Crossmodal emotional modulation of time perception

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Table of Contents

Ⅰ Chapter 1 Introduction 1

1.1 Emotion and time distortion..1

1.2 Mechanisms underlying emotional duration distortions 6

1.3 Open issues related to crossmodal emotional effect...................10

1.4 Cumulative research work 13

Ⅱ Chapter 2 Crossmodal influences of emotion on duration judgment 19

2.1 Abstract 19

2.2 Introduction..20

2.3 Materials and Methods...24

2.4 Results 26

2.5 Discussion 32

Ⅲ Chapter 3 Crossmodal emotional modulation on temporal order judgment.. 38

3.1 Abstract 38

3.2. Introduction...39

3.3. Methods 43

3.4. Results 46

3.5. Discussion...50

Ⅳ Chapter 4 The role of action context on subjective time 54

4.1 Abstract 54

4.2 Introduction..55

4.3 Methods 57

4.4 Results and discussion 60

4.5 General discussion 64

Ⅴ Chapter 5 Deutsche Zusammenfassung 69

Ⅵ References 76

Supplementary materials 87

Acknowledgments 90

Curriculum Vitae 91

Appendix 92

I chapter 1 introduction

'Put your hand on a hot stove for a minute, and it seems like an hour. Sit with a pretty girl for an hour, and it seems like a minute. That's relativity.' — *Albert Einstein*

1.1 Emotion and time distortion

Novikov (1998) once remarked 'time is a uniform river without beginning or end, without source or sink, and all events are carried by the river's flow....' Time is not only unique in our life, but also essential for organizing our daily activities. We enjoy the tempos and rhythms while listening to music or dancing; we automatically make a decision and response to an approaching car in time. Time perception, also referred as temporal experience or psychological time, is an organism's time-related experiences, behaviors, and judgments (Block & Zakay, 2001). One striking feature of time perception is that subjective time is far from veridical and often distorted by a variety of factors, such as stimulus intensity, emotion, action, etc. For example, most of us have experience of stop-clock illusion, also referred to as chronostasis illusion. When we make a saccade to the second hand of a clock from elsewhere, the second hand sometimes appears to stop in place temporarily before it continues to tick at usual pace (Yarrow, Haggard, Heal, Brown, & Rothwell, 2001; Yarrow & Rothwell, 2003). Although different time distortions may involve different types of temporal processing, the consensus of time distortion is that our subjective time is a result of adaption to the situated environments, and subjective time often reflects our embodied processing of time event (see reviews, Clark, 1999; Droit-Volet & Gil, 2009; Engel, Maye, Kurthen, & König, 2013; Shi, Church, & Meck, 2013). Influence of emotion on time perception is one typical example that highlights this embodiment idea. For instance, we often experience 'slowing down' time during a life-threatening situation, such as car accident (Droit-Volet & Meck, 2007; Stetson, Fiesta, & Eagleman, 2007).

1.1.1 Distortions of subjective time

Time perception includes subjective phenomena such as subjective duration, temporal continuity, simultaneity, succession, temporal order, and the present (Pöppel, 1997). Among these subjective phenomena, a large number of time distortions of duration, temporal order and simultaneity have been reported. The term *duration* refers to the continuance of an event within time, including multiple time scales such as milliseconds, seconds, minutes, hours, and days. There are two types of duration distortions: a) *Duration expansion*, also called duration overestimation, means that the perceived duration of an event is longer than its physical time; b) *Duration contraction* or underestimation, an opposite distortion, shows that the perceived duration of an event is shorter than its physical length. Another term, *temporal order* refers to the sequential occurrence of two or more events (Block, 1990). *Simultaneity*, a similar phenomenon to temporal order, is the perceptual simultaneous occurrence of two or multiple events. Distortions in temporal order and simultaneity are often shown with shifts of the point of subjective simultaneity (PSS) or changes of the temporal discrimination sensitivity, or both (Shi, Zou, et al., 2010; Spence & Parise, 2010).

During the past decades, researchers have revealed various distortions of duration, temporal order judgment (TOJ) and simultaneity judgment (SJ), and have identified various factors that cause distortions in time perception. For example, subjective durations are subject to the intensity of the stimuli, spatial configuration (e.g., Kappa effect), internal expectation, action (e.g., eye movement), emotional state, context, and so on (Angrilli, Cherubini, Pavese, & Manfredini, 1997; Cohen, Hansel, & Sylvester, 1953; Fortin & Masse, 2000; Heron et al., 2012; Jazayeri & Shadlen, 2010; Morrone, Ross, & Burr, 2005; Xuan, Zhang, He, & Chen, 2007; Yarrow et al., 2001). For instance, the 'chronostasis illusion' reveals that our eye movements expand the perceived durations (Yarrow et al., 2001). Besides, many of these factors also influence the perceived temporal order or simultaneity (Fujisaki, Shimojo, Kashino, & Nishida, 2004; Miyazaki, Yamamoto, Uchida, & Kitazawa, 2006; Spence & Parise, 2010; Van Damme, Gallace, Spence, Crombez, & Moseley, 2009). Take the prior-entry effect as an example, a priming spatial cue before temporal order judgment could facilitate the subsequent temporal processing of the stimulus at the location of the prior cue, compared to the other stimulus at a different location (see review, Spence & Parise, 2010).

1.1.2 Time distortions induced by emotional states

We perceive external world with our emotion, while emotion also shapes our perception. As James (1890) remarked 'our feeling of time harmonizes with different mental moods', emotional states modulate our time perception (Droit-Volet & Meck, 2007). In recent years, time distortions, particularly duration distortions, induced by emotional states have received more and more attention. However, how emotion influences other types of time perception, such as the temporal order or simultaneity, is by and large unclear.

1.1.2.1 Emotional duration distortions

Langer, Wapner, and Werner (1961) offered one of the earliest experimental evidence of emotional effects on duration perception, that is, subjective duration was expanded with a danger. Recently, adopting materials from scaled emotional systems (e.g., International Affective Picture System from Lang, Bradley, & Cuthbert, 2008), a large number of research confirmed that emotion plays a vital role in duration distortions (Angrilli et al., 1997; Droit-Volet et al., 2004; Droit-Volet, Mermillod, Cocenas-Silva, & Gil, 2010; Noulhiane et al., 2007). For instance, using IAPS pictures, Angrilli et al. (1997) showed that four quadrants of 2-dimenstional emotional organization (i.e., arousal and valence) induced different subjective duration estimates: For high-arousal pictures, the durations of unpleasant slides (e.g., smashed face) were overestimated compared to neutral ones (e.g., book), while the durations of pleasant ones (e.g., naked people) were underestimated. By contrast, for low arousal pictures, the pleasant slides (e.g., dog pets) were overestimated, while the unpleasant ones (e.g., dead cow) in duration were underestimated. Similar findings were revealed in duration judgment of emotional IADS auditory stimuli (Noulhiane et al., 2007). These results showed some interactions between arousal and valence in modulation of subjective durations. Differently, using pictures of emotional facial expressions, Droit-Volet and her colleagues (2004; 2011) found that durations of emotional expressions, such as anger, happiness, fear, and sadness, were overestimated relative to neutral ones, and shame pictures were underestimated, while disgust expression failed to cause any time distortion. Compared to studies of Angrilli et al. (1997) and Noulhiane et al. (2007), the findings by Droit-Volet and her colleagues in duration estimations of facial expressions highlight two points: a)

Durations of positive high-arousal expressions are overestimated, and b) negative high-arousal expressions are not necessary to show duration overestimations.

Emotion is closely related to our actions. Recently, some other studies found actions, action-related meanings, or embodiment play important roles in the emotional modulation of time perception (Nather, Bueno, Bigand, & Droit-Volet, 2011; New & Scholl, 2009; Wittmann, van Wassenhove, Craig, & Paulus, 2010). For examples, the study by Effron et al. (2006) showed that durations of emotional facial expressions were overestimated relative to neutral ones when participant's imitation of faces was free, but this overestimation effect disappeared when their imitation was inhibited by holding a pen in their mouths. Similarly, Nather et al. (2011) found the duration of posture pictures involving more movement was perceived longer than postures requiring less movement, which was also confirmed in the study of Yamamoto and Miura (2012). Besides to these social emotional pictures with action meanings, looming stimuli that indicate threatening-related actions also affect duration judgment: duration of a looming object is judged longer than receding or static objects (van Wassenhove, Buonomano, Shimojo, & Shams, 2008; Wittmann et al., 2010).

1.1.2.2 Emotional distortions on temporal order perception

One fundamental function of emotion is to quickly prioritize attentional resource to the ongoing salient, such as interesting or dangerous, event(s) when multiple events compete for processing. A byproduct of such attentional selection is that the winners are represented at the expense of the competing information (Beck & Kastner, 2009; Desimone & Duncan, 1995; Mather & Sutherland, 2011). Such emotional modulation of attention has been primarily revealed in reaction time and TOJ tasks (Poliakoff, Miles, Li, & Blanchette, 2007; Van Damme et al., 2009). For instance, Van Damme et al. (2009) examined the influence of visual emotion cue (general threat, physical threat, and neutral) on the subsequent auditory or tactile TOJ by manipulating spatial attention. They found that in the tactile TOJ task the tactile stimulus was perceived earlier when it was presented at the same side of the visual physical-threat cue compared to at the side of a general threat and a neutral cue. Conversely, in auditory TOJ, the sound at the same side of a general threat cue was more likely to be perceived earlier relative to the other two conditions.

1.1.3 Factors contributing to emotional time distortions

While a lot of evidence about emotional effects on time perception has been documented (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007), it is still controversial whether the effects of emotion on time perception can be better described by dimensional view (i.e., two emotional dimensions of valence and arousal) (Smith & Ellsworth, 1985), or discrete view (i.e., the specific emotional meanings of a given affective stimulus) (Ekman, Frankenhaeuser, Berglund, & Waszak, 1969; Izard & Ackerman, 2000), or embodiment (i.e., bodily activities) (Niedenthal, 2007), or mixed of those. Based on the dimensional view, Angrilli et al. (1997) and Noulhiane et al. (2007) argued that valence and arousal and their interaction are major factors influencing duration distortions. On this view, stimuli with similar valence and arousal levels should induce similar time distortions. For example, all negative high-arousal stimuli, such as threatening and disgust, should expand duration compared to neutral stimuli. Some other studies (e.g., Gil & Droit-Volet, 2011), however, challenged this view, showing not all negative high-arousal events to be overestimated, suggesting that emotional modulation of time perception must be considered with emotional content and related behaviour, favouring the discrete view (Izard, 1991; Lerner & Keltner, 2001). The discrete view has gained support from recent studies. For instance, a recent study of emotional modulation in TOJ demonstrated that emotional meanings, whether general or physical threat, are strongly tied to specific modalities, touch or audition, which leads to differential facilitation patterns in the TOJ tasks (Van Damme et al., 2009).

In contrast to dimensional or discrete views of emotional modulation that focus on external emotional content, other recent research emphasized the importance of internal bodily states or embodiment induced by emotion on time perception (Effron et al., 2006; Nather et al., 2011), where perception and cognition should be strongly coupled in the sensorimotor loop (Engel et al., 2013). Base on this, Craig (2009) recently proposed the awareness model that subjective time results from the integration of bodily states through moments. When an affective signal, such as a danger, is received, body changes its states, facilitating the generation of emotional moments, and as a result the number of global emotional moments, as an index of subjective duration, increases.

It should be noted that these views are not mutually exclusive. Considering a specific muscle movement (e.g., facial expression) for different emotions (see review Ekman 1992), one original basis of discrete view comes from bodily states or embodiment (Damasio, 1994; Niedenthal, 2007; Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009). In this regard, the action-related meanings of emotional content are actually consistent with embodiment (Gil & Droit-Volet, 2011; Nather et al., 2011). In addition, arousal and embodiment might both contribute to emotional time distortions (see study, Effron et al., 2006). However, to date the relationships among emotional factors haven't been clearly addressed in previous studies.

1.2 Mechanisms underlying emotional duration distortions

Unlike visual and auditory signals that are received and processed by specialized senses (e.g., eyes or ears), time is ubiquitous feature of the stimuli and can be inferred by all senses, which points to a general internal encoding mechanism. It can be dated back to Hoagland (1933) who proposed an internal 'chemical clock' that mediates short durations. Following this idea, researchers have developed several key internal clock models, such as Treisman's model, scalar expectancy theory (SET), and attention-gate model, to explain various timing phenomena (Block & Zakay, 1996; Gibbon, Church, & Meck, 1984; Treisman, 1963). 'Internal clock' models can explain a large proportion of duration distortions, demonstrating its ability and fundamental properties of time and timing processing. However, as for time distortions induced by emotional states, it hasn't reached a consensus on how and which aspects of emotions, arousal, valence, action meanings, or/and embodiment, are involved in internal clock.

1.2.1 The internal clock model and its variations

Classic internal clock models possess three information-processing stages: clock, memory and decision-making stages (see Figure 1.1) (Block & Zakay, 1996; Gibbon et al., 1984; Treisman, 1963; Wearden, 1991). The clock stage consists of a pacemaker, a switch and an accumulator. The pacemaker emits pulses at a certain rate. At the onset of a timing signal, the switch closes, allowing the pulses emitted by pacemaker to pass through to an accumulator. At the offset of a signal, the switch opens and stops the accumulation (Note, the attention-gate model proposed that an attentional gate is placed between the pacemaker and the switch to control attention-sharing between non-temporal and temporal processing). Then, the accumulated pulses are transferred to the working memory, and compared to a reference in reference memory. The reference memory store stores a long-term memory representation of the approximate number of pulses that accumulated before. In the final decision-making stage, the comparator compares two stores based on a relative comparison rule and a response is then made (Buhusi & Meck, 2005; Church, 1984; Meck, 1996; Shi et al., 2013).

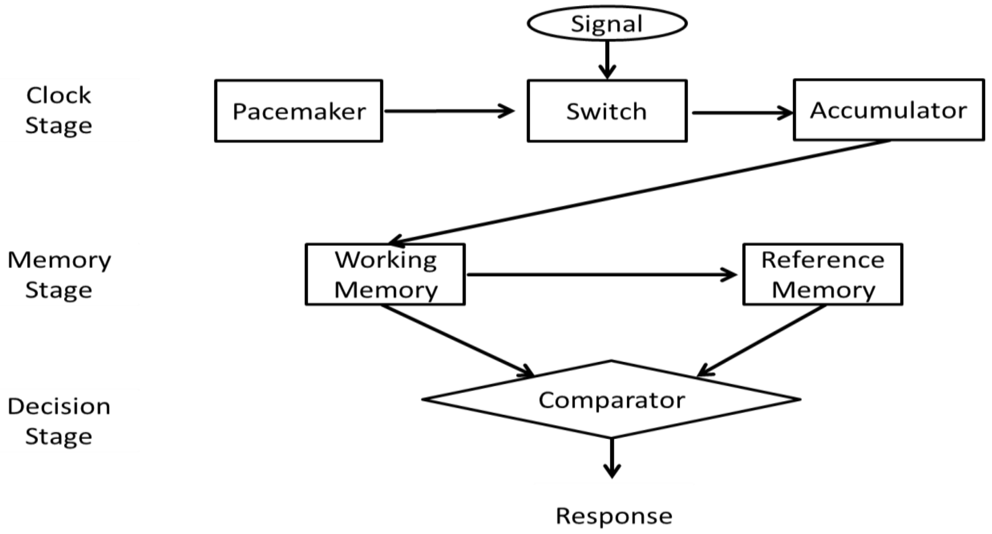


Figure 1.1 Schematic illustration of the classic internal clock model (SET, Gibbon et al., 1984). It consists of three stages: The clock stage shows the information flow among pacemaker, switch and accumulator; the memory stage consists of the working/short-term memory and the long-term reference memory; and the decision stage includes a comparator.

According to the internal-clock model, three key components, involving clock speed, attention, and memory, are suggested as the underlying mechanisms to cause various timing phenomena (Hinton & Meck, 1997; Pouthas & Perbal, 2004; Zakay, 1989). Clock speed mediates the number of the temporal pulses emitted by pacemaker within the physical unit of time. Both general circadian and specific arousal affect clock speed (Block & Zakay, 1996). The pacemaker is sped up as the arousal level increases. Differently, attention controls the latencies of closure and opening of the switch as well as the width of the opening of the gate in the internal clock (Block & Zakay, 1996). For examples, when attention is captured by a temporal event, the closure latency of the switch would become shorter. Besides, attention–sharing modulates opening width of the gate: when more attention is given to temporal event, the gate would open with a smaller width and more pulses would be accumulated. Both clock speed and attention involve their manipulations of the pacemaker-accumulator stage, but their roles could be distinguished. If the 'pacemaker' is sped up, the magnitude of overestimation should increase with the length of the duration (*multiplicative or slope effect*). On the contrary, if the overestimation of duration is mediated by attention, there is no duration length effect (slope effect), rather an *additive effect*, that is, the magnitude of overestimation should be similar between different range durations. In addition, memory mechanism in the internal clock also influences the subjective time. The changes of storage speed, storage number, or criterion distribution can all distort subjective duration. Taken together, the direction and magnitude of duration distortion depend on which mechanisms of the internal clock are affected.

1.2.2 Mechanisms involved in emotional modulation of time perception

Most studies suggest that key factors of emotion (e.g., arousal, valence, action meanings, or/and embodiment, see *1.1.3*) influence duration perception by mediating variation mechanisms in the 'internal clock' during the timing processing. Some studies suggest that the interaction of arousal and valence mediates clock speed (e.g., speeding up) and attention (e.g., earlier closure of the switch), and variations of these mechanisms distort the perceived durations (Angrilli et al., 1997; Droit-Volet & Gil, 2009; New & Scholl, 2009; Noulhiane et al., 2007). For examples, the aforementioned study conducted by Angrilli et al. (1997) argued the different levels of valence and arousal trigger a double motivational modulation: an attention-driven mechanism (i.e., attention-sharing) at low arousal levels, and an emotion-driven mechanism (i.e., clock speed) at high arousal levels. At low arousal levels, pleasant stimuli need more attention resources compared with unpleasant stimuli, and consequently durations of pleasant stimuli were overestimated. Conversely, at high arousal levels, pictures would trigger sensorimotor activation in order to prepare for potential action, such as defensive or appetitive behaviour (Bradley, Codispoti, Cuthbert, & Lang, 2001). On this ground, it is more urgent to prepare fight or flight than a general action when receiving unpleasant compared to pleasant stimuli. The requirement of urgent action for the unpleasant stimuli would cause strong physiological responses, such as increased blood pressure, pupils dilate, and faster heart rate, which are important in changing clock speed (Droit-Volet & Meck, 2007). It should be noted, at the late stage of emotional processing, some other processes such as emotion regulation might take over emotional modulation, given that duration distortions induced by emotional stimuli are only limited to several seconds (e.g., 2s-4s) (Angrilli et al., 1997; Noulhiane et al., 2007).

Alternatively, some other studies propose that action–related meanings and embodiment of emotion are required for arousal to manipulate clock speed in the internal clock (Effron et al., 2006; Gil & Droit-Volet, 2011; Nather et al., 2011; Orgs, Bestmann, Schuur, & Haggard, 2011). For instance, Nather et al. (2011) concluded that pictures with more embodied movement indicate higher arousing stimuli, and then run faster the pacemaker of the internal clock. However, except the explanations of embodiment based on the internal clock model, the recent developed the awareness model directly expains the influence of bodily states (embodiment) induced by emotion on time perception (Craig, 2009). According to this model, the anterior insula cortex is suggested to unify meta-representations of homeostatic feeling states, and these representations produce a cinemascopic 'image' of sentient self aross time. Our subjective time is provided by these moments. These moments run rapidly during the presentation of some emotional stimuli (e.g., physical threat), which increases the amount of global emotional moments, as a consequence, subjective time is expanded. Indeed, the awareness model and the internal clock model are not exclusive in explaining the role of embodiment on time perception. The speeded-up moments seem to corresponds to the faster clock speed, and consequently the increased number of emotional moments is consitent with more temporal pulses accumulated.

Meanwhile, several other hypotheses have also been developed recently to account for duration distortions (Eagleman & Pariyadath, 2009; Kanai, Paffen, Hogendoorn, & Verstraten, 2006; Tse, Intriligator, Rivest, & Cavanagh, 2004). For instance, Eagleman and Pariyadath (2009) suggested that the experience of duration is a signature of the amount of energy expended in representing stimulus.

1.3 Open issues related to crossmodal emotional modulation of subjective duration

To date, most studies concerning emotional modulation of time perception concentrate on time distortions of affective events or stimuli. It is not clear how an affective event received from one modality (e.g., vision) would influence duration and temporal order perception of events from other modalities (e.g., touch). Understanding such crossmodal effects would help us to distinguish whether timing information is processed centrally (amodally) or distributed (modality-specific) in different situations, which is a hot debated topic (see review, Bueti, 2011).

1.3.1 A fundamental issue: Amodal or modality-specific internal clock

A common assumption for the classic internal-clock models is that the ‘internal-clock’ is a ‘centralized’ or ‘amodal’ mechanism (Block & Zakay, 1996; Gibbon et al., 1984; Treisman, 1963). On the contrary, other recent researchers advocate that timing and time processing is ‘distributed’ or ‘modality-specific’ (see reviews, Bueti, 2011; Eagleman, 2008; Grondin, 2010). Additionally, a number of neuroimaging studies identified some common and specific structures that relate to temporal processing (Bolognini, Miniussi, Savazzi, Bricolo, & Maravita, 2009; Bueti, Bahrami, & Walsh, 2008; Grondin, 2010; Kanai, Lloyd, Bueti, & Walsh, 2011). The central issue of this ongoing debate is whether subjective time is processed centrally in general across modalities, or processed and linked to the modality that the timing event is presented. To date, there is no consensus, and both hypotheses are supported by some evidence in time distortions.

One empirical support for the amodal clock hypothesis comes from Penton-Voak , Edwards, Percival, and Wearden (1996), who revealed that a preceding 5s long trains of clicks lengthened both the durations of auditory and visual stimuli relative to no clicks condition. By contrast, a classic example favoring the modality-specific hypothesis is that auditory stimuli are usually perceived more accurate and longer than visual stimuli with the same physical duration when they are randomly mixed across trials (Goldstone & Lhamon, 1974; Penney, Gibbon, & Meck, 2000; Wearden, Edwards, Fakhri, & Percival, 1998). The differences between auditory and visual subjective durations are attributed to different pacemaker speeds and switch latencies (Wearden et al., 1998). Moreover, Morrone, et al. (2005) reported the influence of saccadic eye movements on duration is only limited to visual stimuli, not auditory stimuli, indicating that visual duration, not auditory duration, can be tied to oculomotor movements.

The debate fosters new ideas of multiple 'modality-specific' and 'amodal' timing mechanisms: timing processes for different modalities are usually operated in separate ways, and linked with each other under some specific situations (Wiener, Matell, & Coslett, 2011). In contrast to the traditional internal clock theories, recent developed intrinsic models (e.g., the state-dependent model argue that there is no specialized system for representing temporal information, rather time is an inherent property of neural dynamics (Ivry & Schlerf, 2008). According to this theory, the duration of a target is represented by a specific spatiotemporal pattern of neural activity, which shows different snapshots of active cells at every moment by the continuous spiking. So duration is encoded by the evolution of the neural network with the time (Eagleman, 2008). It should be noted that the intrinsic model failed to explain duration distortions and crossmodal effects (Eagleman, 2008; Eagleman & Pariyadath, 2009; Ivry & Schlerf, 2008).

1.3.2 Open issues in crossmodal emotional modulation of time perception

We perceive external events with multiple senses rather than a single sense. Thus, the perceived information of an event in one modality is likely to influence perception of other events received from different modalities. Ventriloquism effect, McGurk effects, and other crossmodal illusions are the strong evidence of such crossmodal interaction (McGurk & Macdonald 1976; Morein-Zamir, Soto-Faraco, & Kingstone, 2003). Concerning emotional modulation in time perception, its crossmodal effect has been seldomly addressed (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007; Hare, 1963). Further studies are necessary to investigate whether emotional effects on our perception are general for events taking place in the emotional context or only specific to the emotional event itself.

Considering one important function of emotion system is that individuals can quickly respond to external dangerous events for survival, time distortion induced by some emotional stimuli may actually reflect such strong linkage between perception and action. A possible direct way to address the sensorimotor interaction is to examine time perception in action context. Studies have revealed time distortions of action-related events (e.g., approaching objects) (van Wassenhove et al., 2008; Wittmann et al., 2010). For instance, the duration of looming stimuli stimulating approaching movement is demonstrated to be perceived longer than receding and static stimuli (Wittmann et al., 2010). However, it is still an open question if the action context would affect time perception of other events in the whole sensorimotor loop, or just the action-related events.

Besides to possible interactions induced by emotion context in duration among multimodal events, emotional context might shift the limited attention resource among multimodal temporal events, and modulate their time order judgment. For example, it has been demonstrated in non-temporal perception that emotion can modulate the competition of multiple signals and facilitate the processing of the salient event over others (see review, Mather & Sutherland, 2011). In temporal order judgment, the only study revealed that precue of a threatening picture, modulating spatial attention distribution, had a differential facilitation for tactile TOJ compared to auditory TOJ (Van Damme et al., 2009). However, one confounding point of this study is that it is not clear whether attentional bias is shifted in space towards the cued side, or a specific modality, or both. Thus, it is still a question whether and how a spatial uninformative emotional cue would modulate attentional selection in crossmodal temporal order perception.

