THE UNIVERSITY OF HULL

How Slow Can You Go?
The Joint Effects of Action Preparation and Emotion on the Perception of Time

being a Dissertation submitted in partial fulfilment of
the requirements for the Degree of

Doctor of Philosophy

in the University of Hull

by

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February 2017

Summary

People are often found to temporally overestimate the duration of emotionally salient stimuli relative to neutral stimuli. To date there has been no investigation into the behavioural consequences of such an effect or whether such an effect can be enhanced.

Experiments 1, 2 and 3 investigated whether a behavioural advantage to temporally overestimating the duration of emotive stimuli exists. Reaction time facilitation was found following the display of an emotive stimulus which was more frequently temporally overestimated than a neutral stimulus. This provides support for the notion that temporal overestimation due to threat prepares one to act. However, such effects were not found in Experiment 1. Experiments 4 and 5 used multiple experimental manipulations to induce an enhanced temporal overestimation effect. Neither experiment provided evidence that one's perception of time can be distorted to a greater amount than has been previously demonstrated. This is explained by the operation of an internal clock, such as scalar expectancy theory (SET) (Gibbon, Church, & Meck, 1984), operating at some maximum level.

Finally Experiment 6 used electroencephalography to investigate the N1P2 complex in spider phobic and non-phobic individuals. The peak amplitude of the N1P2 complex was not modulated by the spider stimuli, however, the latency of the N1 component was found to be earlier when a spider stimulus was presented. It is suggested that the reaction time facilitation reported in Experiments 2 and 3 of this thesis may not be attributable to temporal overestimation per se, but instead is the result of a general cognitive speeding effect which also leads to temporal overestimation.

Acknowledgments

First and foremost, I would like to thank my parents for their continued and never wavering support throughout my Ph.D. Without you this would not have been possible and I will never be able to express in words my gratitude for your support.

I am deeply grateful to my supervisors Dr. David George and Dr. Mary-Ellen Large for their advice, support and seemingly endless patience. My thanks also to Dr. Jason Tipples who has continued to support my academic endeavours throughout both my undergraduate and postgraduate studies. To the fellow Ph.D students with whom I shared an office I thank you for making the writing process a (relatively) enjoyable endeavour.

Nicole I am grateful for your support and continued faith that I would eventually finish writing this thesis. I am sure there have been times when I have bored you with “interesting” facts regarding the perception of time and for this I offer my sincerest apologies.

I am grateful to Katie Miles, Lucy Howard-Comber, Charlotte Grove, Nam Yip and Tom Strudwick for their assistance with data collection in Experiment 6. I can say with confidence that without your assistance this would have taken many more months to complete. I would also like to thank the participants who took part in the experiments presented here, especially the spider-phobic individuals who took part in Experiment 6.

Finally, I would say to my brother David and good friend Ben that Psychology is indeed a science, trust me…

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1. General Introduction

'What then is time? If no one asks me, I know: if I wish to explain it to one that asketh, I know not.' (St. Augustine, 354 – 430 AD)

The concept of time is one with which we are all familiar; each of us can remember events now consigned to the past, each can envisage winning the lottery and we all experience the present. Yet the straightforward question of "what is time?" is difficult to answer. The Ancient Greek philosophers wrote about the nature of time at some length; Aristotle claimed time was implicitly linked to motion, being nothing more than a number reflecting one motion in terms of another (Aristotle, n.d., as cited in Annas, 1975). St. Augustine also wrote on the subject of time, dedicating an entire book of *Confessions* to the matter. Indeed, St. Augustine's view of a 'present of things present, a present of things past and a present of things future' (Augustine, n.d., as cited in Hausheer, 1937, p. 506) is an appealing, if not confusing, notion. Unfortunately, despite the great technological advancements and improved understanding of the modern era, the question remains largely unanswered. More modern research views time as the change in states of entropy, with time said to be the difference between a state of high entropy and a state of low entropy (Carroll, 2011).

Notwithstanding such a variety of definitions, it is apparent that time is a central concept to human life with the ability to perceive the passage of time crucial for much everyday behaviour. It is clear that attempting even the most basic of everyday tasks would become inexplicably more complicated without the ability to perceive the passage of time; whether it is crossing a road, driving a car or playing sport the capacity to perceive time accurately is of central significance. Although perceiving time accurately is of critical importance for a variety of everyday tasks, research has demonstrated that our ability to perceive time is subject to several distortions. Everyday sayings such as “time flies when you’re having fun” or “a watched pot never boils” are common and demonstrate the fluidity and subjectivity of time perception. However, the notion that one’s perception of time can be distorted so easily may have more severe consequences to human behaviour than people believing they are waiting too long for their morning coffee; behaviours such as crossing the road and driving motor vehicles are dangerous everyday tasks in which accurate perception of time is critical. The notion that one’s perception of time can be distorted with relative ease therefore, warrants further scientific investigation.

The experiments reported in this thesis examined the effects of two such distortions on our temporal processing ability, specifically viewing emotionally salient images and being in a state of action readiness. In the case of emotionally salient stimuli a large body of empirical research exists examining the effect viewing such stimuli has on our perception of time. Despite such a large body of empirical literature investigating the effects of emotionally salient stimuli on the perception of time none have, to date, investigated whether there be any behavioural advantage to the often-reported temporal overestimation effect. Furthermore, the effect of being in a state of action readiness has received relatively little interest. Given the intrinsic link between emotion and action preparation, it is surprising that, to date, no research has considered how the effects of emotion and action readiness combine to affect the perception of time. In general, therefore, the main purpose of the experiments contained in this thesis was to examine whether there is reaction time facilitation following the temporal overestimation of emotive stimuli. In addition, the experiments of this thesis investigated the extent to which emotionally salient stimuli modulate the effect of action readiness on time estimates (i.e., can our brain create a super distortion of time?). To date research has focussed on single experimental manipulations examining how emotion, attention, and action preparation amongst others, affect the perception of time. By testing the joint effects of emotion and action preparation across several experimental paradigms, this thesis represents the first attempt to find evidence of a super or enhanced temporal distortion.

This thesis comprises six empirical chapters which investigate how emotion modulates the effect of action readiness on time estimates. Experiments 1 through 5 use a variety of different experimental paradigms and experimental manipulations to investigate the combined effects of both emotion and action readiness on time estimates. Finally Experiment 6 used electroencephalography (EEG) to further investigate the link between action readiness and temporal overestimation due to threat through examination of the N1P2 complex.

1.1 Psychological Time

Psychologists' interest in the perception of time dates back to the time of Wundt (Wearden, 2016) and with such a long history it is important to discuss the current theoretical landscape. As Grondin (2010) points out, however, such a task is unenviable. Given the rich history of time psychology, the different approaches and the myriad tasks used throughout the field, it is an impossibility to cover all aspects of what is known about human time perception. Consequently, it is inevitable that the following discussion of time psychology will omit, due to necessity, research and theories not immediately applicable to the experiments reported in this thesis.

Within psychology it has been said “Obviously, trying to 'define' time is a fool's errand” (Toda, 1978, p. 371). Nevertheless some have embarked on such an errand and for the present purpose time can be viewed as “the conscious experiential product of the processes that allow the (human) organism to adaptively organize itself so that its behaviour remains tuned to the sequential (i.e., order) relations in its environment” (Michon, 1990, p. 3). Such a definition brings one to the analysis of time as a psychological construct. Psychologists have proposed that time can be thought of in terms of three distinctive parts; succession, duration and perspective (Block, 1990). Although current psychological research has largely focussed on temporal duration, the concepts of temporal perspective and succession have been studied empirically and will be discussed briefly first.

Time perspective is a somewhat confusing notion in that it is an aspect of time to which it is difficult to comprehend an alternative. Specifically, temporal perspective concerns how people relate and view issues relating to the past, present and future. The general consensus, amongst most individuals from Western culture, is that time is linear (Zimbardo & Boyd, 1999). That is to say that many people from Western cultures think of time along a sort of continuum; events approach from the future, are experienced in the present and recede into the past. However, that is not to say that such a linear temporal perspective is the only way to relate to the notions of past, present and future. Rather, many cultures, such as those from Latin America, relate to time as a circular process, one in which the future is not wholly different from the past (Graham, 1981). Often members of such cultures are said to be "present oriented" in that they focus on the present without forming impressions of what the future may bring.

The final two components of psychological time, succession and duration, evidently overlap; without knowledge of when one event ceases (i.e., the duration of an event) another event is unable to take place (and thus the perception of succession). However, the two aspects of psychological time have been considered separately in time psychology literature and thus will be treated so here.

Temporal succession has been described as "the fact that two or more events can be perceived as different and organized sequentially" (Fraisse, 1984, p. 2) and as such succession enables one to perceive two or more events as being different and arranged in some order. Classically, studies investigating the succession of time have concentrated on the perception of successiveness and simultaneity; that is attempting to find at which point one stimulus is perceived as following another compared to when two stimuli are perceived as being presented simultaneously. The point at which such a switch occurs between the perception of successiveness and simultaneity is complicated by the fact that such a point appears to vary dependent on the perceptual system excited by the external stimuli (see, Block, 1990). However, the ability to assign temporal order to events appears to remain fairly constant regardless of the sensory system (Hirsh & Sherrick, 1961).

Another influential line of research regarding temporal successiveness concerns what Clay, and more famously James, referred to as the *specious present* (Clay, 1882; James, 1918). Today the specious present is more commonly referred to as the psychological present; the point of time which we experience as *now*. The main empirical issue regarding the psychological present concerns its upper threshold, or rather the longest duration one can experience as being *now* before it is consigned to having occurred in the past. General consensus amongst researchers finds the psychological present to have an upper threshold of 5 seconds, however, the experience of *now* is said to rarely exceed 2 or 3 seconds (Fraisse, 1984).

The final component of psychological time, and that which has received the greatest amount of attention empirically, is that of duration. If an event lasts for more than a few milliseconds or an event is not judged to have occurred instantaneously, it is said to have duration, (i.e., if an event can be experienced and remembered, one can estimate how long the event lasted). It is this question, how people estimate time, which the subsequent section examines.

1.2 Models of Human Time Perception

There is a wide array of different models which have been proposed that attempt to explain how humans can perceive the passage of time. In general, there have been two distinct ways in which theorists have modelled such behaviour. Dedicated models of time perception, of which internal clock theories are examples, suggest that the perception of time arises from a specific or specialised area of the brain with the sole functioning of timekeeping (e.g., Gibbon, Church, & Meck, 1984). Alternatively intrinsic models of time perception suggest that there is no requirement for a specialised area for temporal information and argue that the brain can extrapolate time information from neuronal activity within the brain (e.g., Staddon & Higa, 1999). Although evidence suggests that dedicated and intrinsic timing models could underpin the human perception of time, this thesis shall concentrate on only the former, dedicated models of time perception due to their explanatory power and continued popularity in research literature. In addition the literature concerning time psychology has made a clear distinction between prospective timing (participants are made explicitly aware that the experimental task requires a time component) and retrospective timing (where participants are unaware that the task is time related) (Brown, 1985). In each empirical chapter of this thesis participants are aware of the time perception nature of the task and as such this thesis shall only discuss internal clock models in relation to prospective timing.

1.2.1 Treisman and the internal clock.

Despite time perception being an area of great interest and being widely researched through the history of psychology, it was not until the latter part of the 20th century when a model of this behaviour was proposed. In 1963 Treisman published the first developed model of an internal clock mechanism (Treisman, 1963). The internal clock model was simple: A pacemaker mechanism was suggested to send a sequence of pulses along a pathway at some arbitrary, constant rate in such a way so that the more pulses received, the more time has elapsed. The emitted pulses are recorded by a counter which later transmits information regarding the number of received pulses to a store. The store is linked to a verbal selective mechanism which contains labels of time durations (e.g., 30 seconds, two minutes etc.). A comparator mechanism is able to read information from both store and counter mechanisms allowing one to compare a previous time duration to a current time duration. As well as the aforementioned mechanisms, Treisman also advocated the inclusion of a specific arousal centre which acted upon the rate of the pacemaker; when one is aroused, it was suggested, the rate of the pacemaker would increase leading to perceptual distortions of time.

Although this model of time perception was certainly the first of its kind, Treisman was keen to advocate that several proposals regarding how humans are able to perceive the passage of time had been made previously. Initially it was suggested that the perception of time be based on the operation of a master chemical clock. In pioneering work Hoagland concluded that the basis of perceiving time was likely the result of chemical reactions occurring within one's brain (Hoagland, 1933), however, due to limited methodology and knowledge of the brain such neural substrates were not hypothesised. Thus, although the model proposed by Treisman was more sophisticated and more fully developed, the notion that there exists a specific structure for perceiving time had indeed already been made. A further feature of Tresiman's internal clock was the idea that time estimates were perceived in relation to previous time estimates which is similar to the ideas of adaptation level theory. Simply stated, adaptation level theory is the idea that one perceives stimuli in relation to how other stimuli of the same sort have been perceived previously (Helson, 1959). Additionally, Treisman's internal clock model incorporated the Weber function which was found to explain the relationship between the just noticeable difference (JND) of temporal durations across a series of experiments.

Nevertheless, the model proposed by Treisman is now recognised as "a landmark in the development of internal clock theory" and yet failed to make a considerable impact when first published (Wearden, 2005, p. 8). Despite the noticeable lack of interest generated by the notion of an internal clock, some research did attempt to relate findings to its functioning. For example, in an attempt to further the pioneering work of Hoagland, Lockhart (1967) also investigated how temperature affected time perception, discussing a similar temporal overestimation finding with reference to Treisman's model.

The most cited model of time perception today bears a striking resemblance to that of Treisman's internal clock model and shares many similar features. The next section of the thesis describes today's most prominent model of human time perception.

1.2.2 Scalar Expectancy Theory

Originally published as a mathematical model by Gibbon (1971, 1977), scalar expectancy theory (SET) is more commonly referred to in its information processing guise. Developed by Gibbon, Church and Meck (1984) SET proposes that one's ability to perceive time arises from the existence of three inter-related information processing stages. As shown in Figure 1 the first or *clock* stage is comparable to that of Triesman's (1963) pacemaker-accumulator pathway. The inclusion of a switch mechanism, however, was novel. Functionally the switch is able to open/close and thus restrict/allow pulses sent from the pacemaker to reach the accumulator, again whereby the more pulses received by the accumulator the more time that has elapsed. Thus, when one is asked to perceive the duration of a given stimulus or event (as in prospective timing tasks) a signal closes the switch allowing pulses to reach the accumulator; once the to-be-timed stimulus disappears a signal opens the switch preventing further pulses contaminating the count in the accumulator. In the *memory stage* the information held in the accumulator is relayed to the working memory store. When a temporal duration has some assigned importance (i.e., when a temporal duration is task relevant) the information held in the working memory store can be reinforced and subsequently stored in the reference memory store; a more permanent memory store. Should reinforcement of a temporal duration not be necessary, the model explains how one is able to make comparative judgements between the two temporal durations. Finally in the *decision stage*, information held in the working memory store is fed into a comparator mechanism along with a task relevant duration stored in the reference memory. Once these two temporal durations are compared one is able to respond based on a decision threshold regarding the task (i.e., say whether one duration is shorter or longer than another). As should be apparent and as has been mentioned previously SET has a striking number of similarities to Triesman's previous model of an internal clock. However, the success of SET was not necessarily due to its modelling, but rather its ability to explain a wealth of data.

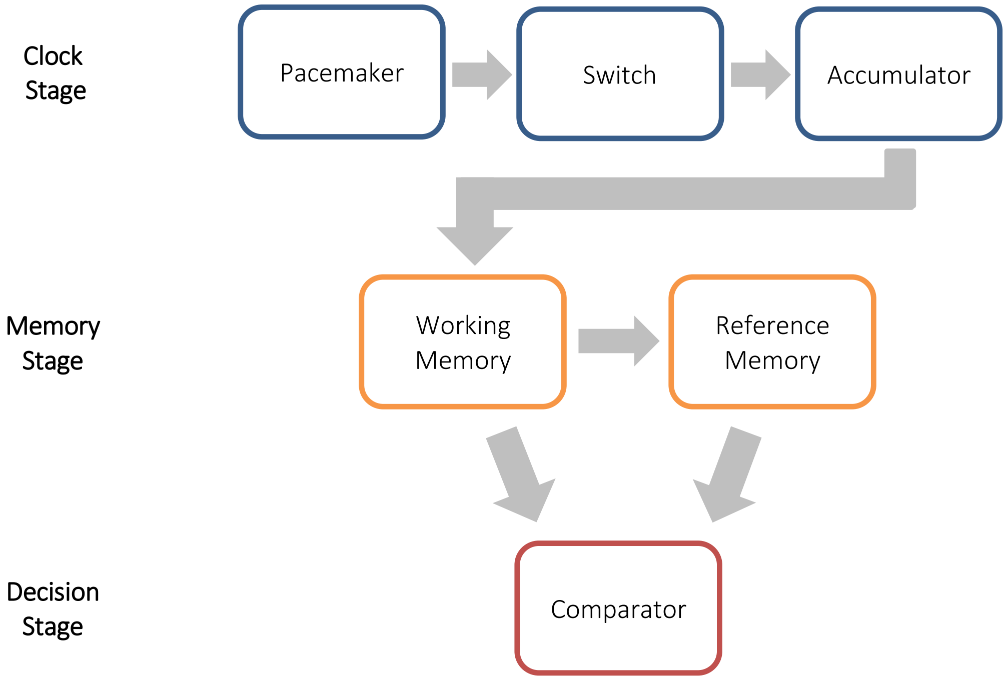


Figure 1. Information processing model of Scalar Expectancy Theory (adapted from Church, 1984).

SET was originally formulated to explain data reported from research concerning animal behaviour and was not explicitly discussed in terms of human timing behaviour for several years. Not until 1988 when Wearden & McShane (1988,

p. 373) commented “a scalar timing system can provide a good description of human performance” was SET explicitly discussed with regards to human time perception. Given the rich history of SET and timing based tasks in animal research a number of empirical studies began adapting methodologies, once previously exclusive to animal research, for human participation (temporal tasks are discussed on page 24). Following the discussion of SET in terms of human timing a burst of interest produced, largely, confirmatory support with SET continuing to influence research today despite initially appearing some three decades ago (Grondin, 2012). Indeed SET has been said to be one of the most prominent and successful applications from the study of animal to human behaviour (Ferrara, Lejeune, & Wearden, 1997).

1.2.2.1 Does Time Have Scalar Properties?

‘Behavioral time, like Einstein’s physical time, is relative’ (Dews, 1970, p. 47)

Initially, SET was formulated in order to explain data collected from studies concerning animal learning using schedules of reinforcement and later explicit timing tasks (Gibbon, 1991). Research had suggested that animals were capable of a type of proportional timing, whereby animals responded depending on the proportion of a stimulus duration as opposed to absolute duration values (for a discussion see Gibbon, 1991). Gibbon (1977) proposed that such behaviour arose from an underlying scalar process. This scalar process posits that time estimates are the result of a variable process which has been scale transformed in some way (Gibbon, 1971).

SET proposes that timing behaviour exhibits two properties: First, mean accuracy is the requirement that time estimates are, on average, equal to real time (Wearden & McShane, 1988). This can be thought of as a requirement that time estimates grow as a linear function of physical time itself (known as the psychophysical law; Grondin, 2014). Whilst there is evidence that this is indeed the case (Allan, 1979), one extensive review of a number of experiments reported contradictory findings (Eisler, 1976). The second property which time estimates must exhibit for scalar timing is the property of scalar variance which means that the proportion of variability to the mean is scalar (Wearden & McShane, 1988) (i.e., conforms to Weber's Law). In practical terms this requirement that Weber's Law (or some derivative, generalised form) holds means that time estimates will show two behaviours. First, time estimates collected from different temporal ranges will superimpose if plotted on the same relative scale. Second, as the to-be-timed time duration increases, the coefficient of variation (standard deviation/mean; CV) should remain constant (Wearden, 1991). A constant CV is best described as conformity to a generalised form of Weber's Law in that timing variability increases proportionally with the target time. Gibbon (1991) comments that conformity to Weber's Law provides only weak evidence for the scalar property. Indeed, the notion that time estimates of different target times superimpose when plotted on the same relative scale, it is argued, provide much more comprehensive support for this scalar property (Gibbon, 1977).

Throughout the early history of research concerning time perception the area of greatest interest was that of psychophysics; specifically, research focused on whether time perception followed apparent *laws* of perception. The most widely researched such law was that of Weber's Law. Weber's Law states that the JND in the perception of a given physical stimulus (e.g., the intensity of a light) is proportional to the original stimulus (Thurstone, 1927). Thus, for time estimates the

JND between two temporal durations should be a given proportion of absolute time. In order to test the scalar property of time there are generally considered three techniques; constant CV as absolute time is varied, superimposition of time estimates when plotted on the same relative scale and finally a simple regression of standard deviation against mean when some time is varied should produce a linear function with high R^2 values.

Although such research amassed large amounts of data, results were, and remain, conflicting. Indeed Allan and Kristofferson report “One fact is clear. Weber’s Law does not hold” (1974, p. 30), however, studies have concluded that a generalised form of Weber’s Law is found in timing behaviour (Getty, 1975; Gibbon, 1977; Treisman, 1963). Some of the most comprehensive support for time estimates conformity to Weber’s Law was produced by the extensive work of Merchant, Zarco, & Prado (2008). Across eight different experimental paradigms Merchant and colleagues report constant CVs (as the absolute time varied the variance increased proportionally with time). In addition, it has been demonstrated that reports of violations of the scalar property do not immediately put such results at odds with scalar timing theory. In a series of two papers Wearden and Lejeune (2008) and Lejeune and Wearden (2006) analysed data from several research articles from both human and animal literatures respectively. The authors report that despite there being several instances where violations of the scalar property had been found, such data could be said to lack empirical scalar timing and not necessarily theoretical scalar timing.

One frequently reported case of a violation to scalar timing is when very short durations are used in timing tasks (e.g., <100ms). In such cases it is often reported that the coefficient of variation is greater for longer durations as compared to these very short durations (reviewed in, Gibbon, Malapani, Dale, & Gallistel, 1997). However, as described by Wearden and Lejeune (2008) this is indeed predicted by SET by the operation of a switch mechanism; the latency of the switch to close will affect extremely short durations more severely than slightly longer durations. Thus, although violations of scalar timing have been reported, a number of such violations have been demonstrated to be reconcilable with an underlying scalar property. Despite this a more recent review of the literature has suggested that there is no scalar property of time estimates and that evidence in which a scalar property has been found have only done so by using very strict experimental criteria. As discussed in detail by Grondin (2014) research which has found evidence of a scalar property often use very restrictive experimental procedures which may be one reason as to why the scalar property is found. For example, in the extensive studies conducted by Merchant and colleagues (2008) the time to be judged was only ever between 350ms and 1000ms. Attempts to replicate the findings of Merchant colleagues has also proven unsuccessful with Grondin (2010b) finding non-constant CV values across similar time durations. In his review of the literature it is concluded “that there is no such scalar property” and moreover, that “the violation of the scalar property calls for a re-examination… of SET” (Grondin, 2014, p. 29).

This issue of whether time estimates do show a scalar property and as a result conform to a version of Weber’s Law is extremely worrying for advocates of SET given that the model relies on such a property. With such debate regarding the existence of the scalar property it is perhaps necessary for newer models of time perception to be developed without reliance on such a property. Despite such violations of the scalar property, however, it is undeniable that SET is able to explain a wealth of data which other models of time perception cannot (Wearden, 1999). Moreover, it is plausible that the lack of a scalar property for time estimates is found below a certain threshold (e.g., when participants begin to spontaneously count). Evidence for this comes from studies which have shown that the scalar property is found for time durations within a specific range (Merchant, Zarco, & Prado, 2008). In terms of the current thesis each empirical chapter uses a similar time range to that of Merchant and colleagues (2008) and as such it should be possible to find evidence for the scalar property; which is most comprehensively tested in Experiment 2.

1.2.2.2 Criticisms of Scalar Expectancy Theory

Despite the general acceptance amongst several researchers within the domain of time psychology and its capability to explain a great deal of empirical data, SET is not without critics. One of the most often cited criticisms levelled at scalar timing theory is that it lacks neurological plausibility (Karmarkar & Buonomano, 2007). The notion of a single pacemaker mechanism has been recently targeted, with neurological based studies appearing to show that human timing processes are much more complex than the information processing account postulates. Indeed Buhusi and Meck (2005) report that temporal based tasks require the use of a variety of neural locations and thus, it is unlikely that a single pacemaker is involved (see also Bhattacharjee, 2006; Coull, Cheng, & Meck, 2011). Nevertheless, some neurological studies have supported SET, with Casini and Vidal (2011) finding evidence for the supplementary motor area (SMA) playing a role akin to that of the proposed accumulator. Despite such evidence it is probable that the information processing model is neurologically implausible; a single pacemaker is unlikely to underlie the variety of brain regions involved in temporal processing given that research has identified different temporal memories for different sensory modalities (Ogden, Wearden, & Jones, 2010). However, it may be argued that such criticisms over neurological plausibility are but a minor hindrance; research has shown that areas of the brain may function in a similar fashion to accumulator like mechanism (Casini & Vidal, 2011) and one internal clock theory in particular shows how a neurologically plausible internal clock may function (see, Buhusi & Meck, 2005).

A further criticism of SET is that parts of the model appear underdeveloped. The inclusion of a working memory store appears to be a weakly formulated component of the information processing model. The working memory store, in terms of SET, is postulated to receive information from the accumulator and relay such information to the reference memory store and comparator mechanism (Gibbon et al., 1984). Although this conceptualisation is elegant and reliance upon a working memory store seems plausible, SET fails to incorporate the vast literature that has arisen from research concerning memory, which is indeed noted by Gibbon and colleagues. One of the most cited models of a working memory store is that of Baddeley and Hitch’s multiple component model consisting of; a phonological loop system, visuospatial sketchpad and a central executive (Baddeley & Hitch, 1974) and the more recent four component model with the inclusion of the episodic buffer (Baddeley, 2000). Given that this influential model of working memory was first conceived a decade prior to the publication of SET’s information processing account, it is surprising that the working memory store was not developed further. Recent research has begun to investigate more closely the relationship between working memory and time perception, with neurological evidence revealing the two share an intrinsic link (Matell, Meck, & Lustig, 2003). In addition it seems apparent that the central executive, or specific components of its functioning, is involved in temporal processing (Brown, 2006; Fortin, Schweickert, Gaudreault, & Viau-Quesnel, 2010; Ogden, Salominaite, Jones, Fisk, & Montgomery, 2011; Rattat, 2010). Research has, however, been less forthcoming for the requirement of a reference memory.

The reference memory store is described as a store of reinforced working memory contents (temporal durations) which can be used in comparison type decision tasks (Gibbon et al., 1984). From this description, it is apparent that, by some process, important or task relevant temporal durations are transferred from the working memory store to reference memory. One of the few models as to how this process occurs suggests that the reference memory does not store single memories for task important memories but rather stores a distribution with an upper and lower limit around the important duration (Jones & Wearden, 2003; Ogden & Jones, 2009). This perturbation model suggests that important time durations are not necessarily stored accurately but rather are stored with some degree of error meaning that each task important duration is stored as a distribution of durations. On a given trial if the task important duration is stored within this acceptable distribution then the stored distribution is unaffected. When, however, the important time duration is stored outside of this distribution the distribution in the reference memory will be altered to accommodate this new important duration representation.

Evidence for this perturbation model comes from the finding that participants do not increase their accuracy of recognising a standard time duration in a temporal generalisation task with increased exposure to the standard duration

(Jones & Wearden, 2003; Ogden & Jones, 2009). If reference memory were a store of remembered, important time durations one would expect that with increasing exposure to an important duration participant recognition of that duration would improve. In a series of studies such an effect was not found by Jones and Wearden (2003) and was later only found when a visual cue was presented prior to the first viewing of the standard duration in a visual based task (Ogden & Jones, 2009). Although the perturbation model of the reference memory store would explain this finding, it does little to explain how participants can complete temporal tasks in which an important or comparison duration has been presented only once.

Previous research has suggested that participants may require only a single presentation of a task-important duration to perform a temporal task. In a series of experiments Wearden and Bray (2001) found that in some conditions only one presentation of a standard stimulus was required for timing behaviours to conform to the properties outlined by SET. After only one presentation of the standard temporal duration, it is improbable that one could reinforce the temporal duration in the working memory store and thus convert to the reference memory store. If participants can complete tasks with temporal durations held in the working memory store as opposed to the reference memory store one may debate the requirement of such a reference memory store. This raises further questions for the information processing account of SET as it is within this reference memory where scalar variance is thought to be introduced.

One of the first publicised accounts of the information processing model of SET discussed where in the model the scalar property or scalar variance was likely to arise. Simply stated the scalar property of time refers to the idea that the perception of time is relative to the temporal duration being judged. For instance, similar to the perception of sound or light, scalar timing theory suggests that the JND between two time durations is a given proportion of absolute time. Gibbon and colleagues (1984) examined each component of the information procession model aiming to establish where the scalar property was introduced into the model. The authors note that the three most likely sources of such variance were the pacemaker, memory stage and decision threshold. However, as discussed previously Wearden and Bray (2001) report a situation in which the requirement of using a reference memory store is unlikely. Thus, if the reference memory store is not as critical to the functioning of one's ability to perceive time, such a property is unlikely to arise solely from memory. The second most likely source according to Gibbon *et al.* (1984) is that of the pacemaker. The pacemaker in SET is most often modelled with Poisson variance whereby the output of the pacemaker has some variably constant rate (i.e., the average number of pulses emitted shall be constant but the delay between emitted pulses may vary). However, the existence of such Poisson variance alone is known to be at odds with scalar timing (Gibbon et al., 1984; Staddon & Higa, 1999; Wearden, 2001). Indeed, SET accounts for such variance by proposing a modification to the rate of the pacemaker resulting in scalar as opposed to Poisson variance (Gibbon et al., 1984). This proposition has been argued by some researchers to be an ad-hoc process used to try and reconcile incompatible data with SET (Staddon & Higa, 1999). Thus, if the scalar property does not arise from within the memory stages or pacemaker, it remains unclear where exactly the source of scalar variance is located. Despite the difficulty in locating the exact source of the scalar property Gibbon has written extensively on the issue stating that even if there is only one source of scalar variance, this would dominate all other sources of variance in the internal clock model leading to an overall scalar process (Gibbon, 1971, 1992; Gibbon et al., 1984).

It is apparent that despite the great successes of SET there remain several issues regarding its conceptualisation including whether time estimates actually exhibit scalar properties. Nevertheless, scalar timing theory has dominated human time psychology for some two decades and despite several competing or alternative models, continues to do so. Although researchers are attempting to isolate the neural underpinnings of time perception, SET remains one of the most influential theories concerning the perception of time (Grondin, 2012). Moreover, owing to the three stage information processing model, researchers are able to easily test and examine each component at an individual level (Meck, 1983). Consequently, due the undoubted success of SET and its continued presence in time perception literature this thesis shall discuss timing behaviours in relation to the operation of an internal clock, such as the one postulated by SET. However, one last objection to the theory will first be discussed before examining the multitude of ways one can investigate timing behaviour.

1.2.2.3 The Attentional Switch

Within the information processing model of SET a switch mechanism is postulated to close, with some latency, when a signal arrives indicating one must begin or stop timing a stimulus. This switch mechanism is proposed to account for the vast empirical literature concerning how attentional demands affect one's perception of time (discussed on page 33). It is argued that when one is distracted from a to-be-timed stimulus, the switch opens preventing pulses from the pacemaker reaching the accumulator resulting in participants underestimating the duration of the timed stimulus (as fewer pulses reach the accumulator). On the contrary, when one pays attention to the passage of time, the switch remains closed allowing the flow of pulses from the pacemaker to reach the accumulator resulting in more accurate time estimates. However, some have argued that the information processing account of SET is inadequate to explain research concerning attention and the perception of time.

Zakay and Block (1997) proposed an attentional gate model, shown in Figure 2, which is almost identical to the information processing model of SET except for the inclusion of an attentional gate mechanism. It was argued that SET should incorporate within the information processing model an attentional gate which would be positioned either before or after the switch or replace the switch altogether (Block & Zakay 1996). Specifically, the attentional gate model postulates that when one attends to time (as in a prospective task) the gate opens wider or more fully allowing more pulses from the pacemaker through to the switch and accumulator. Conversely when one is distracted or not attending to a temporal task the gate narrows, preventing some number of pulses from reaching the accumulator. The switch, it is argued, acts on the accumulator by closing or opening which allows or prevents, respectively, the pulses entering the accumulator. Therefore, the attentional gate model is almost identical to that of the information processing account of SET, differing only with the inclusion of a gate type mechanism which is modulated by attention.

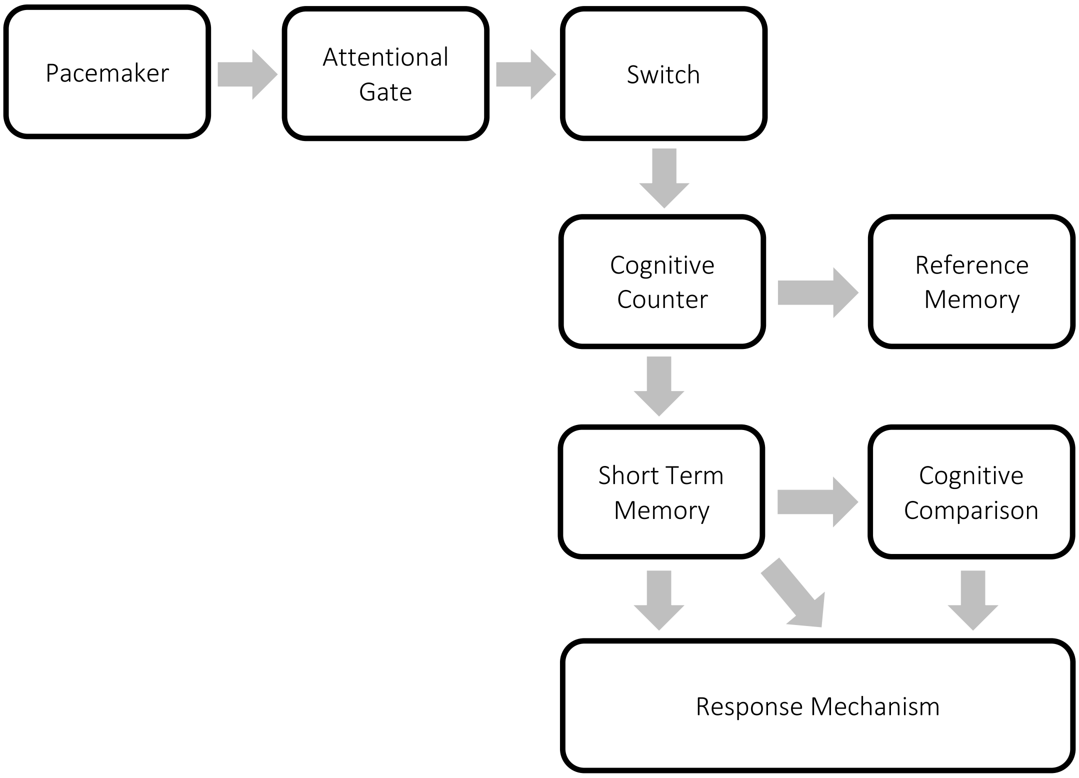


Figure 2. The attentional gate model of time perception adapted from Zakay (1995)

The merits of this gate mechanism were discussed in depth through a series of articles by Lejuene and Zakay. Beginning with Lejuene (1998) the need for this additional attentional gate was challenged with the author concluding that the switch mechanism was able to explain effects of attentional demands without another mechanism such as a gate. Indeed, Lejeune states that the attentional switch incorporated in the information processing variant of SET already adequately explains effects of attention on time estimates. When one attends to time the switch closes leading to accurate time estimates and when distracted the switch opens leading to fewer pulses reaching the accumulator and hence underestimation of time estimates. In addition, Lejeune (1998) argues that the switch can operate in between these two extremes in a flickering mode. This flickering mode would function in a similar way to the proposed attentional gate; in a dual-task paradigm participants are tasked with timing a stimulus as well as completing a distractor task. In such situations participants must “flick” back and forth between the two tasks meaning that the internal clock switch must also have this ability given that the opening of switch does not immediately reset the accumulator (Roberts & Church, 1978). Thus, Lejeune argues that this flickering switch mode functions in the same way as a widening or narrowing of an attentional gate.

Zakay (2000) countered with research suggesting that there was a requirement for a further component to be added to the information processing model of SET for it to fully explain the effects of attention on time perception. In particular it is claimed that the attentional switch is unable to explain findings in which participants must time two intervals separated by only a small inter stimulus interval (ISI) (see, Boltz, 1991). However, in a final paper Lejeune (2000) once more challenged such claims adding that in such circumstances as Boltz’s experiment data could be explained in terms of the reference memory rather than the attentional switch. Lejeune, however, did concede that SET may not fully explain all timing behaviours successfully, but that the attentional gate model “does not seem endowed with anymore supplementary explanatory power” (Lejeune, 2000, p. 75). Despite this lengthy debate the matter of the switch or gate was most comprehensively researched by Burle and Casini (2001).

Although Lejeune and Zakay differed on several of points, one aspect both found agreement with was the operation of the switch. The switch is said to operate in an all or none fashion; either the switch allows pulses to reach the accumulator or it does not. However, the switch is able to alter between open and closed states (i.e., flickers) during individual trials (Church, 1984). Conversely the attentional gate was argued to open more fully when one attends to the to-be-timed stimulus, thus such a mechanism can vary the degree to which pulses reach the accumulator (Zakay & Block, 1997). From this it is evident that the two different mechanisms would, under specific circumstances, predict different effects of attention on time estimates.

As discussed by Burle and Casini (2001) if attention affects the functioning of an all or nothing operating switch, effects of attentional capture should be consistent regardless of the speed of the pacemaker. For example, when the pacemaker is operating more quickly and the switch is open, no pulses will enter the accumulator. However, if attention affects a gate with an ability to vary its openness, a pacemaker operating quicker shall cause a given proportion of pulses to still enter the accumulator at some reduced rate. In a well-designed experiment the authors increased the rate of the pacemaker to establish what mechanism attention was likely to effect. The authors reported that their results supported the notion that attention affects the operation of a switch operating in an all or none manner and so concluding "switchgate". Consequently, throughout the remainder of this thesis the term switch is used.

1.3 Temporal Tasks

Given the long history of research concerning time perception, or indeed animal learning, several tasks have been devised to enable researchers to study the subject. Classical timing tasks include the verbal estimation, reproduction method and method of production tasks (Wearden, 2003). This section shall describe each type of task before going onto to discuss the newer comparison paradigm tasks in greater detail.

1.3.1 Verbal Estimation

One of the oldest methodologies used in human time perception research is the verbal estimation task. In the task a stimulus is presented for a given time duration by the experimenter with the participant asked to estimate the duration of the stimulus. As the name suggests this was originally given verbally, however, in more modern versions analogue scales or computers are used to record the participant estimate. Despite the continued use of the verbal estimation task, there are some limitations to its use. It has been demonstrated that results from experiments using the verbal estimation task exhibit greater variance than other timing tasks when analogue scales are used (Angrilli, Cherubini, Pavese, & Manfredini, 1997; Clausen, 1950; Danziger & Du Preez 1963). Furthermore, there is the issue of the participant converting their time estimate into clock units (for example seconds or minutes). Although most participants are familiar with such clock units, one cannot test young children using this method; in addition this conversion to clock units may introduce added variance to participant answers (Danziger & Du Preez 1963). Moreover, as discussed by Wearden (2014), despite the relative ease of the task and its popularity, there are no models as to how participants complete the task. Thus, it remains to be seen exactly how this conversion from time estimate to clock units happens or, and perhaps more importantly, if such a conversion could introduce extra variance into time estimates.

However, the main issue with the use of such a task is that of participants' reluctance to use the entire number line when estimating the duration of a stimulus. This issue, termed quantization by Wearden (2003) is particularly problematic when researchers are interested in durations which are not whole numbers or seen as participant unfavourable (i.e., do not end in 5 or 0). For example, if a researcher was interested in the perception of a stimulus with duration of 1783ms, it is unlikely that participants will ever give the correct verbal estimate which would violate one of the assumptions of SET (that on average time estimates are accurate). One study which demonstrated this issue clearly is that of McDougall (as cited by; Spencer, 1921) in which a total of 3% of intervals were correctly verbally estimated by participants. Nevertheless, thanks to the tasks relative simplicity the verbal estimation paradigm continues to be used extensively in research today in both healthy individuals and those from clinical populations (e.g., Bauermeister et al., 2005; Mimura, Kinsbourne, & O'Connor, 2000; Pastor, Artieda, Jahanshahi, & Obeso, 1992; Smith, Taylor, Rogers, Newman, & Rubia, 2002; Wahl & Sieg, 1980).

1.3.2 The Reproduction Method

In the reproduction task participants are given a temporal interval by the experimenter (or visually by a stimulus appearing and disappearing on a computer screen) and are asked to reproduce the interval through either a continued button press or two button presses (one to begin and stop the timed interval). The biggest conceptual issue regarding the use of this method is that it heavily relies on the participant's reaction time and motor delay in the pressing of or releasing of a button. As investigated by Droit-Volet (2010), when using the reproduction paradigm one must take into account the fact that individual differences in motor action delay can cause significant delays to time estimates. For example, when children are compared to adults, as in the study conducted by Droit-Volet (2010), it is found that children take longer to initiate action commands than adults. Such a motor delay in children lead to more frequent overestimations of a 2.5 second stimulus compared to adults, despite both age groups initiating the action to stop the temporal interval at the same time. Thus, it is apparent that, for short duration values, the method of reproduction is significantly affected by individual differences in motor delay (see also Szelag, Kowalska, Rymarczyk, & Pöppel, 2002).

One advantage to this task, however, is that the participant gives an absolute time estimation without needing to convert their estimate into clock units. This may be one reason as to why there is considerably less variance in this task than some forms of the verbal estimation method; as the participant is not required to make any sort of cognitive clock unit conversion there is arguably less room for variance. Moreover, such verbal labels of clock units (e.g., 1 second) are not necessarily stable across individuals despite the fact that such labels mark definitive periods of real time (Clausen, 1950). Contrastingly, in the method of reproduction paradigm the scope of individual differences having an affect are lessened to a degree; regardless of how long the participant believes the temporal interval to be (3 seconds or 2 minutes) as long as they reproduce that length of time, they will largely be accurate. However, given the importance of participant's motor delay the task is unable to be used in certain clinical populations where motor ability is compromised (e.g., Parkinson's disease).

1.3.3 The Production Task

The final classical task is that of production; here a given duration is either stated verbally or displayed numerically with the participant tasked to produce the duration through a series of button presses (akin to the reproduction task). In a slight variation of the task, termed production by waiting method, the participant is only tasked with marking the end of the duration as the experimenter marks the beginning of the estimated duration (e.g., Penton-Voak, Edwards, Percival, & Wearden, 1996). Similar to the reproduction method, the production task allows for participants to give an absolute time estimate without the need to convert the participant estimate into clock units. However, the task is rarely used for sub-second durations given that producing a temporal duration of 100ms would be difficult for participants and as such is more suited to investigations of longer temporal durations. Nevertheless, the task has been used recently in an investigation into how emotionally salient stimuli affects our perception of time (Gil & Droit-Volet, 2011b).

