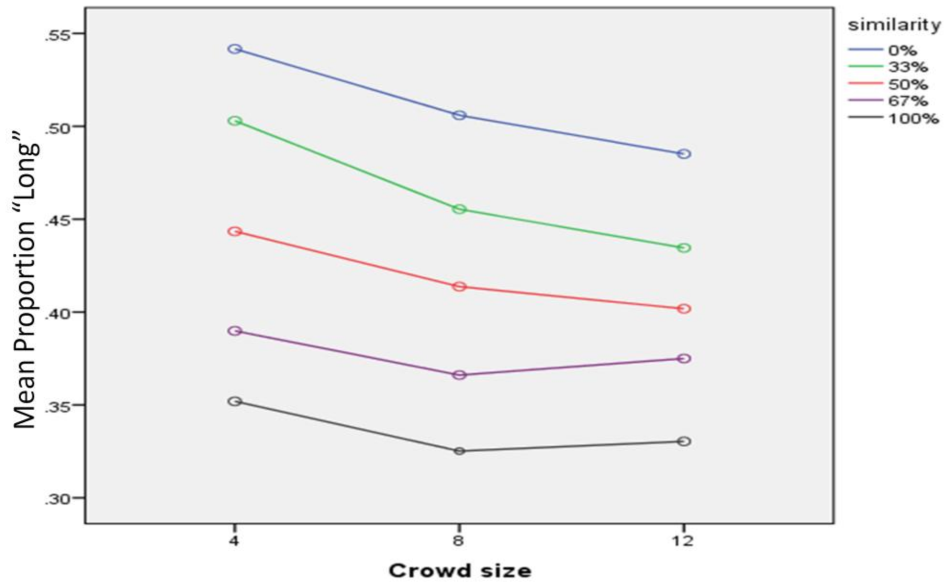

Figure 4.7. The relationship between durations (in msec) and proportion "long" estimates for the different crowd sizes. Notice that proportion "long" decreased with increasing similarity and with increasing crowd size.

In summation, results indicate that an increase in crowd size was related to both slower reaction times and less accurate responses. Furthermore, larger crowd sizes were also associated with a smaller probability of responding 'long' and, consequently, shorter time estimations.

Similarity.

There was a main effect of similarity on reaction times, $F(1.8,41.7)=146.3$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=43.2$, $p<.001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.45$). Pairwise comparisons showed that the similarity between target and distractor significantly influenced the reaction times to the faces. Particularly, as shown in figure 4.5, as the similarity levels increased, so did the reaction times, $p<.001$.

There was also a main effect of similarity on accuracy, $F(4,92)=62$, $p<.0001$. Results indicate that as the task increased in difficulty, the less accurate the responses became. However, a similarity of 67% showed the lowest accuracy levels (M=.71, 95% CI [.67 .75]). Pairwise comparisons showed that there were significant differences in accuracy between 67% similarity level and all other similarity levels ($p<.05$).

Furthermore, figure 4.7 shows that an increase in similarity levels is associated with the decrease in probability of responding 'long'. Figures 4.8 and 4.9 illustrates this decrease in proportion "long" responses as similarity levels increase for neutral and angry distractors respectively. In particular, as depicted in figure 4.10, the 800 ms and the 1000 ms durations showed the largest decrease in 'long' responses as the similarity increased. When fitting a curve to the data, it was apparent that the bisection point analysis confirmed this result, as there was main effect of similarity on bisection point, $F(2.5,58.3)=26.6$, $p<.0001$. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2=23.7$, $p<.005$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.63$). As the similarity between the target and the distractor increased, the bisection point also increased (this equated to a rightward shift in the psychometric curve). Pairwise comparisons show that all nonconsecutive similarity levels had significantly different bisection points, $p<.05$. The bisection points that were closest to the 800 ms duration (i.e., geometric mean) were obtained for trials with the least similarity; 0% similarity level (M=3.99, 95% CI [3.7 4.25]) and 33% (M=4.3, 95% CI [4 4.6]). There was also a significant main effect for similarity on Weber's ratio, $F(4,92)=5.7$, $p<.0001$. An increase in similarity was associated with an increase in Weber's ratio (shallower slopes). Pairwise comparisons showed that there were significant differences between the Weber's ratios for highest similarity level, 100% (M=.5, 95% CI [.42 .61]) as well as the 50% similarity level (M=.35, 95% CI [.25 .46]) and the 33% similarity level (M=.33, 95% CI [.25 .4]), $p<.05$.

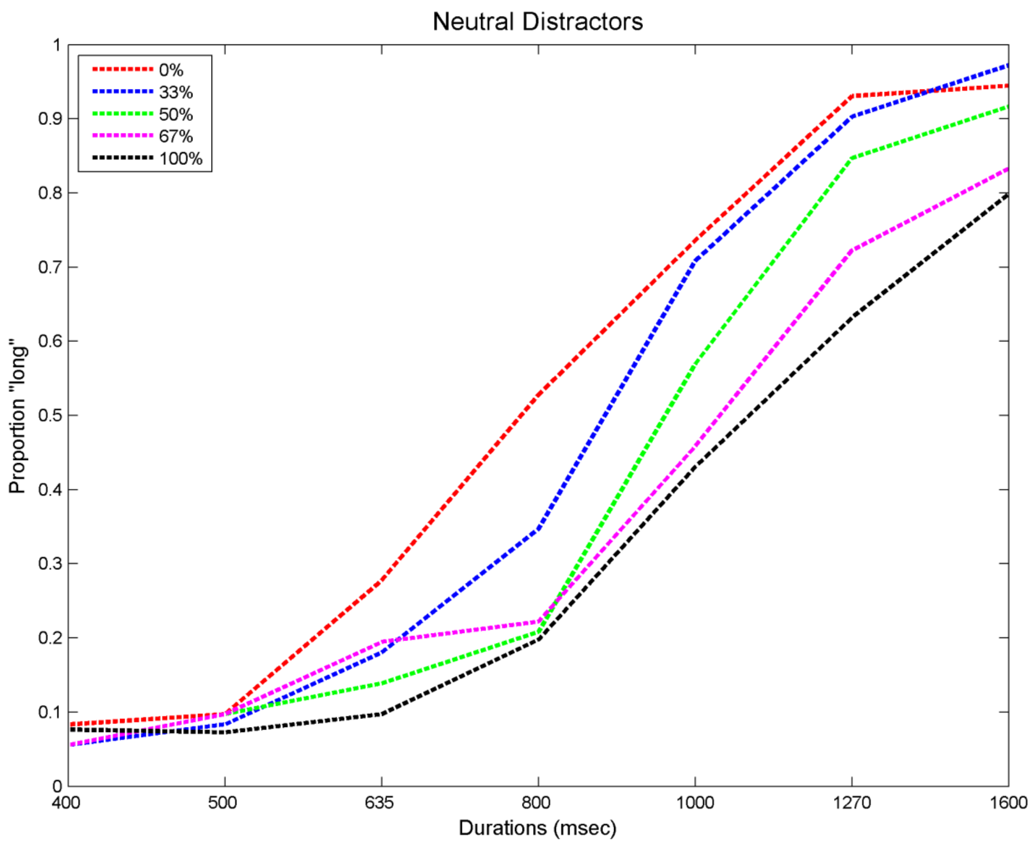

Figure 4.8. The relationship between durations (in msec) and proportion "long" estimates for the different similarity levels (ranging from 0% to 100%) for the neutral distractor block. Notice that an increase in similarity levels is associated with rightward shifts in the curves (shorter time estimations).

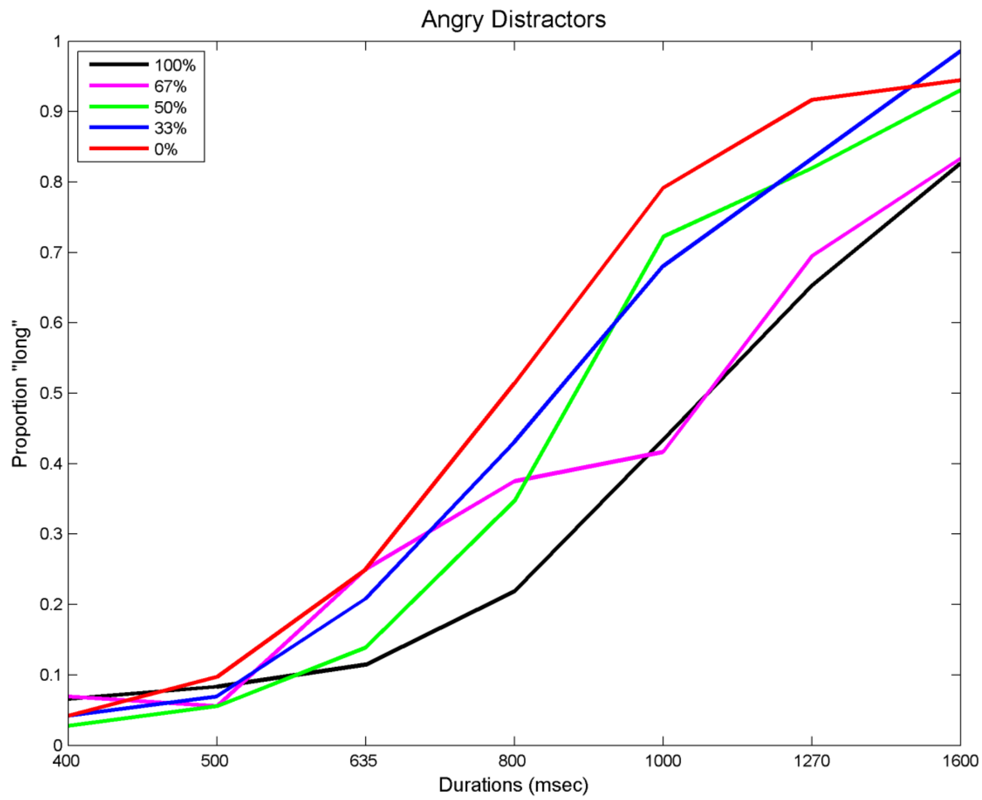

Figure 4.9. The relationship between durations (in msec) and proportion "long" estimates for the different similarity levels (ranging from 0% to 100%) for the angry distractor block. Notice that an increase in similarity levels is associated with rightward shifts in the curves (shorter time estimations).