1.3.3 Conflict accounts for emotional effects on time perception

Up to date, there is no consensus on which emotional factors, arousal, valence, action meanings, or embodiment, are important in duration distortions. Most studies emphasized that the mediations of arousal and valence on clock speed and attention lead to duration distortions (Angrilli et al., 1997; Noulhiane et al., 2007), while other recent studies reveal that action meanings or embodiment are the preconditions for the emotional modulation (Effron et al., 2006; Gil & Droit-Volet, 2011). The roles of emotional factors on time perception have been scarcely distinguished. As for the mentioned issue of crossmodal emotional effect in time perception, it is necessary to undertake a series of studies to differentiate the roles of emotional factors and further reveal the key factors which determine the potential functional linkage.

On this ground, the thesis addressed the following three main open issues: 1) whether emotion/action stimuli can modulate time perception of stimuli in other modalities, and whether this modulation is modality-specific? 2) How does the internal clock operate in emotional contexts, in amodal or modality-specific way? 3) Which factors of emotion (arousal, valence, specific meanings, or/and embodiment), and which variation mechanisms (clock speed or attention) in the internal clock induce crossmodal emotional modulation on time perception?

1.4 Cumulative research work

To address those above issues, the thesis focused on the following three research topics:

1) Crossmodal influences of emotion on duration judgment (Chapter 2)

Some common brain activities (e.g., medial prefrontal cortex and left superior temporal sulcus) for emotion stimuli conveyed by face, body, and voice seem to indicate that the processing of emotion is possibly amodal (Peelen, Atkinson, & Vuilleumier, 2010). Thus, it is possible that the impact of emotional stimulus on duration judgment would extend to other events from different modalities, rather than limit to the modality emotional stimulus is presented. Given that emotion stimuli involve perceptual, somatovisceral, and motoric re-experiencing of the relevant emotion (Droit-Volet & Meck, 2007; Niedenthal, 2007; Niedenthal et al., 2009), some emotional states might activate motivational systems involving sensorimotor loop for action (Bradley et al., 2001). Since touch sense is an important subsystem of sensorimotor system, timing of touch event is likely to be affected by related emotional modulation. In this regard, the first study was planned to test how visual emotion modulates tactile duration judgment. Furthermore, concerning the debate of which factors contribute to duration distortions induced by emotional states, it is worth to testing whether crossmodal emotional modulation is better fitted by dimensional view based on arousal and valence, or discrete view that highlights functions of emotion (i.e., specific emotional meanings).

To answer the above open questions, this study that consists of three experiments examined how different types of emotional pictures influenced subsequent non-emotional tactile duration judgment. Time bisection task was adopted in this study. In each trial, an IAPS picture was presented prior to the presentation of tactile duration. Participants were asked to view the picture and then judge the tactile duration. In order to examine the effects of visual emotional stimuli on tactile duration judgment and emotion views (dimensional vs. discrete), Experiment 1 compared influences of threat, disgust, and neutral pictures on the subjective tactile durations (300/900ms). Results showed an overestimation of tactile duration in the threat condition compared with the neutral and disgust conditions. Experiment 2 further tested whether the tactile duration overestimation induced by threats was due to arousal (*multiplicative effect*) or attention (*additive effect*). The estimates of short-range (300/900ms) and long-range (1000/1900 ms) tactile durations were compared between the threat and neutral conditions. Results of Experiment 2 indicated that threat pictures expanded the subjective short-range tactile durations, but not the long-range tactile durations. Thus, these results ruled out arousal effect, and could not be explained directly by attention gain. If duration expansion here was due to arousal, the magnitude of overestimation should have increased in long-range durations relative to short-range durations; If it resulted from attention capture, the overestimation would have been similar between two range durations. Perhaps some other processing, such as emotion regulation, was involved during the presentation of long-range durations. To identify which the activation of emotion regulation was related to, duration length or the interval gap between picture and tactile stimuli, the following Experiment 3 compared two inter-stimulus intervals (ISIs) (0.5s and 1.5s) between emotional picture and short duration tactile duration (300/900ms) in threat and neutral conditions. The long ISI (1.5s) used here was equal to the gap interval (mean 0.5s in ISI plus mean 1.45s in long-range durations) between picture and the offset of mean long-range durations in Experiment 2. If emotional regulation was related to the interval gap between picture and tactile stimulation, duration expansion would be diminished in long ISI condition; If it was due to duration length, the duration expansion should appear in short and long ISI conditions. In this experiment, the overestimation of tactile durations was manifested in two ISI conditions, suggesting emotional regulation depended on duration length. Overall, this study revealed that visual affective stimuli could expand the perceived tactile duration. However, such crossmodal duration expansion was only induced by the threat, not disgust, affective stimuli. This finding suggested that crossmodal emotional modulation of duration is better explained by the discrete view of emotion. In addition, attentional gain of tactile perception induced by crossmodal emotional linkage (visual-tactile) and the subsequent emotional regulation contribute to crossmodal emotional effects in duration perception.

2) Crossmodal emotional modulation on temporal order judgment (Chapter 3)

In the second study, the roles of arousal, valence, and emotional content (action vs. no action meanings) on crossmodal temporal-order judgments were examined. Given that temporal-order judgments are often influenced by spatial configurations (Keetels & Vroomen, 2005; Spence, Baddeley, Zampini, James, & Shore, 2003), the interaction of emotion and spatial configurations was also examined in this study. The first two experiments compared effects of negative (e.g., snake), positive (e.g., extreme sports), and neutral (e.g., book) high-arousal pictures on audiotactile temporal order judgment. In each trial, an emotional picture was presented concurrently with the audio-tactile pairs. Participants were asked to view this picture while judging the temporal order of audio-tactile events. In Experiment 1, the tactile and auditory stimuli were presented at the same location in front of the observer's body midline. In Experiment 2, the auditory and tactile stimuli were presented at seprate locations, one was to the left and the other to the right side. The results of these two experiments suggested that emotional stimuli (both positive and negative) facilitated tactile over auditory processing when they were spatially separated, but not for spatial collocated. To further distinguish the role of action-related emboded meanings from the arousal effect, the following third experiment compared the modulations of near-body threat (e.g., snake) and remote threat (e.g., car accident) on audio-tactile temporal-order judgments. The faciliatation of tactile processing induced by emotion was only found in the near-body threat condition. In summary, this study further confirmed the importance of the visual-tactile functional linkage triggered by emotion in timing and time perception, and suggested two key factors that affect audiotactile temporal-order judgments: a) embodied or action meanings of emotion; and b) spatial configuration of audiotactile stimuli.

3) The role of action context on subjective time (Chapter 4)

As shown in previous two studies, embodied or action meanings in emotion play a critical role in timing and time perception. The third study continued to examine the influence of embodiment, in particular, action context, in duration perception. The impact of action on time perception has been directly evidenced in two aspects. First, it has been shown that approaching objects implying threatening stimuli are perceived longer than static and other moving objects (Wittmann et al., 2010). Second, actions by observers have been revealed to influence time perception of action-related events, such as chronostasis illusion. These studies indicate that time perception can be better understood in the perception-action loop, which is the central idea of embodiment (Engel et al., 2013). However, it should be noted, in previous studies, the roles of action are specific to action goals or events with action meanings. This study thus aimed to examine whether action as a context would influence time perception of events in the whole sensorimotor loop, rather than just action-related events. If the action context has a general effect on the subjective duration of events, a further concern is whether the possibility of the interaction with action context or embodiment affects duration distortion, such as whether the approaching stimulus is easy to catch or not.

In this study, a real ball with pendulum movement was constructed for creating an action context. Participants were asked to judge tactile duration while viewing an irrelevant moving ball. In Experiment 1, tactile duration judgments were compared among the approaching, lateral moving and static conditions. The results showed that tactile durations were overestimated in the approaching and lateral moving conditions relative to the static condition, and the perceived duration was longer in the approaching condition than in the lateral condition. However, in this visual-guided avoidance collision paradigm, several factors, such as arousal, visual looming and implicit sensorimotor interaction, can all contribute to duration expansion. To disentangle visual looming, arousal from the implicit sensorimotor interaction, in the second experiment, we asked participants to place their right hands under the rest position of a moving ball to equal the possibility of near-body interaction of the approaching and the receding conditions, and results showed a similar tactile duration overestimation between these two movement conditions, thus excluding the looming effect. In the third experiment, we further examined the role of embodiment by designing two approaching conditions: hand-free and hand-occupied, to counterbalance the arousal effect. In the hand-occupied condition, two lightweight objects were placed in participants' hands. The aim of this hand-occupied-by-objects design was to inhibit the implicit sensorimotor interaction between observers and the action context, or embodiment. Experiment 3 showed that the tactile duration overestimation that was manifested in the hand-free condition disappeared for the hand-occupied condition when the sensorimotor interaction or embodiment was inhibited. To sum up, the results in this study reveal that viewing a near-body moving ball may activate action preparation, and such embodied reaction expands the subjective duration in the sensory-motor loop. The amodal operation in the internal clock in action context unifies our perception across modalities, beneficial to react quickly.

In summary, the thesis that consists of three studies investigated how visual affective stimuli or action as contexts influence crossmodal time processing, particularly on the role of the crossmodal/sensorimotor linkage in time perception. By using different types of emotional stimuli (e.g., threat, disgust, and neutral pictures) and manipulating the possibility of near-body interactions, three studies disassociated the impacts of embodied action from emotional dimensions (arousal and valence) on crossmodal emotional modulation in time perception. The whole thesis thus offered the first behavioral evidence that embodied action is an important factor that expands subjective tactile duration and facilitates tactile selection (modality-specific temporal processing) in emotion and action contexts. Moreover, subjective expansion of duration by threat and action contexts may reflect the evolutionary coupling of our perceptual and motor systems to adapt to the specific environments for survival and success.

Ⅱ Chapter 2 Crossmodal influences of emotion on duration judgment

2.1 Abstract

Judging the duration of emotional stimuli is known to be influenced by their valence and arousal values. However, whether and how perceiving emotion in one modality affects time perception in another modality is still unclear. To investigate this, we compared the influence of different types of emotional pictures – a picture of threat, disgust, or a neutral picture presented at the start of a trial – on temporal bisection judgments of the duration of a subsequently presented vibrotactile stimulus. We found an overestimation of tactile duration following exposure to pictures of threat, but not pictures of disgust (even though these scored equally high on arousal), in a short-range temporal bisection task (range 300/900 ms). Follow-up experiments revealed that this duration lengthening effect was abolished when the range to be bisected was increased (1000/1900 ms). However, duration overestimation was maintained in the short-range bisection task regardless of whether the interval between the visual and tactile events was short or long. This pattern is inconsistent with a general arousal interpretation of duration distortion and suggests that crossmodal linkages in the processing of emotions and emotional regulation are two main factors underlying the manifestation of crossmodal duration modulation.

Keywords: duration estimation; emotion; threat; visual-tactile interaction; embodiment

2.2 Introduction

Judgments of time intervals are often distorted by the emotional state a person is in. For instance, when involved in an accident, such as car crash, people often report that they felt the world slow down. Although the phenomenon has been known for long, it has only been sparsely examined (Hare, 1963; Langer et al., 1961), with more systematic studies published only in recent years (Angrilli et al., 1997; Droit-Volet et al., 2004; Droit-Volet & Gil, 2009).

The most simple and classical explanation of interval timing is provided by the internal clock model (Gibbon et al., 1984; Treisman, 1963; Zakay & Block, 1996). This model assumes an internal pacemaker that emits pulses at regular intervals, and a switch that starts and stops the counting of pulses. The pulses recorded by an accumulator represent the subjective time. Studies on emotion and time have shown that emotion can influence the internal pacemaker and/or the switch, and strongly distort perceived duration (see review Droit-Volet et al., 2004). For example, Angrilli and colleagues examined duration estimation for emotional pictures, taken from the International Affective Picture System (Lang et al., 2008), presented for 2, 4, or 6 s. They found that both emotional valence and arousal were important factors in duration judgments. For high-arousal stimuli, negative pictures (e.g., mutilated bodies) were perceived as longer in duration compared to positive pictures (e.g., erotic scenes). In contrast, for low-arousal stimuli, duration of negative pictures was judged shorter than that of positive pictures (Angrilli et al., 1997). Angrilli et al. argued that two different mechanisms, one attentional and the other emotional, play important roles in time judgment. Negative events themselves engage more attentional resources (as also indicated by lowered heart rates). As a result, less attention is devoted to time processing and the negative events' durations tend to be underestimated. For high-arousal stimuli, so they argued, the effect of attention is minimized, and an emotional mechanism triggered by the pictures dominates the time estimation. Since high-arousal negative pictures evoke a defense response (Bradley et al., 2001) , the duration of negative pictures is overestimated. By contrast, positive pictures evoke an approach response and thus their durations are underestimated. Similarly, other studies have shown that angry faces were judged as longer than neutral faces (Droit-Volet et al., 2004; Droit-Volet & Meck, 2007). It has been argued that both anger and fear are arousing emotions (Phelps & LeDoux, 2005), which increase the internal pacemaker rates, leading to temporal overestimation. Besides the visual modality, emotional modulation of time perception has also been found in the auditory modality (Noulhiane et al., 2007). Emotional sounds (e.g., a woman crying) were often judged as longer than neutral ones; and negative sounds were perceived as longer than positive ones (e.g., laughs).

Although there is now ample evidence of how emotion distorts duration perception, most of the studies have focused on unisensory modulation only. Given this, to date, there is still only scant understanding of how emotion induced from one sensory modality influences time judgments in another modality. The likely reason is that emotional effects are generally (and tacitly) assumed to be amodal in nature, that is: emotional arousal or anxiety exerts a general influence, not restricted to one sensory modality. This implicit assumption can be clearly seen in early crossmodal duration studies. For example, Hare attempted to examine how electrical shock influences auditory interval judgments (Hare, 1963) Auditory intervals were defined by two successive clicks. In the shock condition, a moderately painful (tactile) shock was delivered to participants' fingers at the second click, to induce general anxiety. Hare found that anxiety did indeed lead to a greater overestimation of auditory intervals compared to the baseline condition. However, recent crossmodal studies have provided evidence that each sensory system may possess its own clock (see review Bueti, 2011) and time processing is distributed across brain regions (Matell & Meck, 2004) . The sensory-specific clock model is supported by behavioral evidence, such as for modality-specific pacemaker rates (Droit-Volet, Meck, & Penney, 2007; Penney et al., 2000; Wearden et al., 1998), as well as by neurophysiological evidence, for example, for separate brain regions underlying visual and auditory duration processing (Bueti, 2011; Bueti et al., 2008; Ghose & Maunsell, 2002). Studies on non-emotional crossmodal duration judgments have revealed rather complex, and inconclusive results (Chen & Yeh, 2009; Chen , Shi, & Müller, 2010; Chen , Shi, & Müller, 2011; Shi, Chen, & Muller, 2010; van Wassenhove et al., 2008; Walker & Scott, 1981). For example, van Wassenhove et al. (2008) examined influences of visual (and, respectively, auditory) inputs on duration judgments of auditory (visual) events using looming and receding stimuli. They found the duration of auditory events was lengthened or shortened by the presence of conflicting visual information, while the perceived duration of visual events was unaffected by auditory stimuli. However, other studies using static stimuli or implicit measures have reported the opposite effect, that is, perceived visual duration was affected by auditory duration (Chen & Yeh, 2009; Shi, Chen, et al., 2010). Interestingly, in order to explain the crossmodal duration interaction by looming stimuli, van Wassenhove et al. (2008) suggested that salient, looming stimuli might be treated as "threat" signals (i.e., as having a negative emotional valence), causing duration dilation within and across modalities. Again, as concerns emotion, the influence of emotion on duration judgments was implicitly assumed to reflect a sense-independent arousal effect.

However, as suggested by recent discrete emotion theory (Izard & Ackerman, 2000; Mikels et al., 2005), the arousal and valence dimensions may not provide a complete description of emotions. It is also conceivable that different types of emotion link to different behavioral functions and sensory modalities. For example, although both threat and disgust are categorized as high-arousal negative-valence emotions, they activate different processes. Threat activates our defensive system and biases motor responses (Bradley et al., 2001). Given that a threatening or dangerous event is most likely directed towards our body (e.g., the sight of a snake attacking), an association between what we see and what we feel in our body can be quickly established (Poliakoff et al., 2007). This, in turn, may increase the tactile pacemaker speed and/or shorten the latency of the switch. Disgust, by contrast, is more related to avoiding something detrimental to our health or something tasting bad (Droit-Volet & Gil, 2009; Rozin & Fallon, 1987). Given this, the linkage between the visual and the tactile system by disgust events might not be as strong as that by threat events. Consequently, visual disgust signals may have only a relatively weak, if any, influence on the internal clock of the tactile system.

Moreover, duration judgments may also be influenced by the strength of perception-action associations. Research on duration estimation of emotional faces has shown that angry or fearful faces are often perceived as longer than neutral faces (Droit-Volet et al., 2004; Effron et al., 2006). However, when participants in such a study held a pen in their mouth to inhibit imitation of emotional faces, the duration lengthening was abolished (Effron et al., 2006). This finding suggests that perception-action associations are one of the critical factors causing changes of the internal clock system. Crossmodal associations induced by emotional stimuli might have a similar impact on time judgments.

To examine whether crossmodal emotional modulation of perceived duration is a general arousal effect or an emotion-specific effect, we compared modulations induced by three types of emotional pictures (threat, disgust, and neutral) on subsequent judgments of vibrotactile duration (Experiment 1). We chose threat and disgust since both are categorized as high-arousal negative emotions. If crossmodal emotional modulation reflected a general arousal effect, both types of emotional picture would engender similar distortions of tactile duration judgments. On the other hand, images depicting threat or fear may have particularly strong associations with the defensive system, compared to disgusting images. As supported by studies on affective modulation of the human startle blink (Balaban & Taussig, 1994; Stanley & Knight, 2004), blink magnitude was significantly larger during the presentation of frightening pictures compared to disgusting pictures. Thus, an alternative prediction is that threatening pictures would influence perceived duration by related sensory systems, such as touch, more than disgusting pictures would.

To further investigate the mechanisms underlying crossmodal emotional modulation of the internal clock system, we explored effects of emotions by comparing their modulatory influences between short and long tactile durations (Experiment 2) as well as short and long inter-stimulus intervals (ISIs) between the emotional picture and the vibrotactile stimulus (Experiment 3). Analogous to unimodal studies, the rationale was to examine whether the internal pacemaker rate or/and the switch latency in the tactile modality are changed by emotional events from visual modality. If the tactile pacemaker rate is impacted, one would expect a slope effect (multiplicative effect) on short and long duration judgments (Wearden 1992; Wearden, Todd, & Jones, 2006), that is, the crossmodal emotional influence should be greater for long than for short durations. By contrast, if emotion influences only the switch latency, one would expect duration overestimation for both short and long duration conditions. However, if processes of emotional regulation supersede processes of activation during a late stage of processing, one might fail to observe duration overestimation in the long duration condition. Experiments 2 and 3 were designed to examine for these effect patterns.

2.3 Materials and Methods

2.3.1 Participants

14 (6 female; mean age 28), 15 (10 female; mean age 25), and 16 volunteers (10 female; mean age 25) took part in Experiments 1, 2, and 3, respectively. All participants had normal or corrected-to-normal vision, and none reported any somatosensory disorder. Written informed consent was obtained before the experiments.

2.3.2 Materials

The experiments took place in a sound-isolated cabin, which was dimly lit with an ambient luminance of 0.76 cd/m^2. Visual stimuli were presented on a 21-inch Sony CRT monitor with a refresh rate of 100 Hz. The viewing distance was kept constant at 57 cm using a chin-rest. Tactile vibration (250 Hz) was produced by an *AEC* TACTAID *VBW32* vibrator (Audiological Engineering Corp.; Vibrating surface 1.6 × 2.4 cm), which was fixed to the index finger of the participant's right hand. The participant was asked to place her/his right hand, behind a short black curtain, on the table in front of her/him; the curtain ensured that the participant could not see her/his hand, while she/he had a free view of the display screen. Visual and tactile stimuli presentation was controlled by a Matlab program using the Psychophysics Toolbox (Brainard, 1997).

Three types of pictures were selected from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2005): threatening pictures evoking high arousal (such as a snake, shark, etc.); disgusting pictures also classed as high on arousal (such as a burn victim, mutilation); and neutral pictures rated 'neutral' in both valence and arousal. For Experiment 1, we used 5 pictures of disgust (mean valence 1.69; mean arousal 6.90), 5 pictures of threat (mean valence 3.28; mean arousal 6.73), and 10 neutral pictures (mean valence 4.82; mean arousal 2.47). For Experiments 2 and 3, we selected 10 threatening and 20 neutral pictures. Pictures were then evenly divided into two groups, each containing 5 attacking (mean valence 3.3; mean arousal 6.7) and 10 neutral pictures (mean valence 4.9; mean arousal 2.7); these were assigned randomly to one or the other of two test sessions (see details in Procedure section). Descriptions and IAPS numbers of the pictures are given in Supplementary materials S1.

2.3.3 Procedure

We used a temporal bisection task in all experiments. Participants were first trained with two anchor tactile durations: a short vibration (S) and a long vibration (L). Then, in the subsequent test sessions, several probe durations between S and L were presented to participants, who had to indicate whether the probe duration was closer to S or to L. In Experiments 1 and 3, S and L durations were 300 and 900 ms and the probe durations were 400, 500, 600, 700, and 800 ms, respectively. In Experiment 2, there were two different ranges of temporal bisection tasks: 300/900 ms and 1000/1900 ms. For the range of 300/900 ms, S, L, and probe durations were the same as in Experiment 1. For the range of 1000/1900 ms, S and L durations were 1000 and 1900 ms and the probe durations were 1150, 1300, 1450, 1600, and 1750 ms, respectively.

In the training session, an experimenter sat beside the participant to make sure that her/his anchor discrimination performance reached perfect level. Then, the experimenter left the cabin and the test session started. In the test session, a trial started with a ‘go’ display which contained a central blue fixation dot (subtending 0.3° of visual angle) and the blue word “Ready!” just above fixation on a gray background. After the participant pressed a button, the ‘go’ display disappeared and a blank display was shown randomly for 300 to 800 ms. Then a picture, randomly chosen from selected pictures, was presented for 1 second. In Experiments 1 and 2, after a short, random inter-stimulus interval (ISI) of 400 to 600 ms, a vibration was delivered to the participant’s index finger for a given probe duration (see above). In Experiment 3, the ISIs between picture and vibration were fixed to be either short (500 ms) or long (1500 ms). When the vibration had terminated, a question mark was displayed on the screen prompting the participant for a response: she/he had to judge, as accurately as possible, whether the duration of the vibration was closer to S or to L and indicate the choice by pressing keys labeled ‘short’ and ‘long’ on the keyboard. The inter-trial interval (ITI) was set to 4 to 6 seconds, in order to avoid potential inter-trial interference. There were 4 blocks, each of 25 trials. At the beginning of each block, both the S and L anchor durations were presented 5 times each, for refreshing the participant's memory of two anchors. Participants took rests of about 1 minute between blocks.

After the test session, the participant was asked to rate the valence and arousal of the pictures using a sheet of paper with 9-point scales Self-Assessment-Manikin (SAM) (Bradley & Lang, 1994).

2.4 Results

2.4.1 Assessment of Emotions

For Experiment 1, a repeated-measures ANOVA revealed rated valence to differ significantly among threatening, disgusting, and neutral pictures, $F(2,26) = 94.08$, $p<0.01$. Follow-up Bonferroni t-tests showed that the average valence was lower for disgusting pictures compared to both threatening and neutral pictures (both $p<0.01$), and the mean valence of threatening pictures was lower than that of neutral pictures, $p<0.01$. A further repeated-measure ANOVA revealed rated arousal, too, to differ significantly among conditions, $F(2,26) = 112.89$, $p<0.01$. Follow-up Bonferroni t-tests showed that disgusting and threatening pictures were higher in arousal ratings than neutral pictures (both $p<0.01$), without a difference between the former ($p> 0.1$).

The mean valence of threatening pictures was significantly lower than that of neutral pictures, in both Experiment 2 ($F(1,14) = 77.79$ $p<0.01$) and Experiment 3 ($F(1,15) =116.94$, $p<0.01$). Furthermore, repeated-measures ANOVAs revealed the mean arousal to be significantly higher for threatening than for neutral pictures, $F(1,14)=86.30$, $p<0.01$ (Experiment 2) and $F(1,15)=125.88$, $p<0.01$ (Experiment 3).

Thus, the results of the subjective ratings were consistent with the rating of valence and arousal from the IAPS.

2.4.2 Temporal Bisection

The proportions of 'long' responses were calculated for the 5 probe durations and fitted by a logistic function, for each condition and each subject. The temporal bisection point (TBP) was then calculated based on the 50% point of a given estimated logistic function (Treutwein & Strasburger, 1999). To measure the sensitivity of the temporal bisection task, we estimated the just noticeable difference (JND) of the temporal bisection using the half difference in duration between the 25% and 75% point (Shi , Hirche, Schneider, & Müller, 2008; Vroomen & Keetels 2010). In addition, we measured the Weber fraction with the ratio of JND/TBP.