The previously discussed timing tasks have been used to investigate the notion of time perception for a number of years, however, as discussed by Wearden (2014) relatively little is known with regards to how participants make their decisions. Furthermore, research has demonstrated that time estimates differ depending on which of the classical tasks is used in an experiment (Gil & Droit-Volet, 2011). Moreover, results from classical timing tasks are often reported to violate the assumptions of SET; in particular research has found that the scalar property is often not found in data originating from these tasks (for a recent review see, Grondin, 2014). As discussed by Wearden and Lejeune (2008), however, whilst data from such tasks may not display empirical scalar timing, they can still be argued to demonstrate theoretical scalar timing.

The use of the classical timing tasks helped establish human time perception into mainstream psychological research and helped to further our understanding of how humans perceive time. However, recently comparison paradigms have become increasing popular in time perception research; specifically, the temporal generalisation and temporal bisection tasks. Although the temporal generalisation and temporal bisection tasks are widely regarded as new methodologies in human time perception research, the notion of comparison between the duration of two stimuli has existed since the mid-20th century (e.g., Clausen, 1950). What is new, however, is the dramatic increase in the number of experiments utilising these types of methodology.

1.3.4 Comparison Paradigms

The temporal generalisation task and the temporal bisection task are commonly referred to as comparison paradigms (Grondin, 2010). Contrary to classical timing tasks, participants are not asked to give an estimate of how much time has elapsed or how long a stimulus has been displayed for. Rather participants are tasked with judging whether the duration of one stimulus is shorter or longer than another. In the temporal generalisation task this is achieved by displaying a stimulus with a specific duration before a second comparison stimulus is displayed. The participant then responds as to whether the second stimulus was shown for the same or different time duration to the first. This temporal generalisation task, and its slight variants, have been used in human time perception research extensively (Droit-Volet, 2002; Droit-Volet, Clément, & Wearden, 2001; Droit-Volet & Izaute, 2005; McCormack, Wearden, Smith, & Brown, 2005; Wearden, 1992; Wearden & Bray, 2001).

The temporal bisection task was originally used as a way to test animal time perception (Church & Deluty, 1977) and was successfully applied to human research independently by two separate groups of researchers (Allan & Gibbon, 1991; Wearden, 1991). The task itself requires participants to judge whether one duration is closer to one of two previously learnt durations. In an initial training phase participants are taught to distinguish between two durations, with one being somewhat longer than the other. In a later test phase the participant is shown stimuli for either one of the two anchor durations or an intermediate duration. The participant is tasked with deciding whether the presented stimulus had a duration length closer to that of either the short or long anchor duration they had previously learnt in the training phase. The temporal bisection task has been used extensively in time perception research across different stimuli modalities (Jones & Ogden, 2015; Ortega & López, 2008; Penney, Gibbon, & Meck, 2000), with different time duration ranges (Wearden & Ferrara, 1996; Wearden & Thomas, 1997), with different participant age groups (Droit-Volet & Wearden, 2002, 2001; Lustig & Meck, 2001; Mccormack, Brown, Maylor, Darby, & Green, 1999; Wearden, Wearden, & Rabbitt, 1997) as well as in different clinical populations (Carroll, Boggs, O'Donnell, Shekhar, & Hetrick, 2008; Caselli, Iaboli, & Nichelli, 2009; Suarez, Lopera, Pineda, & Casini, 2013). One of the main advantages of this type of methodology is that the participant is not required to have any knowledge of time itself and as such the temporal bisection task (and temporal generalisation task) can be used with young children. A second advantage of this task is that it allows for specific predictions to be made regarding SET as one can attribute variance in participant judgements to specific components of SET (discussed in greater detail during Experiment 2). Furthermore, unlike the classical timing tasks, the comparison tasks produce results which do not violate the assumptions of SET (Kopec & Brody, 2010). As such, given the relative ease of both administering and completing the temporal bisection task, as well as being sensitive to several experimental manipulations, the temporal bisection task was used as the primary temporal task in this thesis. Moreover, the use of the temporal bisection task across two different duration ranges allows one to test for both the scalar property of time and allows inferences to be made on what part of the internal clock was affected by the experimental manipulation (see Experiment 2).

1.4 Distorting Time

Whilst the ability to perceive the passage of time accurately is central to many behaviours, our perception of time is fallible. Time itself is fixed and yet the perception of such durations can be distorted with relative ease. This anomaly is supported by anecdotal evidence; hearing phrases akin to “time flies when you’re having fun” or “a watched pot never boils” is common in western society. Students complain of time dragging when in a boring lecture, lecturers notice time dragging when marking essays yet exciting movies or events end all too suddenly. Given the importance of accurate time perception for much behaviour, the ease with which it may be distorted is surprising. It is this paradox which the following section discusses in greater detail.

1.4.1 Arousal

Treisman’s model of the internal clock (1963) was a landmark moment in time psychology as it was the first fully developed model of such a system. However, another important and influential aspect to his work was the insight that levels of arousal could influence the perception of temporal durations. Although research carried out prior to this pioneering article had investigated the effects of arousal inducing stimuli, the notion that such modulation affected the speed of a pacemaker-type mechanism was first proposed by Treisman (1963).

Early research regarding the perception of time focussed largely on time as a percept from within the domain of psychophysics as opposed to time as a subjective experience. Despite this general trend of research at the beginning of the 20th century, there are examples of research investigating one’s experience of time as opposed to the nature of time itself. Initial research focussing on time perception from this alternate view examined the effect of fluctuations in body temperature. Initially investigated by Piéron and François (François, 1927; Piéron, 1923), work conducted by Hoagland (1933) received greater attention. Hoagland asked his wife, who through illness had an elevated body temperature, to count at a constant rate of once every second. Hoagland reported that his wife’s rate of counting became quicker (that is she counted to 60 sooner) the higher her body temperature was above normal. The same pattern of findings had also reported by François (1927). In their review of the literature concerning body temperature and time, Penton-Voak and colleagues (1996) concluded that of 12 studies directly increasing one’s body temperature, ten provide comprehensive support for the notion that such increases result in temporal speeding. The other two studies analysed by Penton-Voak *et al* show this same effect when temperature is increased to an extreme level, however, failed to show any effect when temperature is increased by a lesser amount. One apparent anomalous result included in the review is reported by Fox, Bradbury and Hampton (1967) reported that an unexpected, shocking low body temperature also causes the participant to produce shorter time durations. However, as described by Penton-Voak and colleagues such a result is reconcilable when one investigates levels of arousal as opposed to specifically body temperature.

In addition to research focussing on effects of body temperature on time, a range of other topics were investigated which yielded a similar, temporal speeding finding. One such example is that of work conducted by Langer, Wapner and Werner (1961). Participants were asked to produce a 5 second interval whilst in a danger or no danger condition. It was found that in the danger condition, as participants were being moved closer to the edge of a stairwell, their subjective experience of time was quickened (their five second interval productions were shorter) compared to when participants were in the no danger condition. Other researchers found experimental manipulations of both stress (Falk & Bindra, 1954) and motivation (Meade, 1959; Schönbach, 1959) also produced temporal distortions to name a few examples. Despite such a range of topics under investigation, they are arguably investigating the influence of a single effecter on one's perception of time perception – arousal.

Indeed, Treisman (1963) was the first to advocate that increases (or indeed decreases) in what he termed specific arousal act to influence the rate of pacemaker and thus cause temporal overestimation (or underestimation). The change to a more general, underlying modulation in levels of arousal brought together the distinct topics that had been investigated up to that time; stress, motivational intensity and indeed body temperature could now all be explained by relative increases or decreases in levels of what Treisman termed specific arousal.

1.4.2 Attention

One psychological factor which is known to impact the ability to perceive time accurately is the amount of attention one pays to the passage of time. Anecdotal evidence for the impact of attention on perceiving time suggests that when one is distracted from the passage of time, one's perception of time speeds up (i.e. people believe less time has passed than in reality). Indeed, giving credence to the phrase "time flies when you're having fun" people are often surprised at how quickly time passes when watching an exciting movie and are consequently not explicitly monitoring the passage of time. Given the rich history of empirical research concerning the effect of attention on time perception a relatively limited number of examples will be discussed in the following section, however, for a more complete review one is directed to Brown (2008).

A number of empirical studies investigating the impact of manipulating one's attention has on the ability to perceive time accurately have used a dual-task paradigm. Here the participant is asked to judge the duration of some to-be-timed-stimulus whilst engaged in a secondary, untimed, concurrent task. Findings from research using this type of task consistently report that participants more frequently underestimate the duration of the to-be-timed-stimulus when also performing the concurrent, distracter task (Brown, 1997, 2006; Brown & Boltz, 2002; Borís, Burle & Casini, 2001; Franssen, Vandierendonck, & Van Hiel, 2006; Gautier & Droit-Volet, 2002). Furthermore, research suggests that when participants are required to share their attention between two tasks, participant timing judgements become more variable; participants are less able to discriminate between temporal durations and as the amount of attention directed toward the timing task lessens temporal judgements become shorter (Grondin & Macar, 1992; Macar, Grondin, & Casini, 1994). Although merely a snapshot of research regarding attention and time perception these findings suggest that diverting attention away from the passage of time produce temporal underestimations (i.e. participants experience a temporal speeding effect where they believe less time has passed than in reality).

As outlined previously scalar timing theory explains temporal underestimations arising from manipulations of attention by the operation of the switch mechanism (Gibbon et al., 1984; Lejeune, 1998, 2000). As opposed to impacting on the speed of the pacemaker, as per manipulations of arousal, diverting one's attention from time is proposed to open the switch linking the pacemaker to accumulator. Consequently, fewer pulses are received by the accumulator and thus, the stimulus which is being timed is underestimated causing participants to experience a shortening of time.

1.4.3 Action and Action Readiness

Despite much more research concerning the distortion of time focussing on attention and arousal, several studies have investigated the extent to which action influences our perception of time. Originally focussing on specific temporal illusions, more recent research has started to investigate the effects of voluntary action on our perception of time. Moreover, many experiments have shown that action itself is not required to distort time, but merely preparing to act or even viewing an action produces temporal distortions. The literature concerning time perception and action is more varied than that of emotion and time perception in that a number of different approaches have been used. Some research has concentrated on time perception for a stimulus delivered to a moving body part, others have investigated the perception of time for implied actions and others still on the effects of action readiness of time estimates. Whilst it is possible that each of the aforementioned areas relate to different processes and separate effects on time they this section briefly describes examples of such studies.

In terms of action affecting time estimates several researchers have investigated an interesting illusion known as chronostasis. The chronostasis illusion emerges when one looks at a clock (i.e., makes a saccadic eye movement) and the second hand appears to momentarily take longer to move than normal (Yarrow, Haggard, Heal, Brown, & Rothwell, 2001). Although the exact mechanisms of the illusion are beyond the current thesis, the existence of such an illusion points to the notion that initiating an action can create temporal distortions. Although it has been claimed that action is not necessary or sufficient for the chronostasis illusion to occur (Hunt, Chapman, & Kingstone, 2008) one study in particular has found evidence to suggest that action itself is able to distort time. Specifically, Press, Berlot, Bird, Ivry and Cook (2014) conducted a series of experiments examining how action effects the perceived duration of an event. For example, in Experiment 1 participants were cued to lift either their index or middle finger after which a vibratory stimulus was delivered to either the congruent finger (same as the lifted finger) or incongruent finger. In comparison to a reference vibratory stimulus delivered when no action was being made it was found that participants overestimated the duration of the vibratory stimulus delivered to only the congruent finger. This experiment, as well as Experiments 2 and 3 of the same paper show that action itself is able to distort our perception of time (Press et al., 2014).

In addition to the experiment conducted by Press and colleagues described above, an increasing number of studies have attempted to measure the effect of action on time perception without any overt action taking place. Instead it has been consistently reported that even at times when no overt action takes place but instead when action is observed time is distorted. A series of papers demonstrate that action observation is enough to cause temporal lengthening even when a static image implying action is shown (Nather & Bueno, 2006, 2008, 2011, 2012; Nather, Bueno, & Bigand, 2009). Even more interesting is the finding that the degree of implied action seems to be linked to the degree of temporal overestimation reported. Such studies again suggest that action plays an influential role in distorting our sense of time. However, the picture is somewhat confused by accounts of temporal underestimation when both elite level pole-vaulters and non-athletes judge the duration of sport actions (Chen, Pizzolato, & Cesari, 2014).

One interesting study of note is that of Hagura, Kanai, Orgs and Haggard (2012) who report that neither overt action nor observing action is necessary for temporal distortions to occur. Rather one's sense of time can be distorted by simply being ready to act. In a series of experiments Hagura and colleagues asked participants to judge the duration of a white circle displayed on a computer screen. On certain trials participants were tasked with making a ballistic movement (touching the computer screen) thus placing participants in a state of action readiness prior to making their temporal judgement. It is reported that when participants are in such a state of action readiness they overestimate the duration of the white circle more frequently compared to when no action is being readied (Hagura, Kanai, Orgs, & Haggard, 2012). Interestingly, the authors go on to state that the effects of action readiness should not be considered as a simple extension of the chronostasis illusion given that chronostasis relates to the temporal dilation occurring after a saccadic eye movement. In contrast the effects of action readiness must occur before an action has taken place.

It is apparent, therefore, that manipulating one's attention, and manipulating levels of arousal as well as levels of action or action readiness (if the two are different) are seen to influence our perception of time in opposing manners. Recently there has been renewed interest in time perception throughout psychology, specifically concerning stimuli which are seen to both capture one's attention and lead to increases in levels of arousal as well as action readiness. Due to these opposite effects, it is perhaps unsurprising that recently there has been a surge in interest concerning the impact of emotionally salient stimuli on our ability to perceive time.

Emotional stimuli are of great interest to research concerning time perception largely because it is unclear which temporal distortion should arise from emotionally salient stimuli. Emotional images are known to induce arousal in people (Lang, Bradley, & Cuthbert, 1998; Mehrabian & Russell, 1977) which would suggest a temporal overestimation effect. In addition, emotional stimuli are seen to evoke an urgency to act (Frijda, 1986) which would further support the temporal overestimation hypothesis. However, conversely one may expect to find people underestimate the duration of emotional stimuli as they are also known to capture one's attention (Arnell, Killman, & Fijavz, 2007; Lundqvist & Ohman, 2005; Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001).

1.5 Emotions

The topic of emotion is one which has been discussed extensively throughout the history of psychology and as such a complete account of current theories and directions in current emotion research is beyond this chapter. Instead this section focusses on three broad models of emotion theory; specifically, discrete models, dimensional models and componential models.

1.5.1 Discrete Models

Proponents of discrete models of emotion posit that there exist a number of basic or fundamental emotions which are biologically pre-determined and have evolved to help us survive (Scherer, 2000). This notion, heavily influenced by the works of Darwin, has been extensively researched and supported by Ekman and colleagues (Ekman, 1994; Ekman, 1992a, 1992b; Ekman et al., 1987; Ekman & Cordaro, 2011), amongst others (Izard, 1992, 2007). However, despite the considerable number of emotion researchers who agree with the general idea of categories of emotion, there is considerable disagreement regarding the number of basic emotions. A widely cited discrete model pertains that there exists six basic emotions (Ekman et al., 1987; Ekman & Friesen, 1971); another contains a list of 7 (Ekman & Friesen, 1986) and a more recent models suggests that there may be as many as 14 (Nummenmaa, Glerean, Hari, & Hietanen, 2014).

Advocates of the approach cite research demonstrating that there appear a number of emotions which can be reliably identified and expressed across a number of cultures, including some with little contact with the outside world. In addition, treating emotions as separate and distinct entities from one another closely mirrors our everyday life. In society people refer to emotions as distinct from one another, using labels like *angry* and *happy* that are easily understood.

A large number of time perception studies concerning emotion have used this discrete model approach; in particular studies which have focussed on facial expressions (Droit-Volet, Brunot, & Niedenthal, 2004; Droit-Volet & Meck, 2007; Effron, Niedenthal, Gil, & Droit-Volet, 2006; Gil & Droit-Volet, 2011a; Tipples, 2008, 2011). As a result, such studies would suggest that there exists a distinct behavioural response (in terms of time perception) for each distinct emotion, in that seeing an angry facial expression produces a distinct effect from a happy face given that such emotions are separate experiences with their own behavioural and physiological responses.

Although a number of researchers support such a view, a large number have continued to criticise the notion that there exists a set of basic, biologically hardwired emotions (Barrett, 2006). Furthermore, research has continually questioned whether certain emotions really can be identified and expressed in the same manner across cultures (Barrett, 2006, 2009; Barrett, Gendron, & Huang, 2009; Gendron, Roberson, van der Vyver, & Barrett, 2014; Jack, Garrod, Yu, Caldara, & Schyns, 2012; Marsh, Elfenbein, & Ambady, 2003; Ortony & Turner, 1990; Russell, 1994). In addition, the search for the biological and neurological basis for each distinct emotion continues to remain elusive, casting further doubt on discrete models of emotion. Perhaps it is a consequence of such research, or a more general unease with emotions being biologically hardwired, that several researchers turned to thinking of emotions along a number of dimensions instead of being distinct entities.

1.5.2 Dimensional Models

Dimensional models of emotion argue that emotions are multi-faceted and place emotion labels along one or more scales depending on particular theorists. The notion that emotions were not discrete but rather could be thought of along a number of dimensions was first suggested by Wundt in 1905 (as cited in, Scherer, 2000). Although the exact dimensions used in each theory differ, general consensus is that the valence property and level of induced arousal (also called activation) are important dimensions (Posner, Russell, & Peterson, 2005; Rubin & Talarico, 2009); indeed valence and arousal have been shown to account for the greatest variance when people are tasked with categorising emotion labels (Feldman, 1995; Kuperman, Estes, Brysbaert, & Warriner, 2014; Lang, Greenwald, Bradley, & Hamm, 1993; Greenwald, Cook, & Lang, 1989). Ranging from pleasant (positive) to unpleasant (negative) the valence property of emotion is linked to the degree to which an emotion engages either the appetitive or defensive motivational system. The second dimension often used, arousal, is concerned with the level of motivational intensity the emotion causes and ranges from low to high.

When such a dimensional approach is used one can compare how relatively similar emotions differ; for example, although sadness and anger are both unpleasant (and so have the same valence) the two emotions differ on levels of arousal. Anger would be considered to have a higher arousal level compared to sadness as anger is a more motivational emotion than sadness. Thus, by using a dimensional approach to emotion classification researchers developed a more comprehensive understanding of the emotional experience as emotions which may appear as similar on levels of valance can vary on their levels of arousal.

In terms of time perception and emotion research the dimensional approach has a number of advantages to discrete models. First, by considering emotion in terms of their valence and arousal more detailed and empirically interesting results can be obtained; for example, as oppose to merely investigating how anger and sadness affect one's perception of time, researchers using the dimensional approach can consider how fear differentially affects time perception compared to sadness (a matched valence but less arousing emotion). In addition, there are now several databases which have extensively categorised emotion inducing stimuli according to their valence and arousal levels. The International Affective Digital Sounds (IADS) and International Affective Picture System (IAPS) (Bradley & Lang, 1999; Lang, Bradley, & Cuthbert, 2008 respectively) are two such databases which have extensively listed stimuli and their valence/arousal properties. A number of studies have used such databases as a way of investigating how time perception is affected by different combinations of arousal and valance (Grommet et al., 2011; Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007), with some findings showing differential effects of valance at different arousal levels (e.g., Angrilli et al., 1997)

Such advantages to the dimensional approach model are not to suggest that the approach does not have its limitations; for example using the valence/arousal continuums it can be difficult to differentiate between some emotions (Tellegen, Watson, & Clark, 1999). Anger and fear, for instance, are both rated as highly arousing and have negative valence so appear almost identical on dimensional models and yet are easily distinguishable from each other in everyday life.

1.5.3 Appraisal (Computational) Models

Appraisal or computational models of emotion operate on the assumption that emotions are the result of a series of cognitive judgements relating to a given situation (Roseman & Smith, 2001). The resulting behavioural/physiological response arising from these cognitive judgements is the overall emotional experience. There are a number of theories which conform to this general cognitive framework although there remains disagreement over which cognitive appraisals people must evaluate as well as the number of emotions one can produce. Lazarus (1991) argues that appraisals will produce a relatively limited number of around 15 major emotions, whereas Scherer states that owing to the potentially unlimited combination of appraisals there is scope for an unlimited range of emotion experiences (Scherer, 2009).

One of the most studied computational models of emotion is that of Frijda's theory of action readiness (Frijda, 1986, 1988, 2004, 2009). The theory of action readiness posits that emotions are intrinsically linked to action readiness; specifically, that being in a state of action readiness is said to be the experiencing of an emotion. Such a claim is somewhat similar to that of dimensional models of emotion, in that emotion is considered closely linked to motivational systems to act. Valence is concerned with whether an emotion evokes an appetitive or defensive motivational response. The main difference, however, is that Frijda argues that being in a state of action readiness is the same as experiencing an emotion.

Support for the theory of action readiness has largely come from Frijda himself over a number of years; one powerful line of support comes from the finding that certain patterns of states of action readiness are related to distinct emotions as are patterns of appraisal (Frijda, Kuipers, & ter Schure, 1989). Frijda (1986) also argues that language has developed in such a way that words for emotions and actions are closely related demonstrating the intrinsic link between them. Furthermore, it is argued that emotive facial expressions cannot be captured using a dimension classification system, however, facial expressions can be are argued to be differentiable based on the state of action readiness they exhibit (Frijda &

Tcherkassof, 1997). Of course, Frijda and the action readiness theory of emotion are not unusual in the notion that emotions and actions are, in some way, intrinsically linked, however, the notion that emotions are merely the experience of action readiness is unique.

With regards to time perception as the computational models of emotion suggest that the emotional experience is based around a series of cognitive appraisals each person undertakes, the emotional experience of people will vary significantly. For instance, for one to experience the emotion “sadness” one first must appraise the situation in a specific way and consequently, there is great scope for different individuals to appraise the same situation differently (i.e., what is sad for one individual may be appraised as shameful or even angry by another). Consequently, the effect each emotion has on the perception of time will largely be the result of how individuals appraise the situation. Thus, the range of temporal distortions for each emotion is much greater given that each individual could appraise the same emotion differently. Following on from this, such differences in appraisal by individuals may account for the varying and often divisive findings concerning one emotion. For example, a number of emotions have been found by different researchers to result in different temporal distortions; the facial expression fear for example has been shown to be both underestimated relative to neutral facial expressions (Zhang, Liu, Wang, Chen, & Luo, 2014) as well as overestimated (Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011a; Tipples, 2008, 2011). It is possible that such differences could be because participant appraisals of the same emotional stimulus were different across the studies. Furthermore, research conducted by Angrilli and colleagues (1997) found varying temporal distortions for similarly categorised emotions. The fact that there were such varying results, which are yet to be replicated, may serve to suggest that individual appraisals account for the breadth of findings.

1.5.4 Emotions Motivate Action

Although many emotion researchers may well question the idea that an emotional experience arises from a set of cognitive based appraisals, as in Frijda's (1986) action readiness theory, it is almost beyond question that emotion shares an intrinsic link with action.

Philosophically speaking emotion and voluntary action may well appear to be at odds with one another; emotions are often considered irrational and as being seated within the limbic system in the brain, whereas voluntary action results from activity in more frontal neural areas. However, it is often difficult to discuss voluntary action without any sort of emotional context. For example, when one is fearful or embarrassed it is often the case that one tries to escape the fearful situation they are in. On the contrary if someone is angry one often tries to confront the cause of the emotion. Although such anecdotes are nothing more than general observations, they do elude to an important psychological notion; emotions make people want to do something. The idea that emotions motivate us to act, however emotions are evoked, is perhaps not surprising. What is somewhat surprising, however, is that often one's motivation to act can be discussed in terms of only two opposing motivations.

The notion that much behaviour can be thought about in terms of two opposing motivational tendencies is by no means a recent psychological development with Freud's seminal works often described as being one of the first writings to draw a similar distinction (Elliot, 2013). More recent theorists often argue that emotions motivate, prime or facilitate one of two broad action tendencies. Typically such action tendencies are described as approach and avoidance (Carver, 2004; Carver & Harmon-Jones, 2009; Elliot, 1999, 2006; Elliot & Covington, 2001; Elliot, Eder, & Harmon-Jones, 2013; Harmon-Jones, Harmon-Jones, & Price, 2013), however, there are a plethora of other names which have been used to describe the same concept throughout psychology’s history (e.g., appetitive vs aversive). Thus, it is apparent that there exists a clear link between action and emotion; emotion serves to motivate us to act in a particular way; either towards or away from a given object.

1.5.5 Attention and Emotion

Emotionally salient stimuli are often reported to capture one’s attention more readily than non-emotive stimuli. Evidence for this comes from a variety of behavioural paradigms across both the visual and auditory modalities (for a review, see Yiend, 2010). A large body of research concerning the effects of emotion on attention comes from studies which have used basic visual search tasks in which participants are required to ignore distractor stimuli and identify a target stimulus. When emotional, particularly threatening, facial stimuli are used as targets in such a task, participants are typically found to be quicker than when neutral facial stimuli are to be detected, similarly when emotional distractor stimuli are used participants are slower to find a target stimulus (Eastwood, Smilek, & Merikle, 2001; Fox et al., 2000; Frischen, Eastwood, & Smilek, 2008; Juth, Lundqvist, Karlsson, & Ohman, 2005; Öhman, Flykt, et al., 2001; Öhman, Lundqvist, et al., 2001). Initially such evidence was largely found for threatening facial stimuli with suggestions that the attentional system could locate such stimuli pre-attentively (e.g., Ohman, Lundqvist, & Esteves, 2001), however, other studies suggest such an advantage is also found for happy and sad expressions (Williams, Moss, Bradshaw, & Mattingley, 2005). Some studies, however, have found no search advantage for emotional stimuli (Tipples, Young, Quinlan, Broks, & Ellis, 2002). Nevertheless, findings from a number of visual tasks, taken together with results from numerous other methodologies, provide strong evidence that emotive stimuli are processed rapidly by the attention system.

In addition, studies examining the link between emotion and attention have used modern technologies such as EEG and MRI methodologies. Two EEG studies have provided support for the notion that emotionally salient stimuli are processed differently to non-emotional stimuli. In particular, three ERP components have been found to be modulated by threatening facial expressions. Initially described by (Schupp, Öhman, et al., 2004) threatening faces were found to elicit an increase in the peak of the early posterior negativity as well as increases in the late positive potential. In a further study similar findings were also reported with increases in both the early posterior negativity and late positive potential (Schupp, Junghöfer, Weike, & Hamm, 2004). The findings from these studies demonstrate that threatening compared to neutral facial expressions are processed differently by the perceptual systems of the brain.

Given such clear effects of emotionally salient stimuli on the human attention system, one may predict that emotional stimuli would be found to be underestimated relative to neutral images given internal clock models such as SET. To recap briefly, SET likens our ability to perceive time to the workings of an internal clock in which an accumulator receives information from a pacemaker with an attention controlled switch located between these two mechanisms (Gibbon et al., 1984). When one is distracted away from the passage of time it is suggested that the switch opens preventing information sent from the pacemaker reaching the accumulator and consequently in this instance one would predict time be underestimated. Indeed, as outlined previously several studies manipulating attention have found this to be the case. However, interestingly emotions also cause participant arousal levels to increase relative to neutral stimuli which would predict the exact opposite result, temporal overestimation. The following section briefly describes empirical evidence for the effects of emotion on participant arousal levels before discussing time perception for emotional stimuli.

1.5.6 Emotions Increase Arousal

Rather than cause temporal underestimation as would be predicted by the effects of attention on the functioning of an internal clock, increases in arousal are reported to increase the speed of the pacemaker resulting in time overestimation. If the pacemaker is modulated by increases in arousal levels, on a given trial when arousal levels are increased the amount of information received by the accumulator is greater resulting in time durations being overestimated. In addition, the two predictions of time underestimation and overestimation can be differentiated between given their respective locations of action. The switch, as has been discussed, operates in an all or none manner so such effects should be additive with real time (i.e., the effect is not greater for longer real time durations) (Burle & Casini, 2001), however, manipulations of pacemaker speed should increase with real time as the effect of an increased pacemaker should be greater for longer real time durations (i.e., the effect is multiplicative with real time) (Droit-Volet & Wearden, 2002; Penton-Voak et al., 1996). Evidence for this has been reported in several studies in which participant's level of arousal has been thought to be heightened. One of the most often used experimental techniques used to speed up the functioning of the pacemaker is through the use of click-trains which have been consistently found to cause temporal overestimation due to an increased pacemaker speed (the reported effects were multiplicative with real time) (Jones, Allely, & Wearden, 2011; Penton-Voak et al., 1996; Treisman, Faulkner, Naish, & Brogan, 1990). As such, if emotional stimuli do increase arousal levels, SET would predict temporal overestimation.

Evidence for the increased levels of arousal for emotional relative to neutral stimuli is relatively scarce in comparison to the literature concerning effects of emotion on attention. One of the techniques most often used to show effects of emotion on arousal is that of electro-dermal responses such as the skin conductance response or galvanic skin response (SCR or GSR respectively), for a review of this literature one is directed to Boucsein (2012). In general it is often reported that when viewing emotionally salient images participant SCR is higher relative to when participants are exposed to non-emotive stimuli (Angrilli et al., 1997; Bradley & Lang, 2000; Khalfa, Isabelle, Jean-Pierre, & Manon, 2002; Lang et al., 1993). Of particular interest is the finding that the SCR measure correlates to the level of arousal induced by the emotional image whereas other electro-dermal measures correlate to the valance of the displayed image (Greenwald et al., 1989). Other methods apart from the SCR have also been used to support the notion that emotional stimuli affect one's level of arousal (e.g., pupil dilation). Here participant pupil size increased when an emotional image was displayed compared to when a neutral image was displayed

(Bradley, Miccoli, Escrig, & Lang, 2008). Together, these studies show that emotionally salient stimuli increase sympathetic activity within the central nervous system which in turn results in increased participant arousal levels.

As there are clear effects of emotion on both arousal and attention, and given that SET predicts different effects of arousal and attention on time perception, it is unclear how effects emotional stimuli should affect time estimates. On one hand, emotional stimuli are predicted to cause temporal underestimations given the effects of emotion on attention. On the other hand, however, SET would predict emotionally salient stimuli to result in temporal overestimations given the literature concerning emotion, arousal and action. The following section describes what is currently known in the literature regarding time perception and emotionally salient stimuli.

1.6 Emotion and Time Perception

Within the last decade research concerning time perception for emotional stimuli has become increasingly popular. This sudden spark of interest concerning emotion and time is somewhat complicated by the fact that several studies have used different types of stimuli to investigate the issue of whether emotional stimuli are temporally over or underestimated relative to neutral stimuli. Many studies have used facial expressions which have, in general, found consistent results; generally speaking, participants are found to overestimate the duration of more arousing facial expressions relative to neutral facial expressions.

Specifically it has been found that participants temporally overestimate the duration of angry and fearful facial expressions more frequently than neutral facial expressions (Droit-Volet et al., 2004; Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011a, 2011b; Tipples, 2008, 2011). Moreover, it appears the more arousing a facial expression is, the more frequently it is temporally overestimated; for instance the emotional facial expressions sadness and happiness have also been found to cause temporal overestimation relative to neutral stimuli but interestingly anger and fearful facial expressions are more frequently overestimated than expressions of sadness and happiness (for a review, see Gil & Droit-Volet, 2011a). To explain effects of emotive facial expressions on time estimates often researchers have interpreted such temporal overestimation findings within the operation of an internal clock mechanism such as SET. Generally it is considered that the temporal overestimation effect of emotive facial expression arises from the pacemaker increasing its speed on emotive relative to neutral trials (Droit-Volet et al., 2004; Droit-Volet & Meck, 2007; Droit-Volet & Wearden, 2002). Evidence for this pacemaker speeding hypothesis comes from studies which have suggested that effects of emotion on time are multiplicative with real time rather than additive with real time.

As discussed in greater detail elsewhere (Gibbon et al., 1984) and indeed in Experiment 2 of this thesis, there are a number of possible ways that experimental manipulations (e.g., displaying emotive stimuli) can, hypothetically, affect the functioning of the internal clock mechanism. One such way is through pacemaker speeding; it follows that if the speed of the pacemaker is increased on some trials relative to others more pulses will reach the accumulator on such trials causing relative temporal overestimation effects. On the other hand, experimental manipulations can also modulate the functioning of the switch mechanism by reducing or prolonging its latency to close or open during the beginning or end of a trial. Due to the mathematical qualities of SET it is possible to distinguish between these two hypotheses and determine which internal clock mechanism an experimental manipulation has affected. It follows that effects of pacemaker speeding due to arousal should be multiplicative with real time given that effects of a speeded pacemaker will affect longer absolute time durations than shorter ones. For instance, if the pacemaker is speeded up due to increases in arousal when one sees an emotive facial expression more pulses will reach the accumulator over the course of a 1200ms trial than a 300ms trial (multiplicative effect). On the contrary manipulations affecting the switch mechanism, due to its operating in an all or nothing manner (Burle & Casini, 2001; Lejeune, 1998), would be additive with real time. When the switch is open, no pulses can reach the accumulator, thus regardless of the absolute time duration being timed (1200ms compared to 300ms) the effect of the closed switch will be constant across these two trials (additive effect). A number of researchers have used such an interpretation when discussing temporal overestimation for emotive relative to neutral trials (Droit-Volet & Gil, 2009; Gil & Droit-Volet, 2012; Mella, Conty, & Pouthas, 2011; Smith, McIver, Di Nella, & Crease, 2011; Tipples, 2008, 2011). In terms of emotive facial expression therefore, the literature is in general agreeance that such facial expressions are temporally overestimated relative to neutral facial expressions due to the increase in speed of an internal clock pacemaker. This general pattern of findings has also been supported by studies which used different stimuli to facial expressions. One study using sound stimuli from the International Affective Digitized Sounds (IADS) database also report time estimates to be longer for emotional relative to neutral sounds (Noulhiane et al., 2007).

Although several studies attribute temporal overestimation to increases in arousal, one study has shown that arousal alone cannot explain the breadth of experimental findings. In a wide-ranging study Angrilli and colleagues (1997) report different effects of similarly arousing emotions dependent on levels of valence; for high arousing stimuli, unpleasant stimuli were judged to last longer than positive stimuli, however, for low arousing stimuli the pattern of results switched as negative stimuli were judged as lasting shorter than positive stimuli. Similar suggestions that arousal alone is not able to explain all instances of temporal overestimation for emotive relative neutral stimuli have also been made elsewhere (Gable & Poole, 2012). Furthermore, one study finds evidence to suggest that a reported temporal overestimation effect is more consistent with effects of the switch rather than pacemaker. Grommet and colleagues (2011) report temporal overestimation for emotive relative to neutral images taken form the International Affective Picture System (IAPS) database, however, such effects were found to be additive as opposed to multiplicative with stimulus duration (read absolute time). Such findings are interpreted as suggesting that the switch mechanism rather than the pacemaker caused the temporal overestimation effect although the authors note that multiplicative effects may have been present but not detected in the experiment.

One rather anomalous finding is the facial expression of disgust which, although a highly arousing facial expression, shows no temporal overestimation effects (Gil & Droit-Volet, 2011a; Grondin, Laflamme, & Gontier, 2014). Interestingly, however, when other stimuli eliciting the emotion of disgust are used (such as disgusting foods) they are found to be underestimated relative to fearful facial expressions (Laflamme, Sablonnière, Fournier, & Grondin, 2012). Again, such studies highlight the issue one encounters when attempting to explain all effects of emotion on time in terms of increases in arousal.

In terms of time perception for other kinds of emotional stimuli the pattern of results produces a somewhat more confusing literature than the research concerning facial expressions; less attractive faces are underestimated relative to neutral and attractive faces (Ogden, 2013), disliked foods are underestimated more frequently relative to neutral images and liked foods (Gil, Rousset, & Droit-Volet, 2009) whilst frightening films cause temporal overestimations of stimuli (Droit-Volet, Fayolle, & Gil, 2011). Moreover, when one uses more multifaceted images from the IAPS database, as Angrilli and colleagues (1997), Smith and colleagues (2011) and Séguin (2013), the effect of emotion on time estimates becomes increasingly complex. As the present thesis does not use images but rather facial expressions an exhaustive explanation of findings from these studies will not be conducted, however, it appears that for more complex images results are dependent on the time duration such stimuli are presented for (Angrilli et al., 1997; Smith et al., 2011).

Whilst there appears to be a fairly consistent pattern of data reported in the literature for facial expressions it is evident that such effects cannot be attributable to arousal levels alone given studies have found no effects of disgusted facial expressions on time estimates. This has been explained in terms of action readiness theories of emotion (Gil & Droit-Volet, 2011a); usually highly arousing facial expressions indicate a need to act but the facial expression of disgust is considered a more social expression which does not require the need for urgent action. Such an explanation fits well with the work by Angrilli and colleagues (1997) who also advocate the effects action urgency have on time estimates.

From the literature, it is clear that emotionally salient stimuli have been found to consistently produce temporal overestimation effects relative to neutral stimuli. In addition, it has been reported that a similar overestimation effect exists when one is preparing to make an action. Given the close link that exists between emotional stimuli and increases in action readiness a number of researchers have tentatively alluded to the idea that functionally temporal overestimation due to threat prepares one to act. Although such an account is plausible and logical, it has yet to receive any empirical validation.

1.7 Rationale of Thesis

The existence of temporal distortions resulting from emotive stimuli is said to be evidence that the internal clock is a “highly adaptive system that enables organisms to adapt efficiently to events in their environment” (Droit-Volet & Gil, 2009, p. 1). As of yet there has been no investigation as to what this adaptive function of the internal clock may be. The experiments reported in this thesis tested the idea that functionally temporal overestimation due to threat prepares one for action. If temporal overestimation due to threat prepares an individual to act, one might assume that effects of emotion on time estimates would increase the effects of action readiness on time estimates. If the consequence of temporally overestimating a threatening stimulus is increased time to act, one expects to find an increase in the effect action readiness has on the perception of time following the presentation of a threatening stimulus.

As previously discussed it is apparent that there exist clear links between emotionally salient stimuli and action readiness. Indeed, one major theoretical stance regards the existence of emotions links them to the knowledge that one is ready to act in some way (Frijda, 1988). Moreover, it has been consistently demonstrated that emotionally salient stimuli cause one's perception of time to be distorted. Recently, similar temporal distortions have also been found when participants are in a heightened state of action readiness (Hagura *et., al* 2012). Given these clear links between action readiness and emotive stimuli as well as the finding that both cause temporal distortions, one also wonders how the two might influence each other if manipulated in the same experimental paradigm. One possibility is that effects of action readiness on time estimates are enhanced by emotionally salient stimuli given their links to action readiness (e.g., Frijda, 1988) which would support the functional explanation of temporal overestimation due to threat. Another possibility is that action readiness and emotive stimuli result in sub-additive effects due to influencing the same mechanism within internal clock models.

From existing research it is apparent that increases in levels of action readiness affect the internal clock mechanism in such a way whereby stimuli are temporally overestimated (e.g., Hagura *et. al.,* 2012). However, it is currently unknown how such temporal distortions are reconciled with the operation of an internal clock such as SET. As discussed, there are two ways for such time overestimations to be brought about, however, to date no experiment has investigated whether action readiness modulates a putative pacemaker or switch mechanism. Investigated directly in Experiment 2, testing these hypotheses would enable researchers to better understand how action readiness influences the operation of internal clock models of time perception. Moreover, such an investigation into how levels of action readiness influence an internal clock mechanism could shed further light on determining whether such an effect reflects a different temporal distortion to emotional stimuli. Despite a great deal of research into emotionally salient stimuli suggesting temporal overestimation is the result of increases in arousal levels, it is apparent that such stimuli also differ to neutral stimuli in terms of their readiness to act. Consequently, if levels of action readiness were found to affect the supposed switch mechanism in internal clock models, it would suggest that effects of emotion are not simply due to the levels of action readiness.

Finally, time perception research has, to date, focussed on only single experimental manipulations which have often resulted in finding temporal overestimations (e.g., increases in arousal, action readiness, stress, temperature and attention to name but a few). However, it is currently unknown to what extent one's perception of time can be distorted to; is it possible to create a super or enhanced temporal overestimation effect? By investigating the effects of two experimental manipulations this thesis is the first to directly test for evidence of such an enhanced time distortion.

In short, the unique contribution of this thesis is threefold; first, Experiments 1 through 3 in this thesis investigated the behavioural advantages to temporally overestimating the duration of emotionally salient stimuli. Current hypotheses suggest such an effect may facilitate reaction times, however, this hypothesis has not been subject to a systematic, empirical investigation. Second, whilst several studies have shown action preparation influences our perception of time it is currently unknown how such distortions arise, in particular the functioning of the internal clock in such situations is yet to be explained. Experiments 4 and 5 more directly investigated the combined effects of emotion and action readiness on one's perception of time. Emotions share clear links with action readiness and as both result in temporal overestimation effects, these experimental manipulations were used to determine whether one’s perception of time can be subject to an enhanced overestimation effect.

2. The Functional Explanation of Temporal Overestimation Due to Threat

2.1 Introduction

To date there has not yet been an empirical investigation into the claim that temporal overestimation due to threat functionally prepares an individual to act. The purpose of Experiment 1 was to investigate whether increases in action readiness prior to seeing an emotive stimulus would produce an enhanced temporal overestimation effect.

The finding that one's perception of time is flexible has been considered evidence that the internal clock is a highly adaptive system (Droit-Volet & Gil, 2009; Gil & Droit-Volet, 2011a). In terms of an adaptive, evolutionary process such a claim makes sense given that emotive stimuli are overestimated relative to neutral stimuli; if the temporal overestimation of a threatening stimulus allows one to prepare to act, one is more likely to be able to flee the threatening stimulus. Somewhat similar claims have been made previously in different psychological literature. In a series of experiments it has been demonstrated that looming auditory tones are perceived as beginning closer and stopping closer than receding tones (Neuhoff, 2001). The author suggests that such an effect could be due to an evolutionary advantage for those who perceive approaching sounds as closer than they are, facilitating one's escape from the approaching stimulus. In addition similar results were found in an ERP experiment in which listener's overestimated the change in loudness of looming tones (Neuhoff, 1998). Such research suggests that evolutionary pressures may have selected for behaviours which allow organisms to both detect and flee threatening stimuli. It remains possible therefore, that temporal overestimation due to threat could have a similarly adaptive function. Although an interesting interpretation this claim has not yet been empirically tested directly in the time perception literature and awaits further investigation.

Previous research has consistently shown that emotive stimuli, in particular threatening stimuli, are temporally overestimated relative to neutral stimuli. More interestingly it is reported that the degree to which each emotive stimulus is overestimated is linked to the degree of action readiness each emotion evokes (Droit-Volet, Brunot, & Niedenthal, 2004; Droit-Volet & Meck, 2007). Highly arousing and action urgent facial expressions such as anger, for example, are overestimated to a greater degree than less arousing and action urgent facial expressions such as happiness (Gil & Droit-Volet, 2011). Moreover, the facial expression of disgust, a highly arousing expression (Lang et al., 1993), does not produce a temporal overestimation effect relative to neutral facial expressions (Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011a; Grondin et al., 2014). The general finding therefore, that highly-arousing stimuli are more frequently overestimated than lesser arousing stimuli appears more complex than it first appears. One study which supports this complex nature is that of Angrilli, Cherubini, Pavese, & Manfredini (1997) who found differential effects of emotional induced arousal and affective valence; low-arousal negative stimuli were found to be judged as shorter than positive stimuli but for high arousal stimuli negative stimuli were judged as longer than positive stimuli. The authors interpret this effect in terms of an action readiness model; low arousal stimuli are processed by a slower, attentional based processes whereas high arousal stimuli are processed by a more rapid, emotional based process. The combination of such findings shows that the effect emotion has on time perception is not simply due to arousal. Moreover, they suggest that the degree to which an emotion is overestimated is perhaps more closely linked to the amount of action readiness each emotion evokes than simply due to differences in arousal level.