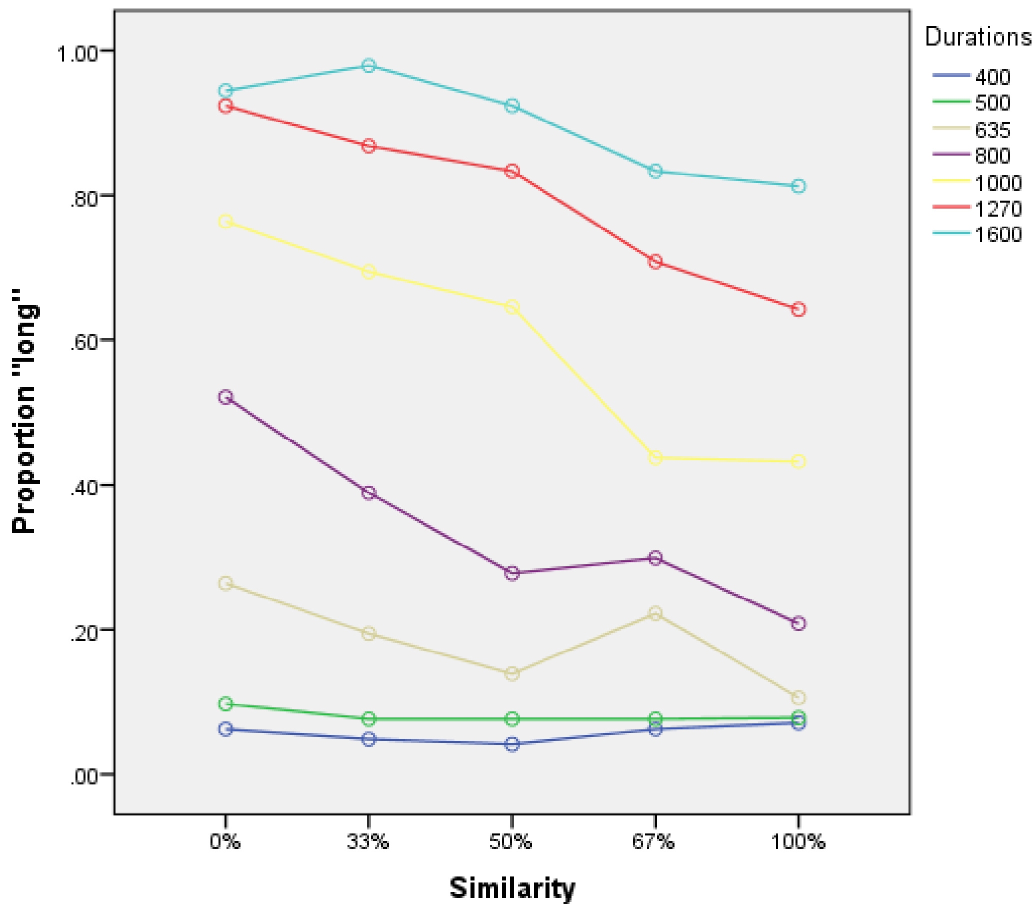

Figure 4.10. The relationship between similarity levels and proportion “long” for the different frame durations (in msec). Notice that the 800 ms and the 1000 ms durations showed the largest decrease in ‘long’ responses as the similarity levels increased.

In conclusion, the results indicate that an increase in similarity between target and distractor was associated with an increase in reaction times, a decrease in accuracy (though 67% showed the lowest accuracy levels), a decreased probability of responding ‘long’ (particularly on trials with 800 and 1000 ms frame durations), an increase in bisection point, and an increase in Weber’s ratio.

Crowd Size x Similarity.

An interaction effect between crowd size and similarity on reaction time was significant, F(8,184)=11.4, p<.0001. As presented in Figure 4.5, reaction times increased as difficulty increased for all crowd sizes, though the increase was smaller for the low similarity (easy) trials and more pronounced as the trials became more similar (difficult). The interaction effect on accuracy was also significant F(5,117)=5.02, p<.0001. Mauchly's test indicated that the assumption of sphericity had been violated (χ^2=55, p<.05), therefore, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=.63). Accuracy decreased as similarity increased for all crowd sizes, though this decrease was very small on low similarity (easier) trials and much more pronounced as similarity increased (trials became more difficult), particularly on 67% similarity level trials.

Distractor Type.

There was a significant difference in reaction times between the angry and neutral distractor types, F(1,23)=29.5, p<.0001. When angry distractors were presented, reaction times was significantly slower (M=1.64, 95% CI [1.53 1.76]) compared to trials with neutral distractors (M=1.49, 95% CI [1.37 1.6]). There was no significant difference in accuracy between angry and neutral distractors, F(1,23)=3.36, p=.08. . Furthermore, following the curve fitting analysis, using Weibull fits, it was evident that there was no significant difference between the bisection points of the two distractor types F(1,23)=2.4, p=.1, nor was there a significant difference between the Weber's ratios (i.e. slopes of the psychometric curve), of the two distractor types, F(1,23)=.92, p=.35.

Distractor x Similarity.

Importantly, there was an interaction between distractor type and similarity level for reaction times, $F(4,92)=2.5$, $p<.05$. When presented with angry distractors, the reaction times were always slower than when presented with neutral distractors across all similarity levels, though less for the 100% similarity level, as shown in Figure 4.4. There was no interaction between distractor type and similarity level on accuracy, $F(2,47.5)=.2$, $p=.9$. As shown in Figure 4.12, similarity affects accuracy levels for both distractors in a parallel fashion. Accuracy levels for angry and neutral distractors across similarity levels are summarized in Figure 4.13.

In addition, there was no interaction effect between distractor type and similarity level on mean proportion "long", $F(4,92)=.41$, $p=.79$. Though the differences are not significant, the results indicate that when the distractors were angry, the probability of responding 'long' was slightly greater than when the distractors were neutral faces, for similarity levels of 50-100% but not for 0 and 33% similarity, as shown in Figure 4.14.

The interaction between bisection points of distractor type and similarity levels was also not significant, $F(4,92)=.34$, $p=.8$. However, the results depict that, across all similarity levels the bisection points were smaller (leftward shift on the psychometric curve) when the participants were presented with angry distractors, than when presented with neutral distractors, as shown in Figure 4.15. The Weber's ratios were also not significantly different, $F(4,92)=.72$, $p=.58$.

Therefore, though reaction times were significantly different across all similarity levels apart from 100%, the Proportion "long" estimates and the bisection points were not. Moreover, there appeared to be a small tendency to respond 'long' with greater probability when presented with angry distractors.

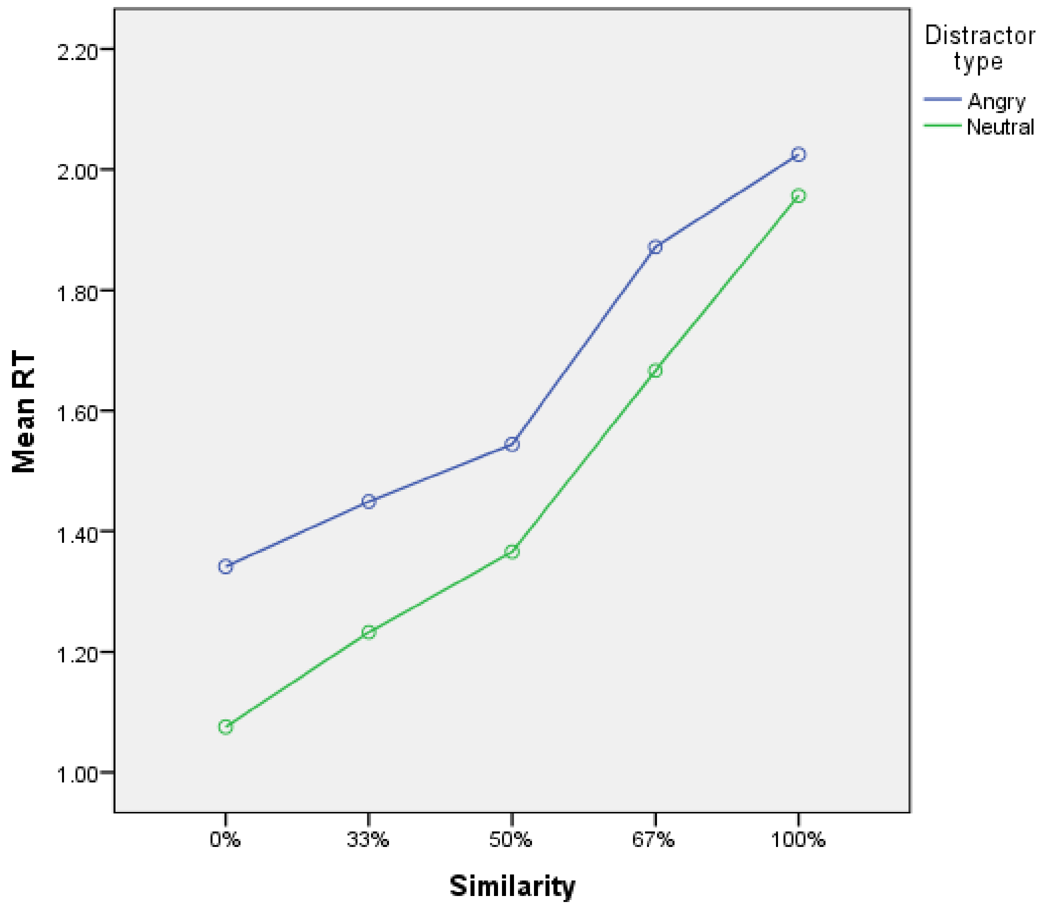

Figure 4.11. The relationship between similarity levels and mean reaction time (in sec) for the different types of distractors. Notice that when presented with angry distractors, the reaction times were slower for all similarity levels.