Figure 2.1 shows average psychometric curves for the three emotion (i.e., neutral, disgust, and threat) conditions in Experiment 1. The mean temporal bisection points (±SE) for the tactile S/L duration pair 300/900-ms were 552±14, 550±19, and 529±15 ms for the neutral, disgust, and threat conditions, respectively (Figure 2.2 a). A repeated-measures ANOVA showed that the type of emotion picture significantly influenced the (subsequently performed) judgment of tactile duration, $F(2,26) = 4.41$, $p<0.05$. Follow-on linear contrast tests revealed tactile temporal bisection point to be significantly lower in the threatening condition compared to both the neutral ($p<0.01$) and disgust ($p=0.05$) conditions, while there was no difference between the latter ($p>0.1$). This pattern indicates that the modulatory influence of emotional pictures on tactile duration judgments was due mainly to the threatening condition. The lower temporal bisection point in this condition means that participants tended to overestimate the physical tactile duration of a vibratory stimulus preceded by a threatening picture. Interestingly, however, the subjective ratings of arousal (mean 7.41) were as high for disgusting pictures as for threatening pictures (mean 6.86). Given that duration overestimation only occurred in the threatening condition, arousal level alone cannot explain the crossmodal emotional modulation of time judgments.

The mean JNDs (±SE) were 72±8, 73±18 and 59±12ms for the neutral, disgust and threat conditions (Figure 2.2 b). A one-way repeated-measures ANOVA on JNDs failed to reveal any difference among three types of emotion pictures, $F(2,26)=0.39$, $p=0.68$. The Weber fractions (±SE) were 0.13±0.01, 0.14±0.04 and 0.11±0.02 for the neutral, disgust and threat conditions respectively. A repeated-measures ANOVA also indicated no difference among three conditions, $F(2,26) = 0.32$, $p=0.73$. Both results suggested that emotional pictures did not influence the sensitivity of the subsequent tactile duration judgments.

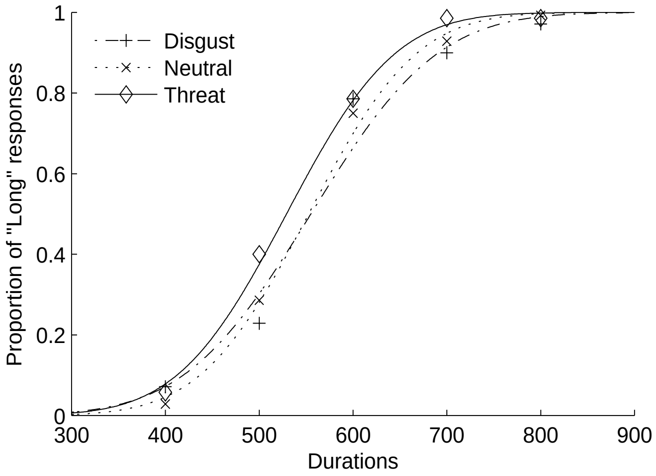
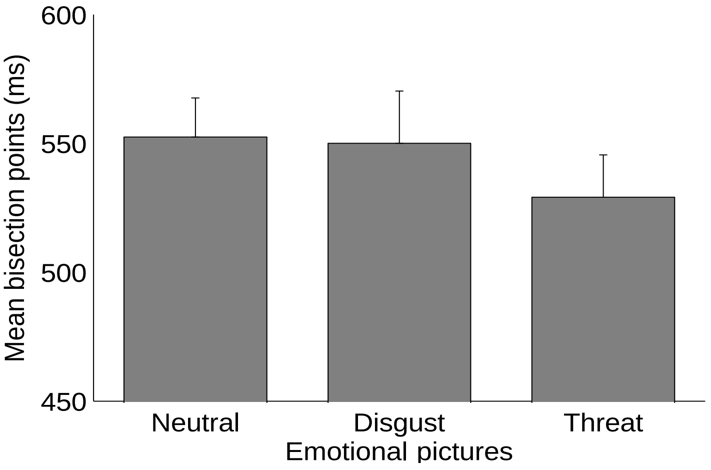
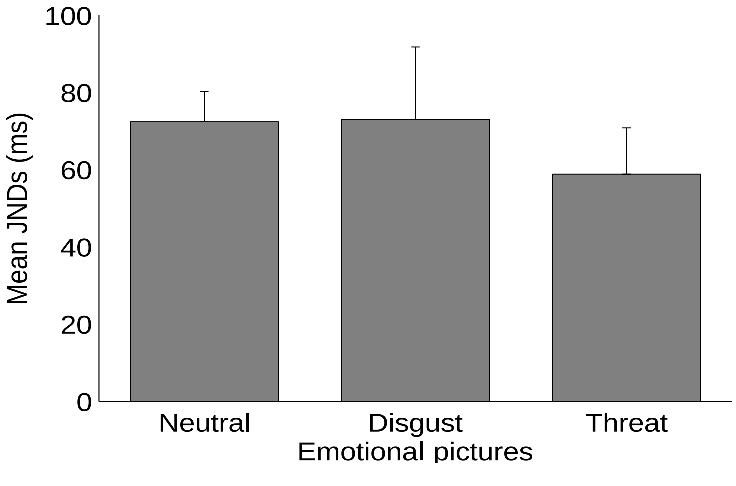


Figure 2.1 Mean proportions of "Long" responses plotted against probe durations and fitted psychometric functions for three emotion conditions (neutral, threat, and disgust). The dotted curve and crosses represent the neutral condition, the dash-dotted curve and pluses the disgust condition, and the solid curve and diamonds the threat condition.



(a)



(b)

Figure 2.2 (a) Mean temporal bisection points and (b) mean JNDs (and associated standard errors) for three emotional conditions (n=14).

Experiment 2 was designed to examine how threatening pictures influence performance on short-range (300/900 ms) and long-range (1000/1900 ms) tactile temporal bisection tasks. In the short-range task, the mean temporal bisection points (±SE) were 550±12 and 573±12 ms for the threat and neutral conditions, respectively; and in the long-range task, the points were 1399±16 (threat) and 1385±18 ms (neutral), respectively (Figure 2.3a). A two-way repeated-measures ANOVA with the factors temporal bisection range (300/900 vs. 1000/1900 ms) and emotional picture type (threat vs. neutral) revealed the main effect of temporal bisection range, $F(1,14)=2136.55$, $p<0.01$, and the interaction, $F(1,14) = 6.18$, $p<0.05$, to be significant; the main effect of emotional picture type was non-significant, $F(1,14)=0.14$, $\mathrm{p}=0.71$. Follow-up simple contrast tests showed that the temporal bisection point was lower with threatening pictures (indicative of a duration overestimation) in the short-range task, $F(1,14) = 5.17$, $p<0.05$, but not in the long-range task, $F(1,14) = 0.71$, $p=0.42$. Thus, while the results from the short-range condition are consistent with those of Experiment 1, there was no evidence of crossmodal duration lengthening in the long-range condition.

The mean JNDs (±SE) were 55±12 and 69±9 ms for the threat and neutral conditions in the short-range task, and 119±21 and 152±12 ms for the threat and neutral conditions respectively in the long-range task (Figure 2.3b). A two-way repeated-measures ANOVA revealed that JND was larger in the long- than the short-range task, $F(1,14)=32.61$, $p<0.01$, and was marginally smaller in the threat than the neutral condition, $F(1,14) = 4.54$, $p=0.05$. This indicated that the threatening picture might increase the sensitivity of the temporal bisection for the subsequent tactile duration task. However, the interaction between the duration range and the emotion type was not significant, $F(1,14)=0.80$, $p=0.39$. To compare task difficulties, we further calculated the Weber fractions. They were 0.10±0.02, 0.12±0.02, 0.09±0.01 and 0.11±0.01 for the threat and neutral conditions in the short- and long-range tasks respectively. A repeated-measures ANOVA revealed non-significant main effects and interaction (duration range: $F(1,14)=0.58$ $p=0.46$; emotion: $F(1,14)=3.62$, $p=0.08$; interaction: $F(1,14)=0.01$, $p=0.97$), which suggested task difficulties were relative similar among different conditions (e.g. the short- vs. long-range task).

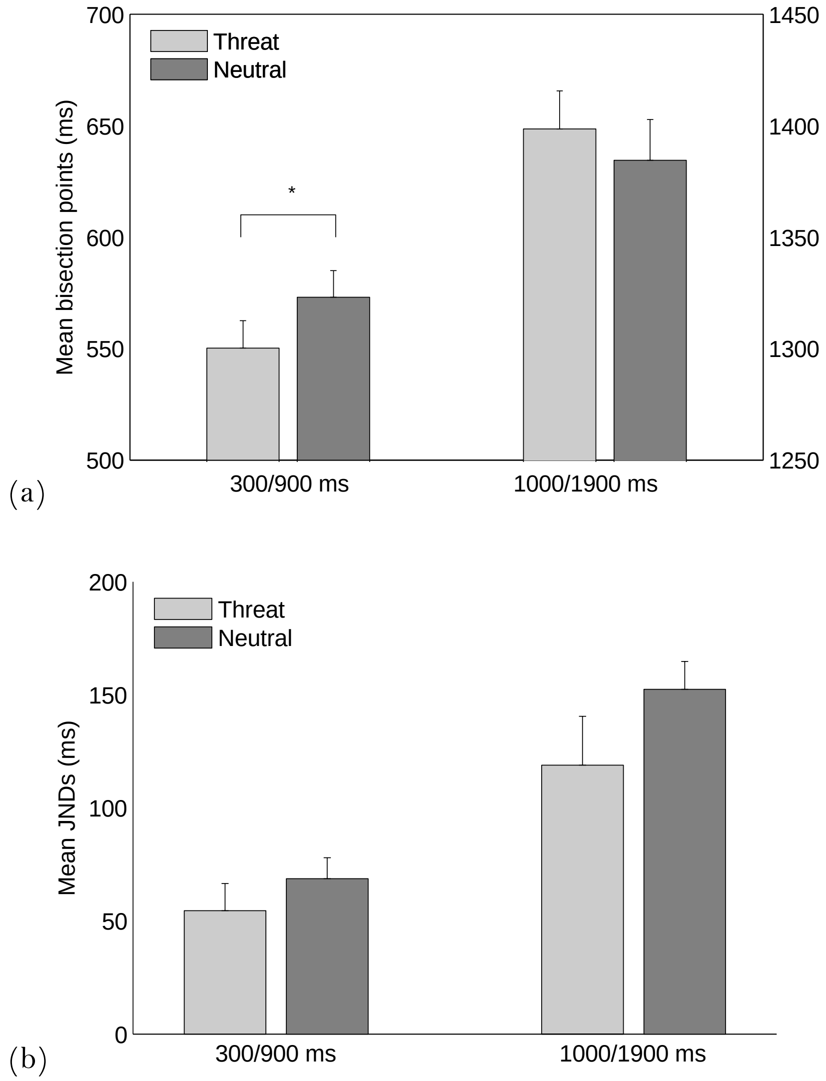


Figure 2.3. (a) Mean temporal bisection points and (b) mean JNDs (and associated standard errors) plotted against threat and neutral picture conditions, for the short-range (300/900 ms) and the long-range (1000/1900 ms) sessions (n=15).

However, it remains unclear from Experiment 2 whether the absence of a crossmodal duration overestimation following threatening pictures in the long-range temporal bisection task (1000/1900 ms) is due to the modulatory effect of emotion passively dissipating over time. Experiment 3 was designed to examine this question by comparing the effects of short (500 ms) and long (1500 ms) ISIs between the emotional picture and the tactile stimulus using the short-range temporal bisection task (300/900 ms). The intervals from the onset of the emotional picture to the offset of the tactile stimulus in the long ISI condition were then similar to that in the long-range condition (Experiment 2). Figure 2.4a depicts the mean tactile temporal bisection points for the neutral and threat picture conditions for short and long visual-tactile ISIs, respectively. The average temporal bisection points (±SE) were 532±12 and 549±11 for threatening and neutral pictures in the short-ISI condition, and 527±12 (threatening) and 549±10 ms (neutral) in the long-ISI condition. A two-way repeated-measures ANOVA with main terms of ISI and emotional picture type revealed the bisection points to be significantly lower in the threatening compared to the neutral condition, for both short and long visual-tactile ISIs. There were no effects involving ISI (main effect, $F(1,15)=0.26$, $p=0.62$; interaction, $F(1,15)= 0.11$, $p=0.74$). This indicates that the modulatory effect of threatening picture in the short-range condition did not simply lessen over time, that is, as a function of merely lengthening the ISI between the emotional picture and the tactile stimulus.

Figure 2.4b depicts the mean JNDs (±SE) for the neutral and threat conditions in the short and long visual-tactile ISIs. A two-way repeated-measures ANOVA revealed that JNDs were not influenced by the visual-tactile ISI, $F(1,15)=0.58$, $p=0.46$, but modulated by the type of pictures, $F(1,15)=4.91$, $p<0.05$. However, there was no interaction between the visual-tactile ISI and the emotion picture, $F(1,15)=3.07$, $p=0.1$. The significant smaller JNDs in the threat than the neutral condition confirmed the finding in Experiment 2. Both results suggest that threating pictures might increase the sensitivity of subsequent tactile temporal bisection task. Weber fractions were 0.10±0.02, 0.16±0.01 for the threat and neutral conditions in the short ISI and 0.15±0.03, 0.15±0.01 for the correspondent conditions in the long ISI. A repeated-measures ANOVA, however, showed no effects of the visual-tactile ISI, $F(1,15)=0.61$, $p=0.45$, the type of pictures, $F(1,15)=3.19$, $p=0.10$, and their interaction, $F(1,15)=2.48$, $p=0.14$.

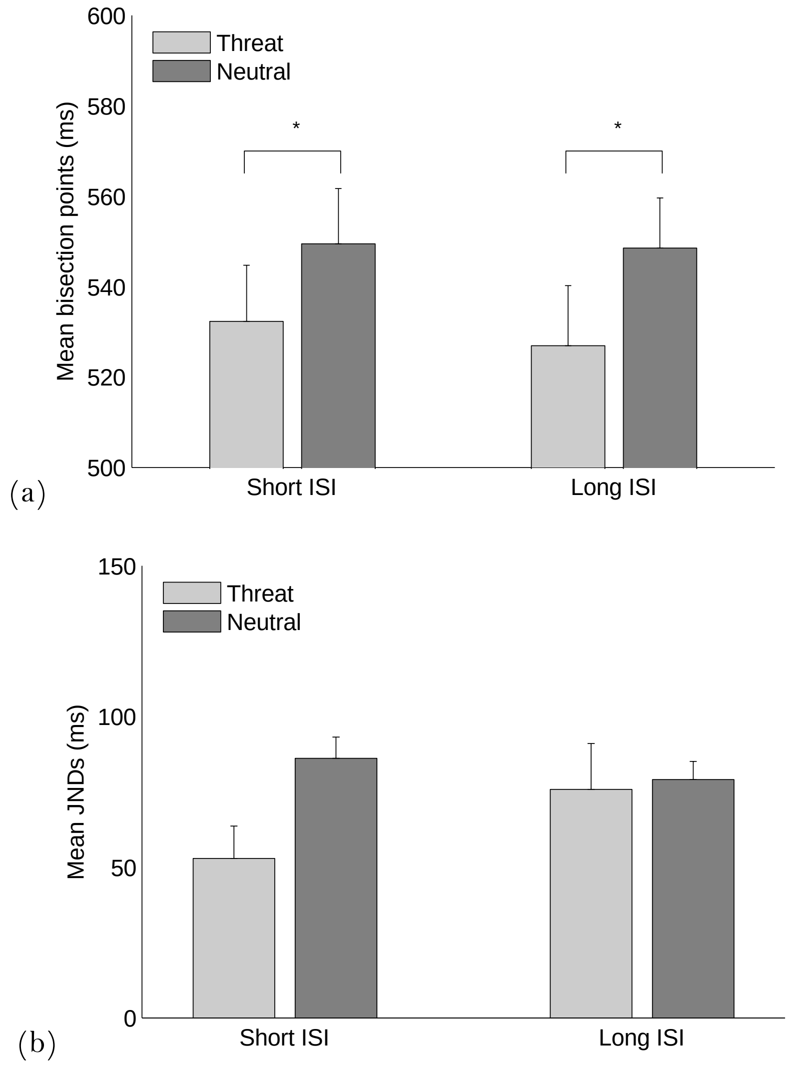


Figure 2.4. (a) Mean temporal bisection points and (b) mean JNDs (and associated standard errors) plotted against threat and neutral picture conditions, for the short-ISI (500-ms) and the long-ISI (1000-ms) session (n=16).

2.5 Discussion

The present study was designed to investigate the effect of viewing visual emotional stimuli on the subsequent estimation of the duration of non-emotional tactile events. We compared the effects of viewing three types of emotional pictures (neutral, threat, and disgust) in a short-range (300/900 ms) tactile temporal bisection task in Experiment 1. The results revealed the processing of threatening pictures to lengthen, relative to the neutral baseline, the subsequent judgments of tactile duration, as evidenced by a lowered mean temporal bisection point in the threat compared to the neutral condition. Interestingly, the lengthening effect was not simply due to the high arousal induced by the threatening pictures: both threat and disgust pictures were rated as high in arousal negative in valence in the subjective ratings (using SAM sheets) of the participants in the present study as well as in the IAPS norms. Yet, no lengthening effect was evident in the disgust condition. This is clearly inconsistent with the predictions deriving from the assumption of a general arousal effect.

Previous studies of judged durations of emotional events themselves have shown that arousal and valences are two main factors for duration distortions (Droit-Volet et al., 2004; Grommet et al., 2011; Noulhiane et al., 2007). Using IAPS pictures, Angrilli and colleagues observed that the durations of high-arousal negative-valence pictures were overestimated (Angrilli et al., 1997). A similar effect has been reported for the auditory modality, with high-arousal negative sounds being judged as longer in duration than positive ones (Noulhiane et al., 2007). Moreover, a recent study suggests that negative high-arousal activation, such as produced by a frightening movie, can also influence the subsequent time judgment of a neutral visual event (Droit-Volet, Fayolle, & Gil, 2011). However, it is not clear from those studies whether arousal activation from one modality can influence time perception in another modality. In contrast to these earlier studies on the temporal perception of emotional events themselves, in the present study, we focused on duration distortions induced by crossmodal emotional linkages. We found that viewing a rather threatening (e.g., a snake attacking), but not a disgusting (e.g., a mutilated body), picture expanded the subsequent tactile duration, although both threat and disgust emotions induced high arousal. Our findings suggest that the crossmodal modulatory effect of emotion depends on the type of emotional stimuli. This is consistent with the ‘discrete emotion’ theory (Izard & Ackerman, 2000; Mikels et al., 2005), which posits that different core emotions (such as disgust, fear, anger, etc.) link different behavioral functions. Studies of the affective modulation of the startle blink reflex (Balaban & Taussig, 1994; Stanley & Knight, 2004) and duration estimation of emotional faces (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007) suggest that the emotion of disgust has less salience than that of threat. A threatening picture often portrays an attack signal, which invokes the anticipation (or fear) of potential damage to perceiver’s body. Thus, the perceiver is put in a state in which she/he needs to react as quickly as possible to the threatening signal (e.g., fight or flight). Indeed, it has been found that automatic defense systems come into operation within an 'eye blink' for biologically relevant threat events (e.g., snakes, spiders), with their activation being based mainly on preattentive coding mechanisms (Öhman 1997; A Öhman & Mineka, 2001). The threatening event also establishes a strong association between the visual and tactile modalities, as suggested by several neuro-imaging studies (Dong, Chudler, Sugiyama, & Roberts, 1994; Gray & Tan, 2002; Keysers et al., 2004; Lloyd, Morrison, & Roberts, 2006). For example, posterior parietal cortex has been shown to play an important role in the early integration of visual information with somatosensory, proprioceptive signals. Lloyd and colleagues found an increase in posterior parietal cortex activity in response to observing a sharp (painful) stimulus, versus a non-painful stimulus, touching a rubber hand in peripheral space, in the absence of any direct tactile stimulation (Lloyd et al., 2006). Consistent with reports such as these, our findings provide further behavioral evidence of visual-tactile associations elicited by threat-type emotional pictures.

The asymmetrical crossmodal modulation of duration judgments by pictures of threat versus those of disgust would also argue in favor of multiple-clock models (Bueti, 2011; Buhusi & Meck, 2005; Ivry & Richardson, 2002). On this notion, time processing is "distributed" to different sensory-specific brain regions, with each of the multiple clocks operating separately. Within this framework, our results complement, rather than being in conflict with, previous, unimodal studies of emotional modulations of duration judgments. These studies have shown that the durations of emotional pictures themselves are overestimated, likely due to the "visual" clock being modulated by the pictures' arousal and valence signals. Our results go beyond this by showing that emotions induced via the visual modality may influence the "tactile" clock, depending on the strength of the emotional association induced between the visual and tactile modalities.

How does visual threat influence the tactile clock? Does exposure to threatening pictures subsequently speed up the tactile pacemaker or/and shorten the switch latency? Using a short- and a long-range temporal bisection task in Experiment 2, we observed a crossmodal duration lengthening by the threatening pictures in the short-range temporal bisection task (300/900 ms), replicating the finding of Experiment 1; by contrast, no such lengthening was observed in the long-range task (1000/1900 ms). The lacking crossmodal modulation in the long-range condition suggests that the tactile pacemaker is unlikely to be speeded up by preceding high-arousal visual stimuli. Otherwise, one would have expected to see a general slope effect, that is, a larger duration expansion in the long-range condition. A recent study (Grommet et al., 2011) of the time estimation of visual fear cues using two different duration ranges (250/1000 ms, 400/1600 ms) concluded that the fear effects were mediated mainly by the switch latency, rather than the speeding up of the internal pacemaker. In the study of Grommet et al., the duration expansion of the fear cue itself was of a similar magnitude in both the short- and the long-range condition.

If the tactile switch latency is shortened by the presentation of threatening images in the present study, then why did we fail to observe a duration lengthening in the long-range condition? No difference on Weber fractions between the short- and long-range conditions suggests that the task difficulty cannot be the reason for the non-effect in the long-range condition. Furthermore, the mean standard errors of the temporal bisection points were not significant different between the short- and long-duration conditions (12 vs. 17 ms, $p>0.1$). This could rule out the potential cause by large variations for long duration estimations. We suggest that the absence of such an effect is due to a dynamic shifting of attention from emotional activation to emotional regulation mechanisms (Casini & Macar, 1997; Fortin, 2003; Macar, Grondin, & Casini, 1994; Zakay, 1989). Emotional activation is often followed by emotional regulation, in line with the existence of two emotional pathways, one subcortical and one cortical (LeDoux, 1995). The former is rapidly activated by potentially dangerous or survival-relevant stimuli – even though the stimuli are not fully processed, facilitating the preparation of (physiologically autonomous) response programs for avoidance (flight) or fight. The cortical pathway, by contrast, processes information more precisely, though this takes more time. Precise cortical stimulus analysis in turn can help to inhibit or correct 'erroneous' early responses elicited by the subcortical pathway, thus readjusting the subsequent behavior. When participants in the present study are exposed to threatening pictures, attentional resources may first be rapidly directed to the defensive system, including the somatosensory system, for preparing a reaction. Possibly, the strong visual-tactile linkage reduces the latency of the tactile switch at the beginning. Consistent with this, tactile duration was overestimated in the short-range temporal bisection tasks of the present Experiments 1 and 2. While the same would apply to the long-range condition, participants (in this condition) would eventually realize that the tactile vibration is not a threat event. Accordingly, attentional resources would be increasingly redirected to processes of emotional regulation. As a consequence, some pulses may be lost in the time accumulation, leading to an underestimation of the tactile duration. The absence of an (overt) emotional modulation in the long-range condition may then arise from the overestimation brought about by the shortened switch latency being nulled by an underestimation owing to the emotional regulation.

It is interesting to note, however, in both short- and long-range conditions the sensitivity of temporal bisection task increased in the threat condition compared to the neutral condition. The higher sensitivity (smaller JND) in the threat condition is further confirmed in Experiment 3 and shown a trend in Experiment 1. These results may well reflect the general alerting effect induced by threatening pictures. However, the alerting could not account for the differential effects in the short- and long-range conditions.

One alternative explanation: general emotional attenuation, might account for the absence of duration lengthening in the long-range condition. As reported in previous unimodal studies (Angrilli et al., 1997; Noulhiane et al., 2007), the duration lengthening induced by emotional stimuli disappeared for the judgment of long durations (usually above 4 seconds). The absence of an emotion effect in these studies has been attributed to dynamic pacemaker changes by emotional attenuation: The pacemaker rate would be increased by the onset of the emotion event and would then gradually return to baseline when emotion attenuates over time. Note, however, that the emotional attenuation could also be the result of emotional regulation – which are the two faces of one and the same coin.

One interesting question, though, is at what point in time emotional regulation takes over. The results of the present Experiment 3 suggest that emotional regulation is unlikely to occur prior to the subsequent (tactile) event. Recall that in the long-ISI condition of Experiment 3, the time interval from the onset of the emotional picture to the offset of the tactile vibration was the same as that in the long-duration condition of Experiment 2. If emotional regulation (or emotional attenuation) took place immediately after the onset of the emotional event, one would predict both conditions to yield the same crossmodal emotional modulation of duration judgments. However, on the opposite (and unlike the nulling effect in the long-duration condition), the tactile duration lengthening effect evoked by threatening pictures was almost as large in the long-ISI as in the short-ISI condition. This suggests that the crossmodal linkage activated by threatening events was not attenuated before the subsequent event, at least within the time rage of our study (3 s). The defensive system appears to be still highly activated and dominant for reacting to the external world after the threatening events. Only when the subsequent event is identified to be non-threatening (as under the long-duration condition of Experiment 2) does emotional regulation become dominant and the emotion-induced defensive bias dissipates gradually.