Whilst the effect emotion has on time perception has been thoroughly researched, investigations into the effects of action and specifically action readiness are more limited. One study by Hagura *et., al.* (2012) found that when participants prepared to make a reaching movement they overestimated the duration of a neutral stimulus more frequently compared to when no action was being prepared. This suggests that action readiness and emotionally salient stimuli produce a similar temporal overestimation effect. The finding that both emotive stimuli and increased readiness to act produce a similar overestimation effect is perhaps not surprising given that emotions and action readiness are closely linked; especially when one considers experiencing an emotion as being the self-realisation that one is ready to act (Frijda, 2004). However, the degree to which these two effects combine remains unknown; does increasing one's level of action readiness modulate the effect of emotion on time perception? Experiment 1 sought to answer this question using a similar methodology to that used by Hagura and colleagues (2012).

One further study of particular interest conducted by Jones and colleagues (Jones et al., 2011) tested the notion that speeding up the internal clock, through the use of click trains, leads to changes in the speed at which other psychological processes are performed. In a series of four experiments Jones *et. al.* presented a sequence of click trains before asking participants to complete a specific task such as a simple reaction time task as in their Experiment 1. Interestingly Jones and colleagues (2011) find that following a series of click trains participant reaction times were faster relative to a condition in which white noise was presented.

When presenting a series of click trains in a timing based task, participants are often found to overestimate the duration of both the series of click itself and preceding stimuli (Droit-Volet & Wearden, 2002; Penton-Voak et al., 1996; Wearden, Pilkington, & Carter, 1999). The overestimation effect caused by such click trains is theorised to be the result of a pacemaker like mechanism of an internal clock speeding up. As such it is concluded by Jones and colleagues (2011) that processes which speed up the internal clock, such as click trains, also facilitate other psychological processes such as response time.

However, in the experiments conducted by Jones *et.al.,* participants were not directly asked to judge the duration of a to-be-timed stimulus and thus, although previously research consistently shows effects of click trains on time perception, it is difficult to definitively conclude that participants did indeed overestimate the length of the click trains given that no temporal judgement was required. Furthermore, the extent to which such processes are facilitated when participants view an emotive stimulus remains unknown; does temporal overestimation due to threat in particular cause other psychological processes to be facilitated?

If temporal overestimation due to threat does functionally prepare an individual to act, one would anticipate emotive stimuli to modulate the effect action readiness has on time perception. For example, if overestimation due to threat results in increases in levels of action readiness, viewing a threatening stimulus should further increase effects of action preparation on time. Such a modulation would support the notion than functionally, temporal overestimation due to threat prepares an individual to act. Another possible finding would be that the effects of action readiness would reduce the effects of emotion on time estimates (i.e., the effect will be sub-additive). Such a finding may suggest the effects of action readiness and emotion affect the functioning of the internal clock model at different time points in that the effect of action readiness, to some degree, masks the effect of emotion on time estimates.

Experiment 1 investigated whether increases in levels of action readiness and viewing emotive stimuli produce an enhanced temporal overestimation effect, as would be predicted by the claim that functionally, temporal overestimation due to emotion prepares an individual for action. The general aim of Experiment 1 was to more fully investigate the link between temporal overestimations of emotionally salient stimuli, increased levels of action readiness and response facilitation.

Specifically, the primary aim of Experiment 1 was to investigate the joint effects of emotionally salient stimuli and action readiness on the perception of time. To date there has been no investigation into the combined effects of factors which are known to distort our perception of time. Research has well established that both emotionally salient stimuli (e.g., angry facial expressions) and increased levels of action readiness (e.g., preparing to touch a computer screen) result in participants overestimating the duration of a to-be-timed stimulus (Droit-Volet et al., 2004; Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011, 2012; Gil, Niedenthal, & Droit-Volet, 2007; Grondin, 2010; Tipples, 2011: Hagura, *et. al.*, 2012 respectively). However, it is unknown to what extent such effects can combine to produce a more pronounced or exaggerated temporal overestimation effect. Thus, Experiment 1 is the first to attempt to try and induce an enhanced or *super* temporal distortion in participants.

A related aim of Experiment 1 was to investigate whether temporal overestimations due to emotive stimuli prepares one to act leading to response facilitation. If temporal overestimation due to threat prepares one to act, as has been claimed, it follows that emotionally salient stimuli should increase the effects of action readiness on time estimates. Furthermore, one would predict reaction times to be faster following emotive stimuli than neutral stimuli potentially due to this temporal overestimation effect. If emotive stimuli do not modulate effects of action readiness on time estimates nor reaction times the claim that there exists a functional explanation of temporal overestimation due to threat cannot be supported. One study has previously reported response facilitation following stimuli which often are found to produce temporal overestimations (Jones et al., 2011), however, Experiment 1 seeks to determine whether such effects are also found when emotive stimuli are presented instead of click trains. Furthermore, Experiment 1 measured reaction times to directly test for a functional explanation of temporal overestimation due to threat; reaction times are not presented in any study investigating the effects of emotion on time perception to date.

In accordance with previous findings, it was hypothesised that participants would overestimate the duration of emotive stimuli compared to neutral stimuli as well as overestimating the duration of stimuli when preparing to act compared to when no action preparation was required. More importantly, however, it is anticipated that when participants are in a heightened state of action readiness (e.g., are readying an action) and see an emotive stimulus (e.g., angry facial expression) the temporal overestimation effect shall be greater than in either the emotive stimulus or action readiness conditions only. Finally, as a direct test of the functional explanation of temporal overestimation due to threat and in accordance with action readiness theories of emotion (e.g., Frijda, 1986) it is predicted that emotive stimuli will shorten participant response times. Following this it would be predicted that participants would be faster to initiate an action following the display of an emotive compared to neutral stimulus.

2.2 Experiment 1

2.2.1 Method

Power Analysis

Prior to Experiment 1 an *a priori* power analysis was conducted to determine appropriate sample size using computer software G Power (Faul, Erdfelder, Buchner, & Lang, 2009). To detect a medium effect size when $\alpha = .05$ and $\beta = .80$ a sample of 34 participants was necessary.

Participants

A total of 28 participants took part in the experiment. The age range of participants was between 18 and 33 with a mean of 21 years of age (SD = 4.4). One participant was male. All participants were psychology undergraduate students attending the University of Hull. Participants received course credit for taking part in the experiment. Prior to commencing the experiment ethical approval was granted from the Psychology Departmental Ethics Committee.

Stimuli and Apparatus

The facial stimuli used had been created by commercial company DAZ Productions, Inc., Draper UT for use with software program Poser 5.0 (Curious Labs Inc., Santa Cruz, CA). Existing research has demonstrated it is possible to model both basic facial expressions (Spencer-Smith et al., 2001) and moving facial expressions (Krumhuber & Kappas, 2005) with the software. The facial stimuli were modified to show a threatening and neutral expression and are shown in Figure 3. The threatening facial stimulus has been used in previous research (for an example, see Tipples, 2007) and exhibited a V-shaped eyebrow; an open, downturned mouth and wide, open eyes. The stimulus had been rated as more highly threatening and arousing than all possible facial constructions of eyebrow shape (V-shaped, flat), mouth type (closed, open), eye type (wide, normal) and mouth curvature type (downturned, upturned) in previous research (Tipples, 2007). The neutral facial stimulus displayed a flat eyebrow, normal eye aperture and a closed, expressionless mouth (see, Tipples, 2011).

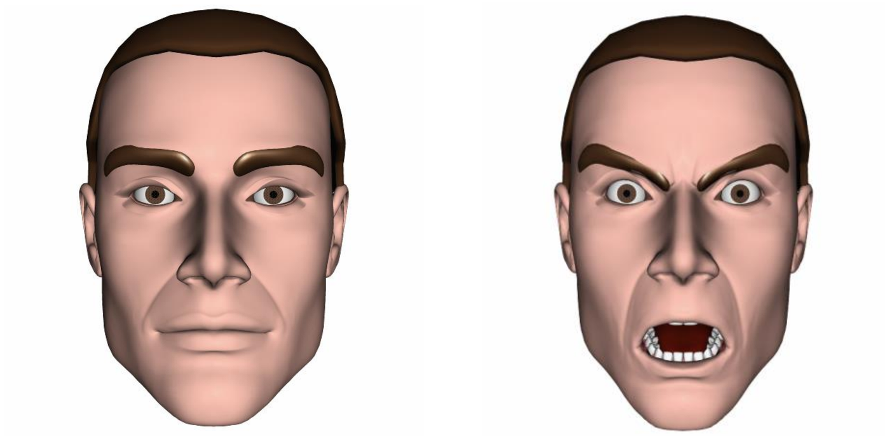


Figure 3. Stimuli used in Experiment 1; left panel showing the neutral expression and right panel the angry expression

The facial expressions measured 16cm in height and 10.5 cm in width. When presented in the centre of the computer screen stimuli measured 16° of vertical visual angle when participants were sat 58cm from the screen. Stimuli were presented using 1 GHz Pentium computer connected to a 21.5-inch Dell ST2220T touchscreen computer monitor (1920 x 1080, 60Hz). E-Prime 1.2 (Psychology Software Tools, Pittsburg, PA, 2002) was used for stimulus presentation and data collection. Participants sat at a comfortable distance from the computer screen but close enough to allow them to reach and touch the computer screen when necessary.

Design and Procedure

Experiment 1 used a 2 x 2 x 7 design with facial expression (angry, neutral), action condition (touch, no action) and duration (400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms and 1600ms) as the three within-subjects factors.

Participants completed a modified version of the temporal task similar to that used by Hagura and colleagues (2012). In this task participants are tasked with judging whether presented stimuli are shown for a period of time more closely resembling a previous learnt *short* or *long* time duration. Participants were instructed to press the *z* key on a standard keyboard to indicate *short* and *m* to indicate *long*. The *short* duration was 400ms and whilst the *long* duration was 1600ms which are typically found in the literature.

Initially participants completed eight practice trials in which they were instructed to either touch the computer screen as fast and as accurately as possible or make no response. Participants were instructed to use the index finger of their dominant hand to press down on the spacebar at the beginning of a trial. When the word *Touch* was presented after a fixation cross, participants had to touch the centre of the computer screen, after which the participant received feedback as to whether they responded correctly. In trials in which no action was required participants saw the action instruction *Don't Touch* and were instructed to remain pressing down on the spacebar for the duration of the practice trial.

Subsequently participants were taught to distinguish between a *short* and *long* time duration using a pink oval in a learning phase. For the first eight trials the pink oval was presented in a predictable sequence (i.e., *short*, *long*, *short*, *long,* etc.) followed by a further eight trials in which the pink oval randomly appeared for either the *short* or *long* duration. Therefore, during the learning phase the pink oval was presented a total of 16 times, eight of which demonstrated the *short* time duration and eight demonstrating the *long* duration. During the learning phase participants received feedback as to whether their response was correct; *YES* was presented in the middle of the screen in green ink if the participant correctly identified the stimulus as either *short* or *long* whereas *NO* appeared in red if their response was incorrect. Feedback was presented for 1000ms as soon as the participant responded.

Finally, in the testing phase angry and neutral facial expressions were presented for either of the two previously learnt durations (400ms and 1600ms) or an intermediate duration (600ms, 800ms, 1000ms, 1200ms and 1400ms). At the beginning of each trial participants were instructed to *press and hold the spacebar*. Participants were then instructed to either touch the computer screen after the presentation of the facial stimulus (*Touch* appeared on the computer screen) or to not touch the computer screen (*Hold Still* was presented on the computer screen), such action instructions were presented for one second. Following this action instruction, a facial expression was presented for one of the durations. After the presentation of the facial stimulus a fixation cross appeared at which time participants had to carry out the respective action instruction by either touching the centre of the computer screen or continuing to hold down the spacebar key. An example trial sequence is shown in Figure 4. Participants had to respond within three and a half seconds in the action condition for their response to be recorded. Finally, participants indicated whether the presented facial stimulus was shown for a period of time closer to either the *short* or *long* time duration; there was no time limit for participants to make this response. There was an inter-trial interval of 500ms throughout the experiment.

In total each participant completed 224 trials derived from 8 presentations of each facial expression across each time duration [7] and action preparation condition [2] separated into four equal blocks of 56 trials. Trials were randomly presented across the four blocks of trials.

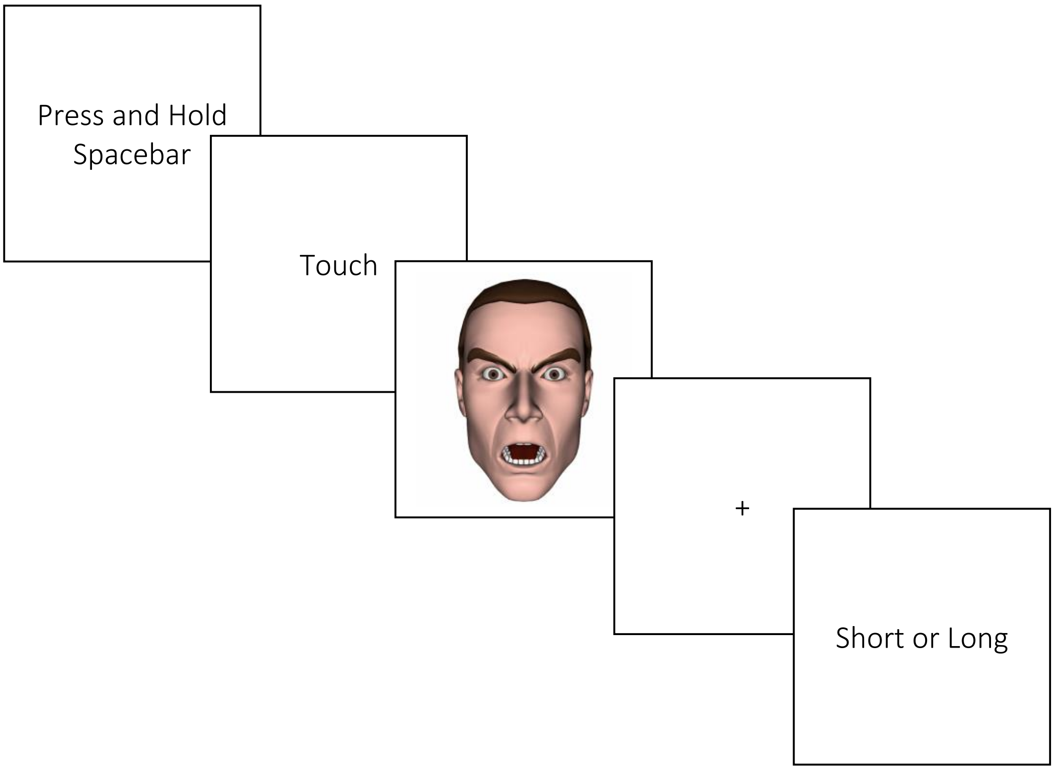


Figure 4. Example trial sequence of the angry touch condition in Experiment 1.

2.2.2 Results and Discussion

Following previous research (e.g., Droit-Volet & Gil, 2009; Tipples, 2008) concerning time perception, the proportion of *long* responses (*p(long)*) at each stimulus duration was calculated for each participant. The *p(long)* data were then transformed into z-scores and using the method of least squares a regression line was fitted to the data. The intercept and slope values of the regression line were then used to calculate the point of subjective equality (PSE or bisection point; BP) and Weber ratio (WR). The PSE is the point at which participants are equally as likely to respond *short* as they are *long* which corresponds to the stimulus duration at which *p(long)* is equal to .5; consequently, a lower PSE value is indicative of temporal overestimation (participants begin responding *long* earlier). The WR is an index of time sensitivity and is closely related to the slope parameter of the regression line fitted to the z-scores. A low WR is indicative of higher discriminability of temporal changes which is reflected in a more step-like psychometric function (Kopec & Brody, 2010), whereas a more gradual psychometric function is produced with poorer discriminability and consequently higher WR.

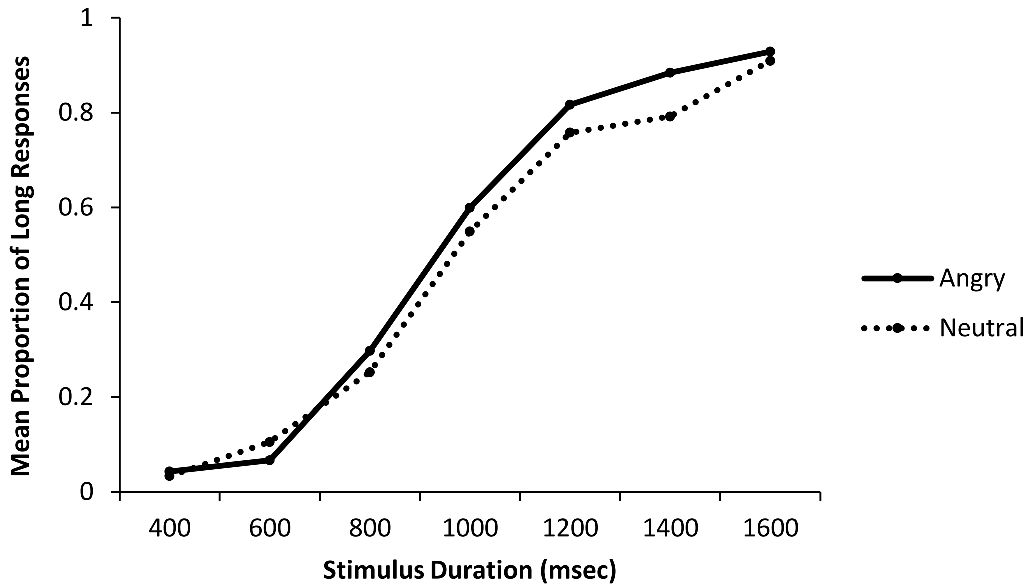
Prior to data analysis a total of three participants were excluded from further analysis due to poor timing performance across the experiment ($R^2 < .55$ in all cases). The mean-goodness-of-fit values (R^2) were calculated by fitting the cumulative distribution to the 7 point (duration) psychometric function of *p(long)* values for each participant.

Proportion of long responses

The mean *p(long)* responses are plotted in Figure 5. After visual inspection of Figure 5 it appears that the psychometric function has shifted to the left (indicative of temporal overestimation) for angry relative to neutral facial expressions in the no action condition only.

In order to test this effect statistically the *p(long)* were analysed using a 2 [action condition; action, no action] x 2 [expressions; angry, neutral] x 7 [duration;

400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms, 1600ms] repeated measures ANOVA. The assumption of sphericity was violated for the effect of duration and all interactions, consequently the Greenhouse-Geisser correction value is reported in such situations. The analysis revealed a significant main effect of expression, F (1, 22) = 4.62, p = .04, η_p^2 = .16, showing that participants overestimated the duration of angry facial expressions (M = .53) more frequently than neutral facial expressions (M = .50). The ANOVA also revealed a main effect of stimulus duration, F (2.91, 69.90) = 312.40, p < .001, η_p^2 = .93, *post-hoc* t-tests with Bonferroni correction showed that each stimulus duration differed from every other stimulus duration (400ms and 600ms condition, p = .012, for all other comparison p < .001, except for the 1000ms and 1200ms conditions as well as the 1200ms and 1400ms conditions p = .06 and .06 respectively). Simple contrasts showed there was a strong linear increase in the *p(long)* with increased stimulus duration, F_{linear} (1, 22) = 1539.54, p < .001, η_p^2 = .99. Finally, the ANOVA revealed a significant action condition x stimulus duration interaction, F (3.58, 85.91) = 2.96, p = .029, η_p^2 = .11. Simple contrasts showed that when effects of action were compared for each stimulus duration to the shortest stimulus duration (400ms) the effect of action condition was greater at stimulus durations of 800ms and 1400ms. No other effects or interactions were significant (p > .05 in all cases).


a. No action condition

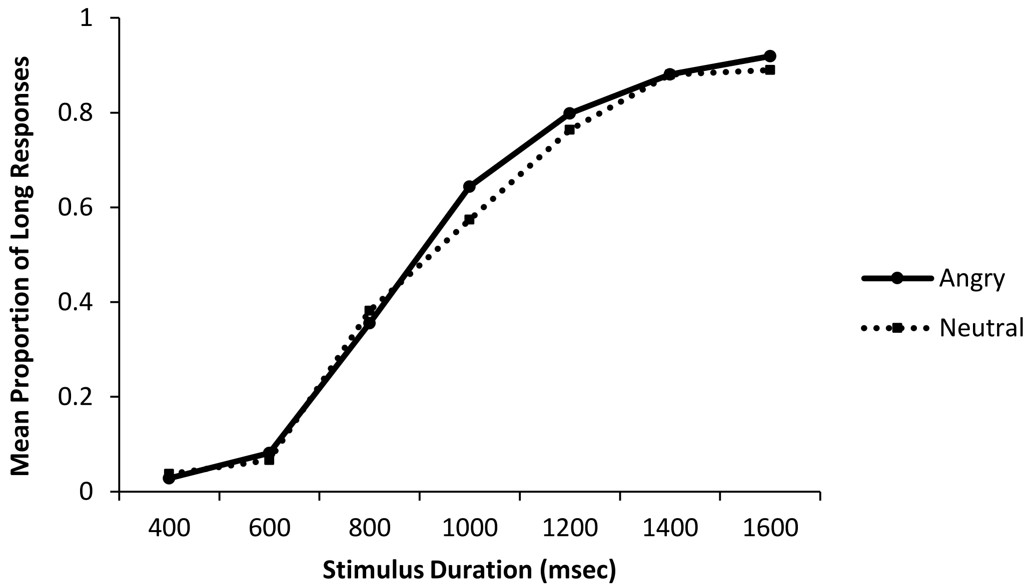

b. Action condition

Figure 5. Mean proportion of long responses for each expression as a function of stimulus duration for each action condition separately; a) no action and b) action.

Point of subjective equality

The PSE for each participant was calculated separately by dividing the intercept value by the slope value derived from the fitting the regression line to their z-scores. The PSEs were entered into a 2 [action condition; action, no action] x 2 [expression; angry, neutral] repeated measures ANOVA. In accordance with the analysis on the *p(long)* data, there was a main effect of expression, *F* (1, 24) = 4.57, p = .043, $\eta_p^2 = .16$, with participants overestimating the duration of angry facial expressions (*M* = 989) compared to neutral facial expressions (*M* = 1029). However, the main effect of action condition as well as the interaction between action condition and expression failed to reach statistical significance (*p* = .25). The mean PSE for each experimental condition is shown in Figure 6.

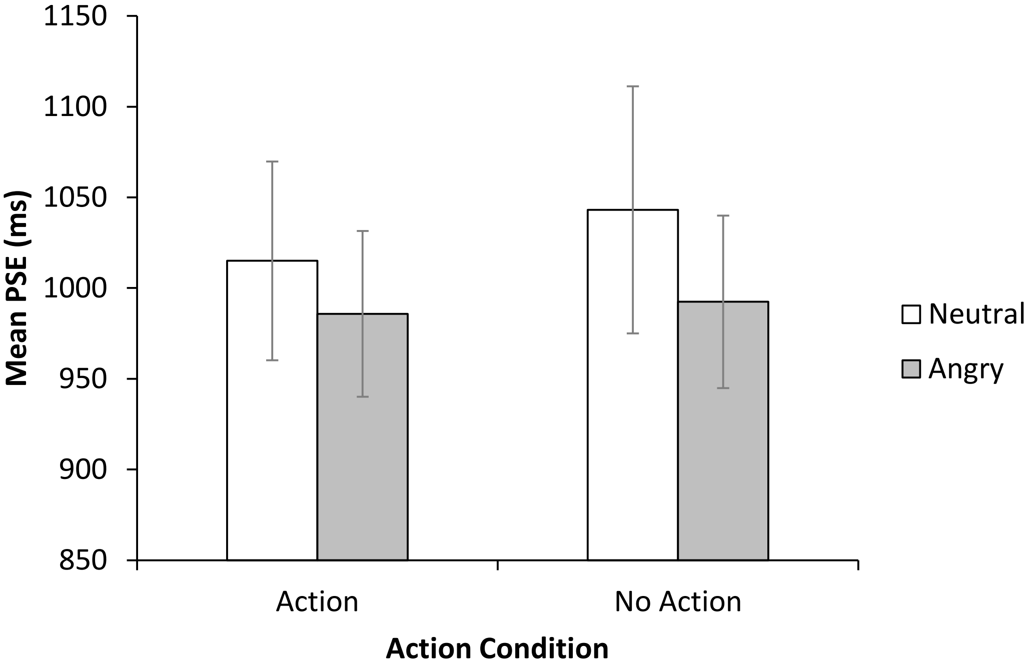


Figure 6. Mean PSE for each expression as a function of action condition. Note: Within subject confidence intervals calculated as described by: (Loftus & Masson, 1994; Wright, 2007).

Weber Ratios

The WR for each participant was calculated by dividing each participant's difference limen by the respective PSE. As described previously the WR is often described as an index of timing sensitivity in that lower WR values are indicative of greater temporal discriminability (i.e., the participant is more sensitive to duration changes). The mean WR for each experimental condition is shown in Table 1. The WR analysis followed the same pattern as the PSE analysis, however, the repeated measures ANOVA failed to show any significant effects ($p > .3$ in all cases).

Table 1. Mean WR for each experimental condition with SD.

	Action Condition			
	Action		No Action	
Expression	Mean	SD	Mean	SD
Neutral	.21	.04	.20	.05
Angry	.22	.10	.20	.05

Reaction Times

Reaction times were collected in Experiment 1 to investigate whether participant's reaction times would be facilitated by the presentation of an emotive compared to neutral facial expression. If action readiness theories of emotion are correct, one would assume response facilitation following an emotive facial expression as one is in a higher state of action readiness. Moreover, if temporal overestimation of threatening stimuli prepares one to act, reaction times should be facilitated following the temporal overestimation of such stimuli. For the purposes of Experiment 1 the reaction time was taken to be the time between stimulus offset and participants touching the computer screen. Thus, the reaction time analysis is centred on the condition in which participants had to touch the computer screen only and are plotted in Figure 7. Due to technical difficulties with the touchscreen computer two participant's reaction time data were not recorded. As a result, a total of 23 participant's reaction time data were analysed. Prior to data analysis participant reaction times were trimmed; reaction times less than 100ms were treated as anticipatory responses and were removed as were reaction times greater than 1500ms. Individual reaction times were treated as outliers and were removed if they were 2.5 SDs away from the participant's average reaction time. Prior to data analysis the reaction times were log-transformed in order to correct for a leftward skew (Ratcliff, 1993). However, the analysis on the log-transformed data did not differ from the raw data analysis; as such raw reaction time data is presented below for ease of interpretation.

To identify where differences in reaction times were found and to aid interpretation reaction times are plotted as function of duration bin (*short*; 400ms, 600ms and 800ms, *medium*; 1000ms and *long*; 1200ms, 1400ms and 600ms duration conditions). Visual inspection of Figure 7 appears to show that the emotional content of the facial expression does not modulate participant reaction times, however, reaction times do appear to decrease as stimulus duration increases.

To test for differences between participant reaction times following the angry and neutral facial expressions a 2 [expression; angry, neutral] x 3 [duration bin; short, medium and long] repeated measures ANOVA was conducted. The analysis revealed a main effect of duration range, F (2, 44) = 22.82, $p < .001$, $\eta_p^2 = .51$, with quicker reaction times occurring in the long duration range (*M* = 1136ms) compared to both the medium (*M* = 1213ms) and short (*M* = 1242ms) duration ranges. The main effect of expression and interaction between expression and stimulus duration failed to reach significance (*p* = .39 in both cases).

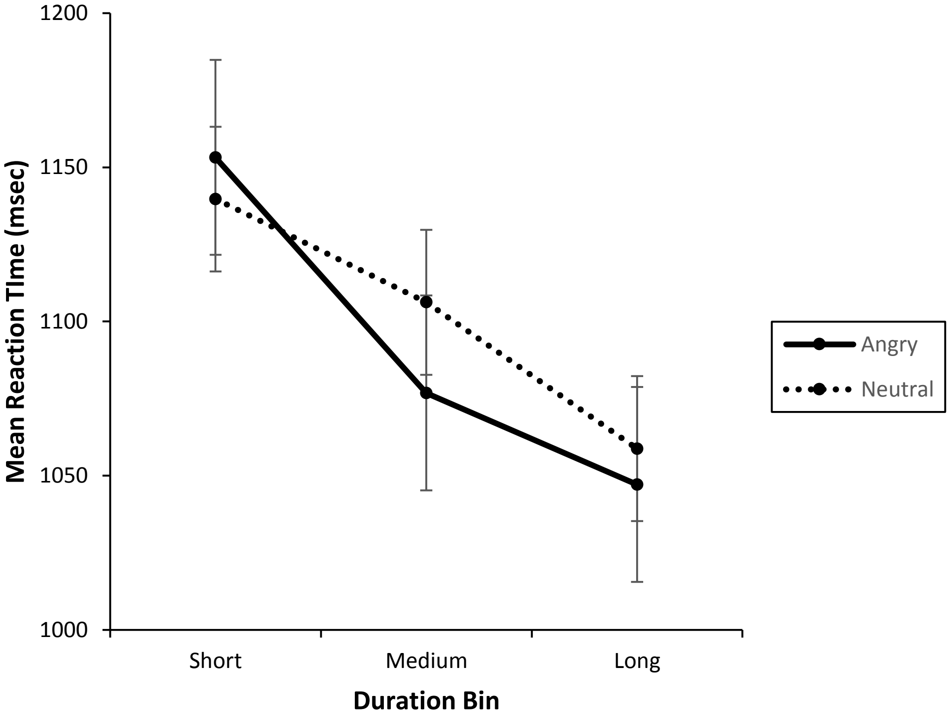


Figure 7. Mean reaction time for both angry and neutral facial expressions as a function of stimulus duration bin. Error bars show standard error of mean.

2.3 General Discussion

The aim of Experiment 1 was to investigate the combined effects emotion and action readiness have on the perception of time by determining whether emotional facial expressions increase effects of action readiness on time estimates. To this effect, it was hypothesised that emotive facial expressions would increase the temporal overestimation effect one finds for increases in action readiness. In addition, following the functional explanation of temporal overestimation due to threat and action readiness theories of emotion it was predicted that participant reaction times would be facilitated following the presentation of an emotive, relative to neutral, facial expression. The results from Experiment 1 failed to provide evidence to support either of these hypotheses. Whilst there were increased levels of temporal overestimation following the presentation of an emotive facial expression the effect was not found to increase when one was also in a state of action readiness. Furthermore, analysis on the reaction data revealed no differences between the emotive and neutral facial expressions. Together, such findings fail to provide evidence that temporal overestimation due to threat functionally prepares an individual to act. In addition, the findings cast doubt on the idea that the internal clock mechanism is able to produce an enhanced temporal overestimation effect.

The primary aim of Experiment 1 was to investigate whether manipulations of emotion modulates the effect action readiness has on time perception. It has been consistently reported that in prospective timing tasks emotionally salient stimuli are overestimated relative to neutral stimuli (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011a, 2012; Grondin, 2010; Tipples, 2008, 2010, 2011). Such an effect is also reported here; participants were found to more frequently overestimate the duration of the angry facial expression compared to the neutral facial expression. The overestimation effect for angry compared to neutral facial expressions is often interpreted in terms of the operation of a pacemaker mechanism within an internal clock such as SET (Gibbon et al., 1984). The pacemaker, as discussed previously, sends information to an accumulator; more arousing facial expressions are argued to increase the pacemaker output causing time to be more frequently overestimated for more highly arousing stimuli. General consensus argues that this increase in pacemaker speed is due to the increased levels of arousal (Burle & Casini, 2001; Droit-Volet et al., 2004; Droit-Volet &

Wearden, 2002; Treisman, Faulkner, & Naish, 1992; Treisman, Faulkner, Naish, & Brogan, 1990; Wearden, Pilkington, & Carter, 1999). One interesting finding from Experiment 1 is that the effect of emotion did not interact with stimulus duration (i.e., the effect of emotion was not found to be multiplicative with real time). Such a finding initially appears at odds with the large body of literature that has supported the idea of arousal inducing stimuli increasing the speed of a pacemaker mechanism within an internal clock. However, there are reports of similar findings, Grommet and colleagues (2011) for instance find evidence to suggest the effects of fearful stimuli from the IAPS database are more closely reconciled with effects of attention rather than pacemaker speeding. The authors state that it is possible that attentional effects masked the effects of arousal which consequently lead to their surprising findings and such a conclusion may also be applicable here. Despite such conclusions, it is noted numerous times in the literature that in order to accurately determine how temporal overestimations are reconciled with the operation of an internal clock mechanism one must test across two duration ranges; Experiment 2 of this thesis addresses this issue more formally.

Research has also found that preparing an action causes participants to overestimate the duration of a stimulus compared to when no action is being prepared (Hagura et al., 2012). However, such an effect was not found in Experiment 1; there was no tendency for participants to overestimate the duration the stimuli when an action was being prepared compared to when no action preparation was required. This null result is interesting given the high level of similarity between the methodology of Experiment 1 and that of Hagura *et., al.* (2012) who report temporal overestimation with increasing levels of action readiness. The absence of an effect of action condition in Experiment 1 suggests that either participants did not adequately prepare to make a response as instructed (which appears likely given the large average reaction times), that the timing task distracted participants from preparing an action or that preparing and completing the action distracted participants from the timing task.

Had participants failed to prepare to initiate an action until they were required to touch the computer screen (as instructed by the *Touch* instruction), it follows that participants would not have adequately prepared the action for long enough for this to manifest any temporal dilation. Unfortunately, it is difficult to determine whether participants did prepare the action prior to its initiation without qualitative data being gathered as to how participants completed the task (one could simply ask participants whether or not they prepared the response when instructed). Consequently, it is difficult to say with certainty whether or not participants carried out the task as instructed and it remains possible that participants failed to prepare to make a response. Although the experiment conducted by Hagura *et., al* (2012) did not include any analysis of participant reaction times, the reaction times reported in Experiment 1 were quite large given that participants should have been ready to initiate an action. Whilst it is possible that the failure to prepare the action at the critical point caused the long average reaction times, it is also possible that such reaction times were caused by the participant's seating position being too far from the computer monitor.

One should also note here that three participants were excluded from data analysis based on poor task performance across the experiment as indicated by extremely low R^2 values (as previously discussed higher R^2 values are indicative of good or rather consistent performance on timing based tasks). Although such figures are not reported by Hagura and colleagues (2012), a number of studies within the wider timing literature report R^2 values typically > .90 across each experimental condition and participant (see, Droit-Volet & Wearden, 2001; Grondin, 2012; Laflamme, Sablonnière, Fournier, & Grondin, 2012; Laflamme, Zakay, Gamache, & Grondin, 2015). In experiment 1, the average R^2 across all experimental conditions and participants was .84 (SD = .05), which when compared to other values from the timing literature is somewhat low. As the R^2 value is a measure of the timing consistency across the experiment it is apparent that several factors will influence this value. One of the main factors which contribute to low R^2 values is participant's level of motivation for completing the task or their level of attention to the task. As such values are comparatively low in Experiment 1 compared to other studies investigating time perception, this may reflect the idea that participants were not motivated to carry out the instructions or task as instructed and thus, failed to adequately prepare the action when instructed.

A further finding from Experiment 1 which fails to support the idea that overestimating threatening stimuli prepares one to act is the absence of a significant difference between participant reaction times following the angry and neutral facial expressions. Frijda (1986, 1988) has provided evidence which suggests that experiencing emotion can simply be reduced to the self-knowledge that one is ready to act in some way. Evidence of this idea is readily available; neurological evidence has, for instance, shown that more muscular activity occurs when an emotive compared to neutral image is displayed (Borgomaneri, Gazzola, & Avenanti, 2014; Coelho, Lipp, Marinovic, Wallis, & Riek, 2010; Hajcak et al., 2007; Pereira et al., 2010;

van Loon, van den Wildenberg, van Stegeren, Hajcak, & Ridderinkhof, 2010). Interestingly, however, one study suggests that increased levels of arousal alone is not sufficient to cause increase motor cortex excitability (Baumgartner, Willi, & Jäncke, 2007). Nevertheless, one may expect temporal overestimation for threatening stimuli to prepare one to act quicker given the increase in motor cortex excitability for emotive stimuli. Furthermore, one study has reported response facilitation following stimuli which cause temporal overestimation, albeit non-emotive stimuli (Jones et al., 2011).

Click trains, as used by Jones and colleagues (2011) have been shown to cause temporal overestimation which is thought to be due to increased levels of arousal affecting the functioning of the pacemaker in an internal clock. The failure of Experiment 1 to show a similar pattern when using emotive stimuli, which also increase participant arousal levels, is surprising. If the temporal overestimation of threatening stimuli were linked to increased preparedness to act, one would have expected to find a general response facilitation following the display of an angry facial expression.

In summary, the results from Experiment 1 failed to support the notion that temporal overestimation due to threat functionally prepares an individual to act. Participants were not found to overestimate the duration of facial expressions when preparing to make a ballistic action which contradicts previous research findings (Hagura et al., 2012). In addition, the results from Experiment 1 fail to find evidence of an enhanced temporal overestimation effect when participants are in a higher state of action readiness and view an emotive stimulus, which was compounded by the null finding of action readiness on time estimates. Moreover, the finding that participant reaction times were unaffected by the emotional content of the facial expression further fails to support the notion that temporal overestimation due to threat prepares one to act. However, the results from Experiment 1 add to a growing body literature showing that emotive stimuli are more frequently temporally overestimated than neutral stimuli.

Given the null finding regarding the effect of action condition on time perception found in Experiment 1, there is a clear need for further experimentation; in particular, a methodology sensitive enough to detect effects of action readiness is required. Although previous studies using similar methodologies to that used in Experiment 1 have found effects of action on time perception (e.g., Hagura *et al.,* 2012), it is apparent that such an experimental manipulation proved unsuccessful here. As such, Experiment 2 used a simple joystick task as a way of manipulating participant levels of action readiness.

3. The Functional Explanation of Temporal Overestimation Due to Threat – Joystick Methods

3.1 Introduction

The findings from Experiment 1 failed to show any effects of action preparation on the perception of time. Given such an effect has been well replicated previously (Hagura *et.,* al 2012) the need for further experimentation was clear. Experiment 2 used a different method of action production to investigate the effects of action preparation on time perception. Specifically, participants in Experiment 1 were tasked with preparing and subsequently making a ballistic movement (touching the computer screen) during the experiment. It is possible that participants failed to adequately prepare to carry out the action instruction such that effects of action preparation were not found. Moreover, Experiment 1 only investigated the effects of one particular action on the perception of time. Here, in Experiment 2, a computer joystick task was used to investigate the effects of action preparation on the perception of time.

Although the term action preparation has been used readily throughout this thesis, all actions are not born the same. The idea that actions are based on two opposing forms of motivation is not new (see, Elliot, 2006) and an ever increasing number of experiments are investigating approach and avoidance behavioural motivations. Although there are some differences in definition, approach motivated actions are considered to be those which reduce the distance between an observer and a stimulus (Elliot, 2006; Elliot et al., 2013; Harmon-Jones et al., 2013; Lang & Bradley, 2008). On the contrary, avoidance motivated actions are considered those in which the observer increases the distance between itself and the stimulus (Elliot, 1999; Elliot & Covington, 2001). Given that emotionally salient stimuli share intrinsic links with action preparation (Frijda, 1986; Frijda & Tcherkassof, 1997), it follows that different emotions are linked to different action tendencies or action motivations.

Anger, although negatively valenced and highly arousing, is often linked to the blockage between an observer and some goal (Berkowitz & Harmon-Jones, 2004; Carver & Harmon-Jones, 2009; Dollard, Miller, Doob & Sears, 1939). As such the observer is likely to approach the agent of their anger in order to remove the blockage and continue with their goal. For example, if one is unable to pursue their goal because of the actions of another they are likely to confront the individual so that they can continue with pursuit of their goal. Therefore, angry facial stimuli should elicit approach motivated actions (Carver, 2004; Carver & Harmon-Jones, 2009; Harmon-Jones et al., 2013, however, see Heuer, Rinck, & Becker, 2007; Marsh, Ambady, & Kleck, 2005; Seidel, Habel, Kirschner, Gur, & Derntl, 2010; Stins et al., 2011).

Tasks in which approach and avoidance motivated actions have been mapped onto computerised joysticks are commonly found in the literature (see, van Dantzig, Pecher, & Zwaan, 2008). One classic investigation into the automaticity of action tendencies and emotion was carried out by Chen and Bargh (1999) who, using a similar experimental design in which a lever was either pulled or pushed, found that emotionally salient stimuli automatically prime specific action tendencies. Participants were faster to initiate an avoidance response (pushing a lever away) when categorising object stimuli as negative, whereas participants were quicker to initiate an approach action (pulling a lever towards themselves) when categorising an object as positive. Therefore, for the purposes of Experiment 2 approach motivated action was defined in terms of pulling the joystick toward one's body whereas pushing the joystick away from oneself was defined as an example of avoidance motivation, following the same distinction used by Chen and Bargh (1999). Although this seminal work found negatively valenced objects to elicit avoidance motivated actions, the emotion of anger is often considered to produce approach motivated action (for a review, see Carver & Harmon-Jones, 2009).

One experiment investigating the effects of approach motivation on time perception reports that stimuli high in approach motivation, regardless of affective valence, cause temporal speeding. In a series of experiments Gable and Poole (2012) reported that when presented with stimuli high in approach motivation participants were found to underestimate the duration of time spent viewing such stimuli relative to stimuli of lower approach motivation. It was argued by the authors that this underestimation of time might serve to enhance or prolong approach motivated behaviour such as achieving one's goals. Such results at first appear at odds with the large literature relating angry facial expressions to temporal overestimations given that anger is considered an approach motivated emotion. However, the study by Gable and Pool (2012) used largely positive images of desserts as well as images taken from the IAPS database instead of facial expressions which are known to show different results. Thus, it is currently not known how time estimates for facial expressions differ when one is asked to approach or withdraw from the facial stimulus.

Finally Experiment 1 found no evidence to support the pacemaker speeding hypothesis as to why emotive facial stimuli are overestimated relative to neutral stimuli as evident by the non-significant expression x stimulus duration interaction. However, Experiment 1 did find evidence to suggest that action preparation influences the functioning of this pacemaker mechanism despite not producing an effect on time estimates itself. To more accurately determine the component of internal clock models which cause the temporal overestimation effect of increases in action readiness two duration ranges were used in Experiment 2. In addition, the use of a shorter and longer duration range in experiment 2 allowed one of the main assumptions of SET to be tested; specifically, the assumption that timing behaviour shows scalar variance. Scalar variance, as discussed on page 11 is the assumption that timing judgements conform to a derivative of Weber's Law; specifically as the duration being judged increases, the coefficient of variation (SD/M) should remain constant (Wearden, 1991; Wearden, 2003). One such way of testing this is by superimposing timing data from one duration range onto data from a different duration range. Given that such a test requires more than one duration range to be tested, Experiment 2 was well placed to test for the scalar property of time.