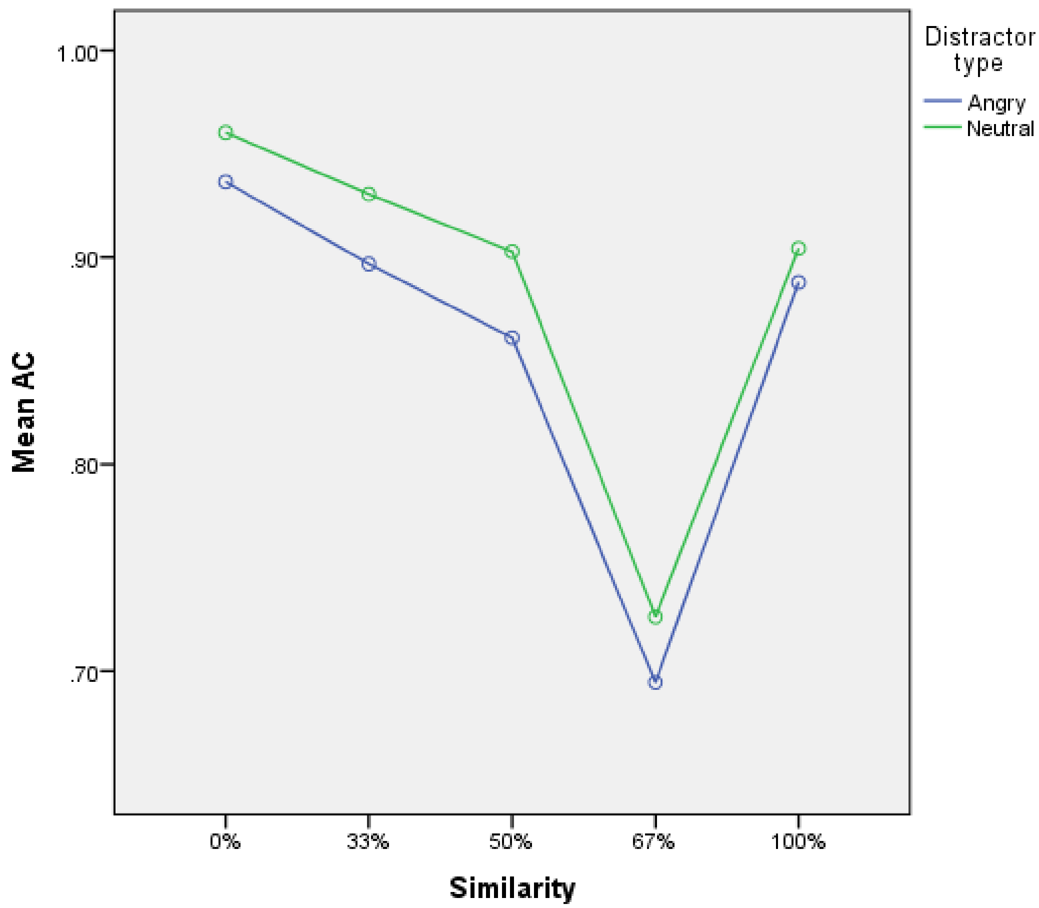

Figure 4.12. The relationship between similarity levels and mean accuracy (in percentages) for the different distractor types. Notice that when looking for the angry target face (neutral distractor block), participants were more accurate, compared to the angry block, for all similarity levels.

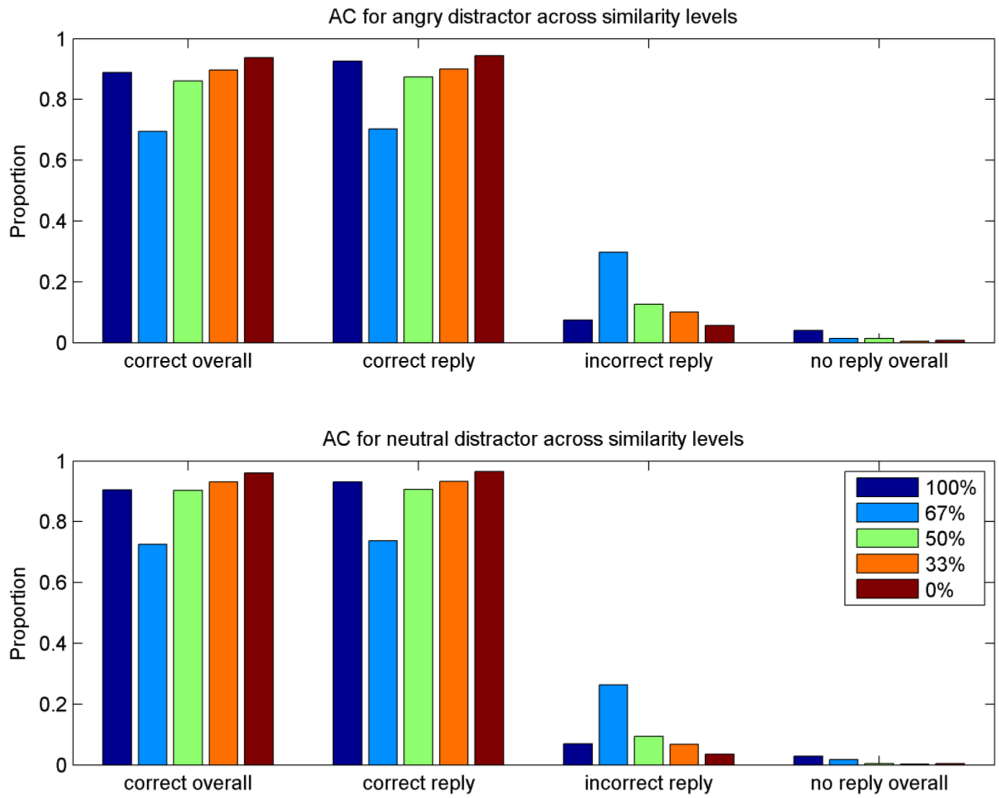

Figure 4.13. Accuracy levels for angry (top figure) and neutral (bottom figure) distractor types for the different similarity levels (ranging form 0% to 100%). This figure shows that the participants were able to perform the visual-search task in the time constrains of the task while still achieving a high degree of accuracy, for both distractor types.
*Proportion correct overall – correct replies out of all trails.
*Porportion correct reply - correct replies out of all trials with responses.
*Proportion incorrect reply – incorrect reply out of all trails with responses.
*Proportion no reply overall – proportion of trials with no reply

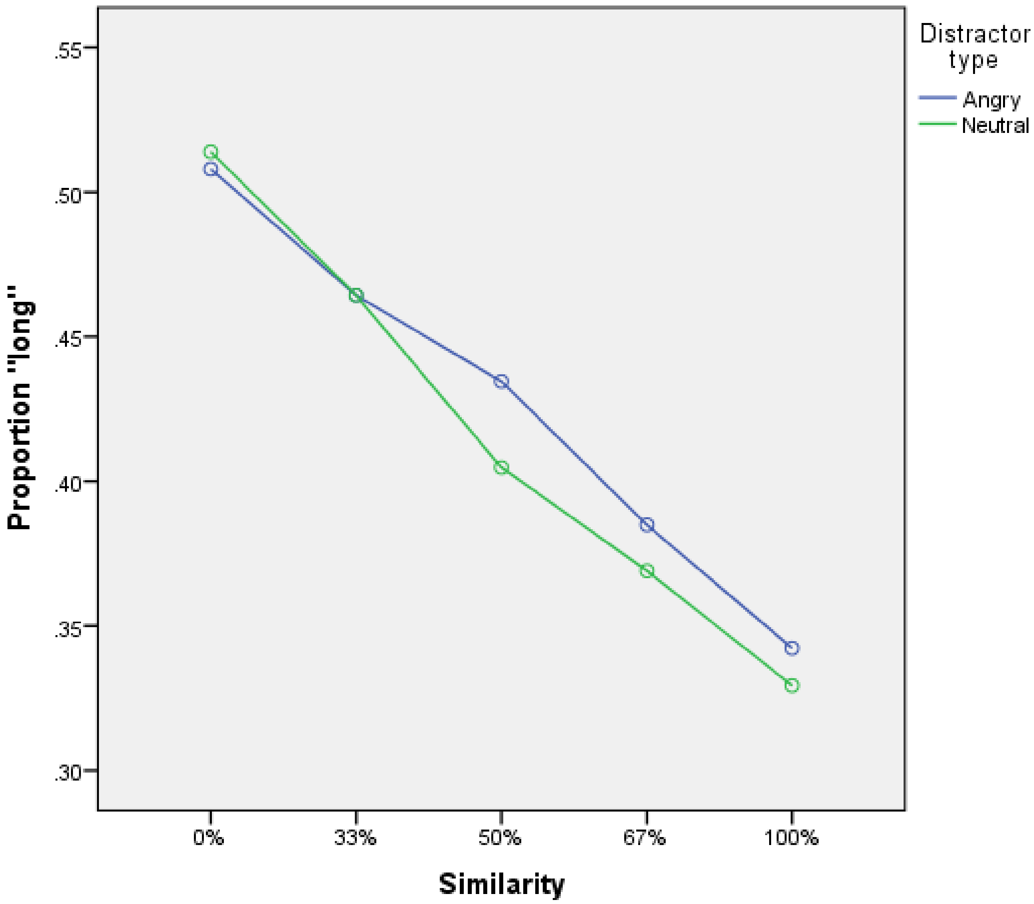

Figure 4.14. The relationship between similarity levels and proportion “long” for the different distractor types. Notice that when the distractors were angry, the probability of responding ‘long’ was slightly greater than when the distractors were neutral faces, for similarity levels of 50-100% but not for 0 and 33% similarity.

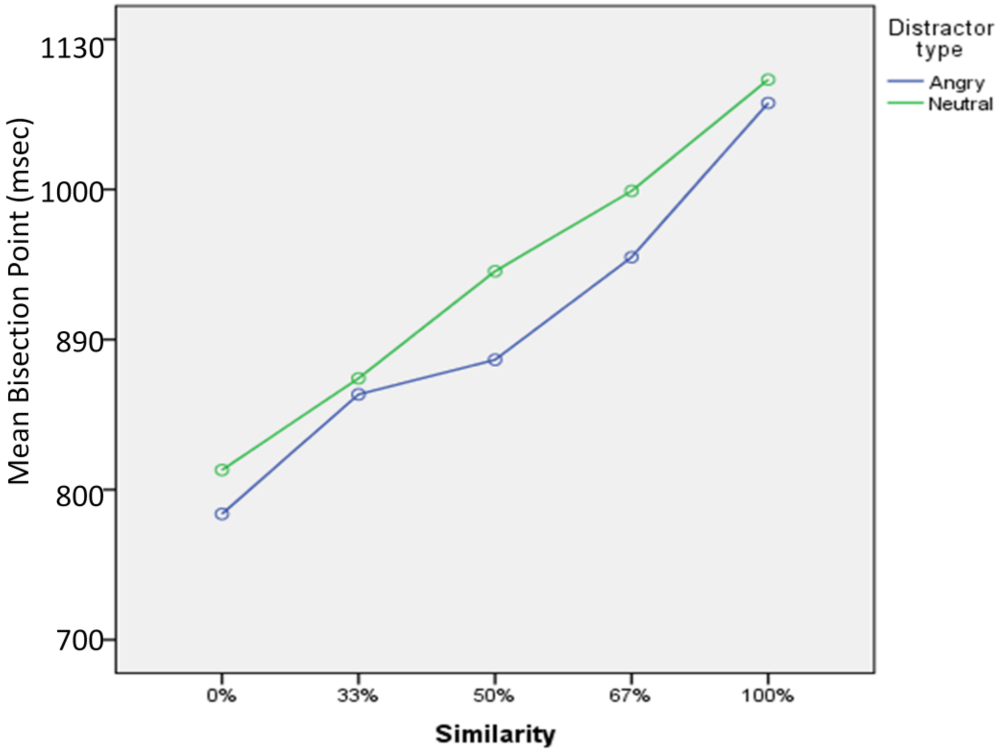

Figure 4.15. Mean bisection point (in msec)* for the different similarity levels for each of the different types of distractos. Notice that when the distractors were neutral, the bisection points were slightly greater (underestimated) than when the distractors were angry faces, for all similarity levels.
*Bisection points (in msec) converted into the 1-7 linear scale: 700=3.5, 800=4, 890=4.5, 1000=5, 1130=5.5.