In summary, the present results indicate that the crossmodal subjective-duration lengthening effect is emotion-specific: tactile duration is overestimated following exposure to pictures of threat, but not to pictures of disgust of the same high-arousal potential. However, the duration lengthening disappears for long-range durations. This pattern may be best explained by the latency of the tactile (clock's) switch being shortened by crossmodal emotional activation, while emotional regulation takes over after the subsequent (tactile) event is identified as a non-threatening signal.

Ⅲ Chapter 3 Crossmodal emotional modulation on temporal order judgment

3.1 Abstract

Although attention can be captured toward high-arousal stimuli, little is known about how perceiving emotion in one modality influences the temporal processing of non-emotional stimuli in other modalities. We addressed this issue by presenting observers spatially uninformative emotional pictures while they performed an audio-tactile temporal-order judgment (TOJ) task. In Experiment 1, audio-tactile stimuli were presented at the same location straight ahead of the participants, who had to judge "which modality came first?". In Experiments 2 and 3, the audio-tactile stimuli were delivered one to the left and the other to the right side, and participants had to judge "which side came first?". We found both negative and positive high-arousal pictures to significantly bias TOJs towards the tactile and away from the auditory event when the audio-tactile stimuli were spatially separated; by contrast, there was no such bias when the audio-tactile stimuli originated from the same location. To further examine whether this bias is attributable to the emotional meanings conveyed by the pictures or to their high arousal effect, we compared and contrasted the influences of near-body threat vs. remote threat (emotional) pictures on audio-tactile TOJs in Experiment 3. The bias manifested only in the near-body threat condition. Taken together, the findings indicate that visual stimuli conveying meanings of near-body interaction activate a sensorimotor functional link prioritizing the processing of tactile over auditory signals when these signals are spatially separated. In contrast, audio-tactile signals from the same location engender strong crossmodal integration, thus counteracting modality-based attentional shifts induced by the emotional pictures.

3.2. Introduction

Efficiently dealing with emotional stimuli, such as threat, is highly beneficial for survival. Many studies have demonstrated that emotional stimuli capture attention in an involuntary or reflexive manner, leading to faster responses to and better sensory processing of emotional stimuli (see review Vuilleumier, 2005). For example, in variants of visual search tasks, reaction times are faster when the target has an emotional meaning, such as an emotional face among neutral faces (Eastwood, Smilek, & Merikle, 2001; Fox, 2002) or a snake or a spider among flowers (Arne Öhman, Flykt, & Esteves, 2001). Sensory processing of emotional stimuli, such as emotional faces, pictures of threat, and emotional sounds or voices, has also been found to be enhanced, relative to neutral stimuli, at early perceptual stages (Eimer & Holmes, 2007; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). The enhancement genereted by emotional stimuli may persist further and give rise to 'prior entry' (Spence & Parise, 2010) for the processing of neutral stimuli presented subsequently at the same location as the emotional stimuli (Phelps, Ling, & Carrasco, 2006; Van Damme et al., 2009).

Emotion-based modulation of attention has mostly been investigated in the visual domain. By comparison, there have been only few studies (Poliakoff et al., 2007; Van Damme et al., 2009) on the effect of emotion on the crossmodal distribution of attention. The scarcity of such research is surprising given that the external world generates a multitude of sensory information streams in parallel, whereas perceptual processing resources are limited – so that, in order to deal with the bottleneck in sensory processing, certain emotional states may bias or prioritize the selection of non-emotional sensory signals over others. However, precisley which sensory signals will be prioritized by emotional states is still inconclusive. In a recent study, Van Damme and colleagues (2009) set out to explore crossmodal emotional modulation of spatial attention using a non-speeded temporal order judgment (TOJ) task. Participants were asked to make a TOJ on a pair of tactile (or auditory) stimuli presented to the left and right hands (or ears). Prior to this pair of TOJ stimuli, an emotional picture (physical threat, general threat, or neutral) was presented in either the bottom left or the bottom right corner of the monitor. Van Damme and colleagues found that the point of subjective simultaneity (PSS) of two tactile stimuli was shifted significantly towards the side preceded by a physically threat picture, as compared to a general threat or a neutral picture. In contrast, for the auditory TOJ task, they found the opposite effect: a sound was more likely perceived earlier if it was presented on the side of a preceding general threat picture, compared to a preceding physical threat or neutral picture. Based on this pattern, Van Damme et al. concluded that "physical threat shifts attention to tactile rather than auditory information" (Van Damme et al., 2009, p. 103). While this conclusion is intriguing, there appear to be two critical limitations: First, the TOJ tasks were conducted within the same modality (in either touch or hearing), that is, there was no direct temporal order judgment between auditory and tactile input information. Second, since essentially a spatial pre-cue was presented (on either the left or the right side) which was not orthogonal to task partcipants had to perform (i.e., to report the side of the first of two tactile or two auditory stimuli), it is not possible to tell whether attention was shifted in space (the cued side) or/and towards a specific modality (e.g., touch). Given this, it remains elusive how multisensory information selection is modulated by emotion when multiple signals from separate modalities (e.g., an auditory and a tactile signal) are presented at the same time.

Recent studies of emotional modulation provide convergent evidence that emotions may not be completely described in terms of their values on the valence and arousal dimensions (Izard & Ackerman, 2000; Mikels et al., 2005). Emotional stimuli with different meanings often involve differential patterns of perceptual, somatovisceral, and motoric (i.e., embodied) re-experiencing of the relevant emotion in the observer (Droit-Volet & Meck, 2007; Niedenthal, 2007; Niedenthal et al., 2009), some of which may activate the whole defensive or, respectively, appetitive systems for action (e.g., fight-or-flight) (Bradley et al., 2001; Lang, Bradley, & Cuthbert, 1997). Accordingly, emotional meanings and related behavorial functions must be considered as crucial factors in emotional modulation. The differential effects of physical threat and general threat pictures on the tactile and auditory TOJs in the study of Van Damme et al. (2009) provide a good example for such an 'embodiment' account. A similar idea is supported by another recent study (Shi , Jia, & Müller, 2012), which showed that distortions of subjective tactile duration can be induced by pictures of physical threat, but not by disgust-arousing pictures, although both types of pictures were evaluated as high-arousal negative stimuli. Findings such as these suggest that physical threat may prime and/or prioritize the processing of certain types of sensory signals in the sensorimotor pathway, in particular: the processing of tactile information. On this ground, we hypothesized that emotional contexts which have the potential to activate action-related sensorimotor processing, might bias the temporal selection of tactile over auditory signals when two such signals compete for processing.

With regard to crossmodal temporal processing, several studies have shown that TOJs can be influenced by exogenous and endogenous orienting of spatial attention (see reviews Spence & Parise, 2010; Spence, Shore, & Klein, 2001) and spatial configurations (Keetels & Vroomen, 2005; Spence et al., 2003; Zampini, Shore, & Spence, 2003a, 2003b). Generally speaking, a stimulus presented at an attended location or in an attended modality will be perceived earlier relative to the same stimulus being presented outside the 'focus' of attention – the so-called prior-entry effect (Spence & Parise, 2010; Spence et al., 2001). Also, the temporal discrimination sensitivity is typically higher when two stimuli are presented at separate locations, rather than at the same position, in particular in crossmodal TOJ tasks involving visual stimuli. This finding has been attributed to multisensory integration being enhanced due to the 'unity effect' for stimuli from the same location (Welch & Warren, 1980); by contrast, stimuli from separate locations convey additional, spatial information for performing the TOJ task, as a result of which they are more likely to escape the unity effect. However, it has also been reported that audio-tactile TOJs are less affected by spatial factors (Kitagawa, Zampini, & Spence, 2005; Zampini et al., 2005). This is likely owing to the reduced role of 'space' in audiotactile interactions, compared to other multisensory interactions involving vision (see review Occelli, Spence, & Zampini, 2011). Note that these facts were established in non-emotional experimental settings. Given this, one interesting question is whether exposing observers to emotional visual stimuli has a more pronounced effect on the crossmodal temporal processing of pairs of auditory-tactile stimuli that are spatially separated, compared to pairs of stimuli that originate from the same location.

On this background, the present study was designed to investigate the influence of emotional (visual) pictures on audio-tactile temporal processing using an unspeeded TOJ task. In contrast to previous prior-entry studies that presented a (lateralized) cue prior to the TOJ stimuli, a (central) picture conveying emotional meaning was presented simultaneously with an audio-tactile pair of stimuli. This was done to examine for instantaneous attentional biases in audio-tactile sensory selection: from the perspective of ecological validity, it seems more meaningful to investigate attentional shifts and attendant reactions during, rather than after, an emotional confrontation. Participants were asked to judge the temporal order of the two, audio-tactile stimuli, while gazing at the picture presented centrally on the monitor. The audio-tactile stimuli were presented at the same location, straight ahead on the observer's body midline in Experiment 1; in Experiments 2 and 3, by contrast, they were presented at separate locations, to the left and the right of the body midline. In Experiments 1 and 2, we examined for basic effects of the valence and arousal associated with the emotional pictures on audio-tactile temporal processing, as well as the influence of spatial factors on any emotional modulations. To this end, we used three typical emotional categories: high-arousal negative, high-arousal positive, and neutral pictures. Furthermore, as emotional context, in particular with regard to action-related meanings, may play an important role in crossmodal temporal processing (see the evidence reviewed above), we further attempted to disentangle the influences of the emotional context (near-body threat, remote threat, and neutral context) from simple arousal and valence effects in Experiment 3. If arousal and valence are the determining factors in audio-tactile temporal processing, we expected threatening pictures with the same arousal level and valence, but different meanings (near-body threat, remote threat), to have the same modulatory effect, relative to the neutral condition. On the other hand, if the emotional context is crucial, as suggested by the embodiment account (Niedenthal, 2007), viewing images depicting near-body threat (e.g., a snake) may activate the defensive system, resulting in prioritization of tactile over auditory processing, compared to images depicting remote threat (e.g., a car accident) or neutral pictures.

3.3. Methods

3.3.1 Participants

A total of 36 paid volunteers took part in the experiments (twelve in each experiment; 22 female; mean age 25.9 years). All participants had normal or corrected-to-normal visual acuity, normal hearing, and no somatosensory disorders. The experiments were approved by the ethics committee of the LMU Psychology Department. Informed consent in accordance with the Declaration of Helsinki (2008) was obtained from each participant before the start of the experiment.

3.3.2 Stimuli and Apparatus

The experiments took place in a sound-isolated cabin with dim ambient lighting (1.65 cd/m^2). Visual stimuli were presented on a 21-inch Sony CRT monitor with a refresh rate of 100 Hz and a screen resolution of 1024 x 768 pixels. Sounds (1000 Hz, 73 dB) were generated and delivered via an M-Audio card (Delta 1010) to the speakers (Figure 3.1). Tactile stimuli were produced using solenoid actuators with an embedded cylinder metal tapper, driven by a Heijo Control Box (Heijo Research Electronics, UK). To attenuate possible noises made by the tactile tappers, these were placed on a large sponge. The experimental programs were developed using Matlab (Mathworks Inc.) and the Psychophysics Toolbox (Brainard, 1997).

The auditory and tactile stimuli were presented in front of the participant. To avoid the audio-tactile stimuli being seen, a black curtain was suspended on a line in-between the stimulus-generating devices and the participants (see Figure 3.1). The height of the black curtain was adjusted individually so that the participant could see the monitor, but not the speakers, the tactile tappers, and their hands. In Experiment 1, the tactile tapper was positioned on the front middle line and the loudspeaker was placed directly behind the tapper. The distance was selected such that participants could comfortably rest their right index finger on the surface of tactile tapper. In Experiments 2 and 3, two tactile tappers were placed symmetrically apart, 30 cm away from the midline to the left and the right, respectively. On each side, a speaker was placed directly behind the corresponding tapper. Participants placed their left- and right-hand index fingers on the corresponding tappers (see Figure 3.1).

Different types of emotional pictures were selected from the International Affective Picture System (IAPS) (Lang et al., 2008). Experiments 1 and 2 included 20 positive pictures (mean valence 7.04; mean arousal 6.56), 20 negative pictures (mean valence 3.18; mean arousal 6.56), and 20 neutral pictures (mean valence 5.07; mean arousal 2.68). Positive (such as an erotic couple) and negative pictures (such as a snake) were balanced for their arousal levels. Experiment 3 used 15 near-body threat pictures (mean valence 2.86; mean arousal 6.52), 15 remote threat pictures (mean valence 2.46; mean arousal 6.36), and 15 neutral pictures (mean valence 5.07, mean arousal 2.68). The images with near-body threat meanings (such as a snake) and remote threat meanings (such as a car accident) were again selected such that their valences and arousal levels were comparable. Specific descriptions and IAPS numbers of these pictures are provided in Supplementary materials S2.

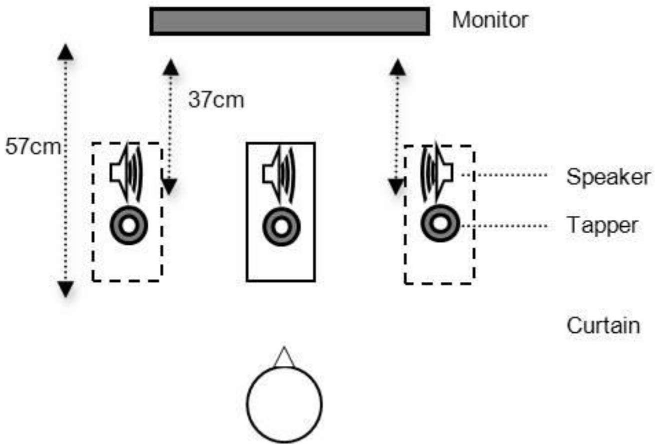


Figure 3.1. Schematic illustration of the experimental setup. In Experiment 1, one speaker and one tactile tapper were positioned straight ahead of the participants, on their body midline, and they used their right-hand index finger for receiving tactile input; see devices framed by the solid rectangle in the figure. In Experiments 2 and 3, two speakers and two tactile tappers were positioned one to the left and one to the right. Participants placed their left- and right-hand index fingers on the top of two corresponding tactile tappers; see devices framed by the dashed rectangles.

3.3.3 Procedure

A trial started with a fixation cross in the center of the monitor for 1 second, followed by a blank display presented for a random duration of 300 to 800 ms. Then, a randomly selected emotional picture was displayed centrally on the monitor for 300 ms. Simultaneously, the first stimulus of a pair of audio-tactile stimuli was delivered for 20 ms. After a variable stimulus-onset asynchrony (SOA: 0, ±40, ±80, ±180 ms, negative SOAs to indicate that the tactile stimulus was presented first), the second stimulus of the pair was presented, also for 20 ms. Note that the maximum SOA between the two stimuli was 180 ms, which was shorter than the picture presentation (300 ms). After 300 ms, the emotional picture was cleared and replaced by a question mark prompting participants for a response. In Experiment 1, participants were asked to "judge the modality form which the signal had come first" by pressing the corresponding foot pedal; the left and right foot pedals were mapped to hearing and touch, respectively, for one half of the participants, and vice versa for the other half. In Experiments 2 and 3, participants were asked to "judge the side from which a signal had come first". To reset picture-induced emotional states, we used relatively long inter-trial intervals, ranging from 3 to 7 seconds. Moreover, to ensure that participants viewed the pictures during the experiment, a red dot was overlaid on the center of the picture on 1 to 4 randomly selected trials in each block (consisting of a total of 42 trials). After a block was over, a random number selected from 1 to 4 was presented on the screen, and participants had to report whether the number of pictures with a red dot in that block was less than, equal to, or greater than the number presented. Participants could take a rest between blocks. All experiments implemented a full-factorial within-subject design, with independent variables of emotion type (3) and SOA (7). There were 20 trials for each emotion type × SOA combination in Experiments 1 and 2, and 30 trials for each combination in Experiment 3. Prior to the experiment, participants performed a block of practice trials.

At the end of the experiment, the pictures used in the experiment were presented again one by one, and participants were asked to rate the valence and arousal of the pictures on a paper sheet of the 9-point SAM (Self-Assessment-Manikin) scale (Bradley & Lang, 1994).

3.3.4 Data analysis

The proportions of "sound-first" responses were calculated for each condition and each participant and fitted by logistic functions. The points of subjective simultaneity (PSSs) and the just noticeable differences (JNDs) were then calculated from the logistic functions (for details method, see Shi, Zou, et al., 2010). Repeated-measures ANOVAs were subsequently carried out on the mean values of the participants' PSSs and JNDs, with the within-subject factor type of emotion (picture). Further LSD contrast tests were the carried as necessary. Analogous ANOVAs were performed on the mean valence and arousal estimates.

3.4. Results

3.4.1 Temporal order judgment

Figure 3.2 shows average psychometric functions and mean PSSs for Experiment 1, in which participants made temporal-order judgments of audio-tactile events that originated from the same location. The mean PSSs (±SE) were 12.5±2.8, 9.9±3.7, and 13.1±4.1 ms for the neutral, positive, and negative emotion conditions, respectively. Positive PSSs (observed in all three conditions) mean that the sound stimulus had to be presented prior to the touch stimulus in order to be perceived as simultaneous; in other words, touch is perceived first when the audio-tactile stimuli are presented synchronously. The PSS values did not differ significantly among three emotion conditions, $F(2, 22)=0.16$, $p=0.85$. Although the mean PSS values were all positive, they were actually not significantly higher than zero (all $p>0.1$), owing to large between-subject variation. The JNDs, that is, the indices of TOJ sensitivity, were 70.9±4.2, 80.7±3.9, and 79.7±5.6 ms for the neutral, positive, and negative conditions, respectively – they did not differ significantly among each other, $F(2, 22) = 0.99$, $p=0.4$, indicating the sensitivity of audio-tactile temporal-order judgments was not affected by the emotional pictures when both (audio-tactile) stimuli were presented at the same location.

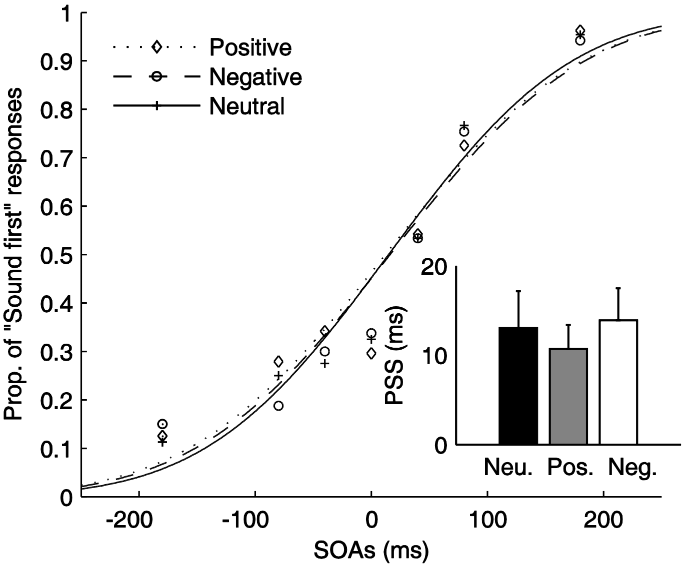


Figure 3.2 Psychometric functions fitted for the three emotion conditions in Experiment 1. The solid curve and crosses represent the baseline neutral condition, the dotted curve and diamonds the positive condition, and the dashed curve and circles the negative condition. The subfigure depicts the mean PSSs (and associated within-subject standard errors of the mean) for the three conditions.

In Experiment 2, in which audio-tactile stimuli were presented separately on the left and the right side and participants were asked to judge which side was stimulated first, the mean PSSs (±SE) were -6.1±2.3, 4.3±3.6, and 8.5±3.3 ms for the neutral, positive, and negative conditions, respectively (Figure 3.3). Like in Experiment 1, positive PSS means that the sound had to be presented prior to the touch stimulus to be perceived as simultaneous. In contrast to Experiment 1, the PSSs were significantly influenced by the type of emotional picture, $F(2, 22) = 4.25$, $p<0.05$. Post-hoc comparisons revealed the PSS to be significantly increased for the positive and negative conditions compared to the neutral condition (both $p<0.05$), indicating participants judged the tactile event to have occurred earlier in the high-arousal (both positive- and negative-emotion) conditions compared to the baseline. There was no difference between the positive and negative conditions ($p=0.41$). The mean JNDs for the neutral, positive, and negative conditions were 70.2±3.3, 69.3±2.9, 83.0±3.0 ms respectively – with significant differences among three conditions, $F(2, 22) = 4.68$, $p<0.05$: temporal discrimination sensitivity was the worst for the negative condition, compared to both the neutral and the positive condition (both $p<0.05$), without a difference between the latter ($p=0.87$).

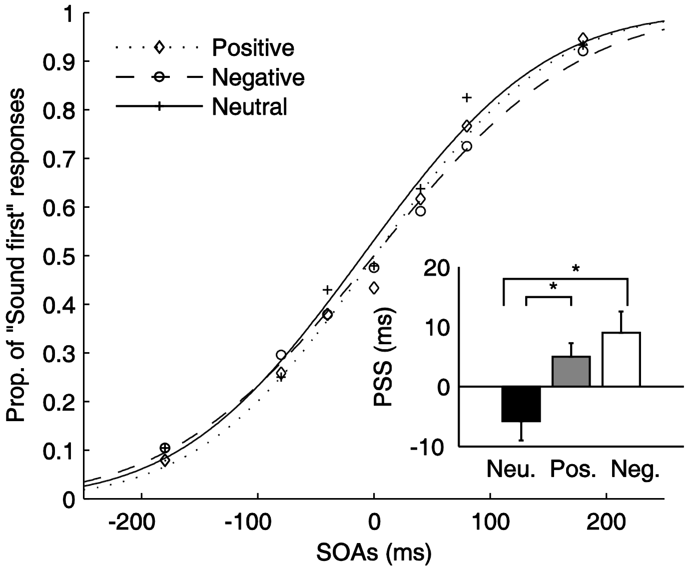


Figure 3.3 Psychometric functions fitted for the three emotion conditions in Experiment 2. The solid curve and crosses represent the baseline neutral condition, the dotted curve and diamonds the positive condition, and the dashed curve and circles the negative condition. The subfigure depicts the mean PSSs (and associated within-subject standard errors of the mean) for three the conditions (all p<0.05).*

To further examine the influence of different emotional meanings on audio-tactile temporal processing, in Experiment 3, we compared near-body threat and remote threat conditions to the neutral baseline – see Figure 3.4 for a depiction of the mean PSS and related psychometric functions. The PSS (±SE) values were -21.8±2.1, -5.5±3.3, and -16.0±2.5 ms for the neutral, near-body threat, and remote threat conditions, respectively – which differed significantly among each other, $F(2, 22)$ =6.92, p<0.01: for the near-body threat condition, the mean PSS was significantly increased compared to remote threat and neutral conditions (both p<0.05), while there was no significant difference between the latter (p>0.1). This effect pattern suggests that only near-body threat biased audio-tactile temporal processing towards the tactile modality. The mean JNDs were 80.9±3.9, 81.3±3.3, and 81.1±3.1 ms for the neutral, near-body threat, and remote threat conditions, without a difference among three conditions, $F(2, 22)$ = 0.003, p=0.99.

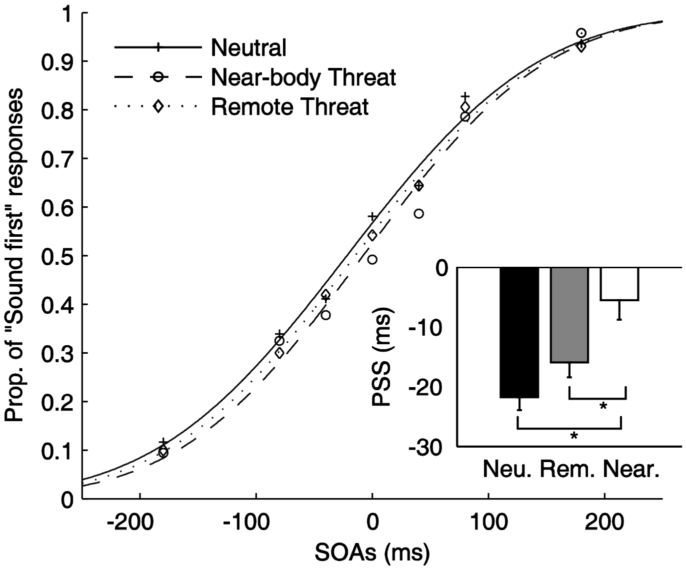


Figure 3.4 Psychometric functions fitted for the three emotion conditions in Experiment 3. The solid curve and crosses represent the baseline neutral condition, the dotted curve and diamonds the remote threat condition, and the dashed curve and circles the near-body threat condition. The subfigure depicts the mean PSSs (and associated within-subject standard errors of the mean) for the three conditions (all p<0.05).*

3.4.2 Emotion assessment

Mean subjective ratings of arousal and valence values for the emotion pictures used in the three experiments are summarized in Table 3.1.