Experiment 2 therefore, builds on the methodology used in Experiment 1 in several ways; first, the use of a computer joystick allowed for a more comprehensive investigation into the effects of action preparation on time given the ability to investigate the effects of both emotionally salient stimuli and the different action types. Specifically, the computerised joystick task allowed for testing whether emotion and action congruent reaction times (i.e., anger and approach motivated action) facilitated response times compared to emotion and action incongruent reaction times (i.e., anger and avoidance motivated action). Second, Experiment 2 used two different duration ranges to establish the mechanism within internal clock models which causes the duration of stimuli to be overestimated when one is in a state of action readiness. Third, the use of two different duration ranges allowed for testing one of the main assumptions of SET.

The aim of Experiment 2 was to continue to investigate the idea that functionally temporal overestimation due to the threat is linked to increased action readiness. Considering the null findings from Experiment 1 the methodology was changed in Experiment 2 to determine whether the null effect reported in Experiment 1 was due to issues with the methodology used. Thus, the methodology of Experiment 1 was changed; specifically, a computer joystick task was used.

A further aim of Experiment 2 was to investigate whether the type of action initiated impacted the temporal overestimation effect for emotive stimuli. With the inclusion of both approach and avoidance actions in Experiment 2 this enabled the investigation of both emotion congruent and incongruent action motivations. This investigation was not possible in Experiment 1.

Finally, Experiment 2 aimed to determine how action readiness impacts the functioning of an internal clock mechanism. Although supportive evidence was not found in Experiment 1, research has well established that emotionally salient stimuli cause temporal overestimation through the increased output of a pacemaker mechanism. As of yet it is unknown how action readiness states influence the operation of internal clock models. One can differentiate between effects of pacemaker speeding and switch latency closure due to the mathematical underpinnings of internal clock models (e.g., SET, Gibbon, Church, & Meck, 1984) when more than one duration range is used. Consequently, Experiment 2 used two different stimuli duration ranges; a *long* duration range 400ms to 1600ms range and a *short* 200ms to 800ms duration range which has been previously used (Grommet et al., 2011).

The hypotheses for Experiment 2 were threefold; first, participants were hypothesised to more frequently overestimate the duration of a stimulus when preparing to initiate an action using a joystick as well as overestimate the duration of emotive facial expressions more frequently than neutral facial expressions.

Second, it was hypothesised that preparing to act influences the functioning of a pacemaker mechanism found within an internal clock. Such a claim is based on the finding in Experiment 1 whereby action condition was found to significantly interact with stimulus duration; this pattern provides initial evidence for the pacemaker speeding hypothesis given that the effect of action varied as stimulus duration increased. Consequently, it is expected that the degree of temporal overestimation for emotive facial expressions and levels of action readiness in Experiment 2 will be greater in the 400ms – 1600ms (*long*) stimulus duration range compared to the 200ms – 800ms (*short*) stimulus duration range.

Third, to test for a functional explanation of temporal overestimation due to threat participants were expected to be quicker to initiate actions following the angry facial expressions. Moreover, reaction times should be facilitated when congruent to the displayed facial expression. Specifically, participants should be quicker to initiate a *pull* response when an angry facial expression is displayed and slower to initiate a *push* response when an angry facial expression is displayed.

3.2 Experiment 2

3.2.1 Method

Participants

A total of 76 participants took part in the experiments. There were 35 participants in the long stimulus duration range with a mean age of 20.4 years (*SD* = 3.87, 12 males) and a further 41 participants in the short stimulus duration range (*M* = 21.3 years, *SD* = 6.20, 4 males). None of the participants took part in both the long and short stimulus duration range experiments. All participants were psychology undergraduate students attending the University of Hull. Participants received course credit for taking part in the experiment. Prior to commencing the experiment ethical approval was granted from the Psychology Ethics Committee at the University of Hull.

Stimuli and Apparatus

The same facial expressions as used in experiment 1 were used. Stimuli were presented using the same apparatus as in Experiment 1 and E-Prime (*E-Prime 1.2*, 2002) was used for stimulus presentation and data collection. Stimuli measurements were the same per Experiment 1.

Design and Procedure

Experiment 2 used a 2 x 3 x 2 x 7 design with stimulus duration range (long, short) a between subjects factor and action condition (push, pull, no action), expression (angry, neutral) and duration (400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms and 1600ms) as three within-subjects factors.

Participants completed a modified version of the temporal bisection task in which participants were asked to judge whether stimuli are presented for a period of time closer to a previously learnt *short* or *long* time duration. Participants were instructed to click the trigger button with their index finger using a Logitech Attack 3 computer joystick to indicate *short* or click a second button with their thumb to indicate *long*. The *short* duration in the long stimulus duration range was 400ms and whilst the *long* duration was 1600ms, compared to a *short* duration of 200ms and a *long* duration of 800ms in the short stimulus duration range.

The procedure for both the long and short stimulus duration range were identical and was based on the temporal bisection task used in Experiment 1. Participants were first taught to distinguish between the respective *short* and *long* time duration using a pink oval in a learning phase. For the first eight trials the pink oval was presented in a fixed sequence (i.e., *short*, *long*, *short*, *long,* etc.) followed by a further eight trials in which the pink oval randomly appeared for either the *short* or *long* duration. Therefore, during the learning phase the pink oval was presented a total of 16 times, eight of which demonstrated the *short* time duration and eight demonstrating the *long* duration. During the learning phase participants received feedback as to whether their response was correct; *YES* was presented in the middle of the screen in green ink if the participant correctly identified the stimulus as either *short* or *long* whereas *NO* appeared in red if their response was incorrect. Feedback was presented for 1000ms immediately after the participant responded.

In the testing phase, angry and neutral facial expressions were presented for either of the two previously learnt durations (200/400ms and 800/1600ms) or an intermediate duration (300/600ms, 400/800ms, 500/1000ms, 600/1200ms and 700/1400ms). Participants were presented with an action instruction of either *pull, push,* or *no action*; the action instruction was presented for one second. After the action instruction, a facial expression displaying either an angry or neutral expression was presented for one of the stimulus durations. Following the presentation of the facial expression a fixation cross was presented for three and a half seconds during which participants had to either *pull* or *push* the computer joystick or produce *no action*. Finally, participants were tasked with judging whether the presented facial stimulus was shown for a period of time closer to either the *short* or *long* time duration which they had learnt in the learning phase; there was no time limit for participants to make this response. An example trial sequence is shown in Figure 8. There was an inter-trial interval of 500ms throughout the Experiment.

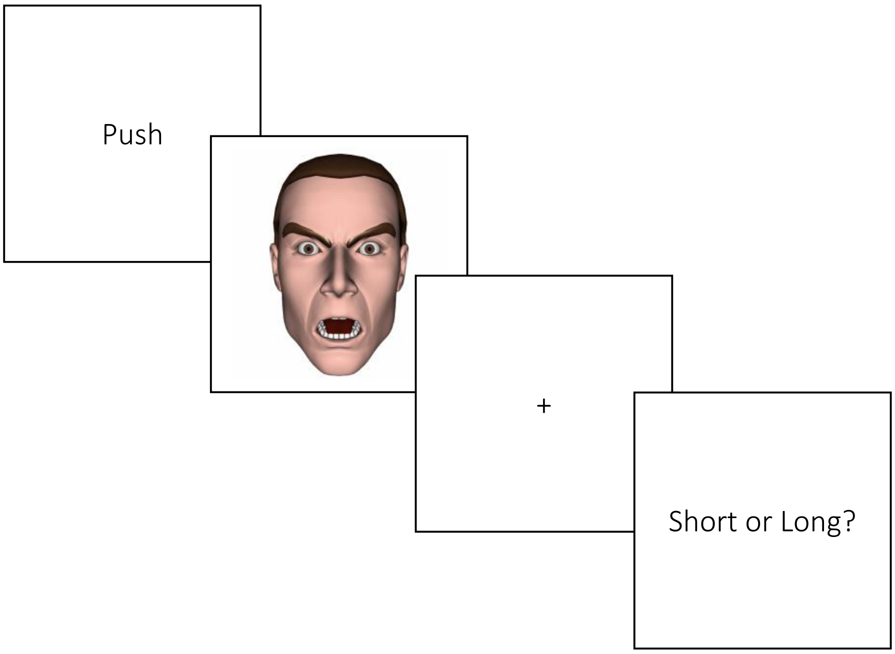


Figure 8. Example trial sequence from Experiment 2 showing the push angry experimental condition.

In total each participant completed 504 trials derived from 8 presentations of each facial expression across each time duration [7] and action preparation condition [3] separated into six blocks of 84 trials. Trials were randomly presented across the six blocks of trials.

3.2.2 Results and Discussion

The data analysis for Experiment 2 followed an identical pattern to that described in Experiment 1. Participants raw data were first converted into *p(long)* which were subsequently transformed into z-scores. Using the method of least squares a regression line was fitted to the data and the intercept and slope parameters from the regression line were used to calculate the PSE and WR.

3.2.2.1 Long duration range (400ms – 1600ms)

Prior to data analysis two participants in the long stimulus duration range were excluded for poor performance on the task ($R^2 < .85$ in all cases). One further participant was removed from the data analysis due to making a high number of incorrect joystick responses (52% incorrect). Incorrect joystick responses (e.g., pushing rather than pulling the joystick), anticipatory reaction times of less than 100ms and reaction time outliers (more than 2.5 times the *SD*) were removed from the data prior to analysis. In total data was analysed for 32 participants.

Proportion of long responses

The *p(long)* responses are plotted in Figure 9. After visual inspection of Figure 9 the psychometric function appears shifted to the left for angry compared to neutral facial expressions in each of the three action conditions. In order to test this statistically the *p(long)* were analysed using a 3 [action condition; pull, push, no action] x 2 [expressions; angry, neutral] x 7 [duration; 400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms, 1600ms] repeated measures ANOVA. The assumption of sphericity was violated for the effects of duration and the interactions between expression and stimulus duration and action condition and stimulus duration, as such the Greenhouse-Geisser correction values are reported.

The analysis revealed significant main effects of expression, F (1, 31) = 12.16, $p = .001$, $\eta_p^2 = .28$, showing that participants overestimated the duration of angry facial expressions ($M = .50$) more frequently than neutral facial expressions ($M = .45$) as well as action condition, F (2, 62) = 8.38, $p < .001$, $\eta_p^2 = .21$. The main effect of action condition showed that participants were more likely to respond long in the pull ($M = .49$) and push ($M = .48$) action condition compared to the no action condition ($M = .46$, $p < .05$ in both cases). The ANOVA also revealed a main effect of stimulus duration, F (2.74, 84.91) = 581.52, $p < .001$, $\eta_p^2 = .95$, *post-hoc* comparisons with Bonferroni correction showed that each stimulus duration differed from every other stimulus duration ($p = .04$ for least significant difference) with the exception of the 1400ms and 1600ms conditions ($p = .109$). Furthermore, polynomial trend analyses showed there was a strong linear increase in the *p(long)* with increased stimulus duration, F_{linear} (1, 31) = 155.71, $p < .001$, $\eta_p^2 = 0.99$.

Finally, the ANOVA revealed a significant expression x stimulus duration interaction, F (4.00, 124.38) = 3.42, $p = .003$, $\eta_p^2 = 0.10$ as well as a significant action condition x stimulus duration interaction, F (6.72, 208.46) = 3.33, $p = .003$, $\eta_p^2 = .10$. In order to test the idea that pacemaker speeding (e.g., due to emotional arousal and action readiness) is indicated by multiplicative effects of expression and action condition polynomial trend analyses (Howell, 2012) of the two interactions were carried out. A Bonferroni correction ($p < .012$) was applied to the set of 4 contrasts. To aid interpretation, the *p(long)* for the 3 shortest duration and the *p(long)* for the longest conditions were calculated to create short, medium (1000ms) and long duration conditions.

For the two-way interaction between expression and duration the data were collapsed across action condition. Next an index of the expression effect (mean *p(long)* for the angry expression minus mean *p(long)* for the neutral expression) was calculated. For the short durations, a one sample t-test showed that the effect of expression did not differ from zero, t (2) = 1.3, p = 0.32. For long durations, however, a one sample t–test of the expression effect showed that the effect of expressions was greater than zero t (2) = 5.90, p = .001. In addition, polynomial contrast analyses were conducted to directly test for a linear increase in the magnitude of the expression effect with stimulus duration increases. The effect of expression increased linearly with stimulus durations F_{linear} (1, 31) = 18.34, p < .001, η_p^2 = 0.37. In short, for the effect of expression, the data followed a multiplicative pattern as predicted by SET.

An identical analysis strategy was used to analyse the two-way interaction between action condition and stimulus duration except that data were firstly averaged across the two expression conditions and secondly averaged across the two action types in order to create an action vs. no action comparison. The index of action condition effect (mean *p(long)* for the action condition minus mean *p(long)* for the no action condition) was calculated. For both the short and long durations the one sample t-test was non-significant (p < .05 in both cases). To further investigate the action condition x stimulus duration interaction polynomial contrast analyses were conducted. The effect of action condition was best described by a cubic trend, F_{Cubic} (1, 31) = 18.55, p < .001, η_p^2 = 0.37. Although the effect of action condition did not increase linearly with stimulus duration, the index of action condition effect was greatest at the 1400ms stimulus duration.

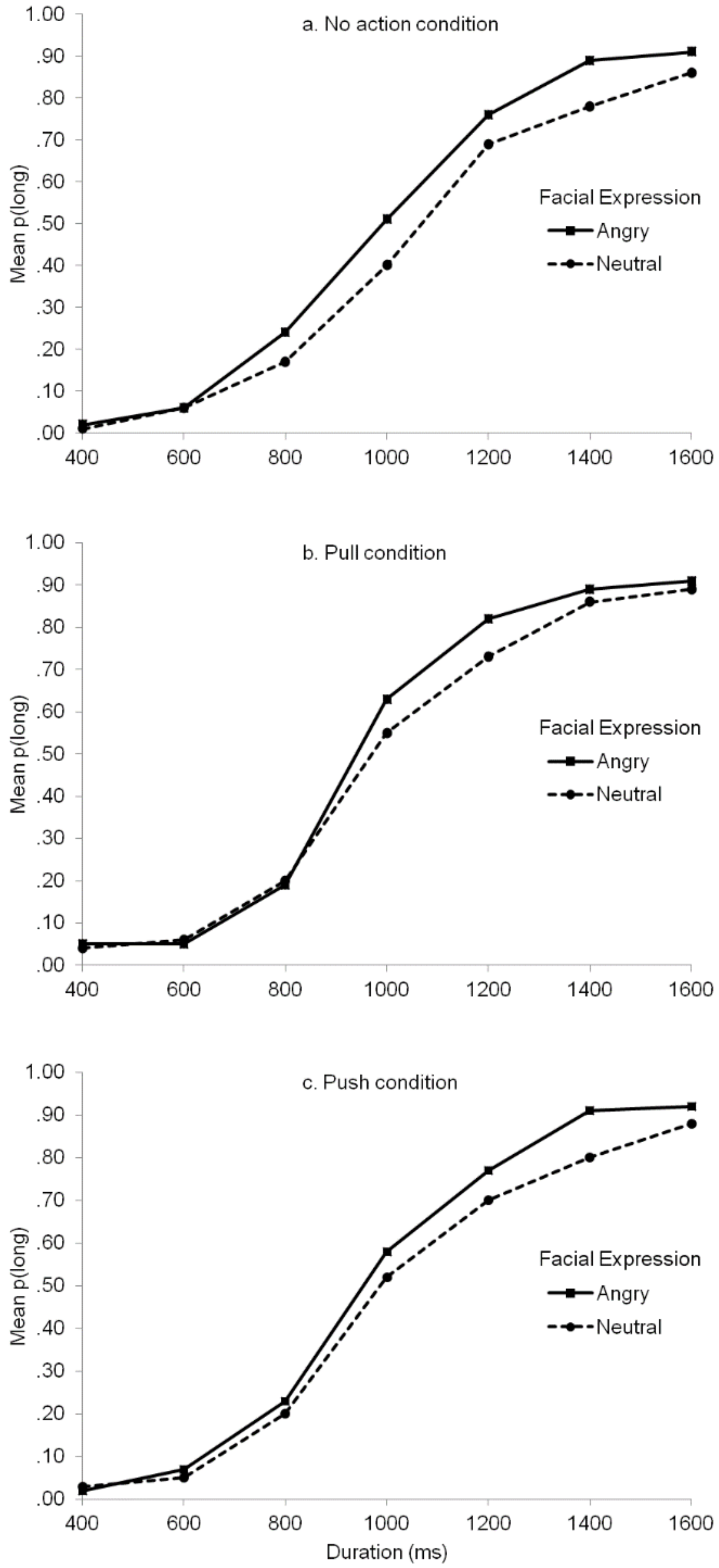


Figure 9. Mean proportion of long responses as a function of duration for each action condition separately, a) no action, b) pull condition and c) push condition.

Point of subjective equality

The PSE for each participant was calculated in the same way as in experiment 1. The PSEs were entered into a 3 [action condition; pull, push, no action] x 2 [expression; angry, neutral] repeated measures ANOVA. The analysis replicated the results derived from the analysis of the p(*long*) data, there was a main effect of expression, F (1, 31) = 13.30, p = .001, η_p^2 = 0.30, with participants overestimating the duration of angry facial expressions (M = 1027) compared to neutral facial expressions (M = 1093). In addition, the main effect of action condition was also significant, F (2, 62) = 4.49, p = .015, η_p^2 = 0.13 showing that participants began responding long sooner in the pull (M = 1040) and push condition (M = 1056) compared to the no action condition (M = 1084). Post-hoc t-tests with Bonferroni correction showed that the PSE for the pull condition was significantly lower than in the no action condition (p = .03) and marginal effects were found between the push and no action condition (p = 0.70). Crucially, the interaction between expression and action condition was not significant (p =.37). The mean PSE for each experimental condition is shown in Figure 10.

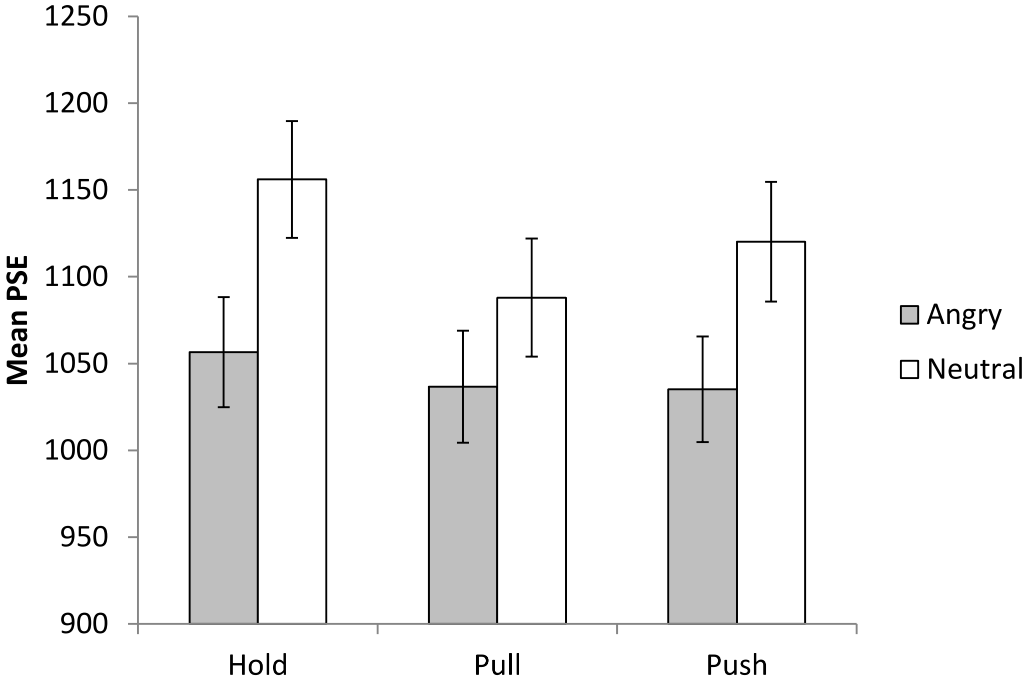


Figure 10. Mean BP for each expression separately as a function of action condition. Note: Within subject confidence intervals calculated as described by: (Loftus & Masson, 1994; Wright, 2007).

Weber Ratios

The WR for each participant was calculated by dividing each participant's DL by the respective PSE following the same procedure as in Experiment 1. The mean WR for each experimental condition is shown in Table 2. The WR analysis followed the same pattern as the PSE analysis, however, the repeated measures ANOVA failed to show any significant effects (*p* > 0.29 in all cases).

Table 2. The mean WR for each experimental condition.

	Action Condition					
	Pull		Push		No Action	
Expression	Mean	SD	Mean	SD	Mean	SD
Neutral	.19	.04	.18	.04	.18	.04
Angry	.19	.06	.18	.04	.18	.02

Reaction Times

For the purposes of Experiment 2 the reaction time was taken to be the time between stimulus offset and participants initiating the action instruction using the computerised joystick. For each participant, incorrect joystick responses, reaction times less than 100ms (anticipatory responses) and reaction times more than 2.5 SDs away from the mean of each individual's overall RT were treated as outliers. A log-transformation was applied to the remaining RTs to correct from a significant leftward skew. For ease of interpretation the data are presented are plotted in Figure 11 as mean RT.

In order to test for differences between participant reaction times following the angry and neutral facial expressions a 2 [action condition; pull, push] x 2 [expression; angry, neutral] x 7 [duration; 400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms, 1600ms] repeated measures ANOVA was conducted. There were main effects of action type, F (1, 31) = 20.16, $p < .001$, $\eta_p^2 = .39$, expression, F (1, 31) = 4.49, $p = .042$, $\eta_p^2 = .13$ and duration, F (6, 186) = 90.99, $p < .001$, $\eta_p^2 = .75$. The main effect of expression showed that participants were generally faster to respond following the angry facial expression (*M* = 790ms, *SD* = 100) compared to a neutral facial expression (*M* = 800ms, *SD* = 97). The main effect of duration showed that reaction times became faster with increases in stimulus duration, F_{linear} (1, 31) = 300.67, $p < .001$, $\eta_p^2 = .91$. There was also a two-way interaction between action type and duration, F (6, 186) = 2.25, $p = .041$, $\eta_p^2 = .07$.

To analyse the two-way interaction between action type and duration F tests of the effect of action type for each duration as simple main effect analyses were conducted. The simple main effect analyses showed that reaction times were faster for pull compared to push responses for the 600ms (*M* = 856 vs. *M* = 896), 1000ms (*M* = 782 vs. *M* = 825), 1200ms (*M* = 732 vs. M = 790), 1400ms (*M* = 702 vs. *M* = 756) and 1600ms stimulus durations (*M* = 670 vs. *M* = 702) ($p < .001$) but did not differ for the 400 (*M* = 890 vs. *M* = 894) and 800ms (*M* = 841 vs. *M* = 843) stimulus durations.

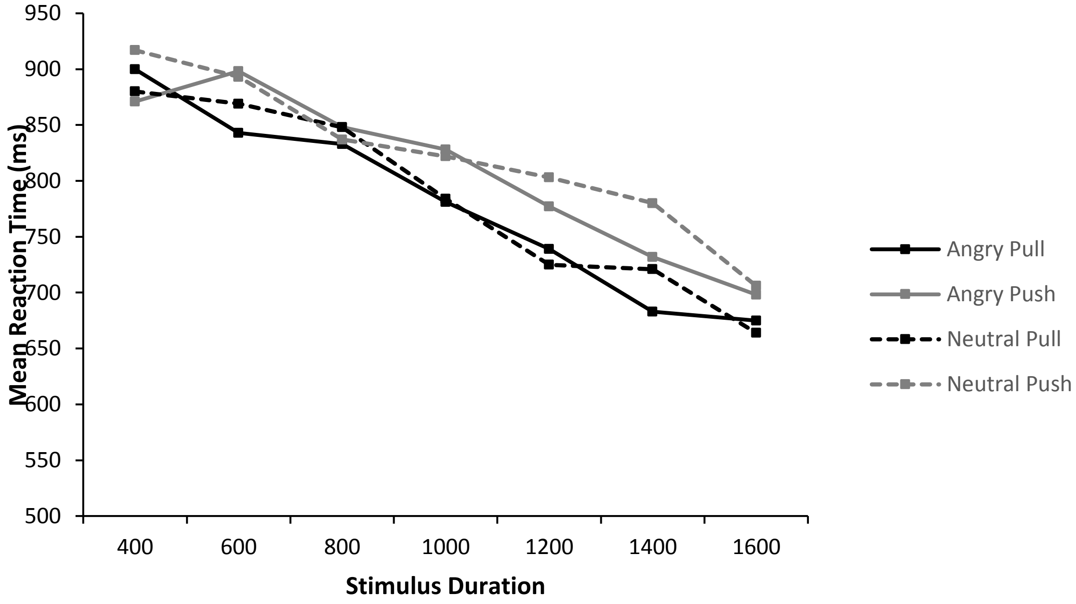


Figure 11. The mean reaction time for each experimental condition as a function of stimulus duration.

3.2.2.2 Short Duration Range (200ms – 800ms)

Prior to data analysis for the short duration range a total of 7 participant's data were excluded from further analysis due to poor timing performance across the experiment ($R^2 < .80$ in all cases) Due to the high number of participants who exhibited relatively poor timing consistency across the experiment the threshold was lowered for the short duration range. As with the analysis for the long duration range RTs quicker than 100ms were treated as anticipatory responses and RTs longer than 2.5 times individual SDs were removed as outliers. A total of 34 participants' data were used in the analysis.

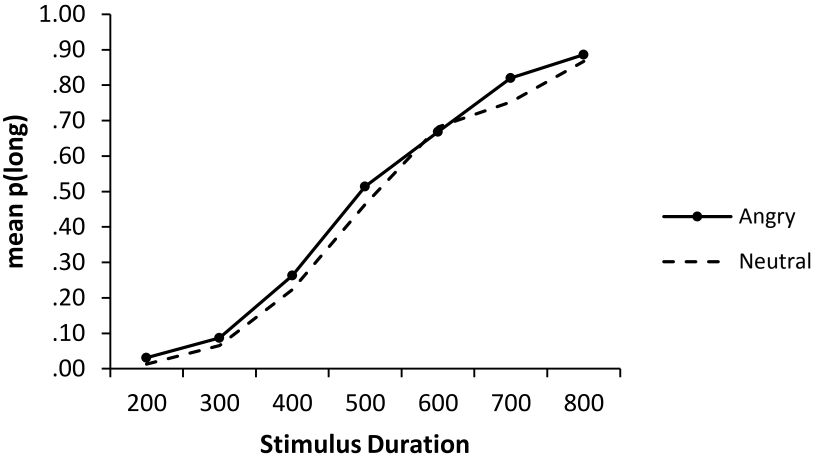
Proportion of Long Responses

The *p(long)* responses are plotted in Figure 12. Similar to the long duration range it appears that the psychometric function is shifted slightly to the left for angry compared to neutral facial expressions in the no action condition only. The same analysis as used for the long duration range was used for the statistical analysis of the short duration range; specifically, a 3 [action condition; no action, pull, push] x 2 [expression; angry, neutral] x 7 [duration; 200ms, 300ms, 400ms, 500ms, 600ms, 700ms, 800ms] repeated measures ANOVA was run. The assumption of sphericity was violated for the effects of duration and each interaction except for the action x expression interaction, as such corrected df values using the Greenhouse-Geisser correction are reported.

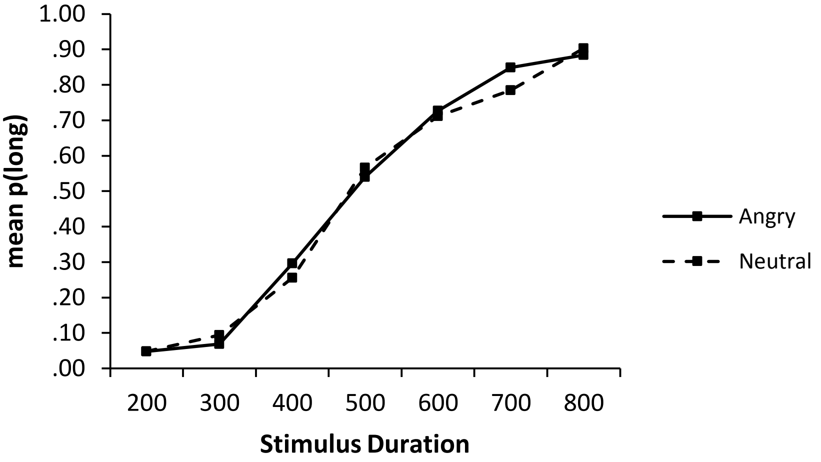
The repeated measures ANVOA showed significant main effects of action condition, F (2, 66) = 4.10, p = .021, η_p^2 = .11, *post-hoc* comparisons with Bonferroni correction revealed that participants more frequently responded long in the pull relative to no action condition (M = .48 and .45 respectively, p = .026), however no difference between the pull and push or push and no action conditions (p = .97 and .27 respectively). There was also a main effect of expression, F (1, 33) = 6.72, p = .014, η_p^2 = .17, showing that participants were found to respond long more frequently to angry facial expressions than neutral expressions (M = .48 and .46 respectively). There was also a main effect of stimulus duration, F (2.62, 86.28) = 380.03, p < .001, η_p^2 = .92, *post-hoc* comparisons with Bonferroni correction revealed each duration significantly differed from each other (p < .008 in all cases). Polynomial trend analyses further confirmed this by showing that there was a strong linear increase in the *p(long)* with increases in stimulus duration, $F_{\text{linear}}(1, 33) = 1230.53$, $p < .001$, $\eta_p^2 = .97$.

Interestingly the ANOVA did not show any significant interactions; expression x action condition ($p = .38$), expression x stimulus duration ($p = .11$), action condition x duration ($p = .16$) and the three-way interaction ($p = .60$) were all non-significant. The expression x action condition interaction shows that there was no increased temporal overestimation effect when participants were asked to prepare to make an action and viewed an emotive stimulus; that is the effects of emotion did not increase the frequency with which participants overestimated a stimuli when preparing an action. The expression x stimulus duration and action condition x stimulus duration suggest that the effects of expression and action condition did not increase as stimulus duration increased. This contrasts with the findings from the long duration range in which interactions between these variables were found suggesting that as stimulus duration increased the effects of both emotion and action readiness increased also (i.e., multiplicative effects of both emotion and action readiness).

a. No action condition



b. Pull condition



c. Push condition

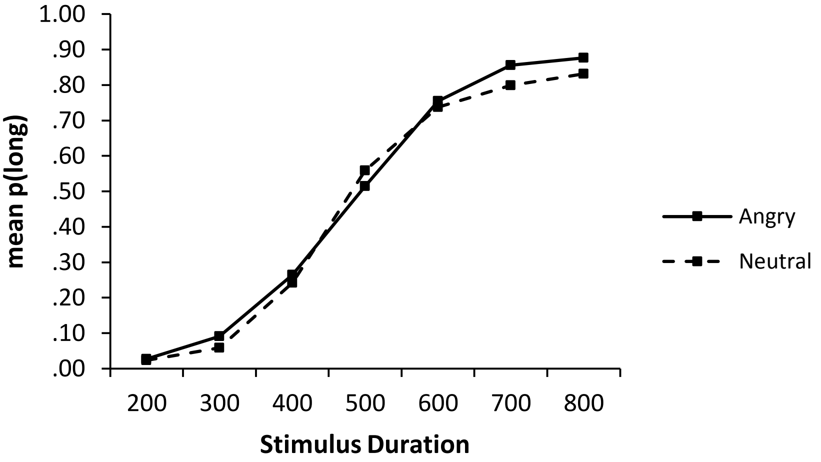


Figure 12. The mean proportion of long responses as a function of stimulus duration for each action condition separately; a) no action, b) pull and c) push.

Point of subjective equality

The PSE for each participant was again calculated per Experiment 1. The PSEs were entered into a 3 [action condition; pull, push, no action] x 2 [expressions; angry, neutral] repeated measures ANVOA. The findings were similar to the findings from the *p(long)*analysis; there was a main effect of action condition, *F* (2, 66) = 3.14, *p* = .40, η_p^2 = .09 *post-hoc* comparisons with Bonferroni correction showed no significant differences between action conditions, however, the comparison between the pull and no action condition approach significance (*p* = .055). A main effect of expression was also found, *F* (1, 33) = 9.38, *p* = .004, η_p^2 = .22 with participants responding long sooner for angry compared to neutral facial expressions (*M* = 533 and *M* = 551 respectively) but no action condition x expression interaction (*p* = .23). The mean PSE for each experimental condition is shown in Figure 13.

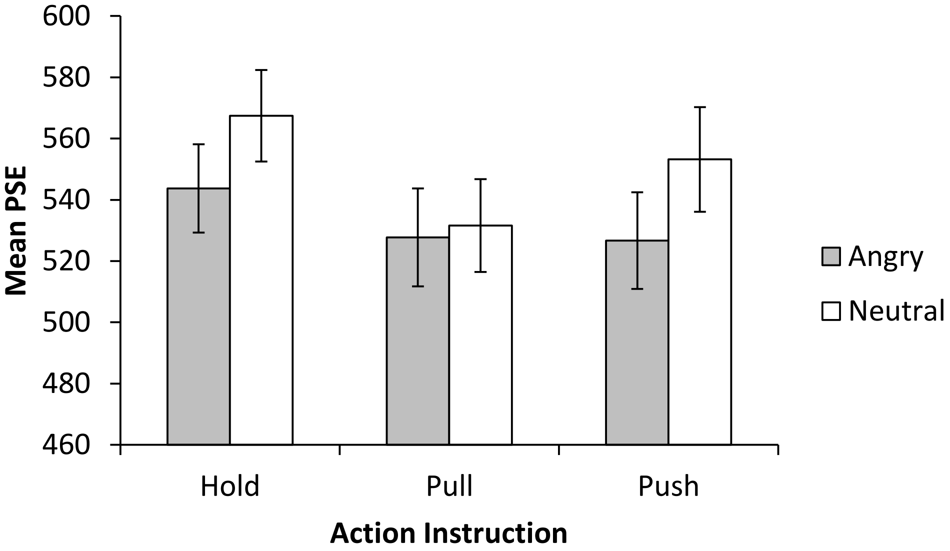


Figure 13. Mean PSE for each expression separately as a function of action condition. Note: Within subject confidence intervals calculated as described by: (Loftus & Masson, 1994; Wright, 2007).

Weber Ratios

The WR for each participant was calculated in the same way as Experiment 1. The mean WR for each experimental condition is displayed in Table 3. As per Experiment 1 the WRs were analysed using a repeated measures ANOVA and similarly no significant differences were found; lowest *p* = .11.

Table 3. The mean WR for each experimental condition.

	Action Condition					
	Pull		Push		No Action	
Expression	Mean	SD	Mean	SD	Mean	SD
Neutral	.27	.10	.24	.06	.23	.04
Angry	.27	.13	.25	.13	.25	.09

Reaction Times

Reaction times were analysed in the same way as per the long duration range; incorrect joystick responses, reaction times less than 100ms and reaction times greater than 2.5 SDs away from the mean of each individual's overall reaction time were removed. A log-transformation was also applied to the reaction times in order to correct for a significant leftward skew; for ease of interpretation the reaction time data are presented in Figure 14 as means.

A 2 [action condition; pull, push] x 2 [expression; angry, neutral] x 7 [duration; 200ms, 300ms, 400ms, 500ms, 600ms, 700ms, 800ms] repeated measures ANOVA was run. There was a main effect of expression, *F* (1, 33) = 4.67, *p* = .038, η_p^2 = .13 with participants faster to initiate a joystick action following the angry facial expression (*M* = 676ms) compared to the neutral facial expression (*M* = 684ms). There was also a main effect of duration, for which the assumption of sphericity was violated so Greenhouse-Geisser values are reported, *F* (3.734, 123.212) = 19.103, $p < .001$, $\eta_p^2 = .367$, *post-hoc* comparisons with Bonferroni correction showed that there were significant differences between the 200ms condition and the 400ms, 500ms, 600ms, 700ms and 800ms conditions, between the 300ms condition and 600ms, 700ms and 800ms conditions, between the 400ms condition and 700ms and 800ms conditions, as well as between the 500ms and 700ms and 600ms and 700ms conditions. In short, the reaction times were found to decrease in a linear fashion as stimulus duration increased, F_{linear} (1, 33) = 46.35, $p < .001$, $\eta_p^2 = .584$. The main effect of action condition was not found to be significant ($p = .234$) nor were any interactions ($p > .10$ in all cases).

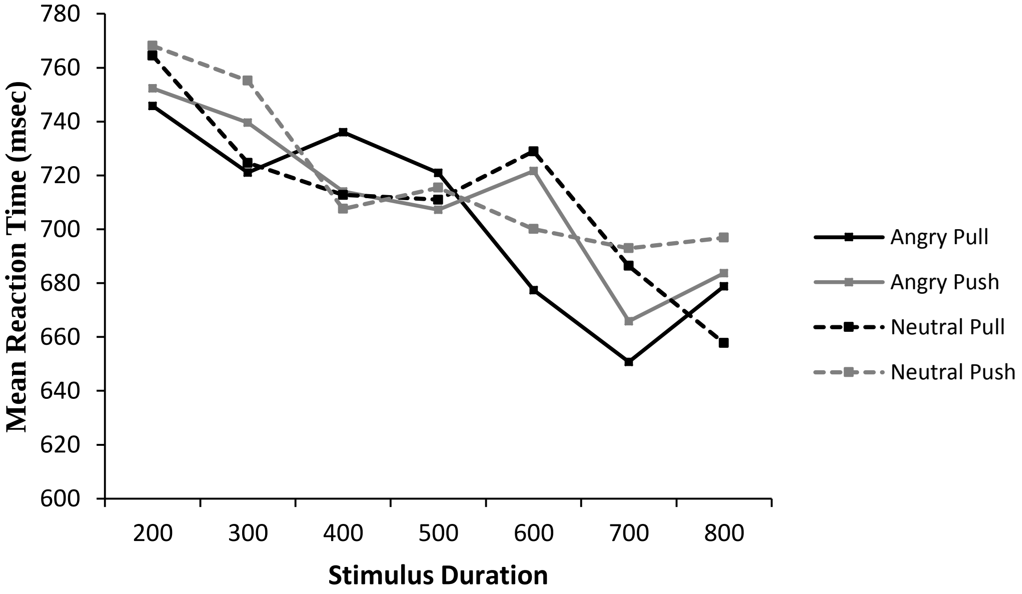


Figure 14. The mean reaction time for each experimental condition as a function of stimulus duration.

3.2.2.3 Scalar Property

To test for the scalar property of time superimposition was used whereby task performance across the different duration ranges (200ms/800ms and 400ms/1600ms) are plotted on the same relative scale; the relative scale is obtained by dividing the actual stimulus duration by the duration of the long anchor duration. As a result, the proportion of long responses for each of the two duration ranges were collapsed across all conditions giving each participant one mean *p(long)* value which are plotted in Figure 15. Visual inspection of Figure 15 suggests that the property of superimposition was relatively well met with only small deviations. In order to confirm this statistically a two-way ANOVA was conducted with duration range as a between-subjects variable to test for systematic differences. For the main effect of duration range the ANOVA failed to show any significant differences between the two duration ranges, F (1, 64) = .02, p = .89, η_p^2 = .00 as would be predicted by the scalar property of time.

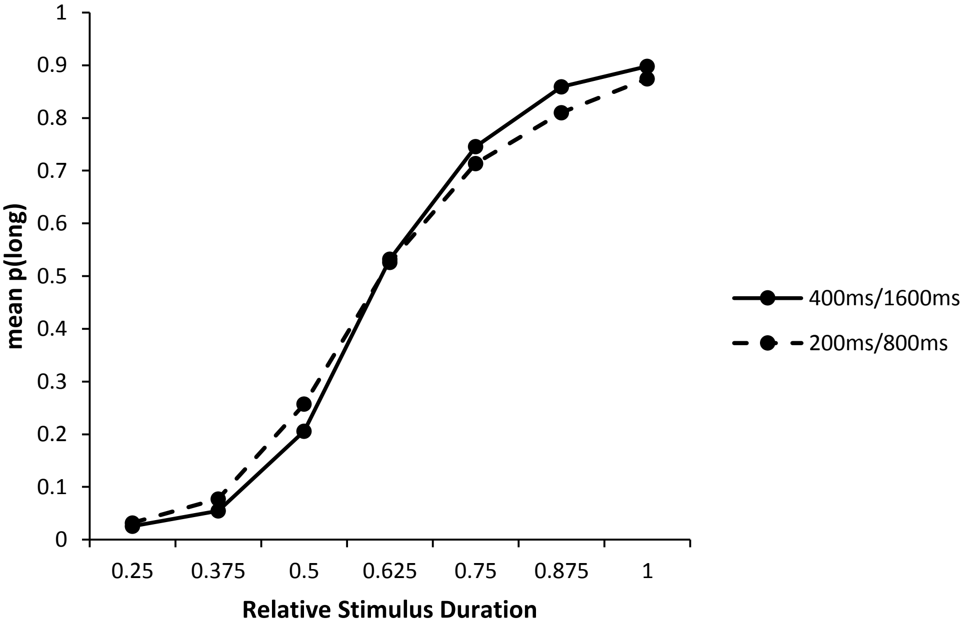


Figure 15. The mean p(long) for each stimulus duration range plotted as a function of the relative stimulus duration as a test for the scalar property of time.

3.3 General Discussion

The aim of Experiment 2 was to further investigate the combined effects emotion and action readiness have on the perception of time. Specifically Experiment 2 changed the methodology from Experiment 1 in order to determine whether the null findings from Experiment 1 were due to the experiment manipulations used. It was hypothesised that effects of emotion would increase the effects of action readiness on time estimates due to a possible functional explanation for temporal overestimation due to threat. Furthermore, it was predicted that participant reaction times would be quicker following the presentation of an emotive, relative to neutral, facial expression. The results from Experiment 2 largely support these hypotheses; participants were found to overestimate the duration of facial expressions more frequently when preparing to make an action. In addition, reaction times were found to be facilitated by emotive relative to neutral facial expressions, suggesting that temporal overestimation due to threat may ready one to act. The finding that participant reaction times were facilitated following temporal overestimation is the first example of support for a functional explanation of temporal overestimation due to threat. However, Experiment 2 did not find evidence to suggest that effects of emotion on time modulate the effects of action readiness on time. Put simply, an enhanced temporal overestimation effect was not found despite finding independent effects of action readiness and emotion on time estimates. Finally, based on the findings from Experiment 1, it was hypothesised that preparing to act influences the functioning of a pacemaker mechanism found within internal clock models of time perception; the findings reported from Experiment 2 supported this hypothesis.