Results of comparison (4A vs. 4B)

There was no significant difference in reaction time between the experiment with the time estimation (4B) and without (4A), $F(1,23)=.01$, $p=.9$. Accuracy levels also did not significantly change between experiments, $F(1,23)=.49$, $p=.48$. Interestingly, the interaction effect on reaction time between the experiment session and the crowd size was significant, $F(2,46)=33.9$, $p<.001$. As in the comparison between experiments 3A and 3B, both the larger crowd sizes (eight and 12 faces) improved reaction time between Experiment 4A and 4B, however, the small crowd size showed an increase in reaction time in Experiment 4B (see Figure 4.16). The accuracy differences for the interaction effect were also significant $F(2,46)=4.67$, $p<.05$. Accuracy improved for large crowd sizes, which had the lowest accuracy ratings, yet decreased slightly for smaller crowd sizes.

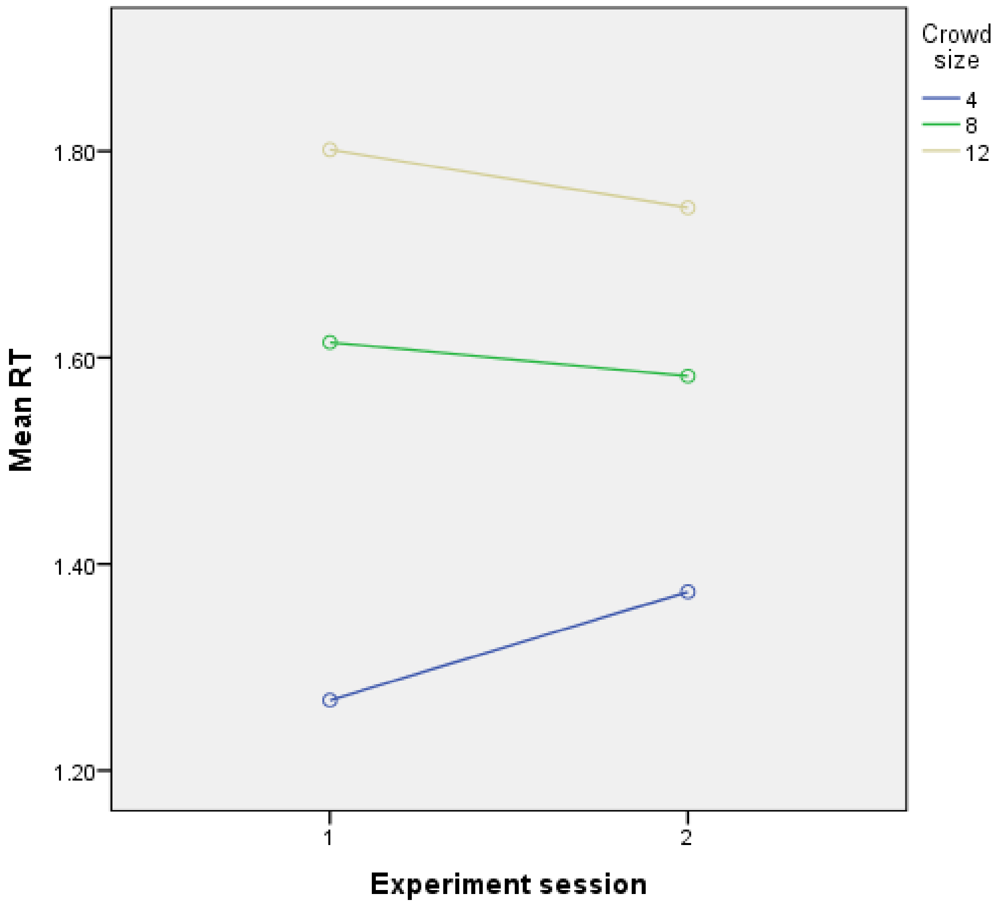

Figure 4.16. (1 – single task vs. 2 – dual task) on mean reaction time (in sec) for the different crowd sizes. Effects of experimental session (1 – single task vs. 2 – dual task) on mean reaction time (RT; in sec) for three crowd size conditions. Notice that for trials with larger crowd sizes, reaction time improved between sessions, yet became worse for the small crowd size condition.

Discussion of Experiment 4

In this experiment, attention was manipulated in three ways. Executive control was manipulated by the difficulty of the task (influenced by similarity levels and crowd size), alerting was manipulated by the instructions the participants receive at the beginning of the block (i.e., search for an ‘angrier face’ among the neutral faces), and orienting was manipulated by having angry distractors (i.e., distractors that capture and hold attention) as compared to neutral distractors. The addition of the temporal bisection task to the search task with emotional expressions allowed for a thorough examination of the relationship between the three components of attention: executive control, alerting, and orienting, (as focused on emotion) on time perception estimations.

As in Experiment 3, results have shown that the executive attentional manipulation in this experiment significantly influenced the reaction times and accuracy levels of the participants. The result of the attentional manipulation obtained by the different levels of similarity and the different crowd sizes were compatible with the results obtained in Experiment 3; increased similarity levels and larger crowd sizes were associated with an increase in reaction time and a decrease in accuracy.

The interaction effects between crowd size and similarity on reaction time and accuracy levels were also consistent with the results obtained in Experiment 3. Reaction time increased and accuracy decreased as difficulty increased for all crowd sizes, though the differences were smaller when it was easy to detect the target (low similarity trails) and more pronounced as it became more difficult to detect the target (high similarity trials) (see Figure 4.2). This effect is in accordance with claims of parallel search for low similarity levels and serial search for high similarity levels.

The comparison between experiments 4A and 4B provided an indication for the differences between performing the emotional-faces visual-search task with and without the timing task. The result showed that when presented with many distractors on the screen (eight or 12) participants improved their reaction time (shorter reaction time), though when presented with few distractors the reaction times increased. This result is likely due to the dual-task procedural difference. Particularly, when presented with four distractors, the reaction times were fast, thus, they occurred early on in the trial. It is likely that by adding a frame to be timed close to the beginning of the trial, participants were forced to respond to the visual search task during the frame's presentation on the screen (as opposed to later responses made after the frame's disappearance, for the trials with larger crowd sizes). Therefore, the dual task procedure (visual search and bisection timing task) influenced the reaction time for the trials with small crowd size, increasing their reaction times.

By adding a temporal task to the visual search task with emotional faces, it was possible to study the relationship between the reaction time results and the time estimations reported. Once again, the results have shown that there is a clear association between the attentional load, manipulated by difficulty of the visual search task (i.e., executive attention), and responses on the timing task. Specifically, results indicate that an increase in reaction time (slower reaction time), evident when trials increase in crowd size (see figure 4.5) and/or similarity levels (see Figure 4.11), is associated with smaller probability of responding 'long' (see figures 4.8 and 4.9), larger bisection points and consequently, shorter time estimations bisection point (see Figure 4.15). This association is consistent with the results obtained in experiments 2B and 3, and with the idea that time perception is determined by the amount of attention allocated to time (e.g., Block et al., 2010). Longer reaction times to a non-temporal task indicate that attention was shifted away from timing, and therefore, time estimates become shorter.

In summation, results associated with the visual search manipulations associated with executive attention (difficulty variances) were comparable to the results obtained when presented with neutral expressions in Experiment 3. This strengthens the interpretation that the visual search task is a reliable means for manipulating attention. As mentioned above. However, the comparison of the experimental blocks in this experiment highlights an important distinction; angry distractors were associated with both increased reaction time and decreased accuracy as compared to neutral distractors. This result is consistent with the prediction that the angry block is processed differently than the neutral block. Specifically, that there is an asymmetry of search between the blocks associated with both alerting and orienting differences. The angry distractor faces demanded more attentional resources to disengage from (i.e., slower reaction time for angry block) while the search for angry faces (in the neutral block) required participants to be more alert (i.e., faster reaction time for neutral block).

In addition to the relationship between Proportion "long" and reaction time, apparent when manipulating executive attention (i.e., difficulty), this task allowed the examination of the effects of attentional alerting and orienting on time perception estimations. By asking participants to search for an angrier face among neutral distractors, in accordance with the threat-advantage hypothesis, participants were primed to engage additional attentional resources (Hansen & Hansen, 1988; Horstmann, 2007; Lamy et al., 2008). As opposed to an increase in reaction time associated with increased difficulty of the task, increased alerting is associated with a decrease in reaction time. Higher alerting requires additional attentional resources which, in turn, allows for the faster detection of the target face in the visual search task. As expected, reaction times when looking for an angry face among neutral faces were faster for all similarity levels (see Figure 4.11). These results imply that alerting to the angrier faces was associated with faster detection of the target stimulus, even at 67% similarity levels (i.e., the distractors are neutral and the target is a morphed stimulus of 67% neutral, therefore, not especially angry expression). Though still faster during neutral distractors, this reaction time difference becomes less distinguishable during 100% similarity (i.e., 'absent' target condition). Furthermore, the 'angry' face (i.e., 0% and 33% neutral) is presented within the neutral block only a quarter for the trials. Therefore, results are consistent with the notion that the template for 'the angry face' was guiding the attention (i.e., alerting) and not the stimulus itself.

In addition to the faster reaction times for the neutral block due to alerting, it is also likely that the participants' reaction time was slower when presented with the angry block due to orienting. In the angry distractor condition, participants were to search for a more neutral face among the angry distractors. This task was more difficult to accomplish because of the tendency for angry faces to capture attention (as observed in Experiment 2). In addition to faster engagement with angry facial expressions, such expressions are associated with a tendency to hold attention (i.e., difficult disengagement). Therefore, the angry distractors would distract more attention away from the target faces; the participants would thereby need to utilize more attentional resources to orient to the target faces (e.g., Weissman et al., 2009).

Though reaction times were significantly different between angry and neutral distractors across all similarity levels (apart from 100%), the accuracy levels, proportion "long" estimates, bisection points and Weber's ratios were not significantly different between distractor type. However, there appeared to be a small tendency to respond ‘long’ with greater probability when presented with angry distractors, or alternatively to respond ‘short’ with greater probability when presented with neutral distractors (i.e., searching for angry) (see figures 4.14 and 4.15).

This experiment, therefore, strengthened the proposition that time perception estimations are related to, and influenced by, the executive attentional allocation to temporal processing. Consistent with Experiment 3, this study showed that an increase in difficulty of a non-temporal task systematically increased reaction time allocated to processing the stimuli, therefore allowing fewer resources to be devoted to the timing of the duration of the task.