Table 3.1 Mean assessments of emotional pictures (± standard error)

	Experiment 1			***Experiment 2***			***Experiment 3***		
	Neu.	*Pos.*	*Neg.*	*Neu.*	*Pos.*	*Neg.*	*Neu.*	*Near*	*Remote*
Valence	*5.1*	*6.4*	*3.5*	*5.3*	*6.4*	*2.9*	*5.5*	*3.2*	*2.7*
	(0.38)	*(0.17)*	*(0.37)*	*(0.08)*	*(0.21)*	*(0.28)*	*(0.18)*	*(0.26)*	*(0.22)*
Arousal	*4.1*	*6.7*	*6.3*	*3.5*	*6.7*	*6.7*	*3.5*	*6.9*	*7.1*
	(0.20)	*(0.20)*	*(0.47)*	*(0.33)*	*(0.21)*	*(0.30)*	*(0.34)*	*(0.27)*	*(0.29)*

Note: *Neu., Pos., Neg., Near, and Remote represent the neutral, positive, negative, near-body threat, and remote threat pictures, respectively.*

The results show the subjective ratings of valence and arousal level to differ significantly among the positive, negative, and neutral pictures used in

Experiments 1 and 2 (valence: $F(2,44) = 61.62$, $p<0.05$; arousal: $F(2,44) = 48.26$, $p<0.05$), without the ratings varying between Experiments 1 and 2 (valence: $F(1,22) = 0.74$, $p=0.4$; arousal: $F(1,22) = 0.18$, $p=0.68$). This argues against the differential patterns of audio-tactile TOJs between Experiments 1 and 2 being attributable to differences in rated arousal levels and valences. In Experiment 3, the subjective ratings differed significantly different among the three conditions (valence: $F(2,22) = 40.50$, $p<0.001$; arousal: $F(2,22) = 67.05$, $p<0.001$). Post-hoc test indicated that two types of negative pictures (i.e., the near-body threat and remote threat) were rated as significantly more unpleasant and more arousing (all $p<0.001$) than the neutral pictures. However, there was no difference in terms of subjective valence and arousal levels between two types of negative pictures (all $p>0.05$), again suggesting that valence and arousal were not the main causes for the differential biases in the audio-tactile TOJs.

3.5. Discussion

We investigated emotional modulation of audio-tactile temporal processing in three experiments. When audio-tactile stimulus pairs were presented at the same location centrally in front of the participant, we failed to find any influence of simultaneously presented emotional pictures on the audio-tactile TOJs of which signal (modality) was presented first (Experiment 1). The PSSs did not differ among the three emotional conditions. However, when auditory and tactile signals were delivered one to the left and the other to the right of the participant and the task was to judge on which side a signal came first, we found that the tactile signal was perceived first in both high-arousal negative and positive conditions, compared to the neutral condition in Experiment 2. However, from Experiment 2, it is not clear whether the shift toward tactile modality in temporal processing is due to high-arousal activation or touch-related (embodiment) meanings induced by the emotional stimuli (e.g., preparation of defensive action against snakes or priming of the sense of touch by erotic pictures). To disentangle these two factors, in Experiment 3, the effects of near-body threat were compared and contrasted with those of remote threat. The results revealed that only exposure to the near-body threat pictures did induce a shift toward the tactile modality in audio-tactile temporal processing.

Previous studies employing spatial cueing paradigms often found that attention was involuntary directed towards the location at which the emotional stimulus was presented, facilitating the processing of any subsequent stimulus presented at the same location (Poliakoff et al., 2007; Van Damme et al., 2009) – a typical prior-entry effect (Spence & Parise, 2010; Spence et al., 2001). It is important to note, however, that in the previous study examining the influence of emotional cues on TOJs (Van Damme et al., 2009), the experimental design was not orthogonal, that is, the cue was presented on the left or the right, on the same, spatial dimension as the task response . Thus, it was not clear whether the prior-entry effect was a spatial or a modality effect. Unlike previous studies that employed spatially informative cues (e.g., Poliakoff et al., 2007; Van Damme et al., 2009), we used spatially uninformative emotional stimuli. The emotional pictures were presented in the center of the screen, conveying no spatial information with regard to the audiotactile signals. In addition, we delivered audio-tactile signals during the exposure to the emotional stimuli. Such a design allowed us to examine for instantaneous emotional modulations of audio-tactile temporal processing. In Experiment 1, we specifically asked "which modality came first" when audio-tactile signals were presented at the same location. To control for potential prior entry on a particular sensory modality, in Experiments 2 and 3, we used an orthogonal cueing paradigm, that is, the response 'dimension' (left or right: "which side came first?") was orthogonal to that of the modality (auditory or tactile) within which crossmodal temporal processing was examined. The findings of Experiments 2 and 3 demonstrate that the tactile signal is more likely to be prioritized compared to auditory signal if (i) the two signals are spatially separated and (ii) accompanied by a high-arousal picture conveying near-body interaction meanings (such as appetitive or defensive meanings of seeing erotic pictures or near-body threat pictures, respectively). In contrast to the modulation of spatial attention (Phelps et al., 2006; Poliakoff et al., 2007; Van Damme et al., 2009), our findings highlight crossmodal attentional shifting by emotion, that is, spatially uninformative high-arousal pictures with appetitive or defensive meanings do bias temporal processing towards the tactile modality when audio-tactile signals are competing for processing.

It should be noted that emotional modulation of audio-tactile temporal processing is dependent on certain conditions. Experiment 3 demonstrated that not all high-arousal stimuli, but only depictions of near-body threat, could bias audio-tactile temporal processing toward the tactile modality. This is consistent with Van Damme et al.'s (2009) claim that physical threat signals can cause a shift of attention to the tactile, as opposed to the auditory, modality. By contrast, high-arousal remote threat (such as car accidents) did not influence the audio-tactile temporal order judgments. The differential effects between near-body and remote threats suggest that the impact of emotional context, in addition to the arousal-biased competition (see review Mather & Sutherland, 2011), must be taken into account in explaining crossmodal temporal processing. The findings thus confirm the idea that near-body physical or eminent threat prioritizes information processing towards action-relevant sensory modalities (Cornwell, Echiverri, Covington, & Grillon, 2008; Shi et al., 2012), thus facilitating action preparation with the aim of minimizing the influences of impending danger (Carlsson et al., 2006; Pichon, de Gelder, & Grèzes, 2012; Ploghaus, Becerra, Borras, & Borsook, 2003). Note that Experiment 2 also revealed that positive stimuli could bias attention to the tactile modality. This is presumably also attributable to those pictures having embodied meanings, such as erotica and sport pictures which are closely related to action. Neuroimaging studies have provided evidence that viewing emotional stimuli with action meanings (either defensive or appetitive) activates the action-related brain regions, such as the primary and secondary somatosensory cortices along with premotor and superior temporal regions (Dong et al., 1994; Gray & Tan, 2002; Keysers et al., 2004; Lloyd et al., 2006). For example, Lloyd and colleagues (2006) found that the posterior parietal cortex was activated preferentially in response to viewing a rubber hand being touched by a sharp (painful) stimulus as compared to a blunt (non-painful) stimulus. The posterior parietal cortex plays an important role in the early integration of visual information with somatosensory, proprioceptive, and vestibular signals. Thus, the neural network revealed in the above studies would have the potential for prioritizing the processing of touch over that of hearing in action-related contexts.

One further issue requires discussion: We found a clear emotion-induced modality-based shift in audio-tactile temporal processing when the two signals came from different locations, but not when they originated from the same location. What might be the reason for this dissociation? Studies of multisensory integration suggest that multisensory stimuli coming from the same origin are more likely to be integrated as one single, multisensory 'object' than two spatially separate signals (Stein & Stanford, 2008; also see the assumption of unity, Welch & Warren, 1980). Neurophysiological studies have shown that when multisensory stimuli (e.g., an audiotory and a visual signal) are presented within the overlapping receptive fields of a superior colliculus (SC) neuron, neuronal responses are enhanced (Stein & Meredith, 1993; Stein & Stanford, 2008). Behavioral studies have similarly revealed that the integration window is larger and crossmodal temporal discrimination diminished for vision-related multisensory integration at the same location, compared to separate locations (Spence et al., 2003; Zampini et al., 2003a, 2003b). However, it is still controversial whether such a spatial modulation would also apply to audio-tactile temporal perception (Kitagawa et al., 2005; Occelli, Spence, & Zampini, 2008; Occelli et al., 2011; Zampini et al., 2005). On this background, our differential effects on audio-tactile TOJs between spatially coincident and separate stimuli may suggest that the 'prior' assumption of unity assumption for audio-tactile stimuli that originate from the same location somehow counteracts the otherwise ensuing modality-oriented attentional bias. This view is also consistent with recent suggestions that crossmodal congruency results in enhanced binding of multisensory stimuli and reduced prior entry effects(Spence & Parise, 2010) .

In conclusion, our findings provide clear evidence that high-arousal pictures with action meanings can facilitate tactile over auditory processing when audio-tactile signals come from different locations. Our results support the notion of a functional linkage between vision and touch by action-related emotional stimulation (Dong et al., 1994; Gray & Tan, 2002; Keysers et al., 2004; Lloyd et al., 2006). However, audio-tactile signals originating from the same location might engender a strong unitary assumption (i.e., integration bias) which counteracts modality-specific attentional shifting.

Ⅳ Chapter 4 The role of action context on subjective time

4.1 Abstract

Time perception in the sub-seconds to seconds range is susceptible to a wide range of factors. In the present study, we examined how implicit action context influences tactile duration judgments. We asked participants to make temporal bisection judgments of vibrotactile events while they viewed a potentially catchable swinging ball in front of them. Tactile durations were judged longer when the ball was moving than when it was static. Approaching movement induced a larger tactile duration overestimation than lateral movement, while receding movement produced a similar duration expansion to approaching movement. The latter suggests that the observed effect is not due to increased arousal or visual looming. Interestingly, however, the effect of the approaching movement on subjective tactile duration was diminished when participants held lightweight objects in their hands. The results suggest that spontaneous re-action induced by visual movement leads to crossmodal temporal expansion in the tactile modality.

4.2 Introduction

A sense of duration and rhythm is fundamental to our daily activities, such as catching an object, dancing, or making music. Yet, time perception in the sub-seconds to seconds range is susceptible to a wide range of factors, including stimulus intensity (Matthews, Stewart, & Wearden, 2011), valence and arousal (Droit-Volet & Gil, 2009; Shi et al., 2012), repetition (Pariyadath & Eagleman, 2008), distribution of presented durations (Gu & Meck, 2011; Jazayeri & Shadlen, 2010; Lejeune & Wearden, 2009), and modality interaction (Ganzenmuller, Shi, & Muller, 2012; Penney et al., 2000; Shi, Chen, et al., 2010; Shi , Ganzenmüller, & Müller, 2013).

Another crucial factor in time perception is action context. For instance, most of us would have experienced 'chronostasis' (Yarrow et al., 2001), an illusion of time in which a clock's second hand appears to stand still when one directs gaze from elsewhere onto it. Chronostasis-like time distortions also occur during manual movements (Park, Schlag-Rey, & Schlag, 2003; Yarrow & Rothwell, 2003), or during action preparation (Hagura, Kanai, Orgs, & Haggard, 2012). In addition to real actions, subjective time is also influenced by static images that trigger dynamic representations of action or motion (Gable & Poole, 2012; Nather et al., 2011; Orgs et al., 2011; Yamamoto & Miura, 2012). For example, when asked to estimate the duration of a body posture image, participants judged postures that required more movement as longer than postures involving less movement, for the range of short durations (Nather et al., 2011; Orgs et al., 2011). It should be noted, though, that these studies have focused on duration distortions of events that are specific to action goals(Yarrow et al., 2001; Yarrow & Rothwell, 2003) or events with action meanings(Gable & Poole, 2012; Nather et al., 2011)

The evidence of action influencing time perception suggests that subjective time is not a pure perceptual phenomenon, but can only be fully understood by taking the larger context of the perception-action loop into consideration. The notion of a tight linkage between perception and action is central to the 'embodiment' and 'enactive' views (e.g., see Clark, 1999; Engel et al., 2013), which argue that perceptual and cognitive processes are subject to the constraints of action, or intended action, to external dynamic stimuli. Based on this idea, we hypothesized that action context, including action and (explicitly or implicitly) intended action, influences time perception of sensory events in the whole sensorimotor loop, rather than just the motor itself or events relating to the action goals. If this assumption held, action context should have a wide impact on the perceived time of events, including even action-irrelevant events, within the sensorimotor loop.

To test this hypothesis, we examined whether an implicit action context induced in participants by watching a near-body moving object, a 'ball', could influence the perceived duration of an irrelevant tactile event delivered to participant's hand. If the implicit action context has a wide impact on the subjective duration of events, a distortion of the concurrent action-irrelevant tactile duration may also be observed. The distortion effect may critically depend on the possibility of potential interaction, such as whether the moving object would, or would not, be easy to catch. To address this, we first examined influences of approaching and, respectively, lateral ball movements on perceived tactile duration, given that an approaching ball may be expected to induce a more robust implicit 're-action' compared to a lateral movement and a static baseline condition (Experiment 1). However, action contexts or types of visual movements (e.g., looming vs. receding) may also cause an increase in arousal (Hodinott-Hill, Thilo, Cowey, & Walsh, 2002; van Wassenhove et al., 2008), which potentially contribute to the duration distortion, that is, a duration expansion. To control for this and disentangle the effects of arousal and visual looming on subjective duration from those of an implicit interaction, we compared and contrasted the impacts of approaching and receding movements in Experiment 2. To further support our 'embodied view' of subjective duration expansion, we examined whether the subjective time expansion would be diminished when the activation of an embodied re-action is inhibited. To this end, in Experiment 3, we presented participants with approaching movements while they held two lightweight objects in their hands (this was meant to inhibit implicit re-actions to the ball), and compared their tactile duration judgments under this hands-occupied condition to their judgments in the hands-free approaching-movement and the static baseline conditions.

4.3 Methods

4.3.1 Participants

A total of 40 participants took part in the Experiments 1, 2, 3a, and 3b (10 in each experiment; 23 female; mean age 25 years). All participants had normal or corrected-to-normal vision and no somatosensory disorders. They gave written informed consent prior to the experiment and were paid at a rate of 8 Euro/hour.

4.3.2 Stimuli and apparatus

All three experiments were conducted in a sound-isolated and dimly lit (0.76 cd/m^2) cabin. Vibrotactile (200 Hz) stimuli were produced by a vibrator (*AEC* Tactaid *VBW32*) and delivered to the participant's right-hand index finger. A simple pendulum was constructed with a metal ball (2 cm in diameter) suspended on a string (108 cm) from the ceiling of the cabin. At its resting position, the ball was 4.5 cm above the table (at which the participant was seated); a black fixation cross marked the table right below this position. During each trial, the pendulum swung back and forth for one cycle, with a swing amplitude (i.e., the ball's maximum angular displacement from its equilibrium position) of 27°, 20°, and 20°, in Experiments 1, 2, and 3b, respectively (see Figure 4.1A). Note that Experiment 3a implemented a control condition to Experiment 3b without any ball movement. In Experiments 3a and 3b, two lightweight objects (black ¾ cylinders 2.5 cm in height and 4.2 cm in diameter, 93 g) were placed in participants' hands in order to inhibit interaction. In Experiment 3b, skin conductance responses (SCRs) were recorded additionally at a sampling-rate of 500 Hz using a BioPac system (*MP35*).

4.3.3 Design and Procedure

Participants were asked to put their hands comfortably on the table in palm-up position, and the tactile vibrator was attached to their right index finger by using an elastic finger sleeve. The hands' positions relative to the ball moving trajectories are illustrated in Figure 4.1B-D. A temporal bisection task, which required participants to classify the vibrotactile duration presented on a trial into the categories 'short' or 'long', was used in all experiments. At the beginning of the experiment, participants were first trained to discriminate two vibrotactile standard durations, one short (200 ms) and one long (600 ms), until they could perfectly classify the two standards. Then, a formal test session began. On each test trial, a probe vibrotactile duration randomly selected from 200, 300, 400, 500, and 600 ms was delivered to the participants. Participants were asked to indicate whether presented vibrotactile duration was closer to the short or the long standard, by pressing either the left or the right one of two foot-pedals.

During the test session, we manipulated the ball movements, which were totally irrelevant to the temporal bisection task. We used three types of movements: approaching, lateral, and 'static', in the Experiment 1 (Figure 4.1B), and approaching, receding, and 'static' Experiment 2 (Figure 4.1C). Next, we compared tactile duration judgments between the hands-free and hands-occupied conditions without ball movement in Experiment 3a, which served as a baseline test for Experiment 3b. In the hands-occupied condition, two lightweight objects (see above) were placed in the palms of participants' left and right hands. Finally, in Experiment 3b (Figure 4.1D), we compared duration judgments among three conditions: (i) approaching movement, hands-free (same as the approaching condition in Experiment 2); (ii) approaching movement, hands-occupied; and (iii) static condition, with half the trials hands-free and half hands-occupied.

At the beginning of trials with ball movements, the experimenter held the ball and the mouse in her right and, respectively, left hand. She initiated a pendulum movement by simultaneously releasing the ball and the mouse button, with the latter as a trigger of the onset of the swing. The temporal discrepancy between her left and right hand release was measured 100 times prior to the experiment, which yielded a mean difference of 3 ms, with a standard deviation of 12 ms and a maximum difference of 42 ms. Thus, compared to the 2-sec of whole cycle of the pendulum swing, the temporal discrepancy was small and can be regarded as a randomly jittered onset of the swing. A vibration was delivered to the participant's index finger during the first half cycle of the pendulum swing; the vibration started with a random onset (200–400 ms) relative to the start of the swing and ended within the first half cycle of the swing. The experimenter quietly grasped the ball when it swung back after one cycle.

During the trial, participants were instructed to fixate their eyes on the ball in front of them. The movement conditions were tested block-wise, in order to avoid the experimenter frequently changing her position. At the beginning of each block, 5 top-up trials with the short and long vibrotactile stimuli (200 and 600 ms) were presented to refresh the participant's memory of the two standards. There were 12 blocks, each consisting of 25 trials, in Experiments 1, 2, and 3b, and 8 blocks of 25 trials in Experiment 3a. Each experimental condition was repeated 20 times.

After the formal test session in Experiment 3b, the participants were asked to rate the valence and arousal of the movement using a 9-point scale Self-Assessment-Manikin (SAM) survey (Bradley & Lang, 1994), in order to test if arousal levels were similar between hand-free and hand-occupied approaching conditions.

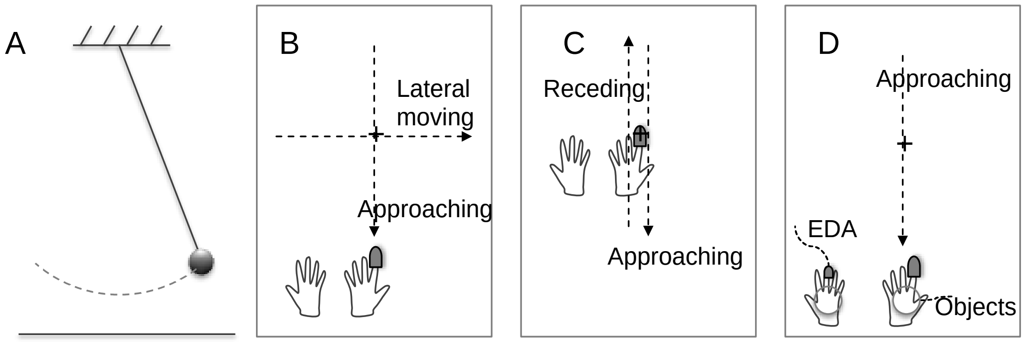


Figure 4.1 Schematic illustrations of the set-up used in the three experiments. A. A pendulum swing was constructed with a metal ball. B. In Experiment 1, participants placed their two hands, one next to the other, such that the right hand was close to the near end point of the maximum pendulum swing in the approaching-movement condition; the viewing distance to the center of the fixation marker was 57 cm. C. In Experiment 2, participants placed their hands such that the right hand just rested on the fixation marker (the left hand was comfortably at rest next to the right hand); D. In Experiment 3b, participants placed their hands again such that the right hand was close to the near end point of the maximum pendulum swing in the approaching-movement condition. Two skin conductance response (SCR) sensors were attached to the left-hand index and middle fingers. In the hands-occupied blocks, two light objects were placed on the participants' palms throughout the duration of the trial blocks.

4.3.4 Data analysis

For the temporal bisection task, we first calculated the proportions of 'long' responses for the five probe durations, separately for each participant and condition. We then fitted psychometric curves using logistic regression. From the fitted curves, the points of subjective equality (PSE) of the temporal bisection could then be estimated as the respective duration corresponding to the 50%-threshold. In a similar way, the just-noticeable differences (JNDs) could be calculated, using half the difference in duration between the 25%- and 75%-thresholds. In Experiment 3b, SCRs were measured in micro-ohms to monitor arousal changes, and ΔSCRs were calculated after baseline correction for the time window of 1–4 seconds after stimulus onset.

Repeated-measures ANOVAs were conducted separately on the PSE and JND estimates with type of visual movement as factor in all experiments. Based on the ANOVA results, further relevant post-hoc contrast tests were conducted to ascertain significant differences among specific conditions. Repeated-measures ANOVAs were also applied to the SAM ratings, and to the physiological (SCR) data in Experiment 3b.

4.4 Results and discussion

4.4.1 Experiment 1

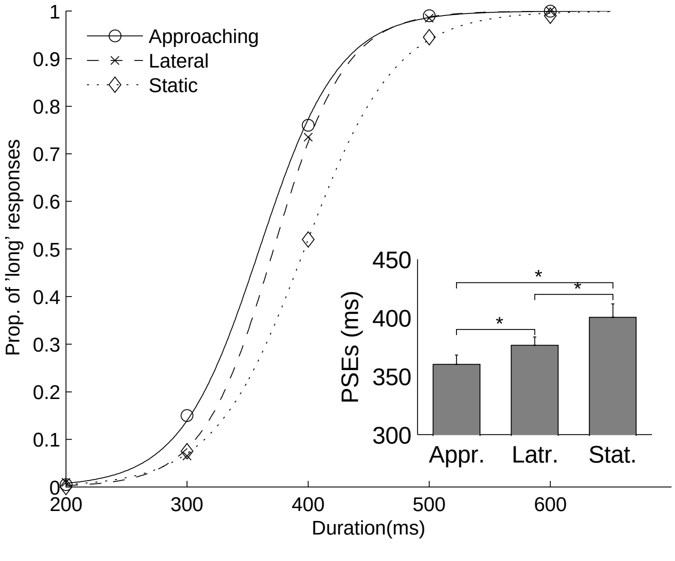


Figure 4.2 Results of Experiment 1. Mean proportions of 'long' responses in the tactile duration bisection task, and the fitted psychometric functions, are plotted against the probe durations for the three visual movement conditions. The inset figure shows the mean PSEs, and related standard errors, for the three conditions, which differ significantly among each other (p<0.05).*

Experiment 1 examined the influences of approaching and lateral movements on vibrotactile temporal bisection performance. Figure 4.2 shows the psychometric curves of the tactile duration bisection tasks for the three ball movement conditions. The mean PSEs (±SE) were 360±8, 376±7, and 400±11 ms for the approaching, lateral movements, and baseline conditions, showing significant influences of the pendulum movements during the tactile stimulation, $F(2,18) = 10.04$, $p<0.01$, $\eta_p^2 = 0.53$. The follow-up contrast tests revealed the mean PSE to be significantly lower for the approaching movement compared to the other two conditions (both $p<0.05$), and the mean PSE to be lower for the lateral movement than for the static condition ($p<0.05$). Lower PSEs compared to the baseline mean more 'long' responses, indicating a subjective duration expansion. Thus, the results of Experiment 1 demonstrate that the vibrotactile durations were overestimated in both movement conditions compared to the static baseline, with the strongest overestimation manifesting in the ball approaching condition. In contrast to the PSE, the discrimination sensitivity measured by the JNDs (or slopes of the psychometric functions) did not differ significantly among the three conditions, $F(2,18) = 1.59$, $p=0.23$, $\eta_p^2 = 0.15$. This suggests that the ball movement did not affect the sensitivity of temporal bisection performance.

4.4.2 Experiment 2

Experiment 1 demonstrated the largest duration overestimation in the approaching-movement condition, which could be attributable to a visual-looming effect (Wittmann et al., 2010) and/or an arousal effect (Droit-Volet & Meck, 2007). Previous studies have shown that looming signals, compared to receding and static signals, are particularly salient events that as such might provoke the relatively large duration overestimation (van Wassenhove, Wittmann, Craig, & Paulus, 2011; Wittmann et al., 2010). Quite possibly, looming signals may have a general effect on subjective duration, as a result of which so the duration of concurrent tactile events would also be affected. This would predict a differential time distortions between approaching and receding movements. Experiment 2 was designed to examine this prediction by comparing the vibrotactile temporal bisection judgments among the approaching, receding, and static (movement) conditions.

Again we found a significant impact of the ball movement on the tactile duration judgments, $F(2,18)=7.29$, $p<0.01$, $\eta_p^2=0.45$. The mean PSEs (±SE) were 380±10, 381±13, and 407±12 ms for the approaching-movement, receding-movement, and static baseline conditions, respectively (see Figure 4.3). The post-hoc contrast tests revealed the PSEs to be significantly lower in both the approaching and receding conditions compared to the static baseline (both $p<0.01$), while no significant difference between the approaching and receding conditions ($p=0.95$). This pattern indicates that overestimation of tactile duration is not attributable to the type of stimulus movement (i.e., a looming effect); rather, it is likely due the implicit reaction induced by the moving object.

Similar to Experiment 1, the JNDs did not differ among the three conditions, $F(2,18)= 0.92$, $p=0.42$, $\eta_p^2 = 0.09$, suggesting that the pendulum movement did not change the temporal discrimination sensitivity.