Following the null findings of action readiness in Experiment 1 the primary aim of Experiment 2 was to find a methodology capable of producing effects of action preparation on time perception. A computerised joystick task was used which has been used extensively as a method of investigating action effects (Heuer et al., 2007; Krieglmeyer & Deutsch, 2010; Newhagen, 1998; Rinck & Becker, 2007). When this experimental manipulation was used in Experiment 2 participants more frequently overestimated the duration of facial stimuli when in a state of action readiness. This finding supports existing research which has shown preparing to act affects one's perception of time (Hagura et al., 2012). Similarly, existing research has well established the effects emotional stimuli have on the perception of time with consistent reports of temporal overestimation for such stimuli relative to neutral stimuli (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011a, 2012, Tipples, 2008, 2010). Once more, this effect is reported in Experiment 2; participants began responding *long* sooner to the angry facial expression relative to the neutral expression. The results from Experiment 2 therefore, show independent effects of both action preparation and emotion on one's perception of time. As such, Experiment 2 is the first experiment which has manipulated more than one experimental effect in a single experimental paradigm.

Although Experiment 2 aimed to find evidence of such an enhanced slowing in one's perception of time by investigating the combined effects of two experimental manipulations no such evidence for a super temporal overestimation effect was found. This finding mirrors that of that Experiment 1, however, Experiment 1 failed to find any effects of action condition and thus the failure to find a significant interaction between emotion and action condition in Experiment 1 was not surprising. In Experiment 2, however, the experimental manipulation was sensitive enough to find effects of both emotion and action condition yet the interaction between these two failed to reach significance. This null finding of an enhanced overestimation effect may shed light on the functioning of an internal clock mechanism,

Internal clock models which include a pacemaker-accumulator type stage (e.g., SET; Gibbon, Church, & Meck, 1984) argue that one's perception of time is based on the number of pulses of information which reach the accumulator. It follows that the quicker the pulses are sent, the more time that has elapsed. Such cognitive models of time perception have yet to determine the exact functioning of such a pacemaker – accumulator pathway; it is unknown, for instance, at what rate the pacemaker emits these pulses. The pacemaker rate is said to be constant on any given trial but is able to vary from trial to trial (Gibbon et al., 1984). Despite this the exact rate at which the pacemaker sends pulses to the accumulator is unknown. The results from Experiment 2 suggest that the rate at which the pacemaker sends information to the accumulator has some upper limit.

A related aim of Experiment 2 was to investigate the effects of action preparation one time more fully by determining which mechanism of internal clock models is affected by increased levels of action readiness. Experiment 1 found evidence to suggest that overestimations of time due to increased action readiness are caused by an increase in the pacemaker activity which was further investigated in Experiment 2. Whilst similar pacemaker speeding effects are often reported for effects of emotion on time (Droit-Volet, Brunot, & Niedenthal, 2004; Droit-Volet & Wearden, 2002; Penton-Voak, Edwards, Percival, & Wearden, 1996) effects of action readiness on time estimates are yet to be reconciled with internal clock models. In order to determine which component of SET is affected by modulations of action readiness two duration ranges are required to see if the effect of action readiness is greater at longer durations than lesser durations (Grommet et al., 2011). As effects of the pacemaker are considered multiplicative with real time, the effect should be greater across the longer duration range. Alternatively, if the magnitude of the effect of action readiness is similar across the two duration ranges (i.e., the effects are independent of duration range) the most likely cause for such an overestimation effect is that of the switch mechanism. The results from Experiment 2 extend the findings from Experiment 1; specifically, the results support the notion that manipulations of action readiness increase the rate of a pacemaker type mechanism found within internal clock theories of time perception. Evidence for this comes from the finding that action readiness was found to interact with stimulus duration only in the long duration range of Experiment 2. As effects of the pacemaker are found to be multiplicative with real time this finding is the exact pattern one would predict if action readiness modulated pacemaker speed.

The finding that the pacemaker cannot be distorted to produce super time overestimations can perhaps be explained by alternative models of time perception besides SET. More biologically plausible models, such as the striatal-beat frequency model (SBF; Buhusi & Meck, 2005; Matell & Meck, 2004) posit that the brain itself is able to code the temporal properties of a stimulus by analysing firing rates of neurones without the need for an internal clock per se. Although an oversimplification the SBF model argues that striatal spiny neurones are able to detect the neuronal activity of oscillatory cortical neurons and continually compare such neuronal activity to the activity recorded at some reward point. When cortical activity is synchronised at the beginning of a to-be-timed duration, coincident neural activity is detected by spiny neurons in the striatum. Thus, the coincident neural activity found in the oscillatory cortical neurons can be likened to the pacemaker-accumulator pathway. In such biological models like the SBF, it is evident that the rate of the pacemaker may not be able to be infinitely increased, rather such a rate is determined by analysing the neuronal activity across groups of neurons. In terms of the functioning of such a model on the task used in Experiment 2, the cortical neurons would either fire more rapidly due to the increases in action readiness and emotion or more neurons would fire. In the case of the SBF model the rate of the abstract pacemaker is more likely dependent on the number of neurons which fire simultaneously given that neurons fire in an all or nothing manner and include a recovery period in which further firing is impossible. In this model therefore, the number of neurons which can physically fire simultaneously will be limited, despite there being several thousand neurons connected to each striatal spiny neuron (see, Matell & Meck, 2004). Consequently, there will be some upper limit to the level of coincident neural activity which can be detected by the striatal spiny neurons. The fact that Experiment 2 does not find a significant interaction between action condition and emotion could be due to this upper limit being reached; when one is in a state of action readiness the amount of coincident neural activity is already at some maximum limit meaning no further neurones could fire when later modulations of emotion occur. In short, it is possible that the pacemaker is already operating at some maximal rate of output when one is preparing to act leading to no further temporal overestimation when emotional arousal is increased.

A further possible explanation for not finding any modulation of the action readiness overestimation effect is that emotionally salient stimuli are intrinsically linked to action readiness. For instance, angry facial expressions prepare an individual to act and consequently when one sees an angry facial expression their level of action readiness may not be able to be increased further. Such an explanation relies on the emotion overestimation effect being driven by action readiness as opposed to increases in physiological arousal for which there is empirical evidence. First, disgusted facial expressions are not overestimated but are highly arousing (Gil & Droit-Volet, 2011a), moreover studies have shown that arousal alone does not adequately explain effects of emotion on time estimates (Angrilli et al., 1997). Second, studies have shown that there are apparent timing differences between physiological arousal changes and the time course of time perception experiments (Schirmer, 2011; Schirmer & Escoffier, 2010). As a result, it is possible that when one who is already in a state of action readiness sees an emotive image one is unable to be in any heightened state of action readiness than they were previously. Although speculation, the evidence suggesting action readiness and not arousal drives the emotion overestimation effect would predict such a failure to find an increased temporal overestimation effect as in Experiment 2.

The use of two duration ranges in Experiment 2 allowed for testing one of the main assumptions of the SET model; scalar variance. The notion that timing judgements are scalar is one of the central assumptions of SET; the model assumes that the coefficient of variation (SD/mean) remains constant as the absolute duration varies. As detailed elsewhere (Wearden, 1991; Wearden & Bray, 2001; Wearden, 2003) one simple way of testing this assumption is to show the property of superimposition in timing data. For the scalar property of time to hold, timing data from different stimulus duration ranges should superimpose on each other when they are plotted on the same relative scale. Given the use of a short and long stimulus duration in Experiment 2, such a test was able to be performed. As is evident from the results for the data collected in Experiment 2 time estimates conformed to the scalar property; the data from the short and long duration range experiments superimposed well and furthermore, no systematic difference between participant timing performance was found across the two duration ranges.

A further aim of Experiment 2 was to determine whether participant reaction times were facilitated by emotional facial expressions relative to neutral expressions. Whilst Experiment 1 of this thesis failed to show any response facilitation following the presentation of an angry compared to neutral facial expression there is a wealth of evidence to suggest that emotions ready one to act (Frijda et al., 1989; Hajcak et al., 2007; van Loon et al., 2010). Using a different methodology Experiment 2 found evidence to support this notion; participant reaction times were quicker after an angry facial expression was presented compared to when a neutral facial expression was presented. Coupled with the finding that participants in Experiment 2 more frequently overestimated the duration of angry facial expressions compared to neutral facial expressions, Experiment 2 is the first empirical research which has demonstrated that temporal overestimation due to threat may ready one to act. Moreover, the findings from Experiment 2 show that such an effect was not modulated by the duration of the stimulus meaning that response facilitation for emotive stimuli was equally as strong after 400ms compared to 1600ms. This finding supports previous research by Jones, Allely, and Wearden, (2011) who showed that 5 second click trains, which frequently lead to overestimations of elapsed duration, caused response facilitation and other psychological processes to run faster. However, the results from Experiment 2 show such an effect is much stronger for emotive stimuli given the comparatively short duration the facial expressions were displayed for. The idea that there exists a functional explanation behind the temporal overestimation effect for emotive stimuli is not new, however, previous studies have failed to provide any direct, empirical evidence for this functional explanation. Thus, Experiment 2 provides preliminary evidence that temporal overestimation due to threat prepares one to act.

Given the suggestion that temporal overestimation due to threat prepares one to act, one wonders how such an effect would manifest itself. There are two alternate possibilities, one is that temporal overestimation affects the attentional system; it is possible that stimuli which are temporally overestimated are perceived as more salient or are attended to quicker than stimuli which are not temporally overestimated. Another explanation is that activity in the motor system is heightened following the presentation of a stimulus which is temporally overestimation. Previous research investigating the previously discussed looming motion effect suggests that the motor system is primed by looming visual stimuli (Skarratt, Gellatly, Cole, Pilling, & Hulleman, 2014). Whilst further research would be needed to determine whether such results would also be found in time perception experiments, the finding in Experiment 2 that reaction times were facilitated following the temporal overestimation of a stimulus suggest that the motor system is indeed primed in some way. Consequently, the temporal overestimation effect may not give people more to act per se, but rather primes the motor system.

Similar to Experiment 1 the findings from Experiment 2 show that as the stimulus durations increased participant's reaction times became quicker, likely owing to the increased time participants could prepare to make their response. However, the findings from Experiment 2 show that the emotive content of the facial expression modulated this effect; participants were faster to respond to the angry facial expressions compared to the neutral facial expression (i.e., participant reaction times decreased more steeply for emotive compared to neutral facial expressions). Once more this finding provides support for a functional explanation of temporal overestimation due to threat; when one overestimates the duration of an emotive stimulus, one is in a state of higher action readiness and as such can act more quickly. The facilitated action initiation following an emotive stimulus supports action readiness of theories (e.g., Frijda, 1986; Frijda & Tcherkassof, 1997); emotionally salient stimuli prepare one to act. The results from Experiment 2 expand on this notion by suggesting that increases in the degree to which one is ready to act following an emotive stimulus may be, at least in part, due to such stimuli being temporally overestimated.

Finally Experiment 2 found that participants were quicker to initiate the *pull* action instruction quicker than the *push* action instruction for all but the 400ms and 800ms stimulus durations. It is possible that an advantage for the *pull* compared to *push* action instruction is due to the use of only angry facial expressions in Experiment 2. Emotions are considered to ready an individual act; however, different emotions are considered to ready different actions. As mentioned previously anger readies an individual to approach a stimulus (for a review, see Carver & Harmon-Jones, 2009). As Experiment 2 used only angry and neutral facial expressions it is possible that participants were continually primed throughout the experiment with this approach action motivation. However, such an explanation does not consider why for the 400ms and 800ms conditions there was no difference between reaction times for the two action instructions. Moreover, if this were the case one would expect to find an interaction between action condition and expression for the reaction times; with facilitated *pull* actions occurring when participants saw an angry facial expression compared to a neutral expression. As such an interaction was not found it may have been the case whereby due to the experimental set up participants merely found the *pull* action condition to be easier to initiate. Within the field of biomechanics it is well understood that pulling an object be easier than pushing the same object. Whilst the explanation for such a finding relates to the differences in the experience of friction during these movements, it is possible that in terms of biomechanics pulling is an easier movement than pushing.

In summary Experiment 2 continued the investigation into the combined effects of action readiness and emotion on the perception of time by using a different method of action initiation as well as different stimulus duration ranges. The main finding of Experiment 2 was that effects of emotion did not further increase the effects of action readiness on time estimates. However, Experiment 2 found that effects of action readiness on time estimates were due to increases in pacemaker speed which may have prevented an enhanced temporal overestimation effect from being found. Alternatively, the failure to find such an effect could be due to the way temporal information is coded for in the brain. Nevertheless Experiment 2 did find that participant reaction times were facilitated by threatening (angry) facial expressions, which were temporally overestimated relative to neutral expressions which were not overestimated. This novel finding is the first which has found empirical evidence for response facilitation following temporal overestimation due to threat. In short Experiment 2 provides some evidence for a functional explanation of temporal overestimations due to threat.

Whilst Experiment 2 provided some support for a functional explanation of temporal overestimation due to threat; Experiment 3 sought to determine the robustness of such an effect by using a different timing task. In addition, Experiment 3 included the emotional facial expression of fear to more fully investigate the differential action motivations that each emotion evokes.

4. The Robustness of the Functional Effect of Temporal Overestimation Due to Threat

4.1 Introduction

Experiment 2 found no evidence of an enhanced temporal overestimation for the effect of action readiness when an emotive stimulus was displayed. However, Experiment 2 did find evidence consistent with the notion that temporal overestimation due to threat functionally prepares an individual to act; participants were faster to initiate an action when an angry facial expression was displayed and such stimuli were more frequently overestimated compared to neutral facial expressions. Experiment 3 therefore, investigated the robustness of this finding. Experiment 2 found that participants were quicker to initiate the *pull* action instruction for all but two stimulus duration conditions in the long duration range. To more fully investigate the effects of action tendency (e.g., approach vs. avoidance) on time perception Experiment 3 included a time judgement for fearful facial expressions.

The findings from Experiment 2 showed that participants were quicker to act following angry facial expressions, which were also more frequently overestimated, providing evidence consistent with a functional explanation as to why emotive stimuli cause a temporal slowdown. Experiment 3 therefore, aimed to replicate this finding using a different temporal task. Whilst there are numerous reports of temporal overestimation for emotive relative to neutral stimuli a large number of such reports use the same temporal task; specifically the temporal bisection task is frequently used (e.g., Droit-Volet & Wearden, 2001; Gil, Niedenthal, & Droit-Volet, 2007; Gil, Rousset, & Droit-Volet, 2009; Grommet et al., 2011; Millot, Laurent, & Casini, 2016; Schirmer, Ng, Escoffier, & Penney, 2016; Tipples, 2008, 2010, 2011; Wearden & Ferrara, 1996; Wearden & Thomas, 1997). However, in a review of the different tasks used to investigate the perception of time it was found that only three tasks were sensitive to behavioural effects of emotion. Specifically, the bisection, production and verbal estimation paradigms were found to produce effects of emotion on time but the reproduction and generalisation tasks were not (Gil & Droit-Volet, 2011b). As a result, Experiment 3 used the verbal estimation task in order to determine the robustness of the functional explanation of temporal overestimation due to threat. The verbal estimation task was chosen as the task is easy to administer, requires little instruction and has been found to produce reliable effects of experimental manipulations on one's perception of time. Moreover, the reproduction task, although sensitive to effects of emotion, is heavily influenced by participant motor responses because the participant must press a button to stop the interval being timed (Droit-Volet, 2010). Given that participants were also instructed to initiate an action prior to this temporal judgement, the verbal estimation task allowed for better pacing of the experiment.

Following from the review of different temporal tasks by Gil and Droit-Volet (2011), it is evident that temporal tasks rely on different psychological processes; for example, in a bisection task participants are not required to explicitly give temporal labels to different stimulus durations, one duration is merely judged as being shorter than or longer than another. However, in other tasks, such as the verbal estimation task, participants are required to convert their subjective experience of some duration into clock units (e.g., seconds). Further evidence of such discrepancies across timing tasks comes from research by Ogden and colleagues who found that different executive functions are required for different temporal tasks (Ogden, Wearden, & Montgomery, 2014).

As discussed previously (page 33) attention plays an influential role in the perception of time as when participants are distracted or have an increased memory load, time estimates are generally found to be shortened (for a review, see Brown, 2008). Moreover, there is a wealth of evidence to suggest that timing behaviour is, to some degree, dependent on executive function. Evidence for this comes from studies in which bidirectional interference is found when participants perform timing and executive function tasks in single and dual-task conditions (Brown, 2006; Champagne & Fortin, 2008; Fortin, Champagne, & Poirier, 2007; Kladopoulos, Hemmes, & Brown, 2004; Ogden, Salominaite, Jones, Fisk, & Montgomery, 2011; Rattat, 2010).

One of the most cited models of executive function is that of Baddeley and Hitch’s working memory model in which the central executive is said to drive three slave systems and co-ordinate higher cognitive processes (Baddeley, 1986; Baddeley & Hitch, 1974b). More recently, however, it has been argued that executive function should not be a unified concept but is rather a collection of separate mechanisms. Work conducted by Miyake and colleagues (2000) suggests there are three components of executive function; the ability to switch between thinking about two or more concepts simultaneously (shifting), updating and monitoring incoming information (updating) and inhibiting responses (inhibition). Moreover, Fisk and Sharp (2004) have more recently argued for the inclusion of a fourth component which is linked to one’s ability to access stored long term memories termed access to semantic memory. Importantly, research has shown that such executive functions are not recruited similarly across all cognitive tasks (Miyake et al., 2000). In terms of time perception tasks, as one may predict, Ogden and colleagues report that such executive functions are not recruited similarly across tasks commonly used in the literature. When describing the verbal estimation task, as used in Experiment 3, research has shown that access to semantic memory in particular is critical to performance (Ogden et al., 2014). This reliance on access to semantic memory in the verbal estimation task is likely due to the need to label subjective clock units (e.g., the stimulus lasted for 2 seconds) and also the need to access stored memory durations (i.e., participants must be able to remember how long 1 second actually is). When comparing such executive functions across timing tasks it is possible that such differences in terms of how participants perform such task explain why some tasks are found to be sensitive to behavioural effects whereas others are not (see, Gil & Droit-Volet, 2011).

Although there have been attempts to model participant behaviour for a number of temporal tasks, the classical timing tasks have proven more difficult than newer comparison style tasks. For the temporal bisection task it is generally thought that participants use the arithmetic mean of the two anchor durations, if the stimulus durations are spaced linearly, as a benchmark for their short or long duration judgement (Wearden, 2004). Evidence for this is largely based on the finding that the PSE is generally found to be around the arithmetic mean (Kopec & Brody, 2010; Wearden & Ferrara, 1995, 1996) but there are reports of the PSE being found closer to the geometric mean (Ortega & López, 2008). Regardless of the exact location of the PSE such simple models do not tell the full story as participants are able to perform the bisection task without a short or long anchor duration being made explicit (Wearden & Bray, 2001). Without any reference to what a short and long duration is, it follows that participants cannot use the middle of such durations as some threshold for judging what is short and what is long. Instead of using the arithmetic mean of these anchor durations then Wearden and Bray (2001) propose that participants use the arithmetic mean of all stimuli durations that are presented and not that of the two anchor durations.

Surprisingly, relatively little is known about how participants perform the classical timing tasks such as verbal estimation (Wearden, 2014), although attempts to model the reproduction task have been made (Wearden, 2003). In the verbal estimation task it is clear that participants convert their subjective experience of time into clock units and that whilst this conversion is generally accurate the precise mechanism by which this occurs is not well understood (Wearden, 2003). Moreover, one must consider the effects of quantisation when using the verbal estimation task. Quantisation, as described by Wearden (2003), is considered as the tendency for participants to respond on verbal estimation tasks using values which predominately end in either a 0 or 5. The reason for this occurring is not well understood except for that participants seem to prefer such values. More pressing, however, is that it is not well understood how this quantisation behaviour affects performance on the verbal estimation task. One interesting theory suggests that the issue of quantisation causes data obtained from verbal estimation tasks to violate the assumption of scalar variance found in SET. One often reported finding is that classical timing tasks do not show this scalar type of variance (page 29) but perhaps it is participant preference for quantisation of verbal estimates which causes such violations; it could be that the raw verbal estimates do conform to the scalar property but when quantised this property is no longer found (Wearden, 2003).

From the literature it is apparent that performing different temporal tasks require different psychological processes. So far, Experiments 1 and 2 have exclusively used the bisection task in a way to investigate the functional explanation of temporal overestimation due to threat. If, however, this functional explanation were true, one would expect the effect to hold across different temporal tasks; for there to be an advantage of overestimating a stimulus' duration it should be a robust effect.

Furthermore, Experiment 1 and 2 have used only two facial expressions, specifically angry and neutral. If temporal overestimation of threatening stimuli gives one more time to act, the same effect found in Experiment 2 using angry facial expressions should also hold for fearful facial expressions. The emotional experience of fear, like anger, has a negative valance, is highly arousing and causes temporal overestimations (Grommet et al., 2011; Hare, 1963; Tipples, 2011; Watts & Sharrock, 1984). Interestingly, however, fearful stimuli are proposed to elicit avoidance based action tendencies rather than approach (Frijda, 1986; Heuer et al., 2007; Rinck & Becker, 2007).

Consequently, the use of both a different temporal methodology alongside the inclusion of fearful facial expressions allows Experiment 3 to further investigate the functional explanation of temporal overestimation due to threat. Finally the inclusion of a fearful facial expression allows Experiment 3 to more fully investigate the effects of action tendency on time perception.

The primary aim of Experiment 3 was to investigate the robustness of the action facilitation effect of temporal overestimation found in Experiment 2. The temporal task used in Experiment 3 was changed in order to look at the generality of the effect found in Experiment 2. Here participants completed a verbal estimation task to test this generality as well as the task potentially being sensitive to the combined effects of both action condition and emotion as well as each effect separately.

The secondary aim of Experiment 3 investigated the effect of both angry and fearful facial expressions. The addition of the fearful expressions allowed Experiment 3 to investigate the effects of both approach and avoidance action tendencies on the perception of time. Fearful facial expressions should evoke avoidance based behaviour instead of approach motivation behaviours. The use of two facial expressions alongside the use of the joystick task allows for a more comprehensive investigation.

It was hypothesised that participants would overestimate the duration of both angry and fearful facial expressions relative to neutral expressions as well as when participants are instructed to prepare to initiate an action compared to when no action initiation is required. Furthermore, it was hypothesised that there would be a greater degree of temporal overestimation in the combined action and emotive facial expression condition than in either the action only or emotive facial expression only conditions. In addition, it was hypothesised that there would be an action facilitation advantage from temporally overestimating the duration of emotive stimuli relative to neutral stimuli; that is participants were predicted be quicker to initiate an action following the display of an emotive facial expression.

A final aim of Experiment 3 was to investigate the different action tendencies which are evoked from angry and fearful facial expressions; participants were expected to be quicker to initiate *pull* joystick responses when approach action tendencies are primed (angry facial expression) and quicker to initiate *push* action tendencies when avoidance action tendencies are primed (fearful facial expression).

4.2 Experiment 3

4.2.1 Method

Participants

Forty one undergraduate students ranging between 18 and 48 years of age (*M*=21.4, *SD*=5.7, 7 males) from the University of Hull took part in the Experiment and received partial course credit on completing the experiment. The experiment was approved by the ethics committee in the Department of Psychology at the University of Hull.

Apparatus and Materials

The same facial stimuli as used in Experiments 1 and 2 were used in Experiment 3. The fearful facial expression which was not used in the previous experiments was used creating the same computer software as the angry and neutral facial expressions. The fearful facial expression had also been used previously within the time perception literature (Tipples, 2011). The fearful facial expression is displayed in Figure 16. All stimuli measurements were the same as in Experiment 1.

Figure 16. The fearful facial expression used in Experiment 3.

Design and Procedure

Experiment 3 used a 3 x 3 x 5 design with facial expression (angry, fear, neutral), action condition (pull, push, no action) and duration (500ms, 900ms, 1300ms, 1700ms, 2100ms) as three within-subjects factors.

Participants completed a verbal estimation task. In an initial training phase participants were taught to distinguish between two anchor durations. In a later testing phase participants were presented with stimuli displayed for a duration between the anchor durations. This was achieved using a pink oval stimulus that was presented for either 500ms (shortest duration) or 2100ms (longest duration) in a random sequence for 12 trials. Participants were asked to type how long the pink oval was displayed for using a standard keyboard in milliseconds. Participants were told that the pink oval would be presented for either 500ms or 2100ms in the training phase.

After the initial training phase participants were told that on subsequent trials the pink oval would be replaced by a facial expression displaying either an angry, fearful or neutral expression which would either be displayed for a period of time in between the two durations learnt previously (900ms, 1300ms or 1700ms) or one of the previously learnt durations (500ms or 2100ms). Prior to the facial expression being displayed, an action instruction of either push, pull or no action was displayed on the computer screen for one second. Participants were asked to carry out the action instruction using a joystick once a fixation cross appeared on screen after the facial expression. Following one participant's high number of incorrect joystick responses in Experiment 2 leading to exclusion from data analysis, participants received feedback regarding the action initiation; if the correct action was initiated a high-pitched sound was played through the computer speakers, on the contrary a low-pitch sound was played if the incorrect joystick movement was initiated. Following the initiation of the action instruction, participants were asked to make their temporal judgement by typing, in milliseconds, the length of time the facial expression was shown for. On this temporal judgement screen participants were reminded that the facial expression could have been displayed for any period of time between 500ms and 2100ms and that 1000ms was equal to 1 second. Participants were instructed to judge the duration of the facial expression as best they could.

There were 270 trials derived from the factorial combination of number of stimulus presentations (6) x duration (5) x expression (3) x action condition (3). A randomised trial order was generated for each participant. The E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) was used to control trial presentation and data collection.

4.2.2 Results and Discussion

Prior to data analysis participant verbal estimates were screened for outliers and incorrect action responses. Trials where an action was incorrect (i.e., participant pushed the joystick when no action was required) were excluded from further analysis as were trials in which participants' verbal estimate was outside the 500ms to 2100ms anchor duration range. As a result, four participants' data was excluded from further analysis for having too many verbal estimates outside this range or too many incorrect joystick responses (> 50% in either case). The analysis on the remaining 37 participants' data was conducted in two stages. First, in accordance with previous research and as has often been used in classical timing tasks an index of time was created where the target duration was subtracted from the verbal estimate before being divided by the target duration (*T* corrected = [*T* estimated – *T* target]/*T* target) (Brown, 1985; McConchie & Rutschmann, 1970; Treisman, 1963). This index is often used when using the verbal estimation task as it allows one to clearly identify temporal over or underestimations (Angrilli et al., 1997; Noulhiane et al., 2007). Second, participant reaction times, taken from the time the fixation cross was displayed to the time the action was initiated using the joystick, were also analysed.

Index of Timing

Figure 17 shows the mean *T* corrected scores for each facial expression and action condition as a function of stimulus duration. As is evident from Figure 17, participants underestimated each duration except for the very shortest duration (500ms). Moreover, visual inspection of the data suggests that the degree of underestimation is greater for the longer stimulus durations. One sample t-tests confirmed that each verbal estimate was significantly underestimated compared to the stimulus duration, except for in the 500ms condition where there was significant overestimation compared to the stimulus duration; 500ms, $t(36) = 9.98$, 900ms, *t*(36) = 5.85, 1300ms, *t*(36) = -6.04, 1700ms, *t*(36) = - 7.81 and 2100ms, *t*(36) = - 11.77 all significant at the *p* <.001 level.

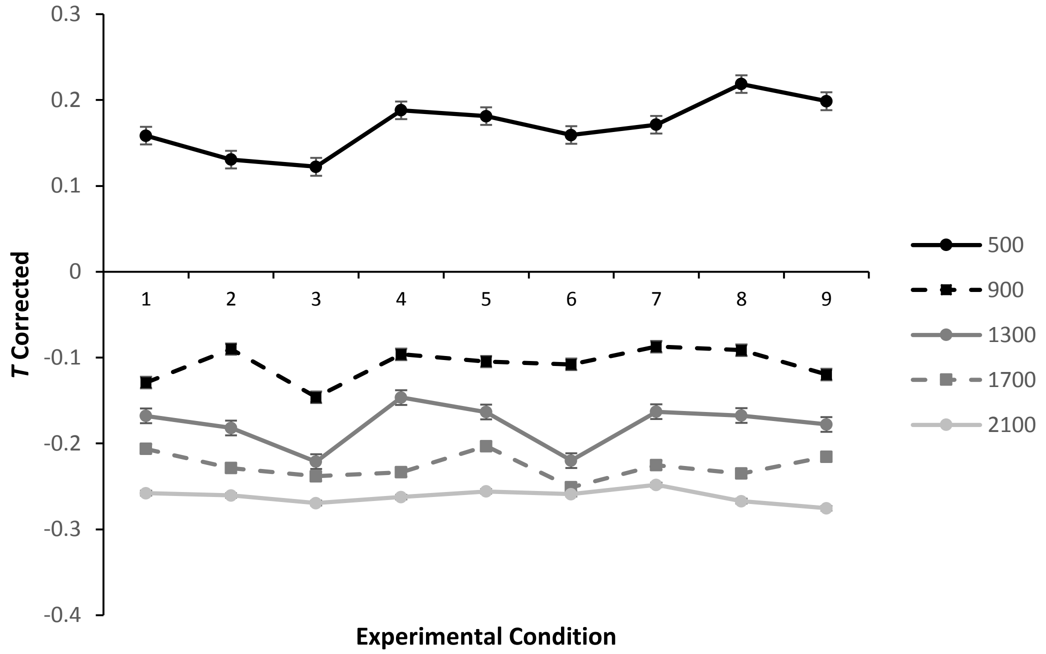


Figure 17. Mean T corrected score for each stimulus duration as a function of experimental condition. 1; no action angry, 2; no action fear, 3; no action neutral, 4; pull angry, 5; pull fear, 6; pull neutral, 7; push angry, 8; push fear, 9; push neutral condition. Error bars show SE.

The *T* corrected scores were analysed using a 3 x 3 x 5 repeated measures ANOVA. The effect of duration violated the assumption of sphericity and so Greenhouse-Geisser corrected values are reported. The ANOVA on *T* corrected scores revealed main effects of action condition, *F* (2, 72) = 3.91, *p* = .024, η_p^2 = .10, expression, *F* (2, 72) = 3.28, *p* = .043, η_p^2 = .08 as well as duration, *F* (1.682, 60.546) = 99.37, *p* <.001, η_p^2 = .73, no interactions were found to be significant (largest *F* = 1.49 and smallest *p* = .160).

Post hoc tests (with Bonferroni correction) were conducted following the significant effects of action condition, expression and duration; for the effect of action condition the post hoc tests revealed less frequent underestimations when participants were instructed to push (*M* = -.11, *SD* = .12) compared to the no action

(*M* = -.13, *SD* = .10) condition (*p* = .016), but not when instructed to pull (*M* = -.12, *SD* = .12) compared to the no action condition (*p* = .237). Post-hoc tests on the main effect of expression revealed fearful facial expressions (*M* = -. 12, *SD* = .11) were less frequently underestimated than neutral facial expressions (*M* = -.14, *SD* = .11, *p* = .034) but angry facial expressions were not underestimated less frequently (*M* = -.11, *SD* = .12, *p* = 0.188) than neutral expressions. For the main effect of duration, post hoc tests revealed a significant difference between every possible duration combination except for the 900ms and 1300ms conditions and the 1700ms and 2100ms conditions; 500ms condition (*M* = .17, *SD* = .10), 900ms condition (*M* = -.11, *SD* = .11), 1300ms condition (*M* = -.18, *SD* = .18), 1700ms condition (*M* = -.23, *SD* = .18) and 2100ms condition (*M* = -.26, *SD* = .13).

Reaction Times

Prior to the analysis reported an initial 3 x 3 x 5 repeated measures ANOVA was conducted in order to test for facilitated emotion congruent action effects. However, this analysis revealed significant differences between the action conditions, *F* (1, 36) = 19.71, p < .001 η_p^2 =.35 with participants quicker to initiate the pull action (*M* = 626ms) rather than the push action (*M* = 662ms) irrespective of the facial expression displayed. Consequently, in order to test the idea that temporal overestimation due to threat prepares one to act, reaction times were averaged across the two threatening facial expression (anger and fear) in order to create a threatening vs. neutral facial expression comparison. Mean reaction times are plotted in Figure 18. Reaction times were trimmed as per Experiments 1 and 2. The reaction times were analysed using a 2 x 3 x 5 repeated measures ANOVA.

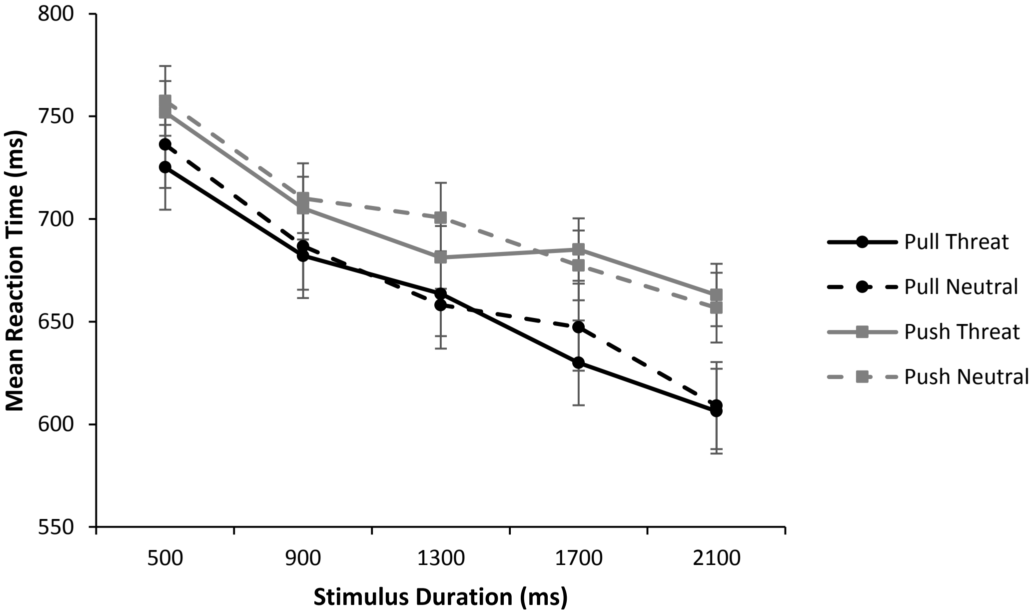


Figure 18. Mean RT for each experimental condition as a function of stimulus duration. Error bars show SE.

The main effect of duration violated the assumption of sphericity and so the Greenhouse-Geisser corrected figures are reported. The ANOVA revealed a main effect of action, *F* (1, 36) = 18.13, *p* < .001, η_p^2 = .36 showing that participants were quicker to initiate the pull action instruction (*M* = 660ms, *SD* = 147.24) compared to the push action instruction (*M* = 695ms, *SD* = 147.37). In addition, there was a significant main effect of expression, *F* (1, 36) = 4.50, *p* = .028, η_p^2 = .41 whereby reaction times were facilitated by threatening (*M* = 674ms, *SD* = 148.17) relative to neutral facial expressions (*M* = 682ms, *SD* = 142.80). Finally, there was a significant main effect of duration *F* (2.875, 103.487) = 36.34, *p* < .001, η_p^2 = .50 which showed reaction times became quicker as stimulus duration increased. No interactions were found to be significant (lowest *p* value = .29).

4.3 General Discussion

The primary aim of Experiment 3 was to investigate the robustness of the finding that temporal overestimation due to threat prepares an individual to act. In addition, Experiment 3 investigated the effects of both angry facial expressions and fearful facial expressions as a way to further investigate the different action tendencies each emotional expression prime.

The results from Experiment 3 further corroborate the findings from Experiment 2; participant reaction times to initiate action instructions were facilitated following the presentation of an emotive stimulus which were more readily temporally overestimated than neutral facial expressions. In addition, similar to Experiment 2, participants were quicker to initiate the *pull* action instruction quicker than the *push* action instruction, despite the inclusion of the fearful facial expression in Experiment 3. Finally, Experiment 3 did not yield a significant interaction between facial expression and action condition again failing to provide evidence of an enhanced temporal overestimation effect. Together, these findings again provide limited support to the notion that temporal overestimation due to threat functionally prepares an individual to act. Furthermore, Experiment 3 provides evidence to suggest that temporal overestimation due to threat specifically primes an individual to approach a threatening stimulus.

Experiment 3 investigated whether action facilitation following a threatening stimulus would continue to be found when a different temporal task was used than the bisection task as used in Experiments 1 and 2. The results from Experiment 3 showed that such action facilitation following a temporally overestimated threatening facial expression is a consistent and robust effect; participants were quicker to initiate an action instruction when they had previously seen a threatening facial expression. Coupled with the finding that participants more frequently overestimated the duration of both the angry and fearful facial expression, Experiment 3 provides further support for the notion that temporal overestimation due to threat functionally prepares an individual to act. The finding that the temporal overestimation gives one time to prepare to act has a clear evolutionary advantage and demonstrates that the internal clock mechanism is a highly adaptive survival mechanism which is capable of producing potentially lifesaving temporal distortions as has been previously suggested. In this view it is unsurprising therefore, that people overestimate the duration of potentially life-threatening events such as crimes (Loftus, Schooler, Boone, & Kline, 1987; Yarmey & Matthys, 1990). In circumstances such as these the difference between survival and non-survival could be a matter of a milliseconds, thus initiating action quicker during highly threatening events could be key. The results from Experiment 2 and 3 provide evidence for the hypothesis that in times of immediate threat, the internal clock is able to slow down the passage of time to such a degree that one sees facilitated action initiation following the display of a threatening stimulus. What is currently unknown, and cannot be answered by Experiment 2 and 3, is how the internal clock and motor systems interact in order to produce this adaptive function which shall be returned to in Experiment 6.

One interesting finding from Experiment 3 was the finding that participants, on average, underestimated the duration of each stimulus compared to the actual duration each stimulus was displayed for. As shown by the *T corrected* index participants underestimated each of the 5 stimulus durations except for the shortest, 500ms duration condition. Such effects, known as Vierordt's Law, are commonly reported when using the classical timing tasks (for a review, see Lejeune & Wearden, 2009). Initially this effect was reported by Vierordt (Vierordt, 1868 as cited in Lejeune & Wearden, 2009) with such an effect proving remarkably consistent over the course of his numerous experiments. Quite simply Vierordt's Law states that short time durations are overestimated whilst long durations are underestimated with some point in between being judged accurately, known as the indifference point (Lejeune & Wearden, 2009). Despite the fact that such a law is almost always found to hold true for timing data (however, see Woodrow, 1930; 1933) attempts to explain why such an effect occurs have been rather limited. One explanation of this effect is related to the idea of "memory-mixing" which suggests that memories of time durations are associated with a single memory distribution (Gu & Meck, 2011). Here it is suggested that the storing of temporal durations as a single distribution is sufficient to produce effects consistent with Vierordt's Law. Alternatively, and to simplify somewhat, Wearden (2003, 2004) proposes that in reproduction tasks participants respond at some point before the critical time but their motor response delays the actual stopping of the to-be-timed duration so that in actuality the response occurs close enough to the duration being timed. For example, if a participant is asked to time a 200ms duration and they initiate an action when 60% of this timed duration has elapsed and their motor response takes 300ms to initiate a button press, the total to be timed duration will be 320ms (the duration is overestimated). On the contrary for longer stimulus durations, say 800ms, the duration will be timed as 780ms and so underestimated. Although this model rather elegantly models Vierordt's Law for temporal reproduction tasks by including participant's motor response, it does not explain why such a law holds for verbal estimation tasks when no such motor response is required. As a result it remains unexplained why or how participants overestimated the shortest duration in Experiment 3 but underestimated each other stimulus duration.

A further finding from Experiment 3, which was also found in Experiment 2, was that participants were faster to initiate the *pull* action instruction for every stimulus duration rather than the *push* action instruction. Although this finding in Experiment 2 could perhaps have been accounted for by the exclusive use of angry facial expressions, which prime approach based behaviours, this finding in Experiment 3 is surprising given the use of both angry and fearful facial expressions. Although anger is considered to evoke approach motivated actions, fearful stimuli prime avoidance motivated actions (Cain & LeDoux, 2013; Klein, Becker, & Rinck, 2010, however see Marsh, Ambady, & Kleck, 2005). It is commonly reported that actions are generally facilitated when in congruence with the action motivation evoked by the stimulus (Chen & Bargh, 1999); *pull* actions are generally found to be quicker when a positive or appetite stimulus (angry facial expression) is displayed whereas quicker *push* actions are found when an aversive stimulus is displayed (fearful facial expression). The finding in Experiment 3 that participants were consistently quicker to initiate the *pull* action instruction is therefore unusual given the inclusion of both angry and fearful facial expressions.

One potential explanation for this finding is that the mapping of approach and avoidance motivated actions onto joysticks or computer levers is subjective. For the purposes of Experiment 2 and 3 *pulling* the joystick was considered to be an approach based action as the participant is moving an object closer to their body, on the contrary *pushing* the joystick was considered an avoidance action as the participant was increasing the distance between the joystick and their body.

However, it is possible for these two mappings to be reversed; *pulling* the joystick could be considered as participants withdrawing their hand from the stimulus on the computer and *pushing* the joystick could be thought as moving one’s hand closer to the on-screen stimulus. The subjectivity of such joystick tasks has been previously discussed (van Dantzig et al., 2008). As a result, it is possible that different participants may have considered these two joystick actions differently; indeed counterbalancing the joystick actions would not have resolved the issue given that the two action instructions can be mapped easily onto the opposing joystick movement. A further possible explanation is that, as eluded to in Experiment 2, participants may have simply found the *pull* action easier to initiate given the experimental setup. Although steps were taken to prevent one action from being easier to initiate than the other it is impossible to rule out such an effect. If one wished to further investigate the effects of different action tendencies and time perception it would be beneficial to use different tasks in which approach and avoidance actions are more explicitly defined. The manikin task as used by de Houwer, Crombez, Baeyens, and Hermans (2001) is one such task which could be used. Here, when an approach action is initiated the stimulus grows in size (mimicking the idea of approaching the stimulus) and decreases in size when initiating an avoidance action (mimicking the increase in distance between observer and stimulus).

Finally it is known that different temporal tasks place differing demands both on one’s executive function and on the internal clock mechanism. The rationale for using a different temporal task in Experiment 3 was primarily to investigate the robustness of the finding that temporal overestimation due to threat prepares one for action. In keeping with the results from Experiment 2, main effects of both emotion and action readiness were found in Experiment 3. Such findings add to the growing literature concerning time distortion; specifically adding evidence to new lines of enquiry showing that action readiness in particular can cause temporal overestimations (Hagura et al., 2012). Moreover, and in keeping with functional explanations of temporal overestimation due to threat, participant reaction times were facilitated by the threatening stimuli. As in Experiment 2 this finding again provides evidence that one is able to initiate an action quicker following the overestimation of a stimuli duration. More specifically it appears that temporal overestimation may prepare one to initiate an approach based action. However, once more Experiment 3 fails to find any enhanced temporal overestimation effect as was hypothesised. It is possible that the failure to find such an interaction effect was caused by the experimental manipulations used so far in this thesis. As shown in Experiment 2 manipulations of action readiness are seen to affect the speed of the pacemaker mechanism found in internal clock models of time perception, as do emotive stimuli (Cheng, Tipples, Narayanan, & Meck, 2016; Droit-Volet, Brunot, & Niedenthal, 2004; Droit-Volet & Wearden, 2002; Gil & Droit-Volet, 2012; Penton-Voak, Edwards, Percival, & Wearden, 1996, but see, Lake, LaBar, & Meck, 2016). Consequently the failure to find an enhanced effect may be due to the pacemaker reaching some maximal output; in other words it is possible that the lack of an increased overestimation effect is due to ceiling effects of the pacemaker. One possible solution to this issue is offered by the works of Klapproth & Müller (2008) and Klapproth & Wearden (2011) who used a method to induce temporal overestimation without affecting the pacemaker – accumulator pathway.