In addition to executive control, both alerting and orienting were also associated with time estimation. Increased alerting was associated with a decrease in reaction time, yet also allowed fewer resources to be allocated to the timing of the duration of the task (i.e., attention away from the temporal task). Difficulty orienting away from the angry distractors (i.e., disengaging) was associated with longer reaction times, in addition to even fewer resources to the timing of the duration of the task.

However, to fully understand the differential effects of alerting and orienting on time perception estimations, it is necessary to compare the results obtained in the visual search task without the emotional component (Experiment 3) to the visual search task with the emotional faces (Experiment 4). Particularly, compare the neutral distractor block (which involved increased alerting) and the angry block (which involved increased processing due to slower disengagement) with the Jane and Beth blocks from Experiment 3 (which did not involve differential orienting and alerting attentional functions). This comparison would help tease out the effects of the interaction between emotional arousal and attention on time perception, from the effects of attention alone on time perception.

Comparison between Experiment 3B (Identity) and Experiment 4B (Expression)

Results of comparison

A repeated measures ANOVA with crowd size, distractor type, similarity levels as within-subject factors and experiment type (identity (exp.3) vs. emotion (exp.4)) as the between-subject factor, was used. The results indicate an interaction effect on reaction time between experiment type and distractor, $F(1,45)=1.4$, $p<.005$, as the difference between the reaction time for the angry and neutral distractors was much larger than the difference between the reaction time for the Jane and Beth distractors (see Figure 5.1). This is due to a significant difference in reaction time between neutral and angry distractors but no significant difference in reaction time between Jane and Beth. There was also a significant difference in accuracy between experiments $F(1,45)=6.35$, $p<.05$. The emotion experiment yielded overall more accurate Results of the visual search task ($M=.87$, 95% CI [.85 .88]) than the identity experiment ($M=.84$, 95% CI [.82 .86]), as shown in Figure 5.2.

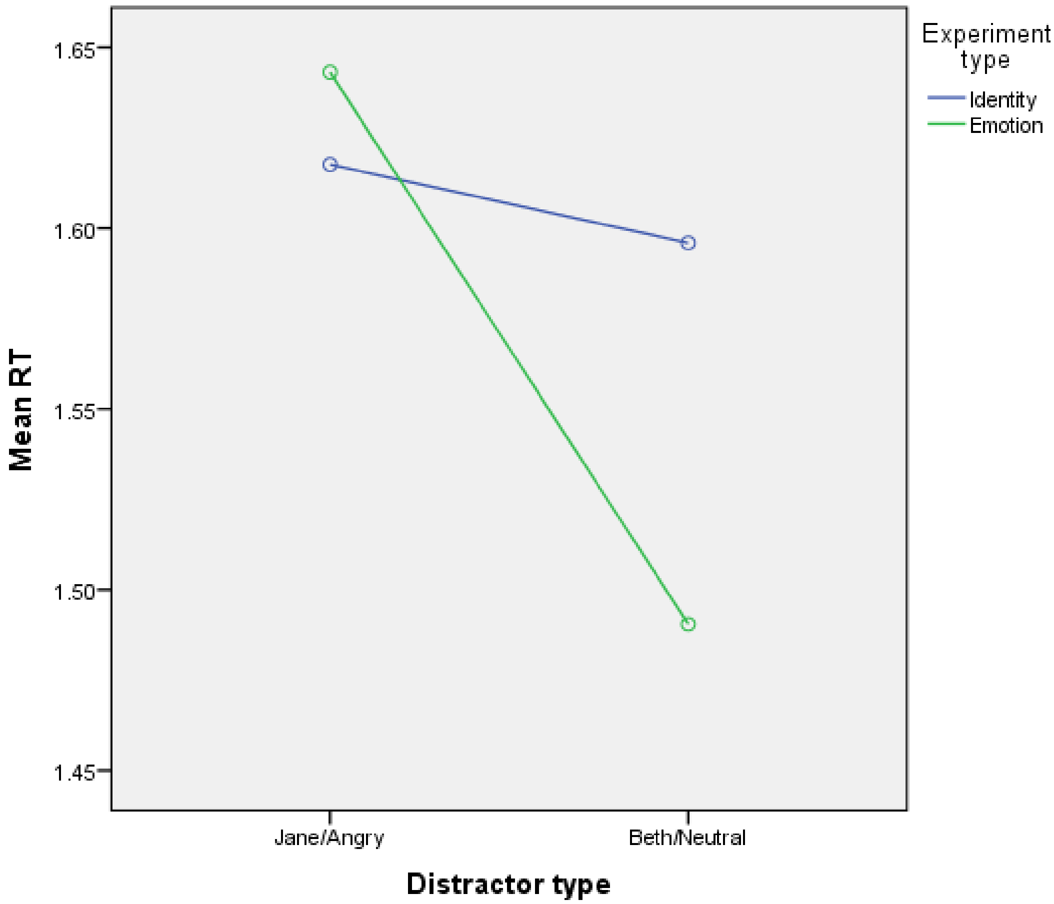

Figure 5.1. Mean reaction time (RT; in sec) for the different distractor types for the Identity Experiment (3B) and the Emotion experiment (4B). Notice that the difference between the reaction time for the angry and neutral distractors was much larger than the difference between the reaction time for the Jane and Beth distractors.

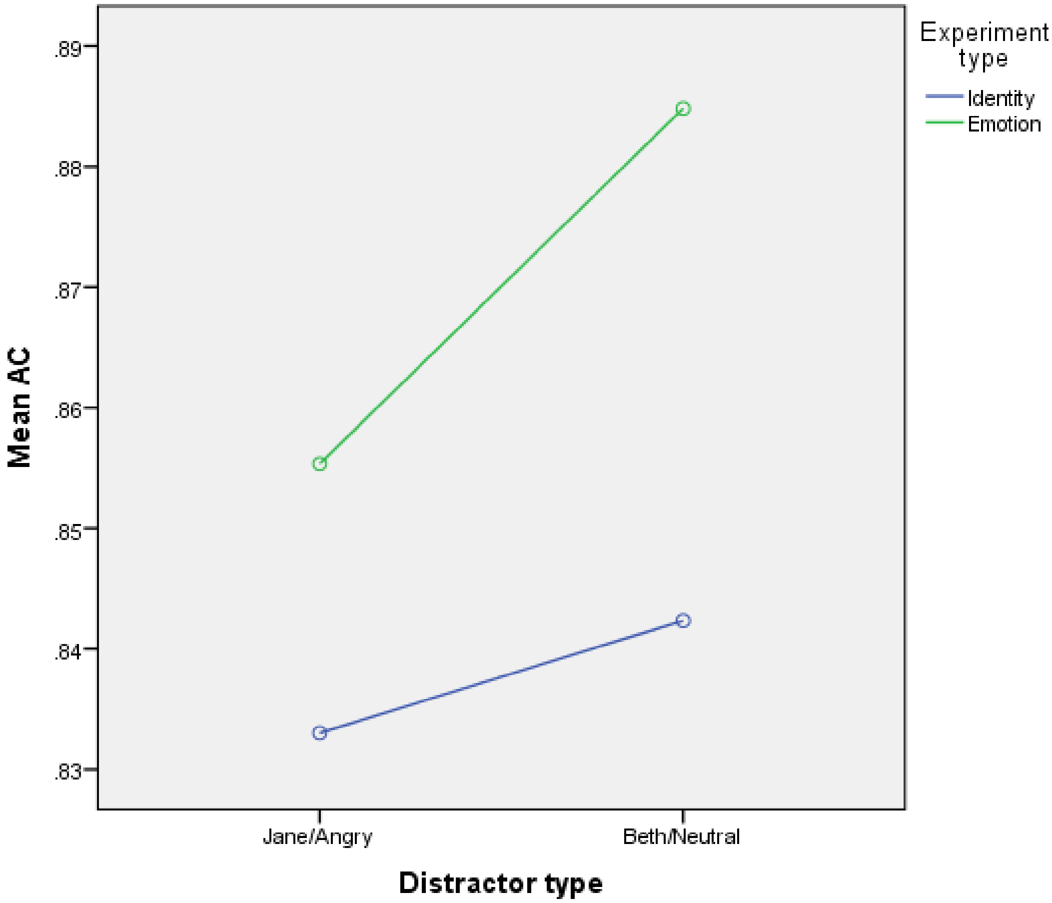

Figure 5.2. Mean accuracy (AC; in proportion correct) for the different distractor types for the Identity Experiment (3B) and the Emotion experiment (4B). Notice that the results of the visual search task with the emotionaly morphed faces were more accurate than the results of the visual search task with the identity morphed faces.

There was no significant difference in bisection points between experiments, F(1,45)=3, p=.09 nor Weber's ratios, F(1,45)=1.86, p=.18. However, the angry (M=4.5, 95% CI [4.3 4.7]) and neutral (M=4.7, 95% CI [4.4 4.9]) distractors yielded a larger bisection point compared to Jane (M=4.4, 95% CI [4.2 4.6]) and Beth (M=4.3, 95% CI [4.1 4.6]) distractors, as presented in Figure 5.3.

To compare among the four distractor types, an ANOVA with distractors as the between subject factor was analysed. There was a significant effect of distractors on mean proportion "long," F(3,9730)=6.3, $p<.0001$. Pairwise comparisons showed that even though there was no significant difference between the Jane and Beth distractors and between the angry and neutral distractors (as indicated in the Results of the distractors before), the neutral distractor, as shown in figure 5.4, was associated with the smallest probability of replying 'long' (M=.42, 95% CI [.4 .43])), and was significantly different from the Jane and Beth distractors. There was also a significant effect of distractors on reaction time, F(3,9730)=47.1, $p<.0001$. Pairwise comparisons showed that the reaction time for the neutral distractor (M=1.5, 95% CI [1.47 1.5]) was significantly faster than all the other distractors, $p<.05$, as presented in figures 5.4 and 5.5.