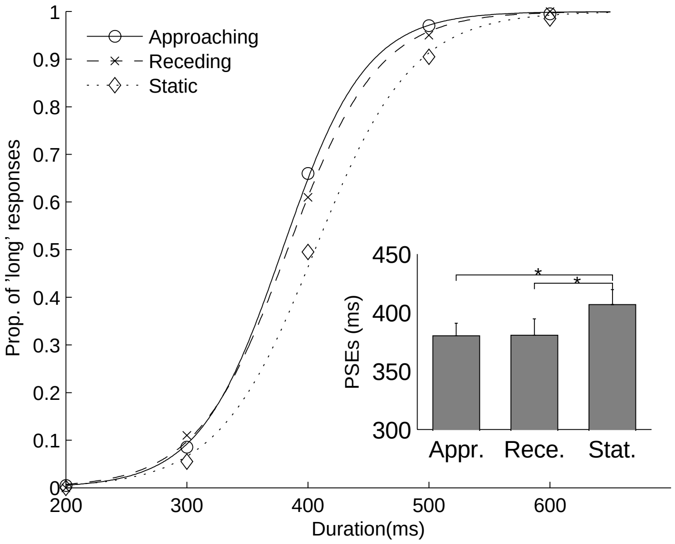


Figure 4.3 Results of Experiment 2. Mean proportions of 'long' responses in the tactile duration bisection task, and the fitted psychometric functions, are plotted against the probe durations for the three visual movement conditions. The inset figure shows the mean PSEs, and related standard errors, for the three conditions, with the approaching- and receding movement conditions differing significantly from the static baseline (p<0.05).*

4.4.3 Experiment 3

Experiment 3a examined whether merely putting two lightweight objects into participants' hands would alter their tactile duration judgments, without them seeing any moving objects. The mean PSEs (±SE) were 422±9 and 421±12 ms for the hands-occupied and hands-free conditions, respectively; that is, there was effectively no difference between the two conditions, $F(1,9) = 0.002$, $p=0.96$, $\eta_p^2 =0.00$. However, the mean JND was larger for the hands-occupied than for hands-free condition, $F(1,9)= 8.88$, $p<0.05$, $\eta_p^2 =0.50$, suggesting that holding the two light-weight objects increased the uncertainty of the tactile duration judgment.

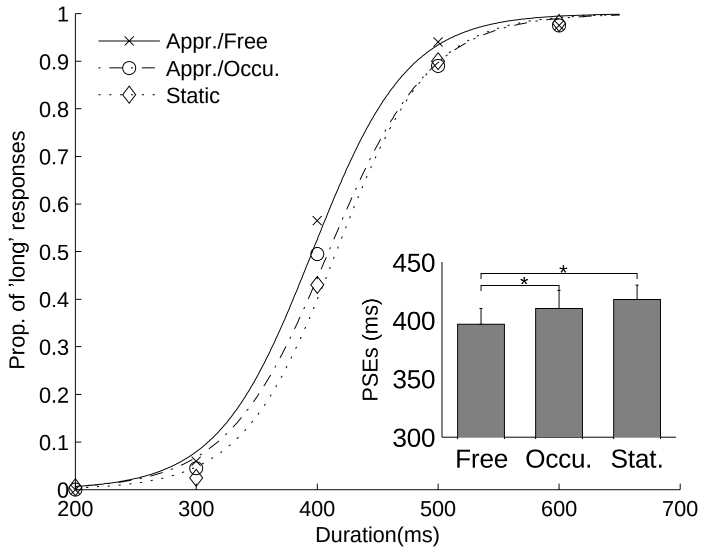


Figure 4.4 Results of Experiment 3b. The mean proportion of "long" responses in the tactile duration bisection task, and the fitted psychometric functions, are plotted against the probe durations for the three ball movement conditions: the approaching hand-free, the approaching hand-occupied, and the static. The inset figure shows the mean PSEs and related standard errors for the three conditions (p<0.05).*

Experiment 3b further tested whether the hands-occupied and hands-free conditions would have differential effects on the duration judgments when seeing a ball approaching. Figure 4.4 illustrates the psychometric curves for the approaching-movement hands-free condition, the approaching-movement hands-occupied condition, and the static baseline condition, along with corresponding mean PSEs of the temporal bisection performance. The mean PSEs (±SE) were 397±13, 410±14, and 418±12ms for the approaching hands-free, approaching hands-occupied, and baseline conditions, respectively. A one-way repeated-measures ANOVA revealed the effect of movement type to be significant, $F(2,18) = 5.84$, $p<0.05$, $\eta_p^2 =0.39$. Follow-up contrast tests indicated that the subjective tactile duration was longer in the approaching hands-free condition compared to the approaching hands-occupied and static conditions (both $p<0.05$), while there was no difference between the latter ($p=0.36$). The pattern suggests that the hand status plays an important role in vibrotactile duration judgments when a moving object is presented. A one-way repeated-measures ANOVA on JNDs revealed no effect of the movement type on the discrimination sensitivity of the duration judgments, $F(2,18)=0.28$, $p=0.76$, $\eta_p^2=0.03$.

Subjective SAM ratings showed that the two (i.e., hands-occupied and hands-free) approaching conditions were rated as slightly higher in arousal (5.6 and 5.5 for the hands-occupied and hands-free conditions, respectively) than the static baseline (3.7), $F(2, 18) = 16.51$, $p<0.01$, $\eta_p^2 = 0.65$; however, there was no difference between the two approaching conditions ($p=0.59$). The differences in (rated) subjective arousal were not confirmed by physiological data. A one-way repeated measures ANOVA failed to reveal any significant modulation of skin conductance responses (Δ SCRs), $F(2,18) = 1.15$, $p=0.34$, $\eta_p^2 = 0.11$. These results suggest that the ball movements did not change the physiological arousal level, and the differential effects on the duration judgments between the two (hands-occupied and hands-free) approaching conditions cannot be attributed to differences in subjective arousal (as the ratings did not differ between these two conditions).

4.5 General discussion

In the present study, we examined whether action context could cause a time distortion in action-irrelevant tactile duration judgments. We measured tactile temporal bisection performance while participants watched a swinging ball. Participants overestimated the tactile duration when the ball was approaching or moving laterally, with the overestimation being more marked for the approaching movement (Experiment 1). Previous studies had shown that a movement event is perceived as lasting longer than a static event of the same physical duration (Brown, 1995; Kaneko & Murakami, 2009) . Our findings go beyond this by indicating that not only the perceived duration of the movement event itself, but also that of other action-irrelevant events in the sensorimotor loop (i.e., in the present study: the tactile event) may also be affected.

It could be argued that these effects are due to the ball movement inducing a general alerting or arousal effect, as suggested by previous studies that showed physically intense stimuli or stimuli with emotional meanings engender high arousal and, as a result, speed up the internal pacemaker, distorting the subjective duration of those stimuli (Droit-Volet et al., 2004; Penton-Voak et al., 1996). However, this is unlikely to account for our results, as we found no physiological indications of increased arousal in the movement conditions (Experiment 3b); that is, the ball swing was not experienced as a highly arousing stimulus, capable of altering the speed of the internal pacemaker. Moreover, the sensitivity of temporal bisection was not changed in the movement conditions compared to the static baseline in any of the three experiments. Even though the SAM rating values were slightly higher in the two approaching-movement conditions compared to the static condition, this increased subjective arousal cannot explain the differential effects between the two approaching (i.e., hands-occupied vs. hands-free) conditions. In this regard, our findings are consistent with the conclusion from saccadic chronostasis studies, namely, that the arousal induced by an action or movement is a not a critical factor for the expansion of subjective duration (Yarrow et al., 2001; Yarrow, Haggard, & Rothwell, 2004).

The subjective expansion of tactile durations induced by the ball movement in our study is also not likely due to the visual looming. Looming visual stimuli have been found to be perceived as longer than receding stimuli of the same physical duration (van Wassenhove et al., 2008; Wittmann et al., 2010). If the visual looming had the same effect across modalities on tactile duration judgments, one would expected more marked subjective overestimations for the approaching- compared to the receding-movement condition. However, we found both approaching and receding visual movements to induce rather similar overestimations of the tactile duration when participants' hands were free (Experiment 2). Moreover, when participants held lightweight objects in their hands, the overestimation was diminished in the approaching condition (Experiment 3b). Thus, the differential effects observed in the present study cannot be attributed to an effect of visual looming.

Instead, we argue that the near-body ball swings may spontaneously activate action preparation, with processes of action planning distorting the subjective time estimates of sensory events taking place in the sensorimotor loop. This view is consistent with recent ‘embodiment’ views on perception and action. According to embodied approach, perception and cognition can only be appropriately understood in terms of sensorimotor interaction (Engel et al., 2013; Varela, Thompson, & Rosch, 1991). This has also been demonstrated in time perception. For instance, individuals often automatically imitate perceived facial expressions, and voluntary adoption of emotional facial expressions distorts the subjective duration of the facial stimuli, giving rise, for example, to a duration expansion for angry faces (Droit-Volet & Meck, 2007; Effron et al., 2006). However, when imitation of facial expressions is inhibited, for instance, by a pen held between the lips, the overestimation disappeared (Effron et al., 2006). A recent study (Gable & Poole, 2012) also demonstrated that stimuli engendering a positive, approach motivation (e.g., delicious desserts) shortened the subjective time, which the authors attributed to the possibility that shortened durations in an appetitive state prolong the pursuit of appetitive objects or goals. It is worth noting, however, that these studies only examined the time distortion of events that (in their task contexts) had ‘action’ meanings. By contrast, our findings suggest further that action-irrelevant events sensed in the sensorimotor loop, such as tactile stimuli, can also be influenced by the implicated activation of sensorimotor interactions, with the magnitudes of this influence depending on the urgency and possibility of interaction. For example, both the approaching and receding movements passed over participants’ right hand with the same trajectory, while the lateral movement swung 57 cm further away from participant’s fingertips. Thus, the urgency of a reaction was higher for the approaching swing compared to the lateral swing, while being similar to the receding swing. As a consequence, the tactile duration expansion was larger in the approaching than in the lateral condition, and was the same as in the receding condition. However, when participants held two lightweight objects in their hands under conditions of approaching movement, the possibility of manually reacting to the ball was limited, and the activation of sensorimotor action preparation (using the hands) was likely inhibited. As a result, the tactile expansion effect was diminished in the approaching-movement hands-occupied condition. Thus, our findings are consistent with and extend the embodiment view of time perception, namely, that embodied actions can distort time estimation (Effron et al., 2006; Nather et al., 2011; Niedenthal, 2007).

One might ask why the action context induced by visual movements does expand, rather than contract, the subjective tactile duration. Overestimation of target durations caused by actions has been shown in various paradigms, such as during saccadic or manual movements (Yarrow et al., 2001; Yarrow & Rothwell, 2003). The overestimation is interpreted as a compensation mechanism in which the onset of the target event is captured by the onset of the action execution (Yarrow et al., 2001). It has also been suggested that activity induced by movement preparation in the motor cortices is linked to the initiation of dynamic movement activity (Churchland, Cunningham, Kaufman, Ryu, & Shenoy, 2010) as well as to modulations of sensory mechanisms that enhance the speed of perceptual processing (Hagura et al., 2012). Similarly, voluntary motor preparation for nearby moving stimuli may increase the speed of somatosensory processing, such that the real action can be targeted more precisely and, thus, be more beneficial for survival. The duration overestimation of tactile events that occurred during the visual movement in the present study may reflect such facilitated sensory processing.

It is, however, worth noting that action does not always expand perceived duration. For example, when an action has a causal effect, the elapsed time between the action and its consequent effects is shortened, which is attributed to 'intentional (action-effect) binding' (Haggard & Clark, 2003; Haggard, Clark, & Kalogeras, 2002). However, this type of shortening effect is specific to causal events, induced by the anticipatory awareness of action effects (Haggard & Clark, 2003; Moore & Haggard, 2008) or general causal binding (Buehner, 2012; Buehner & Humphreys, 2009).

In conclusion, our results provide clear evidence that the action context induced by monitoring a near-body visual movement expanded tactile duration judgments. When induction of this context was physically inhibited, subjective expansion of tactile durations was diminished. These findings support the 'embodiment' view of time perception (Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007) , according to which embodied reactions increase the speed of sensory processing (Hagura et al., 2012) and, consequently, expand subjective time in the sensorimotor loop. Our findings suggest that the subjective duration expansion by embodied action contexts is not limited to the action itself or events relating to action goals, but also found for action-irrelevant events occurring in the sensorimotor loop.

V Chapter 5 Deutsche Zusammenfassung

Wir nehmen oft externe Ereignisse mit mehreren Sinnen wahr. Deshalb ist es wichtig zu verstehen, wie Informationen, die von einer Modalität wahrgenommen werden, die Wahrnehmung von Informationen in anderen Modalitäten beeinflussen. In aktuellen Studien zur Zeitwahrnehmung wurde hauptsächlich untersucht, wie wir Ereignisse wahrnehmen, die in einer einzigen Modalität wahrgenommen werden (z.B emotionale Reize). Hierbei konnte mehrfach gezeigt werden, dass die Dauer von negativen, stark erregenden Stimuli oft als länger wahrgenommen wird als die von neutrale Reize mit der gleichen physikalischen Dauer (Angrilli et al., 1997; Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Noulhiane et al., 2007; Wittmann et al., 2010). Bis heute ist unklar, ob die Wahrnehmung emotionaler Ereignisse in einer Modalität eine Wahrnehmungsverzerrung der Dauer von nichtemotionalen Ereignissen in anderen Modalitäten bedingt.

Eine wichtige Funktion des emotionalen Systems ist es, dass Individuen schnell und genau auf gefährliche, externe Ereignisse reagieren können, da dies für den Erfolg und das Überleben wichtig ist (Darwin, 1872/1998). Deshalb könnte man davon ausgehen, dass die subjektive Verzerrung der Dauer von Emotionen die starke Kopplung von Zeitwahrnehmung und Handlung widerspiegeln. Nach Wahrnehmungs-Handlungs-Kopplungs-Theorien, wie die ideomotorische Theorie und die Verkörperungsansätzen (Embodiment) (Shin, Proctor, & Capaldi, 2010; Varela et al., 1991), ändert eine Handlung Wahrnehmungen, die mit dieser Handlung in Zusammenhang stehen. Tatsächlich hat die aktuelle Forschung gezeigt, dass Handlungen die subjektiv wahrgenommene Dauer von mit der Handlung in Zusammenhang stehenden Ereignissen verlängern (Shin et al., 2010; Yarrow et al., 2001; Yarrow & Rothwell, 2003). Allerdings ist bisher kaum untersucht worden, wie Handlungen Ereignisse, die unabhängig von der Handlung sind, in der Zeitwahrnehmung beeinflussen.

Die Aufmerksamkeit, als begrenzte Ressource, ist ein kritischer Faktor der Zeitwahrnehmung beeinflusst. Wenn Emotionen und/oder Handlungen für die Verarbeitungskapazität in manchen Situationen konkurrieren, ist die

Verarbeitung von Zeit unweigerlich beeinflusst. Beispielsweise hat sich gezeigt, dass Emotionen die Aufmerksamkeit automatisch auf die Stelle im Raum lenken, an der der emotionale Reiz dargeboten wird. Diese Aufmerksamkeitslenkung bewirkt, dass Ereignisse bereits zeitlich verarbeitetet werden, die an dieser Stelle im Anschluss dargeboten werden (Prior Entry Effekt) (Van Damme et al., 2009). Ob eine Handlung oder Emotionen einen modalitätsbasierten Prior Entry Effekt verursachen können, ist noch unbekannt. Die Erforschung dieser Frage könnte eine Verknüpfung zwischen Modalitäten zeigen, die durch Emotionen oder Handlungen in der Zeitwahrnehmung aktiviert werden.

In dieser Arbeit habe ich meinen Fokus auf die crossmodale Emotionsanpassung in der Zeitwahrnehmung gelegt, insbesondere auf die folgenden drei Aspekte: a) wie regulieren Emotionen, die durch visuelle Bilder erzeugt wurden, die subjektive Dauer von nicht-emotionalen taktilen Ereignissen; b) wie beeinflussen irrelevante visuelle Emotionen die Priorität der audiotaktilen zeitlichen Verarbeitung; c) wie regulieren irrelevante Handlungskontexte die taktilen Zeitdauerwahrnehmung.

1) Auswirkung von Emotionen auf Urteile über die Dauer taktiler Reize

Der erste Teil der Forschungsarbeit konzentriert sich darauf, ob negative, stark erregende visuelle Reize darauf folgende subjektive Urteile über die Dauer neutraler taktiler Reize verfälschen können und welche Theorie über Emotionsverarbeitung (dimensional vs. separat) besser geeignet ist, um die beobachteten Effekte zu erklären. (Ekman 1992; Hamann, 2012; Lang et al., 1997; Smith & Ellsworth, 1985). Es wurden drei Experimente durchgeführt. In allen wurde eine gut beschriebene zeitliche Einteilungsaufgabe (temporal bisection) mit taktilen Reizen genutzt. Ein emotionales Bild wurde immer vor der taktilen Zeitwahrnehmungsaufgabe gezeigt. Die Teilnehmer wurden gebeten, die emotionalen Bilder zu betrachten und anschließend die Dauer des vibrotaktilen Reizes zu beurteilen. In Experiment 1 verwendeten wir drei Arten von emotionalen Reizen: neutral, negativ-bedrohlich und negativ-ekelerregend. Die Ergebnisse zeigten, dass die Dauer der taktilen Reizen (300-900ms) nur dann überschätzt wurde, wenn ein negatives-bedrohliche Bild vor den taktilen Reizen präsentiert wurde. Die Wahrnehmungsveränderung der Dauer konnte nicht gezeigt werden, wenn die ekelerregenden Bilder verwendet wurden. Die

Ergebnisse zeigen, dass durch visuelle Reize induzierte Emotionen zu einer Überschätzung der Dauer taktiler Reize führen können. Aber die Wirkung ist abhängig von der Art der emotionalen Reize. Dies ist eher im Einklang mit der Vorstellung von separaten Emotionen, als mit einer dimensionalen Darstellung von Emotionen. Im zweiten Experiment konnte gezeigt werden, dass durch die Betrachtung bedrohlicher Bilder lediglich taktile Reize von kurzer Dauer (300-900 ms) beeinträchtigt waren, im Gegensatz zu Reizen von langer Dauer (1000–1900 ms). Die Ergebnisse können nicht einfach durch Erregungseffekte oder Aufmerksamkeits-verstärkung erklärt werden (Angrilli et al., 1997; Droit-Volet et al., 2004; Grommet et al., 2011). Gemäß des inneren Uhr-Modells (Gibbon et al., 1984; Treisman, 1963), sollte eine hohe erregend durch emotionale Reize zu einer allgemeinen Beschleunigung des Schrittmachers führen. Die führen würde einen größeren Multiplikator-effekt für die Long-Range als die Kurzstrecken-Laufzeiten. Diese Hypothese widerspricht unseren Ergebnissen. Eine Aufmerksamkeitsverstärkung würde auch voraussagen, dass die Aufmerksamkeit, die auf die Zieldauer gerichtet wird, die additive Wirkung für beide Dauer induziert. Unsere Daten unterstützen solche Voraussagen nicht. Sie lassen eher darauf schließen, dass es möglicherweise zusätzliche Verarbeitungs-prozesse gibt, wie Emotionsregulierung, die an dem Prozess der Schätzung der langen taktilen Dauer beteiligt sind. Zur weiteren Bestätigung, wann solche Emotionsregulationen stattfinden, wurde im darauf folgenden dritten Experiment die Einflüsse einer kurzen oder langen Pause zwischen dem emotionalen Bild und dem taktilen Ziel Reiz verglichen (es wurden wieder kurze Zeitintervalle verwendet). Die Ergebnisse zeigten eine ähnliche Überschätzung taktiler Intervalle, sowohl für die Bedingung mit kurzen als auch mit langer Pause. Diese Ergebnisse weißen darauf hin, dass der Einfluss der Emotionsregulation auf Zeitwahrnehmung wahrscheinlich während der taktilen Präsentation, aber nicht während der Pause passiert. Gemäß dem inneren-Uhr-Modell (Block & Zakay, 1996; Gibbon et al., 1984), weisen unsere Ergebnisse nun darauf hin, dass Emotionen, die durch bedrohliche Bilder induziert werden, vor allem die Latenzzeit des Schließung für das Zählen von taktilen Dauer verkürzt, nicht die Geschwindigkeit des Schrittmachers. Wenn das taktile Ereignis als nicht bedrohlich identifiziert wurde, nimmt ein nachfolgender Emotionsregulationsmechanismus über. Deshalb könnten manche Zeitimpulse der taktilen Dauer fehlen, was die Überschätzung nullieren kann, die durch die verkürzte Schließer-Latenzzeit verursacht wurde.

Zusammenfassend zeigt diese Studie eine crossmodale Zunahme der Zeitwahrnehmung je nach emotionalem Kontext, die direkt auf die enge Verknüpfung des Seh- und des Tastsinns bei bedrohlicher Information verweist. Darüber hinaus weisen die Beweise der langen Zeitintervall-Urteilen darauf hin, dass mehrere Emotionsprozesse (z.B. emotionale Aktivierung, Regulierung) während eines langen taktilen Zeitintervalls aktiviert werden können, und diese Prozesse unterschiedliche Auswirkungen auf die subjektive Zeitwahrnehmung haben können.

2) Emotionale Modulation auf zeitliche Ordnung Urteile

Der zweite Teil der Forschung adressiert die folgenden drei Fragen: a) wie beeinflussen irrelevante emotionale Reize die audiotaktile zeitliche Verarbeitung? b) Spielen grundlegende emotionale Dimensionen (Erregung und Valenz) oder spezifische emotionale Bedeutungen eine Rolle bei der audiotaktilen zeitlichen Verarbeitung? Und c) was ist die Rolle von räumlicher Information in crossmodaler emotionaler Regulation bei Urteilen über die audiotaktile zeitliche Ordnung? Aus der ersten Studie ergaben sich Erkenntnisse darüber, dass eine funktionelle Verknüpfung zwischen visuellen und taktilen Modalitäten existiert, die von Emotionen aktiviert wird. Dies spielt eine wichtige Rolle bei der Zeitwahrnehmung. Deshalb stellten wir die Hypothese auf, dass stark erregende Emotionen, die durch visuelle Reize induziert werden, die zeitliche Verarbeitung von taktilen Signalen stärker als von akustischen Signalen beeinflussen würde. Aus diesem Grunde haben wir Urteile über zeitliche Ordnung von audiotaktilen Stimuli in dieser Studie verwendet. Ein räumlich uninformatives IAPS Bild wurde gleichzeitig mit einem Paar audiotaktiler Stimuli gezeigt. Die ersten beiden Experimente zeigten, dass sowohl räumlich uninformative positive als auch negative, stark erregende Bilder die taktile im Gegensatz zur auditiven zeitliche Verarbeitung nur dann erleichtern, wenn auditive und taktile Reize an gegenüberliegenden Stellen präsentiert wurden. Allerdings zeigte sich keine Veränderung, wenn die audio-taktilen Reize am gleichen Ort präsentiert wurden. Um einen möglichen Verkörperungsansätzen-Effekt der emotionalen Bilder von einem allgemeinen

Erregungseffekt zu unterscheiden, wurden in einem weiteren Experiment die unterschiedlichen Einflüsse von einer beinahe Körper Bedrohung (z.B. Schlange, mit der Absicht zu beißen), ferner Bedrohung (z.B. Autounfälle) und neutralen Bilder auf Urteile über die audiotaktile zeitliche Ordnung verglichen. Die Ergebnisse zeigten, dass taktile Stimuli nur in der beinah Körper Bedrohung früher als auditorische Stimuli wahrgenommen wurden, allerdings nicht in der Bedingung „ferne Bedrohung“. Kurz gesagt, bestätigten die Ergebnisse aus dieser Studie die Idee, dass Reize mit Handlungsbedeutung (Embodiment) die zeitliche Informationsverarbeitung in Richtung handlungsrelevante sensorische Modalitäten verschieben (Cornwell et al., 2008), Außerdem unterstützen die Ergebnisse die der ersten Studie, dass die visuell-taktile funktionelle Verknüpfung, die durch emotionale Kontexte induziert wird, eine kritische Rolle in der Wahrnehmung der Dauer spielt. Außerdem haben wir festgestellt, dass die Einheitsannahme (Welch & Warren, 1980) die audiotaktile Integration verbessert, die der Emotionsregulation bei Urteilen über audiotaktile zeitliche Ordnung entgegenwirken kann.