Klapproth and Müller (2008) and later Klapproth and Wearden (2011) found that when placed under time pressure participants overestimated the duration of a neutral stimulus more frequently compared to participants who were not placed under time pressure. Crucially, however, such time pressured decision making was found to influence the decision rule participants used when deciding whether a stimulus was displayed for a long or short duration as in a temporal bisection task. This novel way of inducing action readiness which is not found to affect the speed of the pacemaker shall be returned to in Experiment 4.

In summary, Experiment 3 used a verbal estimation task to determine the robustness of the functional explanation of temporal overestimation due to threat. Findings were consistent with Experiment 2 and showed that participants were quicker to initiate an action following the presentation of a threatening facial expression which were also more frequently temporally overestimated relative to neutral facial expressions. This finding further suggests that temporal overestimation due to threat prepares an individual to act which has clear evolutionary, adaptive implications. Furthermore, participants were found to initiate the *pull* action instruction quicker than the *push* action instruction irrespective of the facial expression displayed. Finally, Experiment 3 failed to show an enhanced temporal overestimation effect. The failure to find this effect could be due to methodological limitations and consequently future experiments in this thesis used novel ways of inducing action readiness which do not affect the pacemaker mechanism.

5. Searching for an Enhanced Temporal Overestimation Effect

5.1 Introduction

The findings from Experiments 1, 2, and 3 showed that participants overestimated the duration of emotive, relative to neutral, stimuli. Furthermore, Experiment 2 showed that when one is in a state of action readiness stimuli are also temporally overestimated. Moreover, Experiments 2 and 3 provided evidence for a functional explanation of temporal overestimation due to threat; participants were found to both overestimate emotive stimuli more frequently than neutral stimuli as well as initiate an action instruction quicker following emotive stimuli. However, neither experiment found evidence of an enhanced or super temporal overestimation effect. One possible reason for failing to find an enhanced temporal overestimation effect - that is an increased effect of action readiness when an emotive stimulus is displayed - is that so far each experiment of this thesis attempted to increase the speed of the pacemaker mechanism in internal clock models. Internal clock models such as SET (Gibbon et al., 1984) generally include a pacemaker – accumulator pathway whereby the more pulses sent by the pacemaker that reach the accumulator the more time has been said to have passed. However, more neurologically plausible models of time perception, such as SBF suggest that neuronal firing rates serve this pacemaker function (Buhusi & Meck, 2005; Cheng, Tipples, Narayanan, & Meck, 2016; Matell & Meck, 2004; Matell & Meck, 2000). Consequently such models would predict that the abstract pacemaker mechanism has some upper limit or maximal rate of pulse output. As a result the failure of each experiment reported so far to find an enhanced temporal overestimation effect may be the result of pacemaker ceiling like effects; effects of action readiness speed the pacemaker resulting in temporal overestimations which prevent further pacemaker speeding when emotive stimuli are displayed. In order to determine whether the failure to find an enhanced temporal overestimation effect is due to a ceiling effect Experiment 4 used an experimental manipulation of action readiness which has been hypothesised to affect a different internal clock component.

Initially investigated by Klapproth and Muller (2008) and then later by Klapproth and Wearden (2011) participants were found to overestimate the duration of a neutral stimulus more frequently when instructed to respond as quickly as possible compared to participants who were instructed to respond as accurately as possible. Crucially for the purpose of this thesis, however, such an experimental manipulation was found to affect the decision rule participants used when classifying whether a stimulus' duration was the same or different to a target duration in a temporal generalisation task. Internal clock models of time perception suggest that one's ability to determine stimulus duration relies on three separate stages of information processing; initially in a clock stage pulses of information are sent to an accumulator from a pacemaker, then in a memory stage the internal clock is able to retrieve previously stored temporal durations which are considered task critical. Finally in the decision stage the duration held in the accumulator is compared to the duration in the memory store allowing one to determine whether two durations are the same, per the temporal generalisation task, or whether a duration is closer to a short or long duration as in the temporal bisection task.

Research concerning the effects of time pressure on time perception suggest it is this final decision stage which is affected by inducing time pressure.

When one is tasked with comparing the durations of two stimuli (e.g., in a temporal bisection task) it is clear that participants must use some decision threshold in order to classify the stimulus duration as being closer to the short or long anchor duration. Research which has modelled participant performance on the temporal tasks have generally employed a decision rule as described by Gibbon and Church (1981) or as later modified by Wearden (1991), however, the decision rule used by participants is clearly governed by the temporal task used. In terms of the bisection task the decision rule, as modelled by Kopec and Brody (2010), states that participants follow a two-step rule whereby participants initially determine whether or not the presented stimulus duration was the same as either the short or long anchor durations. If the presented duration was one of the anchor durations then the participant responds accordingly, if the presented duration is thought to match both the short and long anchor duration the participant guesses with an equal probability of responding short or long. Stage two of the decision rule occurs when the presented stimulus is judged to have been a different duration to either of the two anchor durations. Specifically Kopec and Brody state that one would respond short when $|ts - s| * b < |tl - s|$, where ts and tl are the short and long anchor durations respectively, s is the stimulus duration and b a bias factor. The bias factor is assumed to start at 1 and depending on participant’s previous responses will either increase following a large number of short responses or decrease following a large number of long responses.

When performing the temporal generalisation task under time pressure Klapproth and Wearden (2011) found evidence to suggest that the decision rule is altered due to long durations becoming truncated in one's memory store; it follows that if the representation of the long anchor is under-represented in the memory store (i.e., 1600ms is actually stored as being 1450ms) then participant performance will be affected when stimuli are presented for long durations. Evidence for this truncation of the long stimulus duration comes from experiments in which participants respond different (as in the temporal generalisation task) before the stimuli displayed for longer durations have been terminated on screen (Klapproth & Wearden, 2011).

In addition it is apparent that placing participants under time pressure encourages speeded response times relative to participants who are instead instructed to focus on the accuracy of their decisions. In terms of Experiment 4 this heightened time pressure is analogue to being in a state of action readiness; participants who perform a task under time pressure would be expected to be quicker to respond than participants who prioritise accuracy. As a result participants in Experiment 4, as per previous research, were randomly assigned to either a speeded response group or to an accuracy group.

Inducing time pressure in participants has often been considered one part of a wide ranging psychological debate concerning the so called "speed-accuracy trade-off". Often discussed in terms of decision making the trade-off refers to the notion that as the speed of decision making increases the relative accuracy of such decision decreases and vice-versa (Barack & Gold, 2016; Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010; Forstmann et al., 2008; Garrett, 1922; Salthouse, 1979;

Wickelgren, 1977; Woodworth, 1899). Of specific interest to the current thesis is that recent neurological studies investigating the neural underpinnings of such a trade-off have found that the pre-SMA and basal ganglia in particular appear to be increasingly activated when participants are instructed to respond as quickly as possible (Forstmann et al., 2008). As discussed previously, when participants complete timing tasks activity in the pre-SMA and basal ganglia is also found to increase (Ferrandez et al., 2003; Harrington, Haaland, & Hermanowitz, 1998; Tipples, Brattan, & Johnston, 2014; van Rijn et al., 2014). Furthermore, the striatum is heavily implicated in a neurologically plausible internal clock model (Buhusi & Meck, 2005; Matell & Meck, 2004; Matell & Meck, 2000). Taken together, these separate strands of psychological inquiry suggest that timing behaviours and speeded responses activate the same neurological substrates and consequently could be sufficient to induce a relative super overestimation of time.

In short, the use of time pressure was well suited to investigating the possibility of finding combined effects of action readiness and emotion on time estimates. Previous research suggests that time pressure does not act on the speed of the pacemaker but rather alters the decision rule participants use to make their temporal decision. As such, one limitation to the previous experiments reported so far was circumvented in Experiment 4; in each of the previous experiments it was possible that the failure to find an increased temporal overestimation effect was due, in part, to the pacemaker operating at some maximum output rate when one sees an emotive facial expression or prepares to act. Consequently, Experiment 4 was better suited to finding combined effects of both emotion and action preparation given that the experimental manipulations should affect different components of the SET model. Specifically the use of emotive stimuli was expected to speed the rate of the pacemaker and participants in the speed condition should have a greater bias (or rather a lower decision threshold) for responding long.

Experiments 2 and 3 found that whilst participants were quicker to initiate an action following the temporal overestimation of threatening stimuli there was no increased effect of action readiness on time estimates when a threatening facial expression was displayed. Although the findings from Experiments 2 and 3 provided some evidence for a functional explanation of temporal overestimation due to threat, one would predict to find an increased temporal overestimation effect of action readiness if temporal overestimation due to threat prepares one to act. As Experiments 2 and 3 provided consistent evidence for facilitated reaction times following temporal overestimation due to threat, the aim of Experiment 4 was to try and induce this super temporal overestimation effect in participants.

Experiment 4 therefore, unlike Experiments 1, 2 and 3, did not require any overt action from participants and as such could not answer whether temporal overestimation due to threat prepares one to act through reaction time analysis. Rather Experiment 4 focussed on finding evidence for the functional account of time overestimation from the presence or absence of an interaction between effects of action readiness and effects of emotion on time estimates; one would expect greater amounts temporal overestimation when one is both ready to act and sees an emotive stimulus. To date there has yet to be an empirical investigation into the idea that one’s perception of time can be distorted to a greater degree than effects of singular experimental manipulations. Although Experiments 1, 2 and 3 also tested for such an enhanced effect on time estimates, due to the experimental manipulations of each, Experiment 4 was thought better suited to detecting such enhanced effects.

Based on previous research it was hypothesised that participants would overestimate the duration of stimuli more frequently in the speeded response condition as well as when viewing a threatening facial expression. Crucially, however, the combined effects of these manipulations would, according to the functional explanation of time overestimation, lead to greater amounts of temporal overestimation than in each other experimental condition. Finally, in order to test that participants in the speeded decision making condition had higher levels of action readiness, participant decision making was predicted to be quicker compared to participants in an accuracy condition.

5.2 Experiment 4

5.2.1 Method

Participants

Seventy two undergraduate students ranging between 18 and 56 years of age (*M* = 22.5, *SD* = 8.0, 16 males) from the University of Hull took part in the experiment and received partial course credit on completing the experiment. The experiment was approved by the ethics committee from the Department of Psychology at the University of Hull.

Apparatus and Materials

The same facial stimuli displaying either a neutral, angry or fearful expression, as used in Experiment 3 were used. All stimuli measurements were as Experiment 1.

Design and Procedure

Experiment 4 used a 2 x 3 x 7 design with condition (speed, accuracy) a between subjects factor and facial expression (angry, fear neutral) and duration (400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms and 1600ms) as the three within-subjects factors.

Participants completed a modified version of the temporal bisection task. In an initial training phase participants were taught to distinguish between a long (1600ms) and short (400ms) anchor duration. The training phase consisted of a pink oval being presented in a fixed sequence of short, long, short, long etc for a total of eight trials. A further 8 trials in which the pink oval was randomly presented for the short or long duration was then completed by participants.

After the training phase participants were told that on subsequent trials the pink oval would be replaced by a facial expression displaying either and angry, fearful or neutral expression which would either be displayed for a period of time in between the two durations learnt previously (600ms, 800ms, 1000ms, 1200ms and 1400ms) or one of the previously learnt anchor durations (400ms or 1600ms). Participants were instructed to decide whether the facial stimulus was presented for a period of time closer to that of the short or long anchor duration. An example trial sequence is given in Figure 19. As per the instructions of Experiment 2 participants responded by pressing z to indicate short and m to indicate long.

In addition, after the training phase participants received instructions depending on whether they were randomly allocated to the speed or accuracy condition. The instructions for each condition closely matched the instructions given to participants in a previous study which induced time pressure on participants

(Klapproth & Müller, 2008; Klapproth & Wearden, 2011). Crucially participants in the speed condition were instructed to focus on making their decision regarding the stimulus duration as quickly as possible whereas participants in the accuracy condition were instructed to make their decisions as accurately as possible. One important difference between the present Experiment and that of Klapproth and Muller (2008) is that participants had to respond when the facial stimulus disappeared.

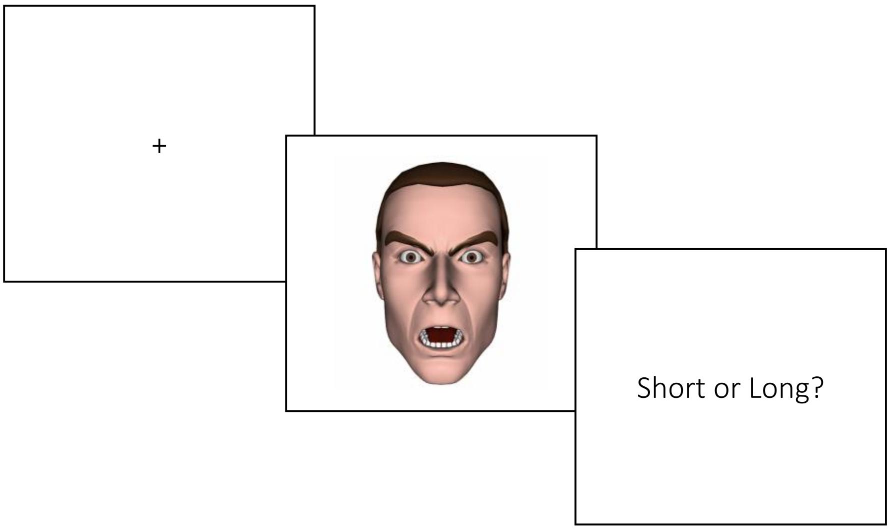


Figure 19. An example trial sequence from Experiment 4. Participants are given instructions relating to the speed or accuracy condition prior to the first trial.

There were 168 trials derived from the factorial combination of the number of stimulus presentations (8) x duration (7) x expression (3). A randomised trial order was generated for each participant. E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) was used to electronically control trial presentation and data collection. Participants were randomly allocated to either the speed or accuracy condition by E-Prime.

5.2.2 Results and Discussion

A total of three participants were excluded from data analysis due to poor timing consistency across the experiment ($R^2 < .7$ in one or more experimental conditions). The remaining sixty nine participants' data were used in the data analysis. Following from previous experiments of this thesis the proportion of long responses, PSEs and WRs were used for statistical analysis. In addition response times were analysed in order to check that the experimental manipulation of a speeded decision task modulated participant's action readiness as evident through faster response times.

Response Times

Unlike the previous experiment reported so far in this thesis participants in Experiment 4 were not tasked with making an overt response (such as pushing or pulling a joystick lever). Rather in Experiment 4 participant response times was the time taken to respond in the 2AFC task and consequently the term response and not reaction time is used. As evident in Figure 20, it is apparent that participants in the speed experimental condition responded quicker during each stimulus duration relative to the participants in the accuracy condition. Moreover, it appeared that participants made their responses quicker following the presentation of an emotionally salient facial expression, particularly for participants in the accuracy condition.

In order to test that participants in the speeded response condition were in a heightened state of action readiness a 2 (condition; [speed, accuracy]) x 3 (emotion; [angry, fearful, neutral]) x 7 (duration; [400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms, 1600ms]) mixed ANOVA was conducted with condition as a between subjects variable. As predicted the ANOVA confirmed that participants in the speed condition responded faster than those in the accuracy condition, *F* (1, 67) = 319.21, p < .001, η_p^2 = .83, (*M* = 347ms and 714ms respectively). In addition the ANOVA revealed main effects of emotion *F* (2, 134) = 15.61, p < .001, η_p^2 = .19, with participants quicker to respond to angry (*M* = 520ms) and fearful (*M* = 524ms) facial expressions compared to neutral (547ms; p < .001 in both cases). The main effect of duration violated the assumption of sphericity. It was, however, still found to be significant, *F* (3.396, 277.505) = 47.65, p < .001, η_p^2 = .42. There were also interactions between duration and condition *F* (6, 402) = 23.00, p < .001, η_p^2 = .26 as well as between emotion and condition *F* (2, 134) = 3.58, p = .031, η_p^2 = .05. The interaction between emotion and duration did not reach significance (p = .111).

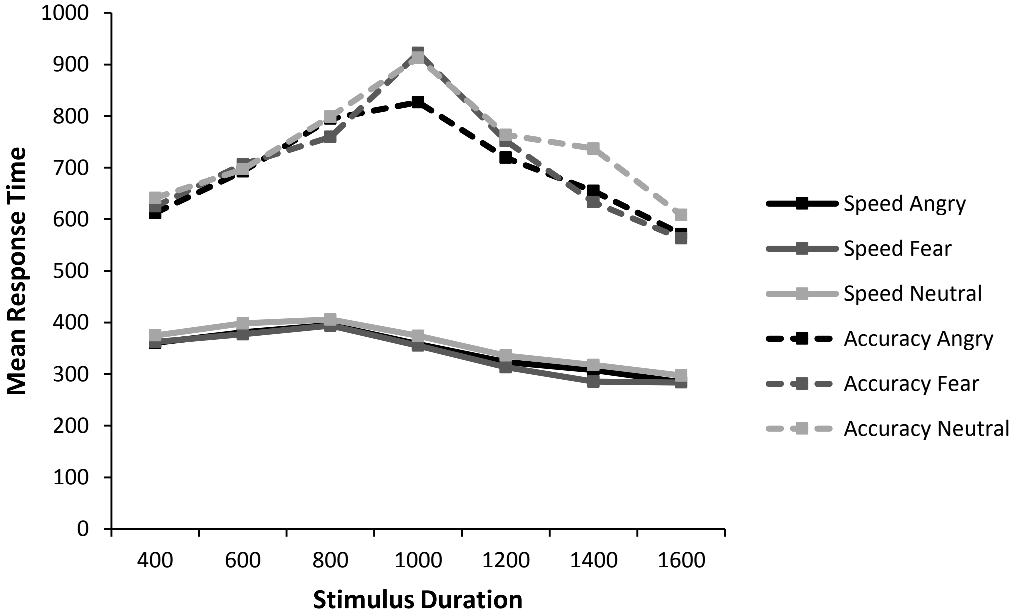


Figure 20. Mean response time for each experimental condition as a funciton of stimulus duration for each experimental condition separately.

In order to determine whether the effects of emotion were driven by response times in either the speed or accuracy condition two, two-way within subject factors ANOVA were carried out for the speed and accuracy conditions separately. This analysis revealed main effects of emotion for both the accuracy, *F* (2, 68) = 9.92, p < .001, η_p^2 = .23, and speed conditions, *F* (2, 66) = 9.14, p < .001, η_p^2 = 22.

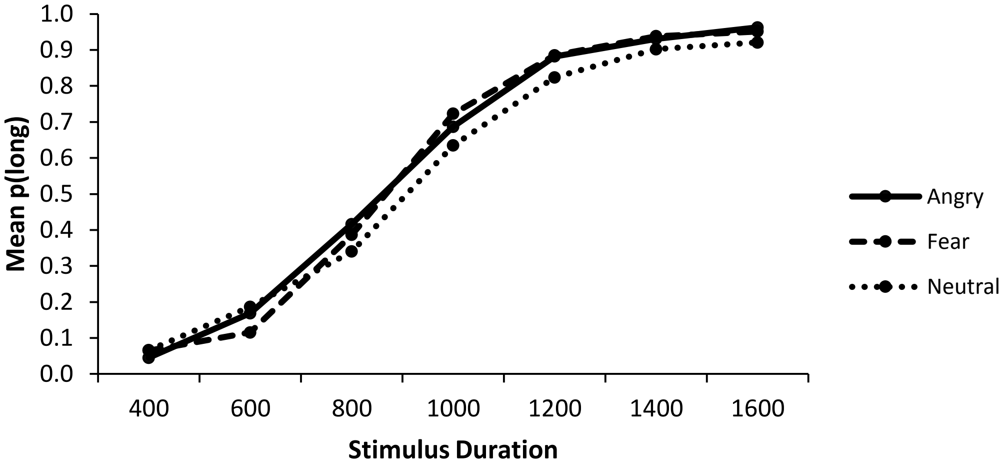
Proportion of long responses

The proportion of long responses was calculated in the same way as in Experiments 1 and 2 and are shown for each experimental condition in Figure 21. The mean *p*(long) were analysed using a 2 (condition; [speed, accuracy]) x 3 (emotion; [angry, fearful, neutral]) x 7 (duration; [400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms, 1600ms]) mixed subject ANOVA with condition as a between subjects variable. The assumption of sphericity was violated for the main effect of duration as well as the interaction between duration and emotion, consequently Greenhouse Gessier corrected values are reported. As shown in Figure 21 the psychometric function was shifted to the left for the angry and fear facial expressions in both experimental conditions, but particularly in the case for the speed condition.

The mixed ANOVA revealed main effects of emotion, *F* (2, 134) = 7.11, p = .001, η_p^2 = .10, duration, *F* (3.444, 230.745) = 1184.18, p < .001, η_p^2 = .95, as well as condition, *F* (1, 67) = 20.54, p < .001, η_p^2 = .24. The main effect of emotion showed that participants made more long responses to the angry (*M* = .55) and fearful (*M* = .54) facial expressions than the neutral facial (*M* = .52) expressions (p = .002 and .028 respectively). The main effect of duration showed significant differences between each level of duration at the p < .001 level. The main effect of condition showed that participants in the speed condition (*M* = .57) made more long responses than participants in the accuracy condition (*M* = .50) as predicted.

There were also significant interactions between duration and condition, F (6, 402) = 9.37, $p < .001$ $\eta_p^2 = .12$, and between duration and emotion, F (8.376, 561.201) = 2.13, $p = .029$, $\eta_p^2 = .03$. The interaction between emotion and condition failed to reach statistical significance ($p = .648$). Following the non-significant interaction between emotion and condition as hypothesised no further analysis was conducted on the mean *p*(long).

a. Speed



b. Accuracy

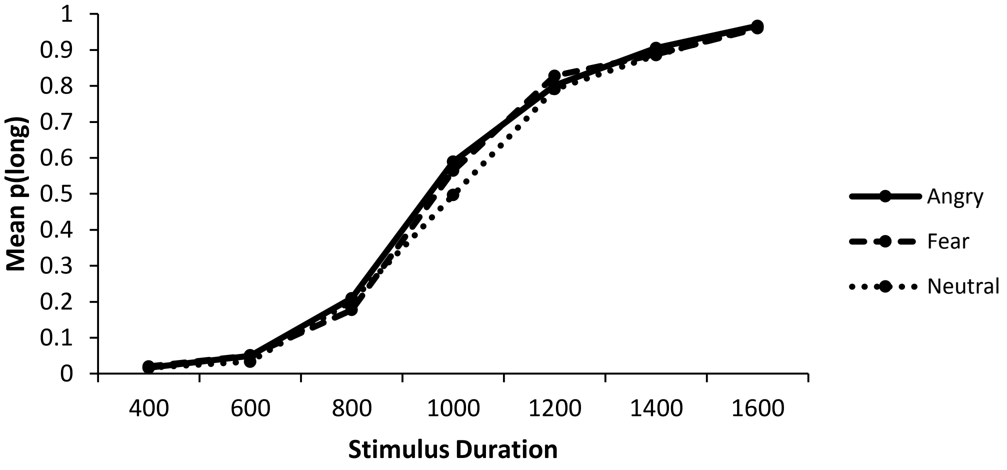


Figure 21. Mean p(long) for each facial condition and experimental condition separately as a function of stimulus duration.

Point of subjective equality

The PSEs were calculated in the same way per Experiments 1 and 2 of this thesis and were analysed using a 2 (condition; [speed, accuracy]) x 3 (emotion; [angry, fearful, neutral]) mixed ANOVA with condition entered as a between subjects variable. As is apparent from visual inspection of Figure 22 the mean PSEs were lower in the speed condition as well as lower for the angry and fear facial expressions in each condition. Reflecting the analysis conducted on the mean *p*(long) the mixed ANOVA revealed a main effect of emotion, *F* (2, 134) = 3.26, p = .041, η_p^2 = .05 as well as a main effect of condition, *F* (1, 67) = 18.88, p < .001, η_p^2 = .22. Post-hoc tests with Bonferroni correction indicated no statistically significant differences between any combination of levels of emotion, however, there was a trend for participants to overestimate angry facial expressions more frequently than neutral expressions (p = .058). The main effect of condition showed participants were more frequently overestimating the duration of stimuli in the speed (*M* = 913) compared to the accuracy (*M* = 1020) condition (p < .001). Similar to the mean *p*(long) analysis the interaction between emotion and condition failed to reach statistical significance (p = .943).

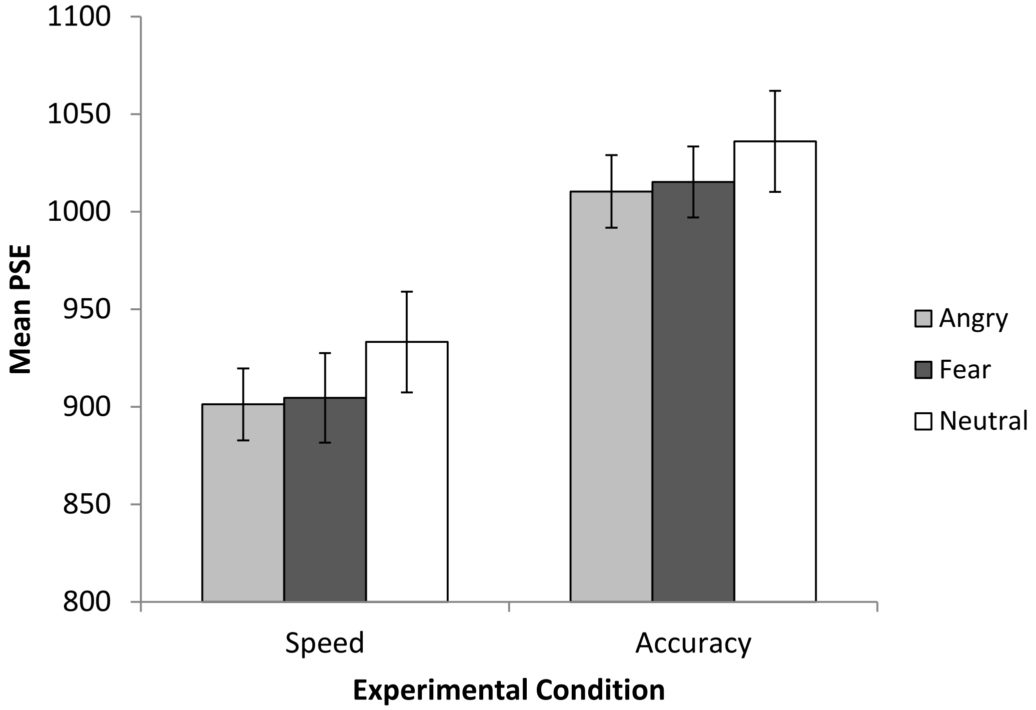


Figure 22. Mean PSE for each facial expression shown as a function of experimental condition.

Weber Ratios

The WRs are shown in Table 5 with higher WR in the speed condition relative to the accuracy condition. The WR analysis followed the same pattern as previous Experiments reported in this thesis; there was no statistically significant effect of emotion or interaction between emotion and condition (p = .193 and .103 respectively). However, there was a main effect of condition, *F* (1, 67) = 30.13, p < .001, η_p^2 = .31 indicating participants showed greater timing sensitivity in the accuracy (*M* = .17) compared to speed (*M* = .23) condition (p < .001).

Table 5. Mean WR for each experimental condition.

	Experimental Condition			
	Speed		Accuracy	
Expression	Mean	SD	Mean	SD
Angry	.22	.06	.17	.03
Fear	.22	.07	.17	.03
Neutral	.25	.10	.17	.03

5.3 General Discussion

Experiment 4 tested the notion that one's perception of time is susceptible to distortion to a greater extent than that which has been previously been found in the literature. Consequently in Experiment 4 participants were asked to judge the duration of emotive and neutral stimuli either as quickly as possible or as accurately as possible in order to investigate the joint effects of action readiness and emotionally salient stimuli on one's perception of time. It was hypothesised that participants would temporally overestimate the duration of stimuli when in a state of action readiness as well as overestimate the duration of emotive stimuli. Crucially, however, it was expected that participants would overestimate the duration of emotive stimuli more frequently when also in a state of action readiness providing evidence for a super temporal overestimation effect. However, despite the findings from Experiment 4 providing more evidence for the first two hypotheses; more frequent temporal overestimations for emotive stimuli as well as when in a state of action readiness, there was no evidence for a super temporal overestimation effect. In addition the results from Experiment 4 also showed that participants were quicker to make the 2AFC decision following the presentation of emotive facial expressions compared to neutral facial expressions. Moreover, this finding was found in both experimental conditions; even when participants were instructed to be as accurate as possible when making their short or long decision, such decisions were made quicker on trials in which the stimulus presented was emotionally salient. Although Experiment 4 did not involve the initiation of any voluntary action per se such a finding does provide support for the functional explanation of temporal overestimation due to threat.

As has been discussed previously it has been demonstrated that temporal overestimation has been shown to be linked to the speeding up of other psychological process, such as reaction time. Jones and colleagues (2011) found that when the internal clock was assumed to have been sped up reaction times were also found to be quickened suggesting that a link between temporal overestimation and facilitated reaction times. Furthermore, in experiments 2, 3, and 4 of Jones *et., al.* it was also found that temporal overestimation was found to increase other psychological processes such as mental arithmetic and memory ability. Interestingly the results from Experiment 4 of this thesis showed a similar pattern; following the presentation of an emotive facial expression participants made the 2AFC decision faster than when a neutral facial expression was displayed. Taken together, the results from Jones *et., al.* and the present experiment show that there are numerous psychological processes which appear to be quickened or facilitated following temporal overestimation. Indeed such evidence would support the claim that the internal clock mechanism is a highly adaptive system which is also to distort one’s perception of time in order to aid survivability (Droit-Volet & Gil, 2009); by facilitating a multitude of psychological processes including reaction time, decision making speed, memory capacity and higher level cognitive functions such as arithmetic, it is evident that the internal clock is potentially life-saving when one is faced with a threat. However, what is currently not known is whether such psychological benefits are due to temporal overestimations per se, or rather are caused by some general increase in cognitive ability which also causes the temporal overestimation. Nevertheless, despite finding further evidence for a functional explanation of temporal overestimation due to threat Experiment 4 once more failed to find any evidence of an enhanced temporal overestimation effect.

The findings from Experiment 4 supported those of Experiment 2 of this thesis; whilst participants were found to overestimate the duration of emotive stimuli as well as the duration of stimuli whilst in a state of action readiness, such temporal distortions were not found to combine and produce a more pronounced overestimation effect. Importantly, the results from Experiment 4 showed that the failure of Experiment 2 to find such an enhanced effect was not caused by only using an experimental manipulation which affects the pacemaker – accumulator pathway. Rather Experiment 4 demonstrated that even when an experimental manipulation known to influence a later component of internal clock models, such as the decision rule in SET, there remains no evidence of a super temporal overestimation effect. In terms of Experiment 4 this super temporal overestimation effect would have been evident through a significant interaction between emotion and experimental condition, specifically one would have expected participants in the speed condition to exhibit more temporal overestimations for emotive stimuli relative to the accuracy condition. Similar to the previous experiments of this thesis such an effect was not found; participants in the speed condition did not show any greater frequency of overestimations for emotive stimuli compared to the participants in the accuracy condition.

However, Experiment 4 provided further evidence that being in a state of action readiness does lead to stimuli being more frequently temporally overestimated relative to not being in a state of action readiness. Despite previous experiments showing such a finding in a number of experimental settings (Hagura et al., 2012) as well as evidence suggesting the temporal overestimation effect of emotive stimuli may well be more closely reconciled with effects of action readiness (Angrilli et al., 1997; Gable & Poole, 2012) Experiment 1 of this thesis failed to support such findings. However, by using an experimental methodology in which no overt action was required to be performed by participants Experiment 4 found clear evidence for such an effect; participants in the speed condition more frequently overestimated the duration of stimuli compared to participants in the accuracy condition. As indexed by quicker participant response times in the speed condition it is clear that such participants were in fact in a heightened state of action readiness compared to those in the accuracy condition and as such Experiment 4, along with Experiments 2 and 3 of this thesis, supports previous work linking action readiness to temporal overestimations. As to the reason why such an effect is not found in Experiment 1 it is possible that participants failed to prepare the action when instructed to although this will discussed in more detail in the general discussion.

Furthermore, Experiment 4 is the first experiment reported in this thesis which found significant differences between WRs. The WR is often considered to be an index of timing sensitivity or rather as a measure of how much a duration must change for participant’s to reliably determine that one duration is different from another (Droit-Volet & Wearden, 2002; Kopec & Brody, 2010). Unsurprisingly the results from Experiment 4 showed that participants in the accuracy condition had significantly smaller WR than those in the speed condition. Simply stated this finding shows that participants in the accuracy condition were more sensitive to changes in stimulus duration than those in the speed condition; specifically participants in the accuracy condition were better able to detect smaller changes in the duration of a stimulus. This result, coupled with the finding that participants in the speed condition displayed quicker response times, highlights the so called speed accuracy trade-off whereby those participants who are relatively more accurate are slower to respond whereas those participants who are relatively quicker to respond are less accurate in their decisions. Interestingly this speed accuracy trade-off has been linked to activity in the striatum as well as pre-SMA areas of the brain (Forstmann et al., 2008). However, the striatum and pre-SMA are also linked to temporal processing; the SBF model in particular suggests that these brain areas are of critical importance to timing behaviours (Buhusi & Meck, 2005). Although speculation and in need of further investigation it is clear that the striatum and pre-SMA play critical roles in both timing behaviours as well as the speed accuracy trade-off. Consequently the failure to find an enhanced temporal overestimation effect may be attributable to neurones firing at an already maximal rate in the striatum/pre-SMA areas due to the speed accuracy trade-off meaning no further neuronal firing was possible when an emotive stimulus was displayed.

Finally, no study to date has investigated the effects of a speeded decision making paradigm on the temporal bisection task with the only empirical experiments using the temporal generalisation task (Klapproth & Müller, 2008; Klapproth & Wearden, 2011). The use of a different temporal task, such as the temporal bisection task here, showed that the experimental manipulation of induced time pressure produces reliable effects of temporal overestimation in different temporal tasks and as such could be used in other temporal paradigms to investigate the effects of the speed accuracy trade-off. As previous research has shown there appears to be differences in the effects and reliability of experimental manipulations on different temporal tasks (Gil & Droit-Volet, 2011b). Consequently, the finding from Experiment 4 that a previously used experimental manipulation in a temporal generalisation paradigm is also found to produce similar effects in a temporal bisection task is an important finding. Despite the temporal bisection and generalisation tasks both being considered as comparison type tasks, the demands on the participant performing each task differ considerably. Therefore, finding that the same experimental manipulation produces reliable effects in both tasks may be of use to future research.

In summary the results of Experiment 4 found that, similar to Experiments 1, 2 and 3 of this thesis, participants were found to overestimate the duration of emotive relative to neutral facial expressions regardless of experimental condition. In addition participants were found to overestimate the duration of stimuli more frequently when placed in a heightened state of action readiness which was induced by time pressure. Moreover, participant response times were facilitated following the presentation of an emotive facial expression. In addition Experiment 4 adds decision making speed to the list of other psychological processes which appear to be facilitated following temporal overestimation; when faced with a threat the internal clock mechanism appears able to distort time in such a way whereby an individual is capable of making decisions more quickly. However, as in Experiments 1, 2, and 3 of this thesis there was no evidence of an enhanced temporal overestimation effect in Experiment 4 despite using an experimental manipulation which did not influence the pacemaker-accumulator pathway of an internal clock mechanism. As such, from the experiments reported so far it is suggested that there is some upper limit to the degree to which one's perception of time can be distorted and interestingly that no enhanced temporal overestimation effect is found when separate components of SET are manipulated. Experiment 5 further investigated the effects of action readiness on time estimates further by using a variable foreperiod paradigm in which the duration between a warning and to-be-timed stimulus is varied.

6. Enhanced Temporal Overestimation Effect – Foreperiod Methodology

6.1 Introduction

The results from Experiments 1, 2, 3, and 4 failed to provide conclusive support for the notion that temporal speeding due to threat prepares an individual to act. Some findings, however, were consistent with this idea. Interestingly, the experiments reported so far in this thesis also failed to find any evidence that one's perception of time can be distorted to a greater extent than when just one experimental manipulation is used (i.e., the effects of the experimental manipulations used so far are not additive). It is possible that the failure to find an enhanced temporal speeding effect was due to effects of emotion on time perception being caused by the effect emotive stimuli have on the action readiness levels of participants. For instance, emotionally salient stimuli are often reported to speed up one's perception of time due to the increases in arousal levels when one sees an emotive relative to neutral stimulus (Droit-Volet et al., 2004; Droit-Volet & Wearden, 2002). However, it is possible that such an overestimation effect is not caused by increased arousal levels but rather because emotional stimuli prepare one to act it (Gable & Poole, 2012). Consequently if the emotion overestimation effect is due to increases in action readiness and not arousal levels it would be expected that the experimental manipulations used so far in this thesis would not evoke any greater levels of temporal distortion. If all of the experimental manipulations used so far increase action readiness levels it is likely that participants will reach a point whereby they cannot be more ready to act.

Whilst there is considerable evidence that emotionally salient stimuli are overestimated relative to neutral stimuli and that such overestimations are caused by increases in arousal (Droit-Volet et al., 2011; Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011a, 2012; Smith et al., 2011) some empirical findings have challenged this idea. For instance, Angrilli (1997) found different effects for high and low arousing stimuli according to the valence of the stimulus; for low arousal stimuli negative valance stimuli were judged as shorter than positive stimuli whereas for high arousal stimuli the duration of negative valance stimuli were judged as being longer than positive stimuli. Moreover, it has been shown that positive approach motivation and not arousal caused temporal distortions in the work conducted by Gable and Poole (2012). In addition, there are reports of highly arousing facial stimuli which do not result in temporal distortions (e.g., disgust) which was interpreted as evidence to suggest a link between temporal overestimations and action readiness (Gil & Droit-Volet, 2011a; Laflamme et al., 2012). Despite these examples, experiments in which participant arousal levels were measured using GSR and pupil dilation show that such measures of physiological arousal are altered by the emotionally stimuli used in time perception research (Lake, 2014; Mella et al., 2011). Nevertheless, some empirical research casts doubt on the view that arousal is the single cause of the temporal overestimation effect for emotional versus neutral stimuli. Rather it is possible that effects of emotionally salient stimuli on time are due to the increased level of action readiness such stimuli express. One way of investigating this further is to use a variable foreperiod task in which a warning stimulus is presented before a to-be-timed stimulus is displayed. Crucially the duration between the warning stimulus and to-be-timed stimulus varies so that at longer foreperiod durations the participant pays more attention to the stimulus (i.e., the participant comes to expect the to-be-timed stimulus to be presented with greater certainty as the foreperiod increases in duration). Consequently, the rationale for Experiment 5 was to investigate the effects of both action readiness and emotionally salient stimuli by ensuring participants were at high levels of action readiness.

While a number of psychological experiments have used varying foreperiod experiments, such as work conducted into simple reaction time (e.g., Niemi & Näätänen, 1981), its use is limited in time perception research. Experiments which have, however, investigated the effects of a varying foreperiod found consistent results; as the foreperiod duration increases (i.e., when the duration between the warning and to-be-timed stimulus was long) participants were found to overestimate the duration of the to-be-timed stimulus more frequently than when the foreperiod duration is shorter (Grondin & Rammsayer, 2003; Los & Horoufchin, 2011; Mo & George, 1977). Grondin and Rammsayer (2003) investigated this effect extensively and interpreted such findings in terms of attention; when the foreperiod duration is long it is argued that participants focus their attention on time and consequently overestimate the duration of the to-be-timed stimulus, although the authors note not all findings supported this attention interpretation. In terms of the functioning of an internal clock mechanism this would manifest in the earlier closing or later opening of a switch mechanism. Crucially, however, experiments to date which have manipulated the foreperiod duration have used neutral not emotionally salient stimuli. As such it is unknown how varying the foreperiod duration affects the perception of emotional stimuli in terms of their duration.

In addition, given the link between longer foreperiod durations and the focussing of attention it was possible that such experimental manipulations would cause a super temporal overestimation effect. According to internal clock models when one pays attention to time a switch closes (with some latency) allowing information sent by the pacemaker to reach the accumulator. Crucially, the amount of attention one pays to time is argued to affect the latency at which this switch mechanism closes (or opens at the end of a trial). Consequently, at longer foreperiod durations the switch should close sooner (or re-open later) allowing more information to reach the accumulator. Combined with the effects of a speeded pacemaker this may result in an enhanced temporal overestimation effect which has yet to be found.

In Experiment 5 I aimed to induce an enhanced temporal overestimation effect by manipulating both the participant attention and emotion. Whilst many reports of temporal overestimation for emotionally salient stimuli report that such effects are due to increases in arousal there are reports where participants overestimated the duration of emotionally salient stimuli but such effects cannot be attributed solely to arousal level increases. As such it remains unclear exactly why participants are found to overestimate the duration of emotional stimuli. If temporal overestimations are due to increases in action readiness the failure of previous experiments in this thesis would be expected. By using a variable foreperiod paradigm in Experiment 5 it was possible to determine whether effects of action readiness do drive the temporal overestimation effect that is commonly reported for emotive stimuli. Specifically, the effects of emotion were expected interact with the foreperiod duration resulting in an enhanced temporal overestimation effect.

Consequently, the hypothesis for Experiment 5 was that there would be an enhanced temporal overestimation effect when the foreperiod duration was long and an emotive stimulus was displayed.

6.2 Experiment 5

6.2.2 Method

Participants

37 undergraduate students from the University of Hull took part in the experiment and received partial course credit on completion of the experiment. The age range of participants was between 18 and 46 (*M* = 22.5, *SD* = 7.6; 9 males). The experiment was approved by the Psychology Department Ethics Committee at the University of Hull.

Apparatus and Materials

The facial stimuli as used in Experiments 1 and 2 were used. All stimuli measurements were as Experiment 1.

Design and Procedure

Experiment 5 used a 2 x 3 x 7 design with facial expression (angry, neutral) foreperiod duration (50ms, 400ms, 1400ms) and duration (400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms and 1600ms) as three within-subjects factors.

Participants completed a temporal bisection task. In the initial training phase participants were taught to distinguish between long (1600ms) and short (400ms) anchor durations. The training phase consisted of a pink oval being presented in a fixed sequence of short, long, short, long etc. for a total of eight trials. A further 8 trials in which the pink oval was randomly presented for the short or long duration was then completed by participants.

After the training phase participants were told that on subsequent trials the pink oval would be replaced by a facial stimulus displaying either an angry or neutral expression for a period of time in between the two durations learnt previously (700ms, 1000ms, 1300ms) or one of the previously learnt anchor durations (400ms or 1600ms). Participants were instructed to decide whether the photograph was presented for a period of time closer to that of the short or long anchor duration. Participants were informed that prior to seeing the facial stimulus a warning signal (white flash) would appear briefly but this was to be ignored. The warning signal was displayed either 50ms, 400ms or 1400ms before the facial stimulus with the inter-stimulus-interval (ISI) duration (duration between warning and facial stimulus) varying on a trial by trial basis. An example trial sequence is given in Figure 23.