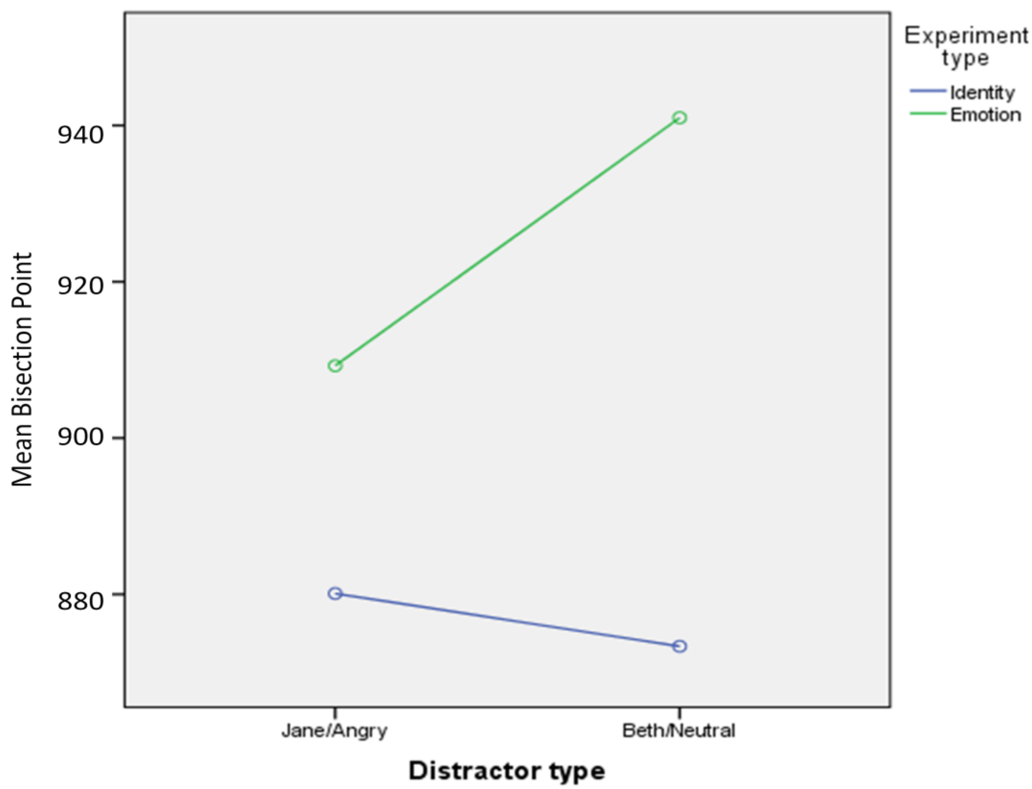

Figure 5.3. Mean bisection point (in msec) for the different distractor types for the Identity Experiment (3B) and the Emotion experiment (4B). Notice that angry and neutral distractors (Experiment 4B) yielded a larger bisection point (shift to the right on the psychometric functions) compared to Jane and Beth distractors (Experiment 3B).

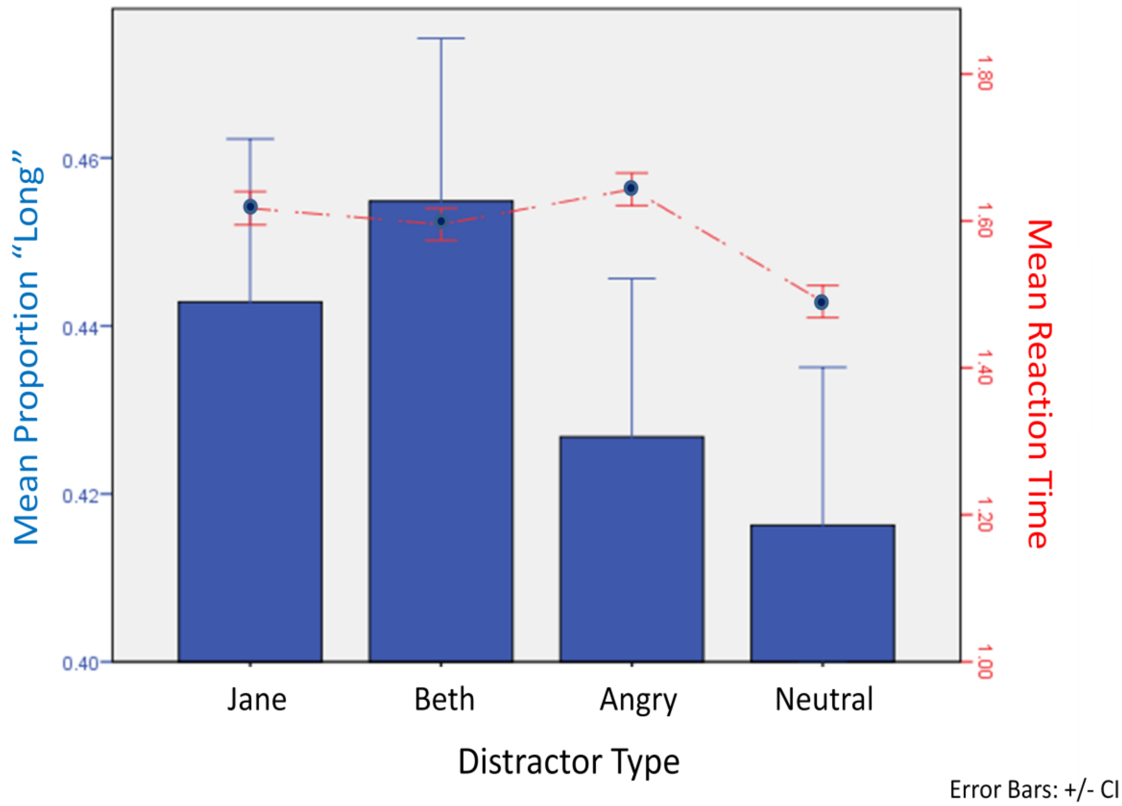

Figure 5.4. The relationship between distractor type (across Experiments 3 and 4) and mean Proportion "Long" (left x-axis) and mean reaction time (in sec) (right x-axis). The blue bars correspond to proportion "long" while the blue circles correspond to mean reaction times (red line serves as a visual aid between the means and not indicative of continuity between the distractors). Results obtained from Jane and Beth distractors, as well as from Angry and Neutral distractor types are within participants factors, however, Jane/Beth versus Angry/Neutral are between participant factors. Results show that when presented with neutral distractors, reaction time was fastest and when presented with angry distractors reaction time was slowest. However, both time perception estimations (proportion "long) for Angry/Neutral were shorter than for Jane/Beth (with angry distractors associated with larger mean proportion "long" estimates as compared to neutral distractors).

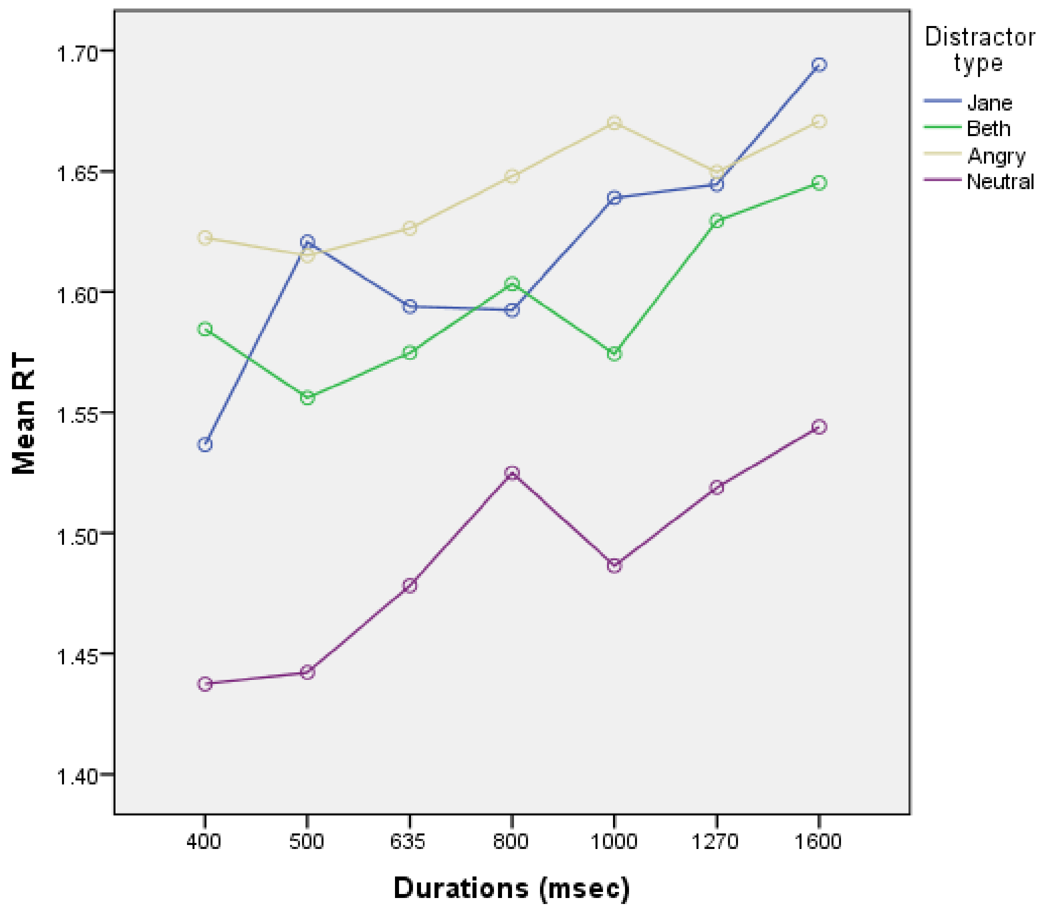

Figure 5.5. The relationship between durations (in msec) and mean reaction time (in sec) for the four different types of distractors in both experiments 3B and 4B. Notice that the mean reaction time for the neutral distractor was faster than all the other distractors.

Discussion of comparison (Experiment 3 vs. Experiment 4)

As the two sets of experiments conducted were designed to be identical with the exception of the stimuli used as targets and distractors, it is only to be expected that the main differences between the identity and the emotion experiments were focused on distractor type. However, because of the interaction between attention and emotion, changing the stimuli from a neutral morphed continuum (in the identity experiment) to an emotional morphed continuum (in the emotion experiment) was associated with a change in the allocation of attention to the task. Comparing among the four types of distractors (i.e., Jane, Beth, Angry and Neutral) allowed for a finer understanding of the relationship between attention, emotional arousal and time estimation.

A careful look at the Results of reaction time among the distractors makes for an unambiguous revelation that when participants were presented with neutral distractors (i.e., looking for an angry target), they tended to reply faster than when compared to the other distractors. Interestingly, the speedy response did not have a negative effect on accuracy, as the detection of angry faces during the neutral distractor block was also the most accurate. This result supports the assumption that there is an interaction between attention and emotion (e.g., Hansen & Hansen, 1988) that influences the processing of this block. Particularly, participants were more alert and vigilant when looking for an angry face among neutral faces, as compared to the other target/distractor conditions. This increase in alerting is associated with an increase in attentional resources to the detection of the angry target face resulting in faster reaction times and more accurate target detection. Therefore, it is understandable that the neutral distractor block was also associated with the smallest probability of replying ‘long’, and was significantly different from the Jane and Beth distractors. Consistent with the attentional gate model (Zakay & Block, 1997), increased attentional resources allocated towards the visual search (non-temporal) task resulted in fewer pulses accumulated in the accumulator of the inner clock and was associated with decreased subjective time estimations (underestimation of objective time). These differences in Proportion “long”, however, were mainly related to the 800 ms duration, which is the geometric mean of the short and long reference durations, and has been shown to be the most ambivalent duration to estimate in Experiment 1A.