3) Die Rolle des Handlungskontexts auf die Wahrnehmung der Dauer

Im dritten Teil der Dissertation untersuchten wir hauptsächlich zwei Fragen: a) Können visuelle, sich bewegende Objekte eine verlängerte wahrgenommene Dauer eines irrelevanten, taktilen Ereignisses induzieren; b) beeinflusst die Interaktion zwischen unserem Körper und einem Handlungskontext die Zeitwahrnehmung? Wir konstruierten ein reales Bewegungsereignis in der Nähe der Teilnehmer mit Hilfe eines Pendelballs. Ein solches Setup könnte einen verstärkten Handlungskontext (z.B. eine automatische Reaktion auf die Kugel) im Vergleich zu herkömmlichen Monitorpräsentationen haben. Allerdings war der Pendelball irrelevant für die Aufgabe. Versuchsteilnehmer mussten wieder eine zeitliche Einteilungsaufgabe mit taktilen Stimuli bewältigen (Halbierung Aufgabe). Die Teilnehmer wurden gebeten, eine taktile Dauer zu beurteilen, während sie einen irrelevanten, sich bewegenden Ball sahen. Im Experiment 1 verglichen wir die unterschiedlichen Auswirkungen der sich annähernden, lateralen und statischen Bedingung auf die Urteile über taktile Dauer. Hierbei konnten wir zeigen, dass die subjektive taktile Dauer in der sich annähernden und lateralen Bewegungsbedingung, verglichen mit der statischen Bedingung überschätzt wurde. Und die wahrgenommene taktile Dauer in der annähernden

Bewegungsbedingung war länger als in der lateralen Bewegungsbedingung. Die Ergebnisse deuteten darauf hin, dass die verlängerte wahrgenommene Dauer in Handlungskontexten einen allgemeineren Effekt hat. Der Effekt war nicht auf den handlungsrelevanten Stimulus begrenzt, was die wichtige Rolle der funktionellen Verknüpfung zwischen der visuell und der taktilen Modalitäten zeigt, die durch emotionsrelevante Zusammenhänge in den ersten beiden Studien induziert wurde. Um eine mögliche Erklärung der Ergebnisse durch den Looming-Effekt und/oder den Erregungseffekt auszuschließen, wurden in Experiment 2 taktile Zeiturteile zwischen den sich annähernden und zurückweichenden Bewegungen verglichen. Die Teilnehmer platzierten ihre Hände in die zurückweichenden und annähernden Bewegungen direkt unter dem Ruhepunkt des Pendels, um ihre Interaktion dem Handlungskontext anzugleichen. Die Ergebnisse zeigten eine ähnliche Verzerrung der subjektiv wahrgenommenen Dauer sowohl in den sich annähernden und zurückweichenden Bewegungen. Hierdurch konnte der Looming-Effekt ausgeschlossen werden. Um den Effekt des Verkörperungsansätzen von dem Erregung Effekt zu trennen, führten wir in Experiment 3 zwei Annäherungsbedingungen durch: eine wobei die Hand durch ein Objekt besetzt war und eine wobei die Hand frei war. Der Hauptzweck der Einführung der Annäherungsbedingung mit besetzter Hand war, den Verkörperungsansätzen Effekt zu hemmen. Die Ergebnisse bestätigten, dass die Annäherungsbewegung das Urteil über die wahrgenommene taktile Dauer verlängerte, wenn die Hände frei waren. Allerdings verschwand diese Überschätzung, wenn die Hände von leichten Objekten besetzt waren. Die Bewertungen von Erregung und Valenz und Hautleitfähigkeit (SCR) ergaben keinen Unterschied zwischen den beiden Annäherungsbedingungen. Dieser Befund in Experiment 3 lässt darauf schließen, dass Verkörperungsansätzen anstatt der Erregung eine wichtige Rolle bei Zeitwahrnehmung in Handlungskontexten spielt. Zusammenfassend liefert diese Studie einen klaren Beweis dafür, dass Handlungskontexte die subjektiv wahrgenommene Dauer irrelevanter Ereignisse (taktiler Ereignisse) erweitern können, die in der sensomotorischen Schleife auftreten. Außerdem unterstützen die Ergebnisse dieser Studie die Verkörperungsansätzen-Sicht der Zeitwahrnehmung (Droit-Volet & Meck, 2007; Effron et al., 2006; Nather et al., 2011).

Zusammenfassend liefern die Ergebnisse der drei Studien neue Beweise für den Einfluss der crossmodalen Emotionsregulation auf Zeitwahrnehmung, vorausgesetzt, dass die innere Uhr auf eine amodale Weise arbeitet. Man muss bestimmte emotionale Bedeutungen (handlungsrelevante Bedeutungen) berücksichtigen, insbesondere handlungsrelevante Kontexte bei crossmodaler zeitlicher Koordinierung und Zeitwahrnehmung. Unsere Ergebnisse deuten auch darauf hin, dass ein diskreter Blick auf Emotionen und Verkörperungsansätzen (Embodiment) gut für die Erklärung der Zeitwahrnehmung geeignet ist, die im Zusammenhang mit crossmodaler emotionaler und Handlungsregulation stehen. Die neurologische Bildgebung könnte der nächste Schritt sein, um Hirnareale, die für die Identifizierung der Handlungsbedeutung von Emotionen und die Manipulation der crossmodalen funktionellen Verknüpfung in emotionalen oder Handlungskontexten zu finden.

Ⅵ References

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

Balaban, M. T., & Taussig, H. N. (1994). Salience of fear/threat in the affective modulation of the human startle blink. *Biological Psychology, 38*(2-3), 117-131.

Beck, D. M., & Kastner, S. (2009). Top-down and bottom-up mechanisms in biasing competition in the human brain. *Vision Research, 49*(10), 1154-1165.

Block, R. A. (1990). Models of psychological time. In R. A. Block (Ed.), *Cognitive models of psychological time* (pp. 1-35). Hillsdale , NJ Lawrence Erlbaum Associates.

Block, R. A., & Zakay, D. (1996). Models of psychological and time revisited. In H. Helfrich (Ed.), *Time and mind*. Kirkland, WA: Hogrefe & Huber.

Block, R. A., & Zakay, D. (2001). Psychological time at the millennium: Some past, present, future, and interdisciplinary issues. In M. P. Soulsby & J. T. Fraser (Eds.), *Time: Perspectives at the millennium* (pp. 157-173). Westport , CT Bergin & Garvey.

Bolognini, N., Miniussi, C., Savazzi, S., Bricolo, E., & Maravita, A. (2009). TMS modulation of visual and auditory processing in the posterior parietal cortex. *Exp Brain Res, 195*(4), 509-517.

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion, 1*(3), 276-298.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49-59.

Brainard, D. (1997). The Psychophysics Toolbox. *Spatial Vision, 10*(4), 433-436.

Brown, S. (1995). Time, change, and motion: The effects of stimulus movement on temporal perception. *Perception & Psychophysics, 57*(1), 105-116.

Buehner, M. J. (2012). Understanding the past, predicting the future: causation, not intentional action, is the root of temporal binding. *Psychol Sci, 23*(12), 1490-1497.

Buehner, M. J., & Humphreys, G. R. (2009). Causal binding of actions to their effects. *Psychol Sci, 20*(10), 1221-1228.

Bueti, D. (2011). The sensory representation of time. *Frontiers in Integrative Neuroscience, 5*.

Bueti, D., Bahrami, B., & Walsh, V. (2008). Sensory and association cortex in time perception. *J Cogn Neurosci, 20*(6), 1054-1062.

Buhusi, C. V., & Meck, W. H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. *Nat Rev Neurosci, 6*(10), 755-765.

Carlsson, K., Andersson, J., Petrovic, P., Petersson, K. M., Ohman, A., & Ingvar, M. (2006). Predictability modulates the affective and sensory-discriminative neural processing of pain. *NeuroImage, 32*(4), 1804-1814.

Casini, L., & Macar, F. (1997). Effects of attention manipulation on judgments of duration and of intensity in the visual modality. *Memory & Cognition, 25*(6), 812-818.

Chen, K.-M., & Yeh, S.-L. (2009). Asymmetric cross-modal effects in time perception. *Acta Psychologica, 130*(3), 225-234.

Chen , L., Shi, Z., & Müller, H. J. (2010). Influences of intra- and crossmodal grouping on visual and tactile Ternus apparent motion. *Brain Res, 1354*, 152-162.

Chen , L., Shi, Z., & Müller, H. J. (2011). Interaction of Perceptual Grouping and Crossmodal Temporal Capture in Tactile Apparent-Motion. *PLoS ONE, 6*(2), e17130.

Church, R. M. (1984). Properties of the Internal Clocka. *Annals of the New York Academy of Sciences, 423*(1), 566-582.

Churchland, M. M., Cunningham, J. P., Kaufman, M. T., Ryu, S. I., & Shenoy, K. V. (2010). Cortical Preparatory Activity: Representation of Movement or First Cog in a Dynamical Machine? *Neuron, 68*(3), 387-400.

Clark, A. (1999). An embodied cognitive science? *Trends Cogn Sci, 3*(9), 345-351.

Cohen, J., Hansel, C. E. M., & Sylvester, J. D. (1953). A New Phenomenon in Time Judgment. *Nature, 172*(4385), 901-901.

Cornwell, B. R., Echiverri, A. M., Covington, M. F., & Grillon, C. (2008). Modality-specific attention under imminent but not remote threat of shock: Evidence from differential prepulse inhibition of startle. *Psychol Sci, 19*(6), 615-622.

Craig, A. D. (2009). How do you feel [mdash] now? The anterior insula and human awareness. *Nat Rev Neurosci, 10*(1), 59-70.

Damasio, A. R. (1994). *Descartes Error: Emotion, Reason and the Human Brain*. New York: G.P. Putnam's Sons.

Darwin, C. (1872/1998). *The expression of the emotions in man and animals*. Oxford, UK: Oxford University Press.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annu Rev Neurosci, 18*, 193-222.

Dong, W. K., Chudler, E. H., Sugiyama, K., & Roberts, V. J. (1994). Somatosensory, multisensory, and task-related neurons in cortical area 7b (PF) of unanesthetized monkeys. *Journal of Neurophysiology, 72*(2), 542-564.

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

Droit-Volet, S., Fayolle, S. L., & Gil, S. (2011). Emotion and time perception: effects of film-induced mood. *Front Integr Neurosci, 5*, 33.

Droit-Volet , S., & Gil, S. (2009). The time-emotion paradox. *Philosophical Transactions of the Royal Society B-Biological Sciences, 364*(1525), 1943-1953.

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

Droit-Volet, S., Meck, W. H., & Penney, T. B. (2007). Sensory modality and time perception in children and adults. *Behavioural Processes, 74*(2), 244-250.

Droit-Volet, S., Mermillod, M., Cocenas-Silva, R., & Gil, S. (2010). The effect of expectancy of a threatening event on time perception in human adults. *Emotion, 10*(6), 908-914.

Eagleman, D. M. (2008). Human time perception and its illusions. *Curr Opin Neurobiol, 18*(2), 131-136.

Eagleman, D. M., & Pariyadath, V. (2009). Is subjective duration a signature of coding efficiency? *Philos Trans R Soc Lond B Biol Sci, 364*(1525), 1841-1851.

Eastwood, J. D., Smilek, D., & Merikle, P. M. (2001). Differential attentional guidance by unattended faces expressing positive and negative emotion. *Perception & Psychophysics, 63*(6), 1004-1013.

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

Eimer, M., & Holmes, A. (2007). Event-related brain potential correlates of emotional face processing. *Neuropsychologia, 45*(1), 15-31.

Ekman, G., Frankenhaeuser, M., Berglund, B., & Waszak, M. (1969). Apparent duration as a function of intensity of vibrotactile stimulation. *Perceptual and Motor Skills, 28*(1), 151-156.

Ekman , P. (1992). An argument for basic emotions. *Cognition and Emotion, 6*(3-4), 169-200.

Engel, A. K., Maye, A., Kurthen, M., & König, P. (2013). Where's the action? The pragmatic turn in cognitive science. *Trends Cogn Sci, 17*(5), 202-209.

Fortin, C. (2003). Attentional time-sharing in interval timing. In W. H. Meck (Ed.), *Functional and neural mechanisms of interval timing.* (pp. 235-260). Boca Raton, FL US: CRC Press.

Fortin , C., & Masse, N. (2000). Expecting a break in time estimation: attentional time-sharing without concurrent processing. *J Exp Psychol Hum Percept Perform, 26*(6), 1788-1796.

Fox, E. (2002). Processing emotional facial expressions: The role of anxiety and awareness. *Cognitive, Affective & Behavioral Neuroscience, 2*(1), 52-63.

Fujisaki, W., Shimojo, S., Kashino, M., & Nishida, S. (2004). Recalibration of audiovisual simultaneity. *Nat Neurosci, 7*(7), 773-778.

Gable, P. A., & Poole, B. D. (2012). Time flies when you're having approach-motivated fun: effects of motivational intensity on time perception. *Psychol Sci, 23*(8), 879-886.

Ganzenmuller, S., Shi, Z., & Muller, H. J. (2012). Duration reproduction with sensory feedback delay: differential involvement of perception and action time. *Front Integr Neurosci, 6*, 95.

Ghose, G. M., & Maunsell, J. H. (2002). Attentional modulation in visual cortex depends on task timing. *Nature, 419*(6907), 616-620.

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

Gil, S., & Droit-Volet, S. (2011). How do emotional facial expressions influence our perception of time? In S. Masmoudi, D. Y. Dai & A. Naceur (Eds.), *Attention, representation, and human performance: Integration of cognition, emotion, and motivation.* (pp. 61-74). New York, NY US: Psychology Press.

Goldstone, S., & Lhamon, W. T. (1974). Studies of auditory-visual differences in human time judgment. 1. Sounds are judged longer than lights. *Perceptual and Motor Skills, 39*(1), 63-82.

Gray, R., & Tan, H. (2002). Dynamic and predictive links between touch and vision. *Experimental Brain Research, 145*(1), 50-55.

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

Grondin, S. (2010). Timing and time perception: a review of recent behavioral and neuroscience findings and theoretical directions. *Atten Percept Psychophys, 72*(3), 561-582.

Gu, B.-M., & Meck, W. (2011). New Perspectives on Vierordt’s Law: Memory-Mixing in Ordinal Temporal Comparison Tasks. In A. Vatakis, A. Esposito, M. Giagkou, F. Cummins & G. Papadelis (Eds.), *Multidisciplinary Aspects of Time and Time Perception* (Vol. 6789, pp. 67-78): Springer Berlin Heidelberg.

Haggard, P., & Clark, S. (2003). Intentional action: conscious experience and neural prediction. *Conscious Cogn, 12*(4), 695-707.

Haggard, P., Clark, S., & Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nat Neurosci, 5*(4), 382-385.

Hagura, N., Kanai, R., Orgs, G., & Haggard, P. (2012). Ready steady slow: action preparation slows the subjective passage of time. *Proceedings Biological sciences / The Royal Society, 279*(1746), 4399-4406.

Hamann, S. (2012). Mapping discrete and dimensional emotions onto the brain: controversies and consensus. *Trends Cogn Sci, 16*(9), 458-466.

Hare, R. D. (1963). The estimation of short temporal intervals terminated by shock. *Journal of Clinical Psychology, 19*(3), 378-380.

Heron, J., Aaen-Stockdale, C., Hotchkiss, J., Roach, N. W., McGraw, P. V., & Whitaker, D. (2012). Duration channels mediate human time perception. *Proc Biol Sci, 279*(1729), 690-698.

Hinton, S. C., & Meck, W. H. (1997). The 'internal clocks' of circadian and interval timing. *Endeavour, 21*(2), 82-87.

Hoagland, H. (1933). TIle physiological control of judgments of duration: Evidence for a chcnucal clock. *Journal of General Psychology, 9*, 267-287.

Hodinott-Hill, I., Thilo, K. V., Cowey, A., & Walsh, V. (2002). Auditory chronostasis: hanging on the telephone. *Curr Biol, 12*(20), 1779-1781.

Ivry , R. B., & Richardson, T. C. (2002). Temporal Control and Coordination: The Multiple Timer Model. *Brain and Cognition, 48*(1), 117-132.

Ivry, R. B., & Schlerf, J. E. (2008). Dedicated and intrinsic models of time perception. *Trends Cogn Sci, 12*(7), 273-280.

Izard, C. E. (1991). *The psychology of emotions*. New York: Plenum.

Izard, C. E., & Ackerman, B. P. (2000). Motivational, organizational, and regulatory functions of discrete emotions. In M. Lewis & J. M. Hairland-Jones (Eds.), *Handbook of Emotions* (pp. 253–264). New York, NY: The Guilford Press.

James, W. (1890). *The principles of psychology Vol.1.* New York, NY, US: Henry Holt and Co.

Jazayeri, M., & Shadlen, M. N. (2010). Temporal context calibrates interval timing. *Nat Neurosci, 13*(8), 1020-1026.

Kanai, R., Lloyd, H., Bueti, D., & Walsh, V. (2011). Modality-independent role of the primary auditory cortex in time estimation. *Exp Brain Res, 209*(3), 465-471.

Kanai, R., Paffen, C. L., Hogendoorn, H., & Verstraten, F. A. (2006). Time dilation in dynamic visual display. *J Vis, 6*(12), 1421-1430.

Kaneko, S., & Murakami, I. (2009). Perceived duration of visual motion increases with speed. *J Vis, 9*(7), 14.

Keetels, M., & Vroomen, J. (2005). The role of spatial disparity and hemifields in audio-visual temporal order judgments. *Experimental Brain Research, 167*(4), 635-640.

Keysers, C., Wicker, B., Gazzola, V., Anton, J.-L., Fogassi, L., & Gallese, V. (2004). A Touching Sight: SII/PV Activation during the Observation and Experience of Touch. *Neuron, 42*(2), 335-346.

Kitagawa, N., Zampini, M., & Spence, C. (2005). Audiotactile interactions in near and far space. *Experimental Brain Research, 166*(3), 528-537.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Motivated attention: Affect, activation and action. In P. J. Lang, R. F. Simons & M. T. Balaban (Eds.), *Attention and Orienting: Sensory and Motivational Processes* (pp. 97-135). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). *International affective picture system (IAPS): Instruction manual and affective ratings*. Technical Report A-8.University of Florida，Gainesville, FL.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International Affective Picture System(IAPS): Affective ratings of pictures and instruction manual*: Technical Report A-8. University of Florida, Gainesville, FL.

Langer, J., Wapner, S., & Werner, H. (1961). The Effect of Danger upon the Experience of Time. *The American Journal of Psychology, 74*(1), 94-97.

LeDoux, J. E. (1995). Emotion: Clues from the brain. *Annual Review of Psychology, 46*, 209-235.

Lejeune, H., & Wearden, J. H. (2009). Vierordt's The Experimental Study of the Time Sense (1868) and its legacy. *European Journal of Cognitive Psychology, 21*(6), 941-960.

Lerner, J. S., & Keltner, D. (2001). Fear, anger, and risk. *J Pers Soc Psychol, 81*(1), 146-159.

Lloyd, D., Morrison, I., & Roberts, N. (2006). Role for Human Posterior Parietal Cortex in Visual Processing of Aversive Objects in Peripersonal Space. *Journal of Neurophysiology, 95*(1), 205-214.

Macar, F., Grondin, S., & Casini, L. (1994). Controlled attention sharing influences time estimation. *Mem Cognit, 22*(6), 673-686.

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

Mather, M., & Sutherland, M. R. (2011). Arousal-biased competition in perception and memory. *Perspectives on Psychological Science, 6*(2), 114-133.

McGurk , H., & Macdonald , J. (1976). Hearing lips and seeing voices. *Nature, 264*(5588), 746-748.

Meck, W. H. (1996). Neuropharmacology of timing and time perception. *Cogn. Brain Res., 3*, 227-242.

Mikels, J., Fredrickson, B., Larkin, G., Lindberg, C., Maglio, S., & Reuter-Lorenz, P. (2005). Emotional category data on images from the International Affective Picture System. *Behavioural Research Methods, 37*(4), 626-630.

Miyazaki, M., Yamamoto, S., Uchida, S., & Kitazawa, S. (2006). Bayesian calibration of simultaneity in tactile temporal order judgment. *Nat Neurosci, 9*(7), 875-877.

Moore, J., & Haggard, P. (2008). Awareness of action: Inference and prediction. *Conscious Cogn, 17*(1), 136-144.

Morein-Zamir, S., Soto-Faraco, S., & Kingstone, A. (2003). Auditory capture of vision: examining temporal ventriloquism. *Cognitive Brain Research, 17*(1), 154-163.

Morrone, M. C., Ross, J., & Burr, D. (2005). Saccadic eye movements cause compression of time as well as space. *Nat Neurosci, 8*(7), 950-954.

Nather, F. C., Bueno, J. L. O., Bigand, E., & Droit-Volet, S. (2011). Time Changes with the Embodiment of Another's Body Posture. *PLoS ONE, 6*(5).

New, J. J., & Scholl, B. J. (2009). Subjective time dilation: Spatially local, object-based, or a global visual experience? *J Vis, 9*(2), 1-11.

Niedenthal, P. M. (2007). Embodying emotion. *Science, 316*(5827), 1002-1005.

Niedenthal, P. M., Winkielman, P., Mondillon, L., & Vermeulen, N. (2009). Embodiment of emotion concepts. *J Pers Soc Psychol, 96*(6), 1120-1136.

Noulhiane, M., Mella, N., Samson, S., Ragot, R., & Pouthas, V. (2007). How Emotional Auditory Stimuli Modulate Time Perception. *Emotion, 7*(4), 697-704.

Novikov, I. D. (1998). *The River of Time*. U.K. : Cambridge University Press.

Occelli, V., Spence, C., & Zampini, M. (2008). Audiotactile temporal order judgments in sighted and blind individuals. *Neuropsychologia, 46*(11), 2845-2850.

Occelli, V., Spence, C., & Zampini, M. (2011). Audiotactile interactions in temporal perception. *Psychonomic Bulletin & Review, 18*(3), 429-454.

Öhman , A. (1997). As fast as the blink of an eye: evolutionary preparedness for preattentive processing of threat. In L. P. J., R. F., Simons, & M. T., Balaban (Ed.), *Attention and Orienting: Sensory and Motivational Processes* (pp. 165-184). Mahwah, NJ: Lawrence Erlbaum Associates.

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*(3), 466-478.

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: toward an evolved module of fear and fear learning. *Psychol Rev, 108*(3), 483-522.

Orgs, G., Bestmann, S., Schuur, F., & Haggard, P. (2011). From body form to biological motion: the apparent velocity of human movement biases subjective time. *Psychol Sci, 22*(6), 712-717.

Pöppel, E. (1997). A hierarchical model of temporal perception. *Trends Cogn Sci, 1*(2), 56-61.

Park, J., Schlag-Rey, M., & Schlag, J. (2003). Voluntary action expands perceived duration of its sensory consequence. *Exp Brain Res, 149*(4), 527-529.

Peelen, M. V., Atkinson, A. P., & Vuilleumier, P. (2010). Supramodal Representations of Perceived Emotions in the Human Brain. *The Journal of Neuroscience, 30*(30), 10127-10134.

Penney, T. B., Gibbon, J., & Meck, W. H. (2000). Differential effects of auditory and visual signals on clock speed and temporal memory. *J Exp Psychol Hum Percept Perform, 26*(6), 1770-1787.

Penton-Voak , I. S., Edwards, H., Percival, A., & Wearden , J. H. (1996). Speeding up an internal clock in humans? Effects of click trains on subjective duration. *Journal of Experimental Psychology: Animal Behavior Processes, 22*(3), 307-320.

Pessoa, L., McKenna, M., Gutierrez, E., & Ungerleider, L. G. (2002). Neural Processing of Emotional Faces Requires Attention. *Proceedings of the National Academy of Sciences of the United States of America, 99*(17), 11458-11463.

Phelps, E. A., & LeDoux, J. E. (2005). Contributions of the Amygdala to Emotion Processing: From Animal Models to Human Behavior. *Neuron, 48*(2), 175-187.

Phelps, E. A., Ling, S., & Carrasco, M. (2006). Emotion Facilitates Perception and Potentiates the Perceptual Benefits of Attention. *Psychol Sci, 17*(4), 292-299.

Pichon, S., de Gelder, B., & Grèzes, J. (2012). Threat prompts defensive brain responses independently of attentional control. *Cerebral Cortex, 22*(2), 274-285.

Ploghaus, A., Becerra, L., Borras, C., & Borsook, D. (2003). Neural circuitry underlying pain modulation: expectation, hypnosis, placebo. *Trends Cogn Sci, 7*(5), 197-200.

Poliakoff, E., Miles, E., Li, X., & Blanchette, I. (2007). The effect of visual threat on spatial attention to touch. *Cognition, 102*(3), 405-414.

Pouthas, V., & Perbal, S. (2004). Time perception depends on accurate clock mechanisms as well as unimpaired attention and memory processes. *Acta Neurobiol Exp (Wars), 64*(3), 367-385.

Rozin, P., & Fallon, A. E. (1987). A perspective on disgust. *Psychological Review, 94*(1), 23-41.

Shi, Z., Chen, L., & Muller, H. J. (2010). Auditory temporal modulation of the visual Ternus effect: the influence of time interval. *Exp Brain Res, 203*(4), 723-735.

Shi, Z., Church, R. M., & Meck, W. H. (2013). Bayesian Optimization of Time Perception. *Trends Cogn Sci, in press*.

Shi , Z., Ganzenmüller, S., & Müller, H. J. (2013). Reducing Bias in Auditory Duration Reproduction by Integrating the Reproduced Signal. *PLoS ONE, 8*(4).

Shi , Z., Hirche, S., Schneider, W. X., & Müller, H. (2008). *Influence of visuomotor action on visual-haptic simultaneous perception: A psychophysical study.* Paper presented at the Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems.

Shi , Z., Jia, L., & Müller, H. J. (2012). Modulation of tactile duration judgments by emotional pictures. *Frontiers in Integrative Neuroscience, 6*.

Shi, Z., Zou, H., Rank, M., Chen, L., Hirche, S., & Müller, H. J. (2010). Effects of Packet Loss and Latency on the Temporal Discrimination of Visual-Haptic Events. *IEEE Transactions on Haptics, 3*(1), 28-36.

Shin, Y. K., Proctor, R. W., & Capaldi, E. J. (2010). A review of contemporary ideomotor theory. *Psychol Bull, 136*(6), 943-974.

Smith, C. A., & Ellsworth, P. C. (1985). Patterns of cognitive appraisal in emotion. *J Pers Soc Psychol, 48*(4), 813-838.

Spence, C., Baddeley, R., Zampini, M., James, R., & Shore, D. I. (2003). Multisensory temporal order judgments: When two locations are better than one. *Perception & Psychophysics, 65*(2), 318-328.