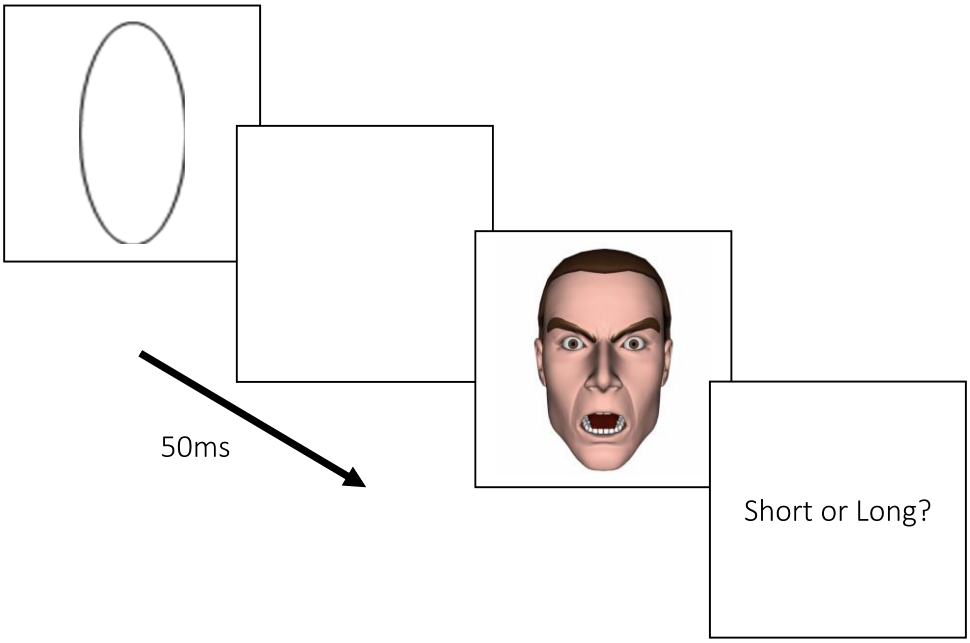


Figure 23. An example trial sequence from Experiment 4. Initially a flashing oval shape acted as a warning signal before a delay of either 50ms, 400 or 1400ms was presented before the facial expression.

The experiment was comprised of 3 blocks of 112 trials with the experiment lasting no longer than 1 hour to complete. After each block of trials the participant was allowed to take a short break (participant paced) before continuing with the experiment.

There were 336 trials derived from the factorial combination of the number of stimulus presentations (8) x duration (7) x expression (2) x foreperiod duration (3). A randomised trial order was generated for each participant. E-Prime 2.0 (Psychology Software Tools, Sharpsburg, PA) was used to electronically control trial presentation and data collection.

6.2.3 Results and Discussion

One participant was excluded from data analysis due to poor timing consistency across the experiment ($R^2 < .7$). As per previous experiments the data analysis is made up of the mean *p*(long), PSEs and WRs for the remaining 36 participants.

Proportion of long responses

The proportion of long responses was calculated in the same way as for Experiments 1, 2 and 4. Figure 24 shows the mean *p*(long) for each experimental condition. The mean *p*(long) were analysed using a 3 (foreperiod duration; [50ms, 400ms, 1400ms]) x 2 (facial expressions; [angry, neutral]) x 7 (duration; [400ms, 600ms, 800ms, 1000ms, 1200ms, 1400ms, 1600ms]) within subject ANOVA.

The within subjects ANOVA revealed main effects of foreperiod duration (Greenhouse-Geisser corrected), F (1.642, 57.454) = 42.16, $p < .001$, $\eta_p^2 = .55$ as well as main effects of duration (Greenhouse-Geisser corrected), F (2.427, 84.954) = 425.58, $p < .001$, $\eta_p^2 = .92$. Surprisingly the main effect of emotion failed to reach statistical significance ($p = .505$). The main effect of foreperiod duration showed that as the duration of the foreperiod increased (as participants became more ready for the facial expression to appear) the more frequently participants responded long (50ms; $M = .48$, 400ms; $M = .51$, 1400ms; $M = .57$). In keeping with the results from previous Experiments of this thesis the main effect of duration was such that with increasing stimulus durations participants responded long more frequently. As showed by *post-hoc* analysis with Bonferroni correction each stimulus duration was statistically different from each other duration at the $p < .001$ level.

There was a significant interaction between foreperiod duration and stimulus duration, $F(7.055, 246.931) = 3.86$, $p = .001$, $\eta_p^2 = .10$. No other interactions were significant (highest $F = 1.66$, lowest $p = .11$).

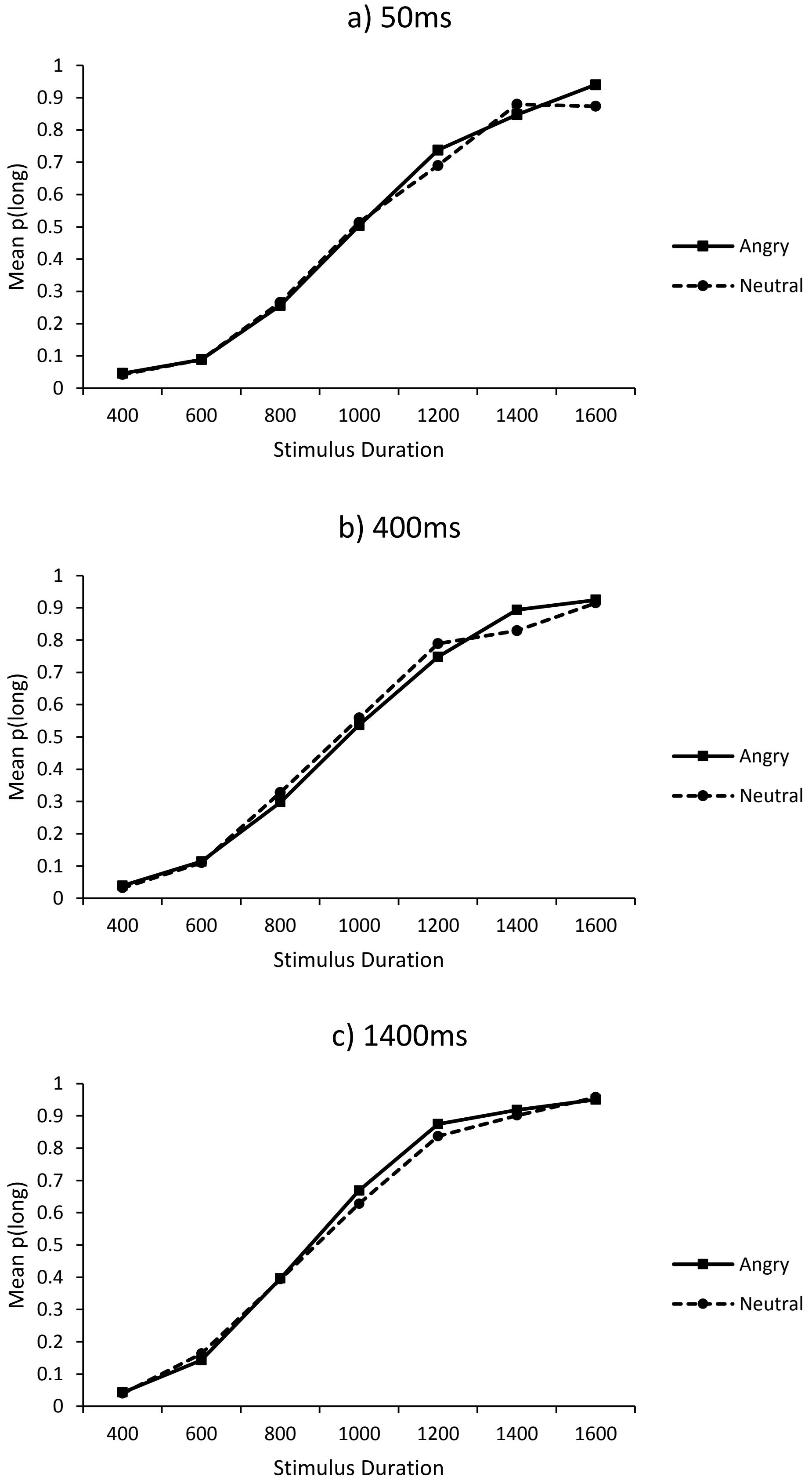


Figure 24. The mean p*(long) for each ISI duration shown separately as a function of stimulus duration*

Point of subjective equality

The PSEs, shown in Figure 25, were calculated in the same way per Experiments 1, 2, and 4 and were analysed using a 3 (foreperiod duration; [50ms, 400ms, 1400ms]) x 2 (facial expressions; [angry, neutral]) within subject ANOVA. The ANOVA revealed only main effects of foreperiod duration (Greenhouse-Geisser corrected), *F* (1.558, 54.547) = 23.86, p < .001, $\eta_p^2 = .41$. The main effect of emotion again failed to reach statistical significance (p = .181) as did the interaction between emotion and foreperiod duration (p = .789). *Post-hoc* tests with Bonferroni correction showed that when the foreperiod duration was 1400ms participants began responding long sooner (*M* = 924) than compared to both the 400ms (*M* = 1006) and 50ms (*M* = 1050) conditions (p = .015 for least significant difference). As per the mean *p*(long) analysis this shows that when participants attention was focussed on the upcoming stimulus they began responding long sooner than attention was not focussed.

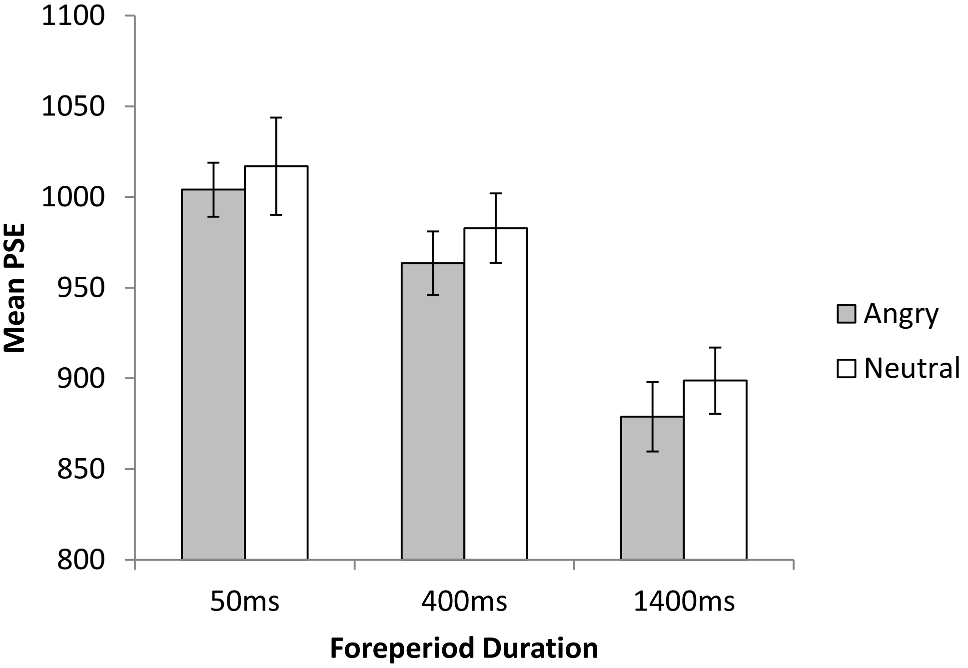


Figure 25. The PSEs for each experimental condition shown as a function of stimulus type for each stimulus duration.

Weber Ratios

The WR analysis followed the same pattern as previous experiments reported in this thesis; there was no statistically significant effect of foreperiod duration, expression or an interaction between foreperiod duration and expression (p = .585, .248 and .569 respectively). The WRs are shown in Table 5.

Table 5. Table showing the mean WRs for each condition separately.

	Foreperiod Duration					
	50ms		400ms		1400ms	
Expression	Mean	SD	Mean	SD	Mean	SD
Angry	.25	.09	.27	.15	.29	.19
Neutral	.25	.07	.27	.10	.28	.13

6.3 General Discussion

In Experiment 5 I aimed to investigate the effects a variable foreperiod paradigm has on the effect of emotive stimuli on time estimates. For previous experiments in this thesis it was possible that the effects of emotion (and consequently the failure to find an enhanced temporal overestimation effect) could be explained in terms of increases in action readiness as opposed to increases in physiological arousal. Consequently, a variable foreperiod paradigm was used in order to manipulate attention in an attempt to find evidence of an enhanced temporal overestimation effect. Specifically, at longer foreperiod durations (when attention was focused) and when an emotional stimulus was displayed (when action readiness levels were high) the internal clock mechanism was expected to create a super temporal overestimation effect. However, the results from Experiment 5 did not support this hypothesis. Participants were not found to overestimate the duration of emotive stimuli, however, participants did overestimate the duration of stimuli as the duration of the foreperiod increased. As a result of the failure to find an effect of emotional stimuli in the variable foreperiod paradigm there was no evidence of an enhanced temporal overestimation effect.

Given the robustness of the emotion temporal overestimation effect the failure to replicate the effect in Experiment 5 is surprising. The effect of emotionally salient stimuli is well documented in the literature and is reliably found across numerous methodologies when using numerous different types of stimuli (Droit-Volet et al., 2011; Gil & Droit-Volet, 2012; Gil et al., 2009; Grommet et al., 2011; Noulhiane et al., 2007; Tipples, 2008, 2011). Given the paradigm used in Experiment 5 there are a number of possible explanations as to why participants were not found to overestimate emotional stimuli more frequently than neutral stimuli. Importantly, it is unclear exactly how the variable foreperiod paradigm affects time estimates. For instance, as suggested by Grondin and Rammsayer (2003) it is possible that the temporal overestimation effect seen at longer foreperiod durations is due to the focussing of attention on the upcoming stimulus. It follows that as participants begin to pay more attention to the stimulus the more likely one is to overestimate the duration of the stimulus (according to internal clock models of time perception). However, there are other possible ways in which a longer foreperiod duration could cause temporal overestimations; first it is possible that rather than attention it is the effect of expectancy which drives the temporal overestimation effect. Second, it is possible that the temporal overestimation effect is caused by increases in participant action readiness. As participants must respond by pressing a button (in the temporal bisection task as used here) it follows that as the foreperiod duration increased so did participant readiness to initiate a button press. Consequently, the explanation for the null effect of emotion on time estimates is dependent on how it is assumed that foreperiod duration increases the likelihood of the participant overestimating the duration.

If the effect of foreperiod duration is due to attention as has been previously argued (Grondin & Rammsayer, 2003) it is possible that the accumulator mechanism at the longer foreperiod durations had already reached its maximum level of information before the emotional stimulus was displayed. As attention is argued to reduce the latency with which the switch mechanism closes at the beginning of a trial (or the latency with which the switch re-opens at the end of a trial) the accumulator may have reached its maximum level of information due to the faster closure of the switch. Consequently, when the emotive stimulus was displayed no more information could enter the accumulator mechanism. Although this may explain why there was no greater overestimation effect at the longer foreperiod durations, it does not explain why no effect of emotion was found at the 50ms foreperiod duration.

Alternatively it could be that the warning stimulus primed participants to respond and thus increased their levels of action readiness. In this explanation the warning stimulus would increase the speed of the pacemaker meaning that when the emotional stimulus was presented the pacemaker was unable to increase its output further leading to the null effects of emotion. This scenario would also explain the finding that as foreperiod duration increased so did the tendency for participants to respond long; given the increased rate of the pacemaker this would affect longer durations more than shorter durations.

A further possibility as to why the emotional stimulus was not overestimated in Experiment 5 relative to the neutral stimulus is due to the effects of stimulus repetition. The emotional stimulus used in Experiment 5 was the same angry facial expression which has been used in each Experiment of this thesis as well as by other researchers (e.g., Tipples, 2007, 2011). In psychological literature it is well understood that presenting the same image across numerous repetitions diminishes the participant's response to that stimulus (e.g., Thompson & Spencer, 1966). In paradigms which measure the brain's electrical activity using electroencephalography (EEG) it is well known, for example, that participant's brain activity is reduced when one sees many repetitions of the same image (Gruber & Müller, 2002) . A similar effect has also been reported in the time perception literature; specifically Matthews (2011) found that repeated stimuli are more likely to be temporally underestimated than novel stimuli. Whilst the findings of Matthews (2011) are seen only when the stimulus is immediately repeated (indeed the effects of repetition are seen to disappear when some lag is present between the stimulus and its repetition) it is possible that similar effects were present in Experiment 5. Given the sample that has been used throughout this thesis and that the emotional stimulus had been used prior to the experiments in this thesis it was possible that the angry facial expression was not as emotionally salient to the participants as it had been in previous experiments of this thesis. As a result, in Experiment 6 different stimuli were used in order to control for this potential experimental confound.

Finally a further possible explanation for the absence of an effect of emotion in Experiment 5 was that the neutral stimulus was also temporally overestimated to a similar degree to that of the emotional stimulus. Although few studies have investigated the issue of expectancy in relation to emotional and neutral stimuli there have been reports of temporal overestimation of non-emotional stimuli in a related experimental paradigm. For instance research conducted by Droit-Volet and colleagues (2010) found that the expectancy of an aversive sound caused more frequent temporal overestimation than the expectancy of a neutral sound. Interestingly, however, the expectancy of a neutral sound was found to cause more frequent temporal overestimation compared to no sound. In terms of Experiment 5 therefore, it was possible that the expectancy of the facial expression, irrespective of its emotional salience, was enough to result in a temporal overestimation effect. Consequently, it was possible that participants did overestimate the duration of the emotional facial expression, however, participants also overestimated the duration of the neutral facial expression leading to null effect of emotion. One crucial difference between Experiment 5 and that of Droit-Volet and colleagues (2010), however, is that in the research conducted by Droit-Volet participants did not judge the duration of the aversive or non-aversive sound, but rather the duration of a preceding stimulus. Again, however, such an explanation based on expectancy levels only explains why the emotive stimulus was not overestimated at the longer foreperiod durations leaving it unexplained why the emotive facial expression was not overestimated at the shortest, 50ms foreperiod duration.

In keeping with the other experiments of this thesis, Experiment 5 also found no evidence to suggest that the internal clock mechanism is capable of producing an enhanced or super temporal overestimation effect. In Experiment 5 one would have predicted that the switch mechanism would have closed earlier at longer foreperiod durations due to the focussing of attention as argued by Grondin and Rammsayer

(2003). In addition when an emotive stimulus was displayed this would speed the pacemaker mechanism and in combination with the earlier switch closure an enhanced temporal overestimation effect was expected. However, due to the null effect of emotion at each foreperiod duration this was not found; participants did not more frequently overestimate the duration of emotive stimuli at longer foreperiod durations compared to shorter foreperiod durations. As with the previous experiments of this thesis this could be explained by the neurological mechanisms of time perception. As discussed previously, neurological plausible internal clock models, such as the SBF (Buhusi & Meck, 2005; Matell & Meck, 2000; Matell & Meck, 2004), suggest that the perception of time is, at some level, coded by the detection of neurones firing in the brain. If true then there will be a limit to the number of neurones which are involved in such time keeping processes and moreover, it is possible that when one experimental manipulation (such as emotive stimuli) is used the maximum number of neurones coding for time perception are recruited. Consequently, when a further experimental manipulation is used (such as increased attention or action readiness) there are no more available neurones to fire, leading to no enhanced temporal overestimation effect as has been found in each experiment of this thesis.

In summary, Experiment 5 used a foreperiod paradigm to further investigate how action readiness affects the perception of time for emotional events. Surprisingly, Experiment 5 failed to find any effects of emotion on the perception of time despite a wealth of empirical research showing strong effects of emotion on time perception tasks. It was possible that the failure to find such effects were due, in part, to using the same emotional stimuli across each experiment. In addition, the emotive stimulus in Experiment 5 was presented after the first experimental manipulation meaning the internal clock may have been operating at its maximal rate before the emotive stimulus was displayed. Finally, as per the other experiments of this thesis, there was no evidence to suggest that the internal clock mechanism is capable of distorting the perception of time to an enhanced degree than that which has already been demonstrated in the literature. Due to the failure of finding an effect of emotion on time perception in Experiment 5, Experiment 6 uses images of birds and spiders in an EEG paradigm in order to investigate the electrical activity of the brain when timing the duration of an emotional stimulus.

7. Does Temporal Overestimation Cause Facilitated Cognitive Processing?

7.1 Introduction

One continued theme throughout this thesis was the idea that temporal overestimation due to threat prepares one to act. This functional explanation of temporal overestimation has been supported by the results of Experiments 2, 3, and 4 as well as by other empirical investigations (Angrilli et al., 1997; Droit-Volet & Gil, 2009; Gable & Poole, 2012; Jones et al., 2011). However, it has yet to be demonstrated that it is the temporal overestimation specifically which leads to these seemingly advantageous outcomes. For instance it has been found, both in this thesis and elsewhere (e.g., Jones et al., 2011), that temporal overestimation is linked to reaction time facilitation. However, it is possible that such facilitation is due to some general cognitive speeding effect when one sees an emotional stimulus as per this thesis. Furthermore, in terms of the work of Jones and colleagues (2011) it is possible that the facilitated reaction times were, as noted by the authors, due to click trains speeding up one's general information processing speed or efficiency, potentially through the process of neural entrainment or brain oscillator synchronisation (for a review see, Burle, Macar, & Bonnet, 2003). Therefore, it is yet to be conclusively shown that temporal overestimation specifically causes cognitive enhancement (e.g., reaction time facilitation). Disentangling between these two alternative possibilities (temporal overestimation causes cognitive speeding vs. increased general information processing speed causes cognitive function to increase including time overestimation) is tricky. Moreover, the two alternative possibilities need not be mutually exclusive; it could be that both temporal overestimation directly as well as increases in information processing speed result in higher level cognitive processes being facilitated. One potential way of investigating this issue is through the use of EEG.

The use of EEG, as well as other neurological techniques, is becoming ever more popular within the field of time perception. Many experiments investigating the neural substrates of the ability to perceive time have attempted to find areas of the brain which may serve the function of an internal clock. Perhaps the most fully developed model of a neurologically realistic internal clock model is that of the SBF model which suggests that the brain is able to perceive the passage of time through coincident neural activity in oscillatory cortical neurones (Buhusi & Meck, 2005; Matell & Meck, 2000; Matell & Meck, 2004). Further evidence for internal clock models has come from brain mapping studies using techniques such as fMRI reporting that specific areas of the brain may act in a way akin to a temporal accumulator. Specifically there is evidence to suggest that the basal ganglia as well as the SMA could serve a temporal accumulation like function (Bueti & Macaluso, 2011; Ferrandez et al., 2003; Macar, Vidal, & Casini, 1999).

One event related potential (ERP) that has been linked to the perception of time is that of the contingent negative variation (CNV). Across a series of papers it was reported that the CNV could be seen as an online index of time perception (i.e., the CNV could act as temporal accumulator). Evidence for this suggestion comes from the finding that in a temporal production task the amplitude of the CNV decreased when participants produced lower durations than a 2500ms target duration (Macar et al., 1999). Furthermore, the amplitude of the CNV is found to peak at the duration of the target stimulus in a temporal generalisation task rather than at the duration of the probe stimulus (Macar & Vidal, 2003) again providing evidence for a temporal accumulation type function. Evidence for the CNV functioning as an accumulator has also come from other research groups (see, Pfeuty, Ragot, & Pouthas, 2003a, 2003b, 2005; Pouthas, 2003; Pouthas et al., 2005; Praamstra, Kourtis, Kwok, & Oostenveld, 2006). Such empirical investigations have supported the notion that the climbing neural activity in the CNV is reflecting a temporal accumulation process (Macar & Vidal, 2009). However, the evidence for a temporal accumulator being indexed through climbing neural activity in an ERP such as the CNV has recently been questioned.

Although it is almost beyond doubt that the CNV is at least indirectly linked to temporal processing (for a discussion see, van Rijn, Kononowicz, Meck, Ng, & Penney, 2011), the suggestion that the CNV serves an accumulator function through climbing neural activity is equivocal. First, it has been demonstrated that participants continue to show timing behaviours after the duration of some standard duration has elapsed (Kononowicz & van Rijn, 2014). Such a finding appears at odds with the suggestion that the CNV functions as an online accumulator; one would expect an accumulator to keep accumulating temporal information as participant's continued to time the duration of a stimulus. Furthermore, in a recent EEG experiment it was found that other ERP components better predicted timing behaviours than the CNV; specifically it was reported that, in a temporal comparison task, the amplitude of the N1P2 complex better predicted participant behaviour on the timing task than did the CNV (Kononowicz & van Rijn, 2014; see also, Ng, Tobin, & Penney, 2011). Taken together these findings cast doubt on the view that climbing neural activity as indexed by the CNV reflects the functioning of a temporal accumulator.

As described by Sur and Sinha (2009) the N1 is a negative going waveform which is often found to have maximal amplitude over frontal electrode sites such as Cz, whereas the P2 component is a positive going waveform which occurs shortly after the N1 component. The N1P2 complex is defined as the "absolute summed amplitude of the N1 and P2 peaks" (Kononowicz & van Rijn, 2014, p. 2932). Whilst Kononowicz & van Rijn (2014) found evidence that the N1P2 complex better predicted participant timing behaviour on a temporal generalisation task they acknowledge that the N1P2 complex is unlikely to index the timing process itself. Rather it is claimed by the authors that the mechanism which generates the N1P2 complex is controlled by temporal processes. Nevertheless, the finding that recent experimental studies have found other ERPs than the CNV are better predictors of participant temporal behaviour warrants further investigation.

To date there is limited evidence for ERP components, such as the N1P2, better indexing a temporal accumulation process than the CNV. One potential way of investigating the link between the N1P2 component and temporal accumulation is through the use of emotionally salient stimuli. To date very few EEG experiments have investigated the N1P2 and the possible link to time perception. In addition those that have largely used auditory stimuli (Kononowicz & van Rijn, 2014; Vatakis, Schuessler, Obermeier, Schröger, & Kotz, 2014). However, the use of emotional stimuli seems well suited to such investigations given the often repeated finding that emotional stimuli cause temporal overestimations (Angrilli et al., 1997; Cheng et al., 2016; Droit-Volet et al., 2004; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2012;

Tipples, 2011). For instance if the N1P2 peak amplitude is linked to temporal processing and facilitation of other psychological processes one would expect the summed amplitude of the N1P2 to be greater when one sees an emotional stimulus compared to a neutral stimulus. Such a finding would provide evidence that temporal overestimation itself can lead to the facilitation of cognitive processes such as reaction time; it follows that if a difference in the N1P2 amplitude is found for emotional compared to neutral stimuli then it is possible that temporal overestimation itself leads to this facilitation.

Alternatively it is possible that temporal overestimation does not directly cause the facilitation of cognitive processes. Rather temporal overestimation and other cognitive processes may be facilitated by a general increase in information processing speed when one sees an emotive stimulus. If this were the case one would expect the amplitude of the N1P2 complex to remain the same across emotional and neutral trials. In this case one would expect the latency (or rise time) of the N1 component to be shorter following the emotional trials compared to neutral trials. Such an effect would suggest that information processing speed is quickened during such trials and consequently it is this general increase in information processing speed for emotional stimuli which causes the facilitation of cognitive processes as well as temporal overestimation. A third possibility is that temporal overestimation is not coded at the neuronal level. For instance if the emotional trials do not influence the N1P2 complex it may suggest that the temporal overestimation effect is not generated at the neuronal level but is instead added after the event has occurred (see, Herbst, Chaumon, Penney, & Busch, 2014).

Experiments 1, 2, 3, 4, and 5 of this thesis have presented the same facial stimuli to participants, however, it was demonstrated that multiple presentations of the same stimuli often lead to weakened responses across time. EEG has also been used to show this effect (e.g., Morel, Ponz, Mercier, Vuilleumier, & George, 2009), however, more strikingly the effect has also been shown in the time perception literature (Matthews, 2011). In terms of this thesis each experiment has presented the same emotional facial stimuli and consequently, due to the limited sample also used in this thesis, it was possible that participants were familiar with the facial stimuli. As a result Experiment 6 used phobic stimuli as these have been shown to cause temporal overestimations more frequently than neutral or non-phobia inducing stimuli. For instance, as originally investigated by Watts and Sharrock (1984) and later by Buetti and Lleras (2012) and Tipples (2015) it has been shown that participants who are spider phobic temporally overestimate the duration of spider stimuli more frequently than neutral stimuli (such as birds as in Tipples, 2015). Interestingly, however, non-phobic participants do not show this tendency to overestimate the duration of spider stimuli. Therefore, in terms of Experiment 6 only spider phobic participants were expected to overestimate the duration of spider images and so crucially amplitude of the N1P2 complex was hypothesised to be modulated only for spider phobic participants when a spider image is presented.

The primary aim of Experiment 6 was to investigate the effects of emotionally salient images on participants temporal processing as indexed by ERPs. Moreover, the use of EEG allows one to potentially distinguish between temporal overestimates driving the speeding of other psychological processes (e.g., reaction time) or that such temporal overestimations are the result of some enhanced cognitive processing speed which also results in other psychological processes being facilitated. One would expect, in the case of the former, that temporal overestimation for emotional stimuli would result in larger ERP amplitudes, however, the time course should be constant for both emotional and neutral trials (i.e., the ERPs should not differ in their onset times across the different trial types). In contrast, if temporal overestimation is due to a faster processing speed one would anticipate ERPs on trials which show temporal overestimations to begin and terminate earlier owing to this quicker cognitive processing speed.

In short there were two hypotheses for Experiment 6; first, spider phobic participants were expected to overestimate the duration of spider images more frequently than images of birds whilst non-phobic participants were not expected to show temporal overestimations. Second, it was expected that the amplitude of the N1P2 complex would be modulated when spider phobic participants viewed spider images.

7.2 Experiment 6

7.2.2 Method

Participants

Twenty seven undergraduate students ranging between 18 and 40 years of age (*M* = 23.1, *SD* = 6.7, 4 males) from the University of Hull took part in the Experiment and received partial course credit on completing the experiment. The Experiment was approved by the ethics committee at the Department of Psychology, University of Hull. Prior to taking part in the experiment participants were asked to respond to whether or not they were fearful of spiders. This lead to the creation of a phobic group and a non-phobic group of participants. There were 13 non-phobic participants (*M* age = 19.3, *SD* = 6.1, 3 males) and 14 phobic participants (*M* age = 24.1, *SD* = 7.4, 1 male). In order to ensure that participants were correctly categorised as being spider phobic each participant completed the Spider Phobia Questionnaire (SPQ; Klorman, Weerts, Hastings, Melamed, & Lang, 1974) following the completion of the experiment. As expected the mean SPQ score was higher for the self-identified phobic participants (*M* = 21.86, *SD* = 3.9) than the self-identified non-phobic participants (*M* = 6, *SD* = 3.6), *t* (25) = 10.56, p < .001.

Apparatus and Materials

The stimuli used in Experiment 6 were images of birds and spiders as used by Tipples (2015). As described by Tipples (2015) the 63 images of spiders were taken from a recent image database (Dan-Glauser & Scherer, 2011) whilst the 63 bird images were collected from the internet having been found to be a similar size, luminance and colour to the spider images. Example images are shown in Figure 26. When presented on the computer screen the images measured 150mm wide and 115mm in height. The stimuli measured 13° of the vertical visual angle when participants sat 50cm from the screen. E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) was used to control stimuli presentation and data collection.

Figure 26. Example stimuli used in Experiment 6; left panel showing example of bird image, right panel example of spider image.

Design and Procedure

Experiment 6 used a 2 x 2 x 5 design with SPQ group (phobic, non-phobic) as a between subjects factor and stimulus type (bird, spider) and duration (400ms, 700ms, 1000ms, 1300ms, and 1600ms) as the two within-subjects factors.

Participants completed a temporal bisection task. In the initial training phase participants were taught to distinguish between a long (1600ms) and short (400ms) anchor duration. The training phase consisted of a pink oval being presented in a fixed sequence of short, long, short, long etc for a total of eight trials. A further 8 trials in which the pink oval was randomly presented for the short or long duration was then completed by participants.

After the training phase participants were told that on subsequent trials the pink oval would be replaced by either a photograph of a bird or spider which would either be displayed for a period of time in between the two durations learnt previously (700ms, 1000ms, 1300ms) or one of the previously learnt anchor durations (400ms or 1600ms). Participants were instructed to decide whether the photograph was presented for a period of time closer to that of the short or long anchor duration. The response buttons of z and m were counterbalanced across participants.

Similar to the methodology used in Tipples (2015) on each trial a spider or bird photograph was selected at random (without replacement) and assigned to one of the 54 repetitions. The experiment was comprised of 6 blocks of 90 trials with the experiment lasting no longer than 1 hour to complete. After each block of trials the participant was allowed to take a short break (participant paced) before continuing with the experiment. Following the completion of the temporal bisection task each participant completed the SPQ (Klorman et al., 1974) in order to create high and low fearful participant groups.

There were 540 trials derived from the factorial combination of the number of stimulus presentations (54) x duration (5) x expression (2). A randomised trial order was generated for each participant. E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) was used to electronically control trial presentation and data collection.

EEG Data Acquisition and Analysis Method

Electrical activity was measured from 64 scalp locations (actiCAP, Ag/AgCl electrodes: Fp1, Fp2, AF7, AF3, AF4, AF8, F7, F5, F3, F1, Fz F2, F4, F6, F8, FT9, FT7, FC5, FC3, FC1, FC2, FC4, FC6, FT8, FT10, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP9, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, TP10, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, POz, PO4, PO8, PO9, O1, Oz, O2 and PO10. In addition a ground electrode was positioned at location AFz and a reference electrode was positioned at location FCz. In order to detect vertical and horizontal eye movements bipolar eye electrodes were placed above and below the participant's left eye and one electrode was positioned to the side of each eye. For all electrode channels the impedance was kept below 20kΩ. Electrode channels were amplified and filtered with a high pass filter of 0.1 Hz and a low pass filter of 100Hz and were recorded using a sampling rate of 1000Hz.

EEG data analysis was conducted using Brainvision Analyzer (Brain Products). The EEG trace was referenced offline to the average activity of all electrodes, a 50 Hz notch filter was applied, data were filtered using a 0.1Hz – 30Hz bandpass filter and the sampling rate changed to 256Hz. The Gratton and Coles (Gratton, Coles, &

Donchin, 1983) ocular correction regression algorithm was used to correct for eye artefacts once trials containing excessive artefacts had been excluded by visual inspection. Trials were baseline corrected to the 200ms preceding stimulus onset.

Creation of the N1P2 summed amplitude was conducted using the same method as described by Kononowicz and van Rijn (2014). The N1 was detected as the lowest amplitude value between 70ms and 160ms after stimulus offset whilst the P2 was the highest value between 140ms and 300ms after stimulus onset. The summation of the N1 and P2 peaks created the N1P2 complex.

7.2.3 Results and Discussion

All participants displayed consistent timing across the experiment leading to no participant exclusions from the data analysis (average $R^2 > .89$ for each participant). The data analysis is made up of both behavioural (mean p(long), PSEs and WRs) as well as EEG analyses.

Proportion of long responses

The proportion of long responses was calculated in the same way as in Experiments 1, 2, 4 and 5. Figure 27 shows the mean *p*(long) for each experimental condition. Mean p(long) were analysed using a 2 (SPQ group; [non-phobic, phobic]) x 2 (stimulus; [spider, bird]) x 5 (duration; [400ms, 700ms, 1000ms, 1300ms, 1600ms]) mixed subject ANOVA with SPQ group entered as a between subjects variable.

The mixed ANOVA revealed main effects of stimulus, *F* (1, 25) = 4.87, p = .037, $\eta_p^2 = .16$, duration, *F* (4, 100) = 465.85, p < .001, $\eta_p^2 = .95$, SPQ group, *F* (1, 25) = 4.93, p = .036, $\eta_p^2 = .17$, as well as a two-way interaction between stimulus and SPQ group, *F* (1, 25) = 6.88, p = .015, $\eta_p^2 = .22$. Interestingly, the main effect of SPQ group showed that participants in the non-phobic group were more likely to respond long than participants in the phobic group (*M* = .56 and .50 respectively). In order to break down the two-way interaction simple main effect analyses for the effect of SPQ group was conducted for spider and bird stimuli separately. This analysis revealed a simple main effect of stimulus for only the spider phobic SQP group, *F* (1, 13) = 6.73, p = .022, η_p^2 = .34 but not the non-phobic SPQ group, *F* (1, 12) = .62, p = .445, η_p^2 = .05. As is shown in Figure 27 participants in the phobic SPQ group were more likely to overestimate the duration of spider images (*M* = .542) than bird images (*M* = .453). No other interactions were significant.

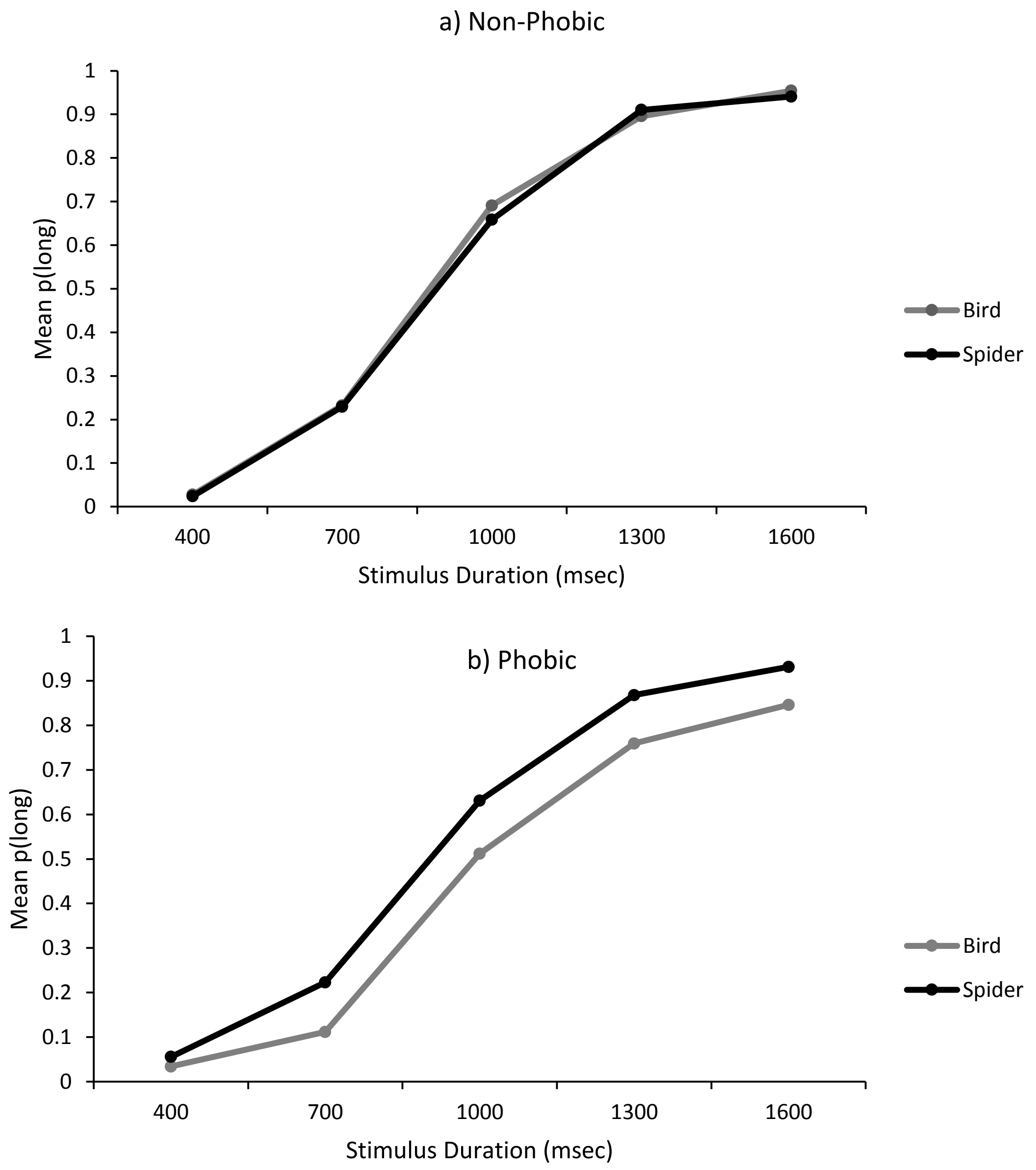


Figure 27. Proportion of mean p(long) for each stimulus type as a function of sitmulus duration shown for both a) non-phobic and b) phobic participants

Point of subjective equality

The PSEs, shown in Figure 28, were calculated in the same way as in Experiments 1, 2, 4 and 5 of this thesis and were analysed using a 2 (SPQ group; [non-phobic, phobic]) x 2 (stimulus; [spider, bird]) mixed ANOVA with SPQ group entered as a between subjects variable. Reflecting the analysis conducted on the mean *p*(long) the mixed ANOVA revealed an interaction between SPQ group and stimulus, *F* (1, 25) = 5.63, p = .026, η_p^2 = .18, a main effect of SPQ group, *F* (1, 25) =

4.32, p = .048, η_p^2 = .15 as well as a marginal effect of stimulus, *F* (1, 25) = 4.18, p = .052, η_p^2 = .14. Similar to the analysis on the mean *p*(long) the effect of SPQ group showed that non-phobic participants (*M* = 952ms) began responding long sooner than phobic participants (*M* = 1040ms).

Simple main effect analysis was again used to break down the two-way interaction between SPQ group and stimulus; specifically, the effect of stimulus for each SPQ group was analysed. The effect of stimulus was only significant for the phobic SPQ group, *F* (1, 13) = 5.65, p = .033, η_p^2 = .30, showing that phobic participants began responding long sooner when spider images were shown (*M* = 964) compared to bird images (*M* = 1116) but not non-phobic participants (p = .553).

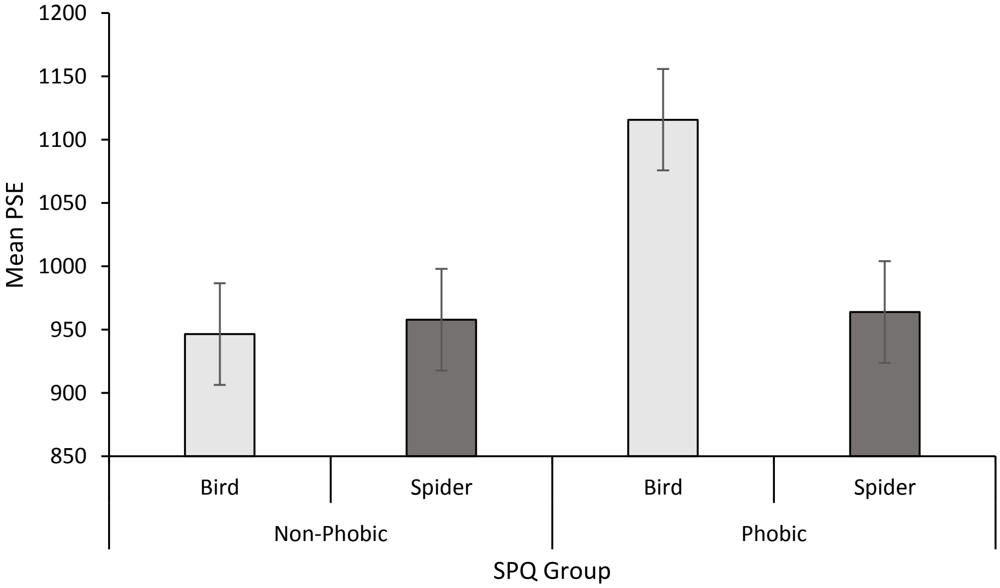


Figure 28. The PSEs for each experimental condition shown as a function of stimulus type for each SPQ group.