In addition to the neutral distractor block, it was expected, based on the threat advantage hypothesis (Hansen & Hansen , 1988), that the angry distractor block would also have a differential effect on attentional allocation. Specifically, that having angry distractors on the screen would be associated with difficulty orienting away (i.e., disengaging) from these distractors during the visual search for the target face. This condition would, therefore, be associated with longer reaction times than the ones obtained when participants were presented with the Jane and Beth distractors. Moreover, this increase in reaction time was assumed to be associated with increased attentional resources to the visual search task and therefore, decreased attentional resources to the temporal task. Consistent with the attentional component of the attentional gate model (Zakay & Block, 1997), this increase in attention resulted in shorter time perception estimations (i.e., a smaller probability of responding "long"), compared to the Jane and Beth distractors. These results indicate that the angry distractor block was also processed differently than the Jane/Beth blocks.

Effects related to saccadic eye movements might also contribute to the results obtained when comparing Jane/Beth distractors with Angry/Neutral distractors. Particularly, the visual search paradigm, used in both experiments, involved saccadic eye movements that redirected the fovea to the faces on the screen and thereby allowed the image to be processed in higher resolution. Since the emotional faces tended to capture attention (i.e., efficient orienting, as in the neutral distractor block when looking for angry target faces) and hold attention (i.e., difficult disengagement, as in the angry distractor block when inhibiting angry distractors), there should theoretically be fewer saccades during the angry and neutral blocks compared with the Jane and Beth blocks. Furthermore, studies have shown that subjective time is influenced by saccades (Yarrow et al., 2001; Morrone, 2005) as saccades are related to the slowing down of time. Therefore, the results whereby Jane and Beth blocks showed an increase in perceived time (higher proportion "long") as compared to the emotional blocks (i.e., angry and neutral) are in accordance with the effects of eye movements. Although the mechanism associated with the effect of saccades on subjective time is unclear, it is likely that attentional processes are involved, as eye movements and attention are considered highly related (e.g., Gersch et al., 2004).

GENERAL DISCUSSION

Attentional gate theory (AGM) predicts arousal and attentional influences on time perception (Zakay & Block, 1997). In accordance with the AGM (see Figure 1), attentional allocation away from timing is associated with the closing of the gate, thereby allowing fewer pulses to accumulate in the accumulator. In contrast, attention allocated towards timing is associated with the opening of the gate, thereby allowing more pulses to reach the accumulator. Attention to non-temporal stimuli, therefore, is related to shorter subjective time estimations (underestimation of objective time) as compared to when attention is allocated towards the temporal aspect of the stimulus.

Unlike attention, in accordance with the AGM, arousal (typically attributed to emotional stimuli) is often assumed to affect the pacemaker rate, thereby directly influencing the accumulation process (Zakay & Block, 1997). Moreover, Burle and Casini (2001), by presenting participants with both an arousing stimulus and an attentional task simultaneously, have argued that arousal and attention are independent of one another, and have additive effects on time perception.

More recent research findings, however, suggest that emotionally arousing stimuli have been tightly-linked to attentional allocation and that the processing of emotional stimuli (e.g., mutilated bodies) requires attention (e.g., Erthal et al., 2005). In addition, more recent advances in neuroscience introduced attention as divided into three functional disparate control networks: alerting, orienting and executive control (Posner & Peterson, 1990; Raz & Buhle, 2006). The connection between attention and emotional arousal can, therefore, be partitioned into the influences of emotional arousal on the different control networks of attention. Specifically, emotionally arousing stimuli is processed faster and more efficiently than neutral stimuli (Derakshan & Eysenck, 2009; Fox et al., 2001). Angry facial expressions, as presented in the experiments herein as the emotionally arousing stimuli, are suggested to elicit fast attentional engagement and slow attentional disengagement, associated with the orienting function of attention (e.g., Georgiou et al., 2005). In addition, according to the threat advantage hypothesis (Hansen & Hansen, 1988), there is an evolutionary advantage to detect threatening stimuli relative to non-threatening stimuli. Therefore, instructing participants to search for angry faces is associated with increased alerting and hence attentional allocation towards the search task, compared to when searching for neutral faces (e.g., Pinkham et al., 2010).

This thesis attempted to study the effects of the interaction between emotionally arousing stimuli and attention on time estimation. Specifically, by creating procedures that allowed for the manipulation of the amount of attentional resources allocated to the emotionally arousing stimuli. This enabled the investigation of the effects of emotionally arousing stimuli (angry facial expressions) on executive attention (i.e., by varying the difficulty of the non-temporal task), on attentional orienting (i.e., by varying the levels of emotional arousal of the stimuli) and on alerting (i.e., by providing participants with different instructions: “search for angry/search for neutral” and thereby changing their predispositions). The addition of the temporal bisection task to these procedures provided the means to measure the influences of these effects on timing estimations.

I was able to replicate and extend previous studies related to the influence of arousal on pacemaker speed (Droit-Volet & Meck, 2007) by having participants passively observe facial expressions presented onscreen while conducting a temporal bisection task. The presence of emotional faces on the screen has been shown to influence arousal even when subjects were not required to process the faces (Droit-Volet et al., 2004). Zakay & Block (1997) posit that arousal increases pacemaker rate so more pulses are recorded by the accumulator, which is associated with an overestimation of objective time. The presence of emotional faces in my experiment was predicted to increase arousal and hence cause subjective time to decrease (slow down time). My findings show that emotional stimuli were associated with increased proportion "long" estimates, which means participants presented with emotional stimuli overestimated the durations of the stimuli presented. However, this effect can also be explained by the attentional process of orienting, instead of arousal, since attentional orienting is associated with fast engagement with the emotional stimuli (Fox et al., 2001). Fast engagement is associated with rapid and more efficient stimulus processing of the faces, that would therefore allow greater attentional resources to the processing of the duration estimations (temporal task). According to the AGM, more attention allocated towards timing is associated with longer time estimations (Zakay & Block, 1997). Faster engagement due to emotional stimuli could potentially be assessed by evaluating the participants' reaction time (as a measure of processing speed). However, the passive viewing condition did not yield reaction time measurements. In order to study the effects of differential processing of the emotional stimuli on reaction time and on time estimations, the task needed to have an active observation condition.

In the active condition of the task (Experiment 2B), participants were asked to indicate the expression of the faces presented on the screen. By adding computations involving decision-making and response (by asking participants to decide whether the expression is closer to angry or to neutral expression), it was possible to study the effects of attention to emotional stimuli on time estimations. Specifically, executive attention was manipulated by varying the difficulty of the task. Thus, it was possible to determine the time necessary to process the emotional stimuli presented, and consequently, to assess if the time it takes to process the faces (measured by reaction time) is related to differential time estimations. As predicted, increased attention to the emotional stimuli (i.e., angry faces) shortened the perception of the frame durations. Moreover, the more ambivalent the facial expression (i.e., 50%), the shorter the duration estimation became. These results support the notion (e.g., Block et al., 2010; Khan, 1989) that subjective time estimation was mainly influenced by the change in executive attention such that increased attention to the difficult expression-recognition task decreased attention to the temporal task causing duration estimates to become shorter. Increased reaction times to the non-temporal task (i.e., faces) were negatively associated with the attentional resources allocated to the timing of the frame, thus causing the duration to be perceived as shorter. In addition, the overestimation effect found while asking participants to passively observe the angry faces was not observed during the active condition. This implies that the increase in attention to the facial expressions (even the angry faces) is associated with the processing speed of the faces rather than arousal independent of attention.

In order to delve further into the relationship between executive attention and time estimation, a visual search task was used, in which the participants had to search for a target in an emotionally neutral field, or in an emotionally charged field (Experiments 3 and 4 respectively). Once again, the results support the association between the duration underestimation effect and executive attention (e.g., Zakay, 1989). Specifically, as the task increased in difficulty, more executive attention was required to complete the visual search task, consistent with previous reports of decreased search performance as target-distractor similarity increases (Duncan & Humphreys, 1989; Eriksen & Yeh, 1985; Muller & Krummenacher, 2006; Wolfe, 1994). In turn, an increase in reaction times for detection of the target face resulted in fewer attentional resources allocated towards timing, and therefore led to shorter time estimations.

Implementing facial expressions for the visual search task allowed the evaluation of the affects of emotional arousal on attention. Early and rapid detection of an emotion-related stimulus, particularly an emotion associated with danger or threat (i.e., an angry face), is essential to our success, health and even survival. Therefore, it has been argued that there is an evolutionary predisposition that guides attention towards threatening stimuli (e.g., Eastwood et al., 2001; Ledoux, 2000; Öhman et al., 2001). In other words, the threatening nature of the stimulus attracts attention. The attention network associated with the efficient capture of attention when presented with an emotional stimulus is orienting. However, if a threatening stimulus is anticipated (expected to appear), then the control network of attention associated with the increased attentional allocation towards the stimulus is alerting. Therefore, depending on the situation, the presentation of an angry face or the expectation of an angry face would increase the attention allocated toward the face (i.e., increased orienting or increased alerting respectively) and away from the temporal task.

When comparing the visual search task with the identity continuum faces to the visual search task with emotional faces (Experiment 3 vs. 4), it was apparent that participants' subjective time estimations were decreased (underestimation of time) in the task with the emotionally arousing stimuli (i.e., angry facial expressions) compared to the identity task. This decrease in subjective time estimation is likely due to increased attentional allocation to the faces themselves (i.e., to the non-temporal task). Attentional allocation to the emotionally arousing stimuli shifted attention away from the temporal task and therefore, resulted in shorter time estimates. Specifically, results showed that an increase in executive attention (associated with the difficulty of the non-temporal task), increase in orienting (associated with slower disengagement from angry distractor faces), or increase in alerting (associated with searching for an angry face), all resulted in shorter subjective time estimations.

Since attentional procedures typically measure participants' processing speed (e.g., Eagleman & Pariyadath, 2009), the procedures used throughout this thesis utilize reaction time responses as a measure of attentional allocation. Although few have combined reaction time tasks involving emotionally arousing stimuli with temporal tasks, by teasing apart the components of attention, it is apparent that the connection between reaction time and time estimation is not straightforward. There appears to be a negative correlation between reaction time and time estimation in relation to executive attention and orienting. Specifically, the more reaction time needed for the non-temporal task, the less attentional allocation to the temporal task, and therefore the shorter the time estimations. However there is a positive correlation between reaction time and time estimation in relation to alerting, as alerting is associated with faster reaction times, but also with shorter time estimates.