Weber Ratios

The WR analysis followed the same pattern as previous Experiments reported in this thesis; there was no statistically significant effect of stimulus, SPQ group or interaction between stimulus and SPQ group (p = .247, .200 and .190 respectively). The WRs are shown in Table 6 below.

Figure 5. Table showing the mean WRs for each condition separately

	SPQ Group			
	Non-Phobic		Phobic	
Stimulus	Mean	SD	Mean	SD
Bird	.31	.13	.27	.08
Spider	.37	.26	.27	.06

EEG Data Analysis

Due to technical issues three participant's data were not recorded during the experiment. The remaining 24 participants data (12 non-phobic and 12 phobic) were entered into the EEG analysis. First the EEG trace was segmented according to stimulus onset. Previous studies (e.g., Kononowicz & van Rijn, 2014) have used the electrode position FCz as the basis for the N1P2 component analysis, however, this was not possible in Experiment 6 due to this position being the reference electrode. Instead electrode position Cz was used as this electrode site has also been found to show a clear N1 component previously.

The grand average ERP for non-phobic and phobic participant is shown in Figure 29. As expected there is a clear N1P2 component, however, visual inspection suggests that the stimulus does not modulate the peak amplitude for either non-phobic or phobic participants. In order to analyse the summed peak of the N1P2 component statistically a 2 (SPQ Group [non-phobic; phobic]) x 2 (stimulus [bird; spider]) x 4 (duration [700ms; 1000ms; 1300ms and 1600ms]) mixed ANOVA was conducted with SPQ Group entered as a between subjects variable. Given the large number of participants (*N* = 14) who did not respond long to any stimulus at the 400ms duration it was excluded from the analysis.

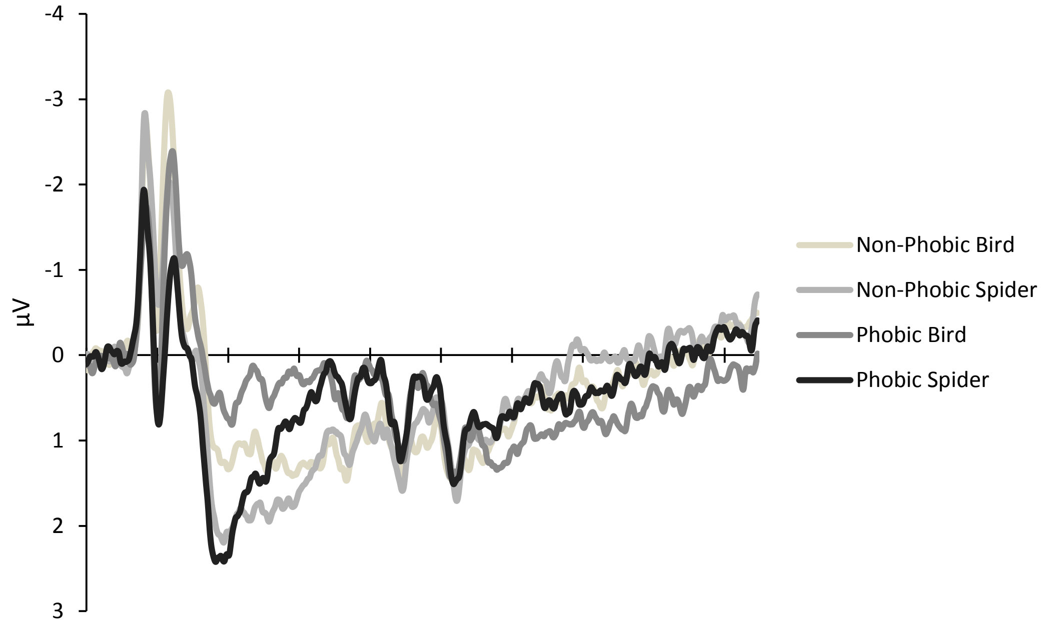


Figure 29. Grand average ERP waveform as a function of participant group and stimulus.

The average summed peak amplitude of the N1P2 complex for each experimental condition is shown in Figure 30. The analysis on the summed peak amplitude of the N1P2 component showed that there was no main effect of either stimulus type, *F* (1, 22) = 1.09, p = .31, η_p^2 = .05, SPQ group, *F* (1, 22) = .90, p = .35, η_p^2 = .04. As such the N1P2 amplitude for spiders (*M* = 5.32, *SD* = 2.60) was not significantly different to the N1P2 amplitude for birds (*M* = 5.31, *SD* = 2.63). Furthermore, there was no difference in the N1P2 amplitude for phobic (*M* = 4.91, *SD* = 3.01) compared to non-phobic participants (*M* = 5.73, *SD* = 2.20). Interestingly there was a main effect of duration (Greenhouse-Gessier corrected), *F* (1.877, 41.290) = 3.46, p = .04, η_p^2 = .14. Post hoc tests with Bonferroni corrections showed that there was a significant difference between the N1P2 amplitude between the 1000ms (*M* = 3.02, *SD* = 6.67) and 1300ms (*M* = 4.13, *SD* = 4.34) condition (p = .03) only. There was a significant interaction between stimulus type and duration, F (3, 66) = 21.91, p < .001, η_p^2 = .50, as this was not of interest no further analysis was conducted. No other interactions were found to be significant (largest *F* value = 2.01, smallest p = .23).

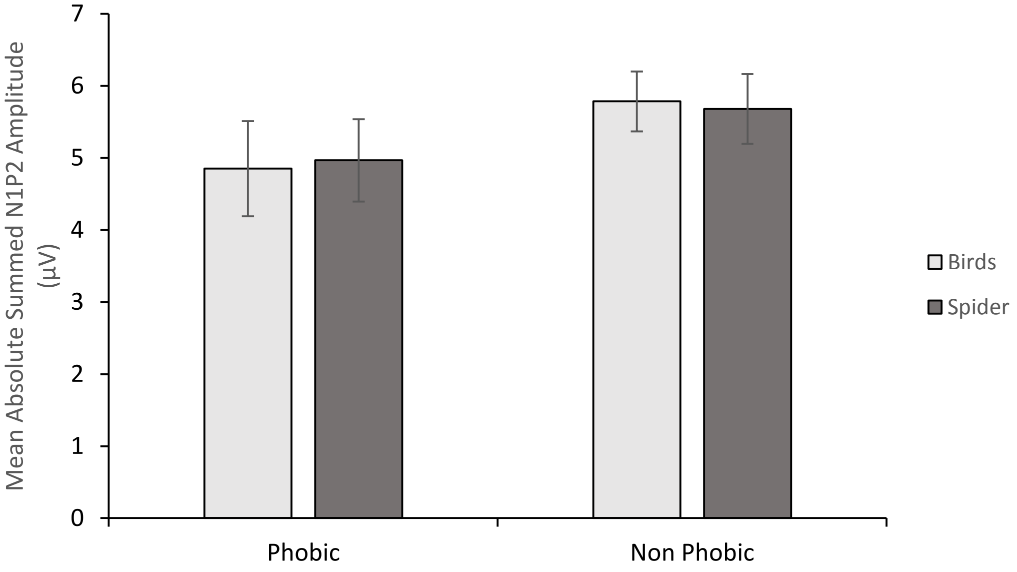


Figure 30. Mean absolute summed N1P2 amplitude as a function of SPQ group.

In addition to the analysis on the summed N1P2 amplitudes a mixed ANOVA was conducted on the latency of the N1 component. The mean latency for the N1 component across all experimental conditions can be seen in Figure 31. The analysis found statistically significant effects of stimulus type, *F* (1, 24) = 4.66, p = .042, η_p^2 = .18 but not SPQ group, *F* (1, 22) = .35, p = .85, η_p^2 = .00 or duration (Greenhouse-Gessier corrected), *F* (1.369, 30.109) = 2.85, p = .091, η_p^2 = .12. No interactions were significant at the p = .05 level. The main effect of stimulus type shows that the N1 component reached its peak sooner when a spider was presented (*M* = 125ms, *SD* = 17.87) compared to when a bird was presented (*M* = 130ms, *SD* = 18.74).

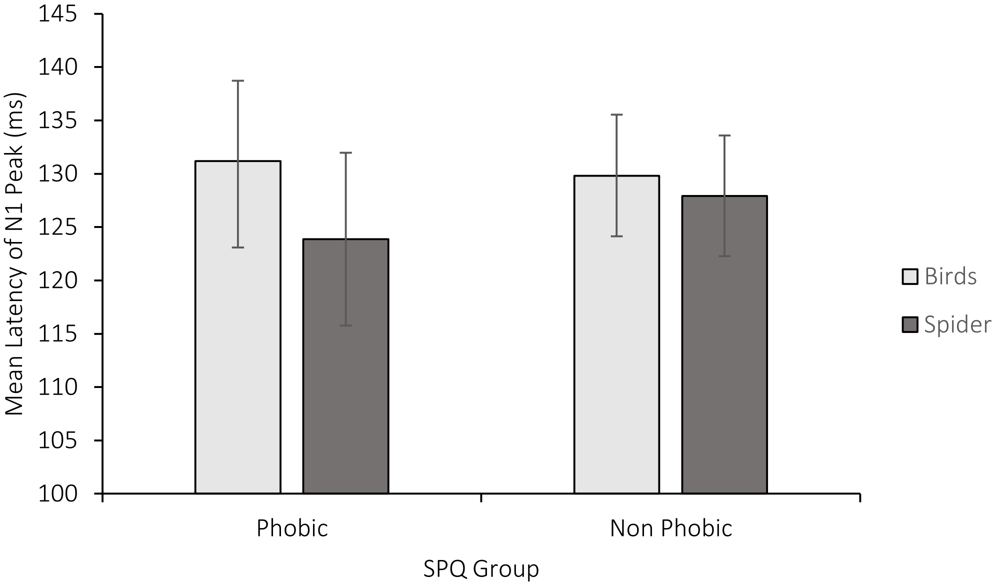


Figure 31. The mean N1 peak latency for each stimulus type as a function of SPQ group. Error bars show standard error.

7.3 General Discussion

The aim of Experiment 6 was to further investigate recent evidence suggesting that the amplitude of the N1P2 complex is linked to temporal overestimation. Recently it was reported that the amplitude of the N1P2 complex better predicted temporal behaviour than climbing neural activity as indexed by the

CNV (Kononowicz & van Rijn, 2014). As such Experiment 6 used EEG in order to measure the amplitude of the N1P2 peak whilst performing a temporal bisection task. It was hypothesised that spider phobic participants would overestimate the duration of spider photographs more frequently than photographs of birds, whilst non-phobic participants would not overestimate the duration of spider photographs relative to bird photographs. Moreover, it was hypothesised that this temporal overestimation by phobic participants would be evident through a greater N1P2 complex amplitude for spider photographs compared to bird photographs. Crucially this difference would only be found in spider phobic participants. The results from Experiment 6 partially support these hypotheses; spider phobic participants did temporally overestimate the duration of spider photographs relative to bird photographs and as expected this pattern was not found in non-phobic participants. However, the results showed that the amplitude of N1P2 complex peak was not modulated by the spider images for spider phobic participants. The lack of modulation of the N1P2 peak amplitude is surprising given the recent evidence supporting the N1P2 as a correlate of temporal processing. Interestingly, however, it was found that the N1 reached its maximal peak amplitude earlier following the presentation of the spider photograph relative to the bird photograph although this was not found to interact with SPQ group as one may have expected.

Whilst the neurology of time perception remains relatively poorly understood he N1P2 complex has recently been linked to temporal processing behaviours (Kononowicz & van Rijn, 2014). Despite such research, Experiment 6 did not replicate this finding; the N1P2 peak amplitude was not modulated by stimulus type. This null effect is surprising given that phobic individuals behaviourally overestimated the duration of spider images as shown by the PSE and mean *p*(long) analysis. Although the results from Experiment 6 did not provide support for the modulation of the N1P2 complex amplitude such modulations have been found elsewhere (Kononowicz & van Rijn, 2014; Vatakis et al., 2014). Whilst this may be surprising there have been reported instances whereby experimental manipulations which cause temporal overestimation have not been reflected in ERPs. In one experimental study Herbst et al., (2014) report that whilst flickering stimuli lead to temporal distortions, such distortions were not found when ERPs were analysed. With such studies in mind it is possible that temporal overestimation is not reflected in ERP waveforms; for instance, it is possible that temporal distortions are not introduced at the neuronal level but are rather caused by higher level cognitive processes. Although speculation it is possible that neurons do not code for time distortions per se but that the perception of time dragging or speeding up is added after an event has occured.

One behavioural piece of research which may support this notion is that of Stetson, Fiesta, & Eagleman (2007). In this experiment the authors measured the speed of participant's visual perception using a handheld device whilst participants experienced a 31m freefall. Interestingly it was found that during the freefall itself participants did not experience time slowing (i.e., they did not improve in the speed of their visual processing) but retrospectively participants temporally overestimated the duration of their freefall. Such a finding suggests that during times of emotional salience participants do not feel that time has slowed but rather when such times are recalled temporal distortions are added to the event. Although it may be argued that flicker fusion detection and time perception rely on different psychological processes other research also supports this notion (see, Herbst, et al., 2014). This may explain why in Experiment 6 the amplitude of the N1P2 complex was not found to be modulated by the spider images; when a phobic individual viewed the spider image they did not perceive time as being distorted (consequently there was not ERP modulated). However, when asked to judge the duration of the spider image they recalled the image as having lasted longer. Whilst this may explain the null effect of emotion on the N1P2 amplitude in Experiment 6 such an explanation needs further investigation which is beyond the current thesis.

Interestingly the results from Experiment 6 showed that the latency of the N1 peak was shorter following the presentation of a spider photograph compared to that of a bird photograph. This provides some evidence for the claim that when one sees a threatening or emotional stimulus the information processing speed of the brain quickens. The idea that emotional stimuli are processed preferentially by the brain is not new and there exist a number of models suggesting the brain processes emotional and non-emotional stimuli in separate systems. One such model suggests that fearful stimuli activate a fear module which is selectivity activated when one sees a threatening or phobic stimulus as in Experiment 6 (Ohman & Mineka, 2001). It is argued that the fear module initiates defensive behaviours such as the fight-flight response along with increase in heart rate and other psychophysical responses. In addition, the fear module is also argued to have a distinct neural circuitry, often linked to subcortical brain regions such as the limbic system, which becomes activated when a phobic stimulus has been seen. In addition to being difficult to interrupt or interfere with the fear module is crucially said to be activated automatically and not through voluntary control. Consequently, due to this automatic activation of the fear module it is proposed that life-threatening stimuli are given priority by the attention systems allowing for more efficient attention capture which has been demonstrated (Öhman, Flykt, et al., 2001; Ohman et al., 2001).

In addition it has been demonstrated that N1 peak latency increases as the processing demands on the participant also increases (Callaway & Halliday, 1982) (i.e., when complex visual stimuli are presented the N1 peak latency is greater compared to simple visual stimuli). This may suggest that the spider photographs shown in Experiment 6 were easier for the attention system to process than the bird photographs as would be predicted by the activation of a fear module as described by Ohman and Mineka (2001). Moreover, the results from Experiment 6 showed that stimulus type did not interact with SPQ group in that the N1 peak latency was found to be earlier for spider photographs across all participants. This would suggest that non-phobic participants, who were not found to temporally overestimate the duration of spider photographs, also processed the spider stimuli preferentially compared to images of birds. Whilst these findings may provide evidence for threatening stimuli as being treated preferentially by the brain it is possible that these results be explained by properties of the stimuli. Whilst the N1 peak latency is affected by attentional demand it has also been shown to be affected by stimuli characteristics such as brightness and stimulus intensity (Peña, Holguín, Corral, & Cadaveira, 1999). Consequently, it is possible that the shorter N1 peak latency found in Experiment 6 is due to differences in stimuli characteristics between the spider and bird photographs rather than the activation of an evolved fear module.

Results from Experiment 6 showed that the duration of spider photographs were overestimated more frequently than neutral (bird) stimuli but only when the participant had a phobia of spiders. This finding has been found previously (Buetti & Lleras, 2012; Tipples, 2015; Watts & Sharrock, 1984) and as such Experiment 6 adds to the literature showing that phobic stimuli are temporally overestimated only by participants who have that specific phobia. Whilst it has been suggested that such effects are due to the modulation of a pacemaker type mechanism more recently it has been shown, using drift diffusion modelling, that phobic participants accumulate temporal information more rapidly when shown the phobic stimulus (Tipples, 2015). Specifically the starting point for information accumulation in spider phobic participants is found to be higher for spider stimuli compared to bird stimuli. This would suggest that there exists some bias in their information processing before seeing the spider stimulus itself. It is also reported that spider phobic participants had a faster drift rate (faster information accumulation) when presented with a spider photograph and this faster accumulation speed could well be the result from increases in arousal levels.

In summary, in Experiment 6 EEG was used to investigate whether the N1P2 complex was modulated by emotionally salient stimuli. Spider phobic and non-phobic participants performed a temporal bisection task in which images of spiders and birds were presented. The results from Experiment 6 did not find any evidence that the peak amplitude of the N1P2 complex was modulated when participants overestimated the duration of phobic stimuli as was hypothesised. However, the results did show that the latency of the N1 peak was shorter for spider photographs relative to bird photographs. It is possible that this shorter peak latency is due to the operation of a fear module which suggests that the information processing speed of the brain is quickened when one sees an emotional stimulus. Furthermore, this finding from Experiment 6 may suggest that the facilitation of psychological processes arises from this increase in information processing speed rather than time overestimations specifically. However, given the prevalence of studies which do find modulations of the N1P2 peak such conclusions need to be treated with caution as the need for further experimentation is clear.

8. General Discussion

The six experiments contained in this thesis tested the notion that temporal overestimation due to threat functionally prepares one to act. Specifically, the experiments here examined whether participants were quicker to initiate a voluntary action following the temporal overestimation of a threatening facial expression. In addition, this thesis examined whether one's perception of time can be distorted to a more dramatic level than has been previously shown in the literature. This was tested using multiple experimental manipulations, known to separately cause temporal overestimation, in a single experimental paradigm. The results of each experiment are summarised as follows.

8.1 Summary of Chapters

8.1.1 Chapter 2

Chapter 2 used an experimental paradigm similar to that used previously by Hagura *et.,al.* (2012) to test for a functional explanation for temporal overestimation due to threat. Participants were instructed to judge whether the duration of a face showing an angry expression was closer to a short or long reference duration. In addition participants were instructed to initiate a voluntary action (touching the computer monitor) on some trials. The results from Experiment 1 failed to provide evidence of a functional explanation for temporal overestimation due to threat. The results showed that participants temporally overestimated the duration of angry facial expressions more frequently than neutral facial expressions, replicating a number of previous experiments (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011, 2012; Tipples, 2008, 2011). However, participants were not found to overestimate the duration of stimuli more frequently when in a state of action readiness despite this effect being found by Hagura and colleagues (2012). Moreover, participants were not found to initiate a voluntary action quicker following the presentation of an angry facial expression as one would have expected if temporal overestimation due to threat functionally prepares one for action.

The finding from Experiment 1 that participants did not temporally overestimate the duration of stimuli more frequently when in a state of action readiness was explained by participants failure to prepare the action as instructed. Evidence for this comes from the similarities between Experiment 1 and that of Hagura *et al.,* (2012). As demonstrated by Hagura and colleagues, the experimental paradigm where participants reach to touch the computer screen is sensitive enough to find effects of action readiness on time estimates. As this effect was not found in Experiment 1 one possibility is that participants did not complete the task as instructed. The null results from Chapter 2 demonstrated the need for further experimentation.

8.1.2 Chapter 3

Chapter 3 used a computerised joystick task and the temporal bisection task to investigate the functional explanation of temporal overestimation due to threat. The joystick task was used as it allowed for differentiation between the motivational tendencies of actions (e.g., approach and avoidance). Crucially Chapter 3 contained two different temporal duration ranges. One bisection task was conducted across the 400ms – 1600ms duration range whilst the other was conducted across the 200ms – 800ms duration range. The use of two duration ranges allowed for the testing of the scalar property of time. In addition the use of two duration ranges allowed one to identify which component of internal clock models is affected by the experimental manipulations (Droit-Volet et al., 2004). The results from Chapter 3 supported the notion that temporal overestimation due to threat functionally prepares one to act; participants were quicker to initiate an action following the presentation of the emotive stimulus which was more frequently temporally overestimated than the neutral stimulus. In terms of action motivation participants were found to be quicker to initiate an approach motivated action, pulling the joystick towards oneself, than an avoidance action, pushing the joystick away from oneself. Finally the results from Chapter 3 found evidence consistent with the hypothesis that action readiness induces temporal overestimation through pacemaker speeding; the effect of action readiness was greater in the long duration range than the short duration range indicative of a multiplicative effect with real time.

The finding that participants were quicker to initiate a voluntary action following the emotive stimuli compared to the neutral stimulus is consistent with the notion that temporal overestimation functionally prepares one to act. It follows that if temporal overestimation due to threat prepares one to act, participants will be quicker to initiate an action following the presentation of an emotive stimulus. What remained unanswered was whether temporal overestimation specifically causes such action facilitation or whether the action facilitation was a consequence of some general cognitive speeding effect which also caused temporal overestimations. Whilst Chapter 3 found evidence consistent with the functional explanation of temporal overestimation due to threat further investigation was required in order to determine the robustness of the effect.

8.1.3 Chapter 4

In Experiment 3 a verbal estimation task was used in which participants responded by typing their estimated duration for an emotive and neutral facial expression. The verbal estimation task was used because it is easy to administer, does not rely on participant motor ability and is sensitive to effects of emotion on time estimates (Gil & Droit-Volet, 2011b). Experiment 3 served as a test of the robustness of the results from Chapter 3 which found evidence consistent with a functional explanation of temporal overestimation due to threat. If such a functional explanation does exist it would be anticipated, given the high survival value of the effect, results consistent with this explanation are found across different experimental methodologies.

The results from Experiment 3 were consistent with the results from Chapter 3; participants more frequently overestimated the duration of emotive stimuli and were quicker to initiate approach-motivated actions following the presentation of an emotive stimulus. These results provided further support for the functional explanation of temporal overestimation due to threat; when faced with a threatening stimulus one’s internal clock is able to slow the perception of time which allows one to initiate an action more readily. Again, however, the results from Experiment 3 do not directly explain the cause of such an effect. One possibility is that temporal overestimation of a stimulus directly causes action facilitation, alternatively a more general cognitive speeding effect might explain this effect. To distinguish between these two alternative explanations EEG was used in Experiment 7 of this thesis. Nonetheless, the results from Experiment 3 were consistent with the predictions of the functional explanation of temporal overestimation due to threat.

8.1.4 Chapter 5

A further test of the functional explanation for temporal overestimation due to threat was to investigate whether emotion modulates the effect of action readiness on time estimates. If such a functional explanation were correct it would be predicted that manipulations of emotion would increase the effect of action on times estimates; if temporally overestimating emotive stimuli causes increases in action readiness, effects of action readiness on time estimates should be increased by emotional stimuli. It was this prediction that Experiment 4 tested. Previous experiments in this thesis also included a test of this prediction of the functional explanation, however, failed to find any effect (i.e., there was no interaction between the effects of emotion and effects of action). However, this may have been caused by the experimental manipulations which were seen to increase the speed of the pacemaker as found in internal clock models. Consequently, Experiment 4 used a speeded response paradigm as this has been found to not moderate pacemaker speed (Klapproth & Müller, 2008; Klapproth & Wearden, 2011).

The results from Experiment 4 were consistent with the previous experiments in this thesis; effects of emotion did not increase the effect of action readiness on time estimates. Despite this, participants were found to more frequently overestimate the duration of stimuli when in a state of action readiness as well as more frequently overestimating the duration of emotive relative to neutral stimuli. Interestingly, participants were also found to make their decision regarding the duration of the stimuli more quickly when the stimulus displayed was emotionally salient. This finding again provides evidence that temporal overestimation due to threat is linked to the speeding of other cognitive processes.

Finally, the results from Experiment 4 cast doubt on the idea that one's perception of time is susceptible to a super distortion whereby it is slowed to a more dramatic level than has been demonstrated previously.

8.1.5 Chapter 6

Participants in Experiment 5 completed the temporal bisection task, however, the foreperiod (duration between a warning signal and a target stimulus) was varied. The warning signal was a white oval which flashed briefly either 50ms, 400ms or 1400ms before the onset of the to-be-timed facial expression. The variable foreperiod paradigm was used to test for a super temporal overestimation effect; specifically, with increased foreperiod duration one expected greater attention to be paid to the to-be-timed stimulus. Therefore, a greater temporal overestimation effect was expected for emotive stimuli at longer foreperiod durations compared to neutral stimuli at longer foreperiod durations or emotive stimuli at shorter foreperiod durations.

The results from Experiment 5 failed to provide evidence for this hypothesis. Participants were not found to temporally overestimate the duration of emotive stimuli at longer foreperiod durations relative to neutral stimuli. However, participants did more frequently overestimate the duration of stimuli at longer foreperiod durations compared to shorter foreperiod durations. Interestingly no effects of emotion on time estimates were found. This was explained by repeated use of the same facial expressions throughout the experiments reported here. Evidence for this potential confound comes from Matthews (2011) who found that participants overestimated the duration of repeated stimuli less frequently than new or novel stimuli. An alternative possibility was that the effects of attention on time estimates occurred at an earlier time in Experiment 5 which prevented effects of emotion being found. In Experiment 5 it was possible that with increasing attention paid during longer foreperiod durations participants were already more likely to overestimate the duration of a subsequent stimulus (i.e., the switch mechanism in internal clock models was already closed prior to the presentation of the to-be-timed stimulus). Thus, as the manipulation of attention in Experiment 5 occurred earlier than the manipulation of emotion, effects of attention and not emotion were found. One test of this hypothesis would be to reverse this paradigm whereby manipulations of emotion occur before manipulations of attention; in such a paradigm effects of emotion and not attention would be expected. The results from Experiment 5 corroborated previous experiments reported here in finding that one's perception of time could not be distorted to a more enhanced level than had already be found.

8.1.6 Chapter 7

The results from Experiments, 2, 3, and 4 suggested that temporal overestimation due to threat was linked with facilitation of reaction times as predicted by a functional explanation. In addition, the results from Experiment 5 suggested that participant decision making speed was facilitated following temporal overestimation due to threat. However, the preceding experiments could not conclusively show that it was the temporal overestimation specifically which caused the facilitation of these cognitive processes. Experiment 6 served to test the different explanations of these findings; specifically, EEG was used to measure participant neural activity during a temporal bisection task.

Analysis of the EEG signal revealed that the peak amplitude of the N1P2 complex, which has been shown to predict temporal behaviour (Kononowicz & Rijn, 2014; van Rijn et al., 2014, 2011), was not modulated by emotion. Consequently, Experiment 6 casted doubt on the functional explanation of temporal overestimation due to threat; if temporal overestimation was the cause of speeded response times one would anticipate effects of emotion to be found in neural correlates of temporal processing. Interestingly the latency of the N1 peak was found to be earlier for emotive images (pictures of spiders) compared to neutral images (pictures of birds). This may suggest that temporal overestimation results from a general cognitive speeding effect which also causes other cognitive processes to be facilitated.

8.2 Functional Explanation of Temporal Overestimation Due to Threat

During times of immense emotional arousal people often report the feeling that time has slowed; car crash survivors are often reported to experience such a temporal distortion. This effect has also been demonstrated experimentally across many experimental paradigms, with numerous different emotionally salient stimuli, in different modalities as well as with clinical participant groups (Angrilli et al., 1997; Cocenas-Silva, Bueno, & Droit-Volet, 2011; Droit-Volet, 2013; Gil & Droit-Volet, 2009, 2011a, 2012; Gil et al., 2007a; Gil, Niedenthal, & Droit-Volet, 2007b; Noulhiane et al., 2007; Tipples, 2008, 2011). Of interest to the current thesis is the finding that, in general, the more action readying an emotion is the more frequently it is found to be temporally overestimated. Facial expressions of anger and fear for example are more frequently temporally overestimation than sadness and happiness (Droit-Volet

& Meck, 2007; Gil & Droit-Volet, 2011a). Moreover, the finding that the facial expression of disgust, a similarly highly arousing facial expression to fear and anger, is not temporally overestimated demonstrates that the degree to which an emotion readies one to act is of critical importance to the temporal overestimation effect (see also, Angrilli et al., 1997).

Following these experimental findings, it has been suggested that temporal overestimation due to threat may serve a functional role (Droit-Volet & Gil, 2009); if temporal overestimation due to threat functionally prepares one to act such an effect would have a clear survival value to the organism. Empirical results have often been found to be consistent with this explanation; Jones and colleagues (2011) report that stimuli often found to be temporally overestimated are also found to speed other cognitive processes. In addition, Gable and Poole (Gable & Poole, 2012) found that motivational intensity and not arousal levels predict temporal behaviour. Furthermore, Hagura *et.,al.* (2012) link temporal overestimation due to increases in action readiness levels to functional consequences. Despite this experimental evidence there did not exist a direct test of the functional explanation for temporal overestimation due to threat prior to this thesis.

8.2.1 Discussion

The purpose of the experiments reported in this thesis was to test the notion that temporal overestimation due to threat functionally prepares one to act. Specifically, this thesis tested whether participants were quicker to initiate a voluntary action following temporal overestimation. In addition, this thesis aimed to investigate the combined effects of action readiness and emotion on time estimates both as a test for the functional explanation of temporal overestimation due to threat and as a test of whether one’s perception of time is susceptible to greater distortion than previously demonstrated. Finally, this thesis aimed to test whether temporal overestimation itself causes facilitation of other cognitive processes or whether a general cognitive speeding effect could cause such effects.

In summary, the results from the experiments reported here provide limited evidence for the functional explanation of temporal overestimation due to threat. Whilst Chapters 3, 4, and 5 provided some evidence for the functional explanation subsequent chapters failed to provide further evidence. In Chapter 3 and 4 participants were found to initiate a voluntary action quicker following an emotive stimulus which were more readily temporally overestimated than neutral stimuli. This finding would be predicted by the functional explanation; temporal overestimation of a threatening stimulus readies one to act and therefore, reaction times were quicker following temporal overestimations. In addition, the result from Chapter 5 showing that participants were quicker to make their decision regarding a stimulus’ duration also supports this functional explanation. However, some results contained in Chapters 3, 4, and 5 as well as Chapters 2 and 6 failed to provide additional evidence for this functional explanation.

The functional explanation of temporal overestimation due to threat predicts that effects of emotion on time estimates should interact with effects of action readiness of time estimates; in short one should find evidence of an enhanced effect of action readiness when emotion is also manipulated in time estimation tasks. Across 6 Experiments no results provided support for this hypothesis; effects of emotionally salient stimuli on time estimates were not found to increase the effect of action readiness on time estimates. As to why each chapter did not show evidence of this effect there are numerous possibilities. First it is possible that the effects of emotionally salient stimuli on time estimates are caused by the increases in action readiness such stimuli evoke (e.g., Gable & Poole, 2012) rather than caused by increases in physiological arousal (see, Lake, 2014). If emotional stimuli affected the internal clock mechanism through increases in action readiness it follows that when participants were instructed to act and then saw an emotive stimulus the participant would already have been in a state of action readiness. This scenario would predict the null effect – independent effects of both action readiness and emotional stimuli but no increased effect of action readiness.

Second it is possible that the experimental manipulations used in the experiments here affected the same component of the internal clock mechanism. In Experiment 2 it was concluded that the effects of action readiness on time estimates are caused through modulation of the pacemaker speed. Previous research has consistently demonstrated that emotionally salient stimuli are also found to modulate this pacemaker mechanism (Cheng et al., 2016; Droit-Volet et al., 2004; Gil & Droit-Volet, 2011a). Therefore, the inability of the experiments contained here to find increased effects of action readiness when an emotive stimulus was presented may have been due to the pacemaker speed having some maximum output rate. The finding in Experiment 2 that the effects of action readiness and emotion on time estimates were both reconciled with the functioning of the pacemaker mechanism suggests that the two effects may not be separate effects.

Third, the null effect may demonstrate that one's perception of time can be distorted to a limited degree and is not susceptible to larger distortions than have been previously reported. In Chapters 3 and 4 the null effect could be explained in terms of the pacemaker in internal clock models, e.g., SET (Gibbon et al., 1984), operating at some maximum rate when the participants was given an instruction to prepare to act. However, Chapters 5 and 6 used experimental manipulations which have been previously demonstrated not to influence the speed of the pacemaker mechanism (time pressure and variable foreperiod durations respectively). Despite the use of these experimental manipulations, Chapters 5 and 6 also failed to provide evidence for an enhanced temporal overestimation effect. The consistency of this null effect is highly suggestive that one's perception of time is susceptible to fairly limited distortions.

Neurologically plausible internal clock models are better placed to explain this finding than the information processing account of SET (Gibbon et al., 1984). The SBF model of time perception (Buhusi & Meck, 2005; Matell & Meck, 2000; Matell & Meck, 2004) suggests that the brain is able to code for the perception of time by detecting coincident neural activity across neurones. It follows that there will be a limited number of neurones able to fire at once which would explain why no enhanced temporal overestimation effect was found here. In contrast, internal clock models such as SET do not address whether the pacemaker – accumulator pathway has some upper limit or maximum value of information which can be transmitted.

A further question posed by this thesis was whether temporal overestimation due to threat itself causes reaction time and decision making processes to be facilitated or whether the effects were due to a more general cognitive speeding effect. The functional explanation of temporal overestimation due to threat clearly predicts that it is the temporal overestimation of such stimuli which causes facilitated reaction times. To examine this, Chapter 7 used EEG to measure the N1P2 complex as this has been identified previously as the best neurological indicator of temporal behaviour (Kononowicz & van Rijn, 2014). Surprisingly the results did not show any modulation of the N1P2 peak when spider phobic participants judged the duration of images of spiders which were temporally overestimated relative to images of birds. However, the results did show that latency of the N1 peak was shorter when a spider image was presented to both phobic and non-phobic participants compared to bird images. This may suggest that the behavioural effects associated with temporal overestimations are due to a cognitive speeding effect rather than directly caused by the temporal overestimation itself. However, there are potential limitations to this interpretation.

First the N1P2 has been consistently found to be indicative of temporal behaviour, however, this was not found in Chapter 7. The failure to replicate this finding suggest that the findings from Chapter 7 need to be treated with caution. Second, previous research has shown that phobic individuals are in fact slower to respond to stimuli relating to their phobia than non-phobic individuals; one example demonstrating this is the Spider Stroop paradigm (Thorpe & Salkovskis, 1997). Consequently it is possible that the phobic participants in Chapter 7 were not quicker to respond following temporal overestimations but rather were slower to respond. This unusual pattern of behaviour, temporal overestimation and slower response times, directly contradicts the predications of the functional explanation of temporal overestimation due to threat.

Third the failure to find to any modulation of the N1P2 complex may be explained by temporal distortions not being coded for at the neuronal level of processing but are rather added at a higher stage of cognition. Some evidence for this notion comes from Stetson et al., (2007) who found that participants during an emotional event (simulated cliff fall) did not overestimate the duration of the event as it was occurring. Instead, participants were found to retrospectively overestimate the duration of the event. More evidence for this possibility comes from Herbst, Chaumon, Penney, & Busch (2014) who report no modulation of the EEG trace for flickering stimuli which are found to be temporally overestimated. One important difference between Experiment 6 and that of Herbst and colleagues is the ERP used. Experiment 6 focussed on the N1P2 complex as identified by Kononowicz & van Rijn (2014) whereas Herbst and colleagues focussed on the CNV which has been previously linked to temporal processing (Macar & Vidal, 2003, 2009; Macar et al., 1999). This difference highlights the difficulty in using EEG techniques in time perception experiments as research remains uncertain what causes the N1P2 and CNV to be modulated when participants are engaged in timing tasks. Nevertheless, the results from Chapter 7 did not provide additional evidence for the functional explanation of temporal overestimation due threat.

One important factor which warrants further discussion is the issue of statistical power, both in terms of the experiments contained in this thesis but also throughout the field of time perception in general. The power analysis conducted prior to Experiment 1 showed that 34 participants were required to find a medium effect size at the appropriate alpha level. From this analysis one can conclude that Experiment 1 of this thesis was, statistically speaking, underpowered given the relatively small experimental sample of 25 participants. As such it is possible that the results from Experiment 1, in particular the null finding regards action preparation on the perception of time, were due to the lack of experimental power. This concern raises the issue of why Experiment 1 used the relatively modest sample size. It is apparent from the analysis contained in Experiment 1 that the null effect of action readiness and in particular the interaction between action readiness and emotion had seemingly large alpha values. Whilst this may be due to lack of experimental power it is important to note that the experimental procedure used in Experiment 1, as used by Hagura and colleagues (2012), was sensitive to effects of action readiness when considerable fewer participants were used, for instance Experiment 2 of Hagura *et. al.* (2012) contained just 9 participants. Consequently it is possible that, given the relatively large sample size of Experiment 1 compared to previous research, effects of action readiness were able to be detected with the sample size used.

A further interesting discussion surrounding the issue of statistical power concerns the finding in Experiment 5 whereby participants were not found to temporally overestimate the duration of emotive stimuli. As discussed at length throughout this thesis the temporal overestimation effect for emotive stimuli is a well replicated and robust experimental finding. One possible explanation of the failure to find this effect was the sample size used, however, as this was more than the initial power analysis indicated was required, such an explanation is not considered valid. One further experiment, Experiment 6, also had relatively fewer participants than indicated by the power analysis. However, due the methodology and experimental design (i.e., an EEG experiment using a between measures design) the initial power analysis conducted is not relevant to this experiment. Indeed when one analyses the sample sizes used throughout the literature concerning time perception and EEG methodologies the sample size used in Experiment 6 is not atypical (e.g., Kononowicz & van Rijn, 2011). Furthermore, literature concerning time perception differences between spider phobic and non-phobic individuals had similar participant numbers (Buetti & Lleras, 2012). Consequently, the issue of statistical power is perhaps most pertinent in the discussion of results from Experiment 1 of this thesis. However, the other experiments contained in this thesis have been demonstrated to have sufficient statistical power based on previous research in the literature.

On the subject of statistical power one remaining issue, which is perhaps more significant than the preceding discussion, is whether the literature surrounding the area of time perception is statistically underpowered as a whole. Whilst the sample sizes throughout the field are likely calculated via power analysis software, a more pressing concern relates to the number of repetitions in each experimental condition. In Experiments 1, 2, 4 and 5 participants were required to judge the duration of emotive and neutral stimuli a total of 7 times for each stimulus duration and action condition in line with previous pieces of empirical research in the area. However, this number of repetitions is considerably smaller than found in other psychological fields of research. In the attention literature for instance it has been commented that between 25 and 100 repetitions per condition are required (Bundesen & Habekost, 2014). Consequently, future research in the area of time perception should take such considerations into account and this could, potentially, explain some of the contradictory findings within the area of time perception.

To conclude, the results from experiments contained here provide partial support for the functional explanation of temporal overestimation due to threat. Participants were found to initiate a voluntary action more quickly following stimuli which were more readily temporally overestimated. However, the support for such an explanation is limited and the need for continued and further experimentation is clear.

8.2.2 Future Research Directions

The results from experiments contained here suggest that there is a link between temporal overestimation due to threat and the facilitation of other cognitive processes such as reaction time and decision making. Further evidence for a link between higher level cognitive processes such as information processing speed and temporal overestimation of neutral stimuli has been found elsewhere (Jones et al., 2011). However, what is currently unknown is whether the temporal overestimation effect specifically causes these other processes to run faster. Although Chapter 7 shed some light on the answer to this question the need for additional research in this area is clear. Whilst definitively untangling these two hypotheses is experimentally tricky, the answer to how temporal overestimation affects other cognitive processes may help better understand how the brain is able to code for temporal information.

Whilst certain results reported here have supported the functional explanation of temporal overestimation due to threat, many have not been shown to support this explanation. Consequently one wonders why participants are found to temporally overestimate the duration of emotive images more frequently than neutral images. As mentioned previously, it is possible that temporal overestimation is nothing special *per se*. Rather it may be the by-product of a cognitive speeding effect induced by the display of an emotionally salient image through activation of the sympathetic nervous system. However, such an explanation for temporal overestimation is difficult to reconcile with some research findings; would images of desserts, found to be temporally overestimated (Gil et al., 2009), induce the same cognitive speeding effect as emotionally salient images, for instance? Combined with the limited evidence for a functional explanation reported in this thesis it remains to be fully understood why such a broad range of stimuli are temporally overestimated by participants.

With regards to finding evidence that one’s perception of time cannot be distorted to a greater degree than has already been demonstrated it is evident that research should focus on unrelated experimental manipulations. There is clear evidence linking emotionally salient stimuli with action readiness (e.g., Frijda, 1988, 2004; Frijda & Tcherkassof, 1997) which may have contributed to the null effects reported in each experiment contained here. Indeed it is possible that the effects of action readiness and emotion are actually the same effect. With that in mind future research should attempt to use unrelated manipulations which are known to influence time estimates. Through the use of two unrelated manipulations research would be able to establish whether the perception of time is susceptible to enhanced distortions or whether, as reported here, the perception of time can be distorted to a limited degree.

Finally, research concerning one’s perception of time has, to date, largely focussed on a very narrow temporal window of only a few seconds. Although many research questions remain unanswered for behaviours relating to such a narrow temporal window research should consider the effects of much longer temporal behaviours. Very few experimental studies have investigated temporal behaviours lasting for several minutes or hours despite much human behaviour operating within this timeframe. One recent area of research has investigated the effects of video games on people's perception of time. Results indicate that participants are more likely to underestimate the duration of a video game compared to a non-video game task of the same duration (Tobin & Grondin, 2009). Moreover, it has been reported that such an effect is found in both expert and novice video game players (Rau, Shu-Yun Peng, & Chin-Chow Yang, 2006). Such an area of research suggests that time perception research could be used in the future as possible intervention strategies for video game addicts. If video game addicts were reminded of the time spent engaged in such an activity it may help reduce the amount of time spent engaged in it. Although an exciting line of research it is worth noting that a similar intervention in gambling addicts was not found to help disengage pathological gambling habits (Ladouceur & Sévigny, 2009).

In short there is still much unknown about human time perception ranging from basic questions regarding how temporal information is coded by the brain to more applied areas of research. Whilst this thesis has been the first to directly test for a functional explanation of temporal overestimation due to threat given the mixed results it is hard to definitely conclude whether such an explanation is warranted. The finding that reaction times are facilitated following stimuli which are more frequently temporally overestimated suggests that such a functional explanation may exist. However, the question whether this functional explanation arises directly from the temporal overestimation of a stimulus requires further experimentation.

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