In summation, it is possible to conclude that the attentional resources allocated towards or away from temporal processes (increasing or decreasing subjective time estimations respectively) are one of the key elements in time perception, while emotionally arousing stimuli (e.g., facial expressions) affect time perception by interacting with attentional processes. Shorter time estimations are associated with increased attentional resources allocated to non-temporal tasks, even if the non-temporal task is emotionally arousing in nature.

These results are in keeping with attentional influences on time perception, as in the AGM (Zakay & Block, 1997). The more resources that are drawn from timekeeping functions to meet non-temporal task demands, the more variable timing performance becomes, because fewer temporal cues are processed and stored. Going beyond the AGM, the present findings support a strong role for the interaction of emotion, arousal and attention – such an interaction impacts time perception.

It is important to recognize that the experiments on the influences of arousal on timing are difficult to generalize to real life situations. Specifically, alerting to facial expressions projected on a computer screen in a psychological laboratory setting is likely to be very different from alerting to real danger. Therefore, general performance in the laboratory may be a poor index of its ecological validity. In addition, the experiments conducted herein manipulated arousal by varying the percentage of emotional expression in the face (i.e., a continuum of faces between angry (0%) and neutral (100%)). It is possible that including morphed faces diluted the emotional arousal effects associated with exposure to emotionally arousing facial expressions. This tempering, in turn, might create the illusion of a more prominent contribution of attention to time perception estimations. Furthermore, in each experiment participants were exposed to the same faces in two sessions. It is possible that the long exposure and familiarity with repeating faces caused habituation and desensitization to the facial expressions, thereby weakening the effects of emotional arousal.

Real-life events that involve highly emotionally arousing scenarios may engage different elements of interaction between attention and emotional arousal. For example, during a car accident, attention is engaged, the driver is alert, reaction time is fast, yet duration estimations reported are “long”. This contradicts the findings that attention to the non-temporal task (e.g., driving) is associated with shorter duration estimations. To resolve this issue, it is possible to consider that in real-life stressful situations, attentional resources are generally depleted (Kahneman, 1973) and attention is allocated toward the passage of time itself. The driver of the car focuses only on the elements that are immediate and most relevant to survival (e.g., stepping on the brakes) while allocating attention to the timing of the responses in relation to the environment (e.g., how long before I hit the other car). The increased temporal awareness is consistent with longer time estimates. Therefore, in such an emotionally arousing, real-life situation, attentional resources are not allocated towards the emotional stimuli (e.g., the car approaching at a high speed) but rather inwards, towards the timing of the event.

Attentional allocation, whether involving executive control, alerting or orienting to an external stimulus, therefore, is a central component in the process of understanding subjective time estimations. The experiments presented employed a dual task procedure and instructed participants to give equal priority to the temporal and non-temporal tasks (similar to Grondin & Macar, 1992; Macar et al., 1994). But despite these instructions, participants may have treated one task as primary and the other as secondary. One potential solution would be to test a wider range of allocation strategies, with subjects instructed to devote different proportions of attention to concurrent temporal and non-temporal tasks. In addition, instead of merely manipulating attentional networks allocated to the non-temporal task, attention can be allocated differentially to the temporal task. For example, manipulation of executive attention allocated towards timing can involve varying the difficulty of the timing task (e.g., by varying the length between the short and long durations in the bisection task) (e.g., Church & Deluty, 1977), manipulation of alerting towards timing might involve differential reinforcement conditions (e.g., money) for timing one event versus another (e.g., Gallistel & Gibbon, 2000), and manipulation of orienting towards timing can involve procedures with simultaneous temporal processing in which cues (e.g., light) will elicit differential engagement or disengagement processes (e.g., Guilhardi et al., 2005). Further research will help further elucidate and tease apart the influence of each of the control networks with emotion, on time estimations.

CONCLUSIONS

The experiments in this thesis support the idea of attentional allocation to and away from timing itself as the main component in subjective time estimation. Emotionally arousing stimuli also have an influence on time estimation. However, going beyond the AGM, it seems that emotionally arousing stimuli influence timing indirectly by affecting attentional allocation. Regardless of whether the attention network involved was executive control, orienting or alerting, attention allocated towards the emotional stimuli resulted in shorter subjective time estimations while attention allocated towards timing elements resulted in longer subjective time estimates. Therefore, in line with the findings presented heretofore, a revised model that accounts for the influence of emotional arousal on the attentional networks will likely pave the road to a more complete understanding of subjective time estimations.

Leading researchers in the field (e.g., Dan Zakay and Richard Block) have recently commented on such a prospect (Block et al., 2010) and findings from the present dissertation provide empirical grounding to corroborate these theoretical advances. For example, in a recent popular piece Dan Zakay stated that "in some cases, emotions demand attentional resources for coping with them, and then duration estimations will be underestimated. In other cases, especially when emotions have a threatening meaning like in the case of fear or pain, time relevance will be high. In such cases the duration estimation will be overestimated" (Zakay, 2012, p. 521). Thus, the AGM model from 1997 requires updating and a more nuanced approach (e.g., accounting for the fact that the contemporary conceptualization of the control network labeled as “alerting” is at least partially overlapping with the historic notion of “arousal”). Future research will have to consolidate these definitional typologies and further tease apart the specific effect of the disparate attention networks and emotion on time perception.

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APPENDIX I: GLOSSARY

Accuracy: Accuracy defined as the precision with which the participants identified the faces. Accuracy is presented on a scale from 0-1 corresponding to accuracy levels on a scale from 0% to 100%.

AGM: The Attentional Gate Model, developed by Zakay and Block (1997) in which an attentional gate was added to the inner clock metaphor.

Angry: A facial expression representing the anger emotion.

Beth: Female face with a neutral expression presented in Experiment 3. A morphed continuum between Jane and Beth was presented.

Bisection point: Bisection Point defined as the point at which the psychometric curve, derived from plotting proportion "long" as a function of durations, crosses the .5 point on the y-axis. Also known as: 'point of indifference' or 'point of subjective equality'.

CI: Confidence Intervals at the 95% confidence level (within 1.96 standard deviations of the mean), used as interval estimates of the population parameter in order to indicate the reliability of an estimate.

Continuum: A continuous series of morphed faces in between two different faces. In Experiment 3 the continuums was in between Jane and Beth, in Experiment 4 the continuum was in between Matt's angry and Matt's neutral facial expressions.

Crowd size*:* The total number of faces on the screen on a given trial was four, eight, or 12 faces.

Distractor: In the visual search task, the distractors are the faces presented on the screen in addition to the target face. Distractors are all the same for each trial within a block.

Frame Duration: The length of objective time in which the gray frames were presented on the screen (between 400 ms and 1600 ms).

Greenhouse-Geisser: A correction factor that is applied to the degrees of freedom used to assess the observed value of *F* when Mauchly's test for Spericity is significant.

Jane: Female face with a neutral expression presented in Experiment 3. A morphed continuum between Jane and Beth was presented.

Matt: Male face presented in Experiment 4. A morphed continuum between Matt's neutral and Matt's angry facial expressions was presented.

Morphed Faces: The different faces developed with the morphing software (see Stimuli for details). Either on the angry-neutral facial expressions continuum (Experiments 1, 2 and 4) or on the Jane-Beth identity continuum (Experiment 3).

Mauchly's test: Tests the hypothesis that the variances of the differences between conditions are equal (i.e., Spericity). If Mauchley's test statistic is significant we must conclude that there are significant differences between the variance of differences, therefore, the condition of sphericity has not been met. If, however, Mauchley's test statistic is nonsignificant then it is reasonable to conclude that the variances of differences are not significantly different (i.e. they are roughly equal).

Neutral: A facial expression representing the neutral emotion.

Objective Time: The qualitative and quantitative description of time that is independent and remains unchanged under different conditions. Typically measured by arbitrary devices such as clocks and calendars

Reaction time: Reaction Time, defined in these experiments as the time in seconds from the onset of the face/faces on the screen to the time the participants responded to the faces by pressing a key on the keyboard.

Similarity: Defined as the similarity between the facial expression of the distractor faces and the facial expression of the target face. The similarity has five levels ranging between 0% similarity (different faces) to 100% similarity (same faces).

Spericity: Refers to the equality of variances of the differences between treatment levels Denoted by ε and sometimes referred to as circularity. Sphericity is violated when the differences between pairs of conditions have unequal variances (calculated by assessing the differences between pairs of scores in all combinations of the treatment levels).

Subjective Time: Our primary experience of duration based on personal interpretations. It is discrete and non-continuous, non-linear, highly context dependent and, therefore, is subject to change with respect to different conditions.

Target: In the visual search task, the target is the face the participant in looking for. The target face can be present or absent in a given trial.

Weibull distribution: A probability distribution fitted using a maximum likelihood method with repeated random sampling (i.e., Monte Carlo). The shape of the curve is determined by the parameters $\{\alpha, \beta, \gamma, \lambda\}$, and is typically a sigmoid function. The parameter γ gives the lower bound which can be interpreted as the base rate of performance. The upper bound of the curve is given by1-λ and is interpreted as the performance level for an arbitrarily large stimulus signal. The shape of the curve is determined by α the curve's displacement along the abscissa) and β (the curve's slope).

Weber's ratio: Weber's Ratio calculated by subtracting the duration at which a subject responded ‘‘long" with probability .75 with the duration at which a subject responded ‘‘long" with probability .25 and dividing the result by the bisection point. The dividend in this equation is also referred to as the ‘‘just noticeable difference", the smallest proportional change in the stimulus that could be detected by the participant.

APPENDIX II: FACE MORPHING METHOD

This list includes 67 specific locations used for creating the morphed continuums. The pictures at the edges of the continuums (i.e., 0% and 100% of P1) were marked with corresponding dots based on these locations.

Each eye:
Inside:
1 on the pupil, in the center of the eye
6 around the iris, as if on a clock face at 12, 2, 4, 6, 8, and 10 o'clock.
2 at the corners of the eyes
Around:
3 around the top crease of the eye lid
3 around the bottom crease under the eye

Each Eyebrow:
4 along the top of the eyebrow
4 along the bottom of the eyebrow

Nose:
1 at the base between the nostrils
4 inside the edges of the nostrils
1 in the very top of the nose
2 on the bottom of the nose
2 on the lower sides of the nose, where the nose begins to flare
2 on the upper sides of the nose, in-between the eyes (e.g. glasses location).

Mouth:
12 surrounding the mouth, including: five on top lip, five on bottom lip, and two at the corners of the mouth.
12 around the inside of the mouth, including: five on the bottom of top lip, five on the top of the bottom lip, and two in the corners of the mouth.

Head:
8 evenly spaced around the oval of the face.

APPENDIX III: TRANSFORMATION BETWEEN A LOGARITHMIC AND A LINEAR SCALE

Log Space	Exponential for base of 2	Linear Space
400	2	1
500	2.33	2
635	2.66	3
800	3	4
1000	3.33	5
1270	3.66	6
1600	4	7