Spence, C., & Parise, C. (2010). Prior-entry: A review. *Consciousness and Cognition: An International Journal, 19*(1), 364-379.

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General, 130*(4), 799-832.

Stanley, J., & Knight, R. G. (2004). Emotional specificity of startle potentiation during the early stages of picture viewing. *Psychophysiology, 41*(6), 935-940.

Stein, B. E., & Meredith, M. A. (1993). *The merging of the senses*. Cambridge, Mass.: MIT Press.

Stein, B. E., & Stanford, T. R. (2008). Multisensory integration: current issues from the perspective of the single neuron. *Nat Rev Neurosci, 9*(4), 255-266.

Stetson, C., Fiesta, M. P., & Eagleman, D. M. (2007). Does Time Really Slow Down during a Frightening Event? *PLoS ONE, 2*(12), e1295.

Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the 'internal clock'. *Psychological Monographs: General and Applied, 77*(13), 1-31.

Treutwein, B., & Strasburger, H. (1999). Fitting the psychometric function. *Perception & Psychophysics, 61*, 87–106.

Tse, P. U., Intriligator, J., Rivest, J., & Cavanagh, P. (2004). Attention and the subjective expansion of time. *Perception and Psychophysics, 66*(7), 1171-1189.

Van Damme, S., Gallace, A., Spence, C., Crombez, G., & Moseley, G. L. (2009). Does the sight of physical threat induce a tactile processing bias?: Modality-specific attentional facilitation induced by viewing threatening pictures. *Brain Research, 1253*, 100-106.

van Wassenhove, V., Buonomano, D. V., Shimojo, S., & Shams, L. (2008). Distortions of Subjective Time Perception Within and Across Senses. *PLoS ONE, 3*(1).

van Wassenhove, V., Wittmann, M., Craig, A. D., & Paulus, M. P. (2011). Psychological and neural mechanisms of subjective time dilation. *Frontiers in Neuroscience, 5*.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, Massachusetts: MIT Press.

Vroomen , J., & Keetels , M. (2010). Perception of intersensory synchrony: A tutorial review. *Attention, Perception, & Psychophysics, 72*(4), 871-884.

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

Walker, J. T., & Scott, K. J. (1981). Auditory–visual conflicts in the perceived duration of lights, tones, and gaps. *Journal of Experimental Psychology: Human Perception and Performance, 7*(6), 1327-1339.

Wearden, J. H. (1991). Do humans possess an internal clock with scalar timing properties? *Learning and Motivation, 22*(1–2), 59-83.

Wearden , J. H. (1992). Temporal generalization in humans. *Journal of Experimental Psychology: Animal Behavior Processes, 18*(2), 134-144.

Wearden, J. H., Edwards, H., Fakhri, M., & Percival, A. (1998). Why "sounds are judged longer than lights": application of a model of the internal clock in humans. *Q J Exp Psychol B, 51*(2), 97-120.

Wearden, J. H., Todd, N. P. M., & Jones, L. A. (2006). When do auditory/visual differences in duration judgements occur? *The Quarterly Journal of Experimental Psychology, 59*(10), 1709-1724.

Welch, R. B., & Warren, D. H. (1980). Immediate perceptual response to intersensory discrepancy. *Psychol Bull, 88*(3), 638-667.

Wiener, M., Matell, M. S., & Coslett, H. B. (2011). Multiple mechanisms for temporal processing. *Frontiers in Integrative Neuroscience, 5*.

Wittmann, M., van Wassenhove, V., Craig, A. D., & Paulus, M. P. (2010). The neural substrates of subjective time dilation. *Frontiers in Human Neuroscience, 4*.

Xuan, B., Zhang, D., He, S., & Chen, X. (2007). Larger stimuli are judged to last longer. *J Vis, 7*(10).

Yamamoto, K., & Miura, K. (2012). Time dilation caused by static images with implied motion. *Experimental Brain Research, 223*(2), 311-319.

Yarrow, K., Haggard, P., Heal, R., Brown, P., & Rothwell, J. C. (2001). Illusory perceptions of space and time preserve cross-saccadic perceptual continuity. *Nature, 414*(6861), 302-305.

Yarrow, K., Haggard, P., & Rothwell, J. C. (2004). Action, arousal, and subjective time. *Conscious Cogn, 13*(2), 373-390.

Yarrow, K., & Rothwell, J. C. (2003). Manual chronostasis: tactile perception precedes physical contact. *Curr Biol, 13*(13), 1134-1139.

Zakay, D. (1989). Chapter 10 Subjective Time and Attentional Resource Allocation: An Integrated Model of Time Estimation. In L. Iris & Z. Dan (Eds.), *Advances in Psychology* (Vol. 59, pp. 365-397). Amsterdam, North-Holland: Levin, I., & Zakay, D.

Zakay, D., & Block, R. A. (1996). The role of attention in time estimation processes. In M. A. Pastor & J. Artieda (Eds.), *Time, internal clocks and movement.* (pp. 143-164). Amsterdam Netherlands: North-Holland.

Zampini, M., Brown, T., Shore, D. I., Maravita, A., Röder, B., & Spence, C. (2005). Audiotactile temporal order judgments. *Acta Psychologica, 118*(3), 277-291.

Zampini, M., Shore, D. I., & Spence, C. (2003a). Audiovisual temporal order judgments. *Experimental Brain Research, 152*(2), 198-210.

Zampini, M., Shore, D. I., & Spence, C. (2003b). Multisensory temporal order judgments: the role of hemispheric redundancy. *International Journal of Psychophysiology, 50*(1–2), 165-180.

Supplementary materials

S1. IAPS stimuli used in the first study (Chapter 2)

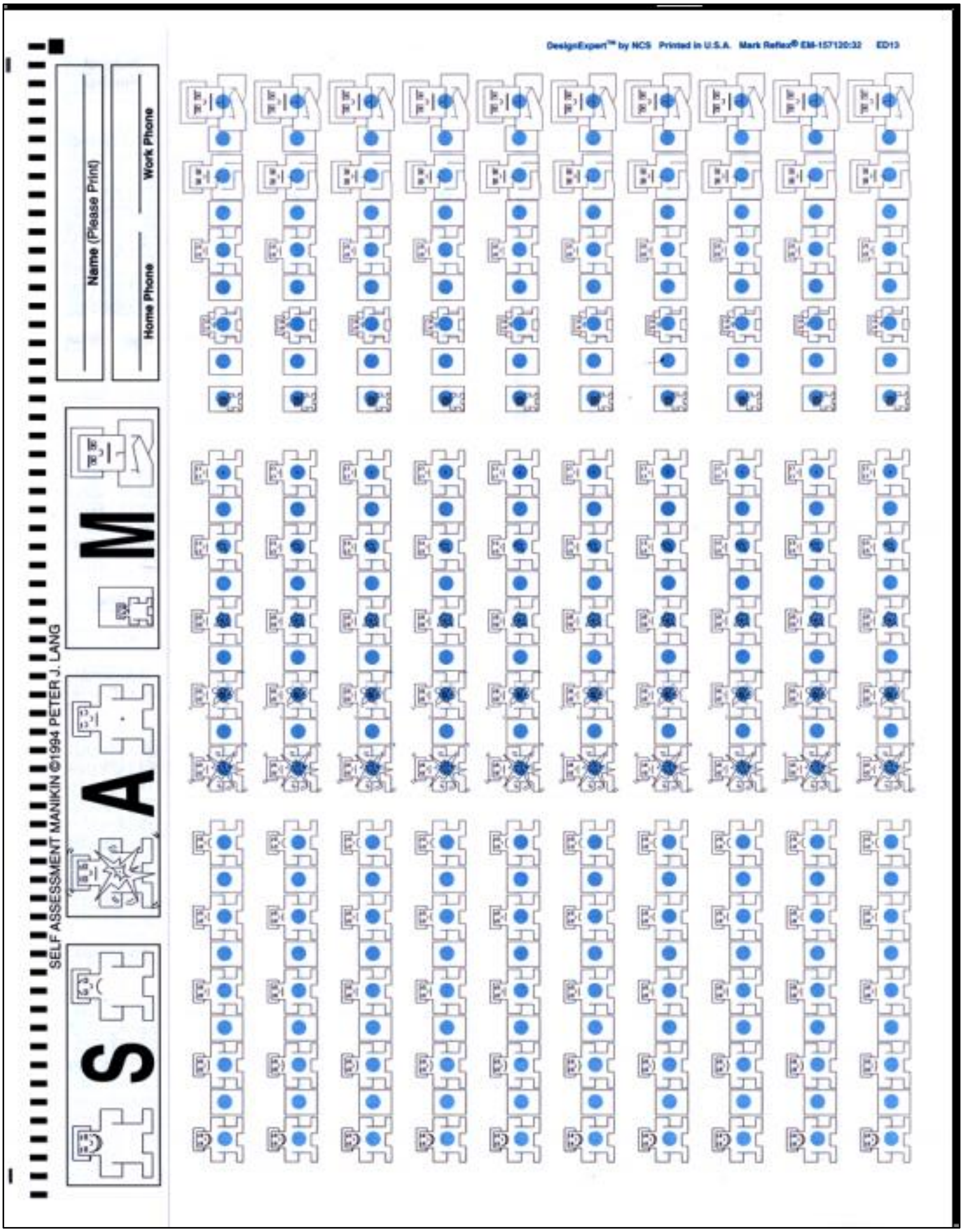
Category of pictures	***IAPS number***	***Picture description***
Mutilation pictures	*3030*	*Mutilation*
	3053	*Burn Victim*
	3060	*Mutilation*
	3071	*Mutilation*
	3120	*Dead body*
Animal or human attacking pictures	*1052*	*Snake*
	1120	*Snake*
	1201	*Spider*
	1300	*Pit Bull*
	1321	*Bear*
	1930	*Shark*
	6250	*Aimed Gun*
	6260	*Aimed Gun*
	6300	*Knife*
	6510	*Attack*
Neutral Pictures	*2840*	*Chess*
	5500	*Mush room*
	7000	*Rolling Pin*
	7009	*Mug*
	7035	*Mug*
	7041	*Baskets*
	7050	*Hair Driver*
	7059	*Key ring*
	7090	*Book*
	7140	*Bus*
	7150	*Umbrella*
	7161	*Pole*
	7185	*Abstract Art*
	7224	*File Cabinets*
	7233	*Plate*
	7235	*Chair*
	7490	*Window*
	7700	*Office*
	7705	*Cabinet*

S2. IAPS stimuli used in the second study (Chapter 3)

	Experiments	IAPS picture numbers
Neutral	*1,2,&3*	*2840, 5390, 5500, 5530, 7009, 7041, 7090, 7100, 7140, 7150, 7175, 7185, 7217, 7224, 7233*
	1&2	*7235, 7490, 7547, 7705, 7950*
Positive	*1&2*	*4608, 4652, 4658, 4660, 4683, 4687, 4689, 4695, 4697, 4698, 5621, 5629, 8080, 8160, 8180, 8186, 8190, 8200, 8341, 8501*
Negative	*1&2*	*1022, 1050, 1052, 1070, 1113, 1114, 1120, 1201, 1300, 1321, 1931, 6231, 6263, 6300, 6312, 6313, 6360, 6370, 6510, 6520*
	3	*5940R, 8485R, 9050R, 9252R, 9254R, 9300R, 9321R, 9600R, 9620R, 9622R, 9810R, 9904R, 9910R, 9921R, 9940R; 1050N, 1051N, 1052N, 1113N, 1201N, 1304N, 6231N, 6263N, 6300N, 6312N, 6313N, 6360N, 6370N, 6510N, 6520N*

Note: R and N represent the remote threat and near-body threat conditions, respectively.

S3. A sheet of paper with 9-point scales Self-Assessment-Manikin (SAM)



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Publications

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Appendix

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Modulation of tactile duration judgments by emotional pictures

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Judging the duration of emotional stimuli is known to be influenced by their valence and arousal values. However, whether and how perceiving emotion in one modality affects time perception in another modality is still unclear. To investigate this, we compared the influence of different types of emotional pictures—a picture of threat, disgust, or a neutral picture presented at the start of a trial—on temporal bisection judgments of the duration of a subsequently presented vibrotactile stimulus. We found an overestimation of tactile duration following exposure to pictures of threat, but not pictures of disgust (even though these scored equally high on arousal), in a short-range temporal bisection task (range 300/900 ms). Follow-up experiments revealed that this duration lengthening effect was abolished when the range to be bisected was increased (1000/1900 ms). However, duration overestimation was maintained in the short-range bisection task regardless of whether the interval between the visual and tactile events was short or long. This pattern is inconsistent with a general arousal interpretation of duration distortion and suggests that crossmodal linkages in the processing of emotions and emotional regulation are two main factors underlying the manifestation of crossmodal duration modulation.

Keywords: duration estimation, emotion, threat, visual-tactile interaction, embodiment

INTRODUCTION

Judgments of time intervals are often distorted by the emotional state a person is in. For instance, when involved in an accident, such as car crash, people often report that they felt the world slow down. Although the phenomenon has been known for long, it has only been sparsely examined (Lang et al., 1961; Hare, 1963), with more systematic studies published only in recent years (Angrilli et al., 1997; Droit-Volet et al., 2004; Droit-Volet and Gil, 2009).

The most simple and classical explanation of interval timing is provided by the internal clock model (Treisman, 1963; Gibbon et al., 1984; Zakay and Block, 1996). This model assumes an internal pacemaker that emits pulses at regular intervals, and a switch that starts and stops the counting of pulses. The pulses recorded by an accumulator represent the subjective time. Studies on emotion and time have shown that emotion can influence the internal pacemaker and/or the switch and strongly distort perceived duration (see review Droit-Volet et al., 2004). For example, Angrilli and colleagues examined duration estimation for emotional pictures, taken from the international affective picture system (IAPS) (Lang et al., 2005), presented for 2, 4, or 6 s. They found that both emotional valence and arousal were important factors in duration judgments. For high-arousal stimuli, negative pictures (e.g., mutilated bodies) were perceived as longer in duration compared to positive pictures (e.g., erotic scenes). In contrast, for low-arousal stimuli, duration of negative pictures was judged shorter than that of positive pictures (Angrilli et al., 1997). Angrilli et al. argued that two different mechanisms, one attentional and the other emotional, play important roles in time judgment. Negative events themselves engage more attentional resources (as also indicated by lowered heart rates). As a result, less attention is devoted to time processing and the negative events' durations tend to be underestimated. For high-arousal stimuli, so they argued, the effect of attention is minimized, and an emotional mechanism triggered by the pictures dominates the time estimation. Since high-arousal negative pictures evoke a defense response (Bradley et al., 2001), the duration of negative pictures is overestimated. By contrast, positive pictures evoke an approach response and thus their durations are underestimated. Similarly, other studies have shown that angry faces were judged as longer than neutral faces (Droit-Volet et al., 2004; Droit-Volet and Meck, 2007). It has been argued that both anger and fear are arousing emotions (Phelps and LeDoux, 2005), which increase the internal pacemaker rates, leading to temporal overestimation. Besides the visual modality, emotional modulation of time perception has also been found in the auditory modality (Noulhiane et al., 2007). Emotional sounds (e.g., a woman crying) were often judged as longer than neutral ones; and negative sounds were perceived as longer than positive ones (e.g., laughs).

Although there is now ample evidence of how emotion distorts duration perception, most of the studies have focused on unisensory modulation only. Given this, to date, there is still only scant understanding of how emotion-induced from one sensory modality influences time judgments in another modality. The likely reason is that emotional effects are generally (and tacitly) assumed to be amodal in nature i.e., emotional arousal or anxiety exerts a general influence, not restricted to one sensory modality.

This implicit assumption can be clearly seen in early crossmodal duration studies. For example, Hare attempted to examine how electrical shock influences auditory interval judgments (Hare, 1963). Auditory intervals were defined by two successive clicks. In the shock condition, a moderately painful (tactile) shock was delivered to participants' fingers at the second click, to induce general anxiety. Hare found that anxiety did indeed lead to a greater overestimation of auditory intervals compared to the baseline condition. However, recent crossmodal studies have provided evidence that each sensory system may possess its own clock (see review Bueti, 2011) and time processing is distributed across brain regions (Matell and Meck, 2004). The sensory-specific clock model is supported by behavioral evidence, such as for modality-specific pacemaker rates (Wearden et al., 1998; Penney et al., 2000; Droit-Volet et al., 2007), as well as by neurophysiological evidence, for example, for separate brain regions underlying visual and auditory duration processing (Ghose and Maunsell, 2002; Bueti et al., 2008; Bueti, 2011). Studies on non-emotional crossmodal duration judgments have revealed rather complex and inconclusive results (Walker and Scott, 1981; van Wassenhove et al., 2008; Chen and Yeh, 2009; Chen et al., 2010, 2011; Shi et al., 2010). For example, van Wassenhove et al. (2008) examined influences of visual (and, respectively, auditory) inputs on duration judgments of auditory (visual) events using looming and receding stimuli. They found the duration of auditory events was lengthened or shortened by the presence of conflicting visual information, while the perceived duration of visual events was unaffected by auditory stimuli. However, other studies using static stimuli or implicit measures have reported the opposite effect, i.e., perceived visual duration was affected by auditory duration (Chen and Yeh, 2009; Shi et al., 2010). Interestingly, in order to explain the crossmodal duration interaction by looming stimuli, van Wassenhove et al. (2008) suggested that salient, looming stimuli might be treated as "threat" signals (i.e., as having a negative emotional valence), causing duration dilation within and across modalities. Again, as concerns emotion, the influence of emotion on duration judgments was implicitly assumed to reflect a sense-independent arousal effect.

However, as suggested by recent discrete emotion theory (Izard and Ackerman, 2000; Mikels et al., 2005), the arousal and valence dimensions may not provide a complete description of emotions. It is also conceivable that different types of emotion link to different behavioral functions and sensory modalities. For example, although both threat and disgust are categorized as high-arousal negative-valence emotions, they activate different processes. Threat activates our defensive system and biases motor responses (Bradley et al., 2001). Given that a threatening or dangerous event is most likely directed toward our body (e.g., the sight of a snake attacking), an association between what we see and what we feel in our body can be quickly established (Poliakoff et al., 2007). This, in turn, may increase the tactile pacemaker speed and/or shorten the latency of the switch. Disgust, by contrast, is more related to avoiding something detrimental to our health or something tasting bad (Rozin and Fallon, 1987; Droit-Volet and Gil, 2009). Given this, the linkage between the visual and the tactile system by disgust events might not be as strong as that by threat events. Consequently, visual disgust signals may have only a relatively weak, if any, influence on the internal clock of the tactile system.

Moreover, duration judgments may also be influenced by the strength of perception-action associations. Research on duration estimation of emotional faces has shown that angry or fearful faces are often perceived as longer than neutral faces (Droit-Volet et al., 2004; Effron et al., 2006). However, when participants in such a study held a pen in their mouth to inhibit imitation of emotional faces, the duration lengthening was abolished (Effron et al., 2006). This finding suggests that perception-action associations are one of the critical factors causing changes of the internal clock system. Crossmodal associations induced by emotional stimuli might have a similar impact on time judgments.

To examine whether crossmodal emotional modulation of perceived duration is a general arousal effect or an emotion-specific effect, we compared modulations induced by three types of emotional pictures (threat, disgust, and neutral) on subsequent judgments of vibrotactile duration (Experiment 1). We chose threat and disgust since both are categorized as high-arousal negative emotions. If crossmodal emotional modulation reflected a general arousal effect, both types of emotional picture would engender similar distortions of tactile duration judgments. On the other hand, images depicting threat or fear may have particularly strong associations with the defensive system, compared to disgusting images. As supported by studies on affective modulation of the human startle blink (Balaban and Taussig, 1994; Stanley and Knight, 2004), blink magnitude was significantly larger during the presentation of frightening pictures compared to disgusting pictures. Thus, an alternative prediction is that threatening pictures would influence perceived duration by related sensory systems, such as touch, more than disgusting pictures would.

To further investigate the mechanisms underlying crossmodal emotional modulation of the internal clock system, we explored effects of emotions by comparing their modulatory influences between short and long tactile durations (Experiment 2) as well as short and long inter-stimulus intervals (ISIs) between the emotional picture and the vibrotactile stimulus (Experiment 3). Analogous to unimodal studies, the rationale was to examine whether the internal pacemaker rate or/and the switch latency in the tactile modality are changed by emotional events from visual modality. If the tactile pacemaker rate is impacted, one would expect a slope effect (multiplicative effect) on short and long duration judgments (Wearden, 1992, 2006), i.e., the crossmodal emotional influence should be greater for long than for short durations. By contrast, if emotion influences only the switch latency, one would expect duration overestimation for both short and long duration conditions. However, if processes of emotional regulation supersede processes of activation during a late stage of processing, one might fail to observe duration overestimation in the long duration condition. Experiments 2 and 3 were designed to examine for these effect patterns.

MATERIALS AND METHODS

PARTICIPANTS

Fourteen (six female; mean age 28), 15 (10 female; mean age 25), and 16 volunteers (10 female; mean age 25) took part in Experiments 1, 2, and 3, respectively. All participants had normal or corrected-to-normal vision, and none reported any somatosensory disorder. Written informed consent was obtained before the experiments.

MATERIALS

The experiments took place in a sound-isolated cabin, which was dimly lit with an ambient luminance of 0.76 cd/m^2. Visual stimuli were presented on a 21 inch Sony CRT monitor with a refresh rate of 100 Hz. The viewing distance was kept constant at 57 cm using a chin-rest. Tactile vibration (250 Hz) was produced by an *AEC* TACTAID *VBW32* vibrator (Audiological Engineering Corporation; Vibrating surface 1.6 × 2.4 cm), which was fixed to the index finger of the participant's right hand. The participant was asked to place her/his right hand, behind a short black curtain, on the table in front of her/him; the curtain ensured that the participant could not see her/his hand, while she/he had a free view of the display screen. Visual and tactile stimuli presentation was controlled by a Matlab program using the Psychophysics Toolbox (Brainard, 1997).

Three types of pictures were selected from the IAPS (Lang et al., 2005): threatening pictures evoking high-arousal (such as a snake, shark, etc.); disgusting pictures also classed as high on arousal (such as a burn victim, mutilation); and neutral pictures rated "neutral" in both valence and arousal. For Experiment 1, we used five pictures of disgust (mean valence 1.69; mean arousal 6.90), five pictures of threat (mean valence 3.28; mean arousal 6.73), and 10 neutral pictures (mean valence 4.82; mean arousal 2.47). For Experiments 2 and 3, we selected 10 threatening and 20 neutral pictures. Pictures were then evenly divided into two groups, each containing five attacking (mean valence 3.3; mean arousal 6.7) and 10 neutral pictures (mean valence 4.9; mean arousal 2.7); these were assigned randomly to one or the other of two test sessions (see details in Procedure section). Descriptions and IAPS numbers of the pictures are given in **Table A1**.

PROCEDURE

We used a temporal bisection task in all experiments. Participants were first trained with two anchor tactile durations: a short vibration (S) and a long vibration (L). Then, in the subsequent test sessions, several probe durations between S and L were presented to participants, who had to indicate whether the probe duration was closer to S or to L. In Experiments 1 and 3, S and L durations were 300 and 900 ms and the probe durations were 400, 500, 600, 700, and 800 ms, respectively. In Experiment 2, there were two different ranges of temporal bisection tasks: 300/900 ms and 1000/1900 ms. For the range of 300/900 ms, S, L, and probe durations were the same as in Experiment 1. For the range of 1000/1900 ms, S and L durations were 1000 and 1900 ms and the probe durations were 1150, 1300, 1450, 1600, and 1750 ms, respectively.

In the training session, an experimenter sat beside the participant to make sure that her/his anchor discrimination performance reached perfect level. Then, the experimenter left the cabin and the test session started. In the test session, a trial started with a "go" display which contained a central blue fixation dot (subtending 0.3° of visual angle) and the blue word "Ready!" just above fixation on a gray background. After the participant pressed a button, the "go" display disappeared and a blank display was shown randomly for 300–800 ms. Then a picture, randomly chosen from selected pictures, was presented for 1 s. In Experiments 1 and 2, after a short, random ISI of 400–600 ms, a vibration was delivered to the participant's index finger for a given probe duration (see above). In Experiment 3, the ISIs between picture and vibration were fixed to be either short (500 ms) or long (1500 ms). When the vibration had terminated, a question mark was displayed on the screen prompting the participant for a response: she/he had to judge, as accurately as possible, whether the duration of the vibration was closer to S or to L and indicate the choice by pressing keys labeled "short" and "long" on the keyboard. The inter-trial interval (ITI) was set to 4–6 s, in order to avoid potential inter-trial interference. There were four blocks, each of 25 trials. At the beginning of each block, both the S and L anchor durations were presented five times each, for refreshing the participant's memory of two anchors. Participants took rests of about 1 min between blocks.

After the test session, the participant was asked to rate the valence and arousal of the pictures using a sheet of paper with 9-point scales self-assessment-manikin (SAM) (Bradley and Lang, 1994).

RESULTS

ASSESSMENT OF EMOTIONS

For Experiment 1, a repeated-measures ANOVA revealed rated valence to differ significantly among threatening, disgusting, and neutral pictures, [$F_{(2,\ 26)} = 94.08$, $p < 0.01$]. Follow-up Bonferroni t-tests showed that the average valence was lower for disgusting pictures compared to both threatening and neutral pictures (both $p < 0.01$), and the mean valence of threatening pictures was lower than that of neutral pictures, $p < 0.01$. A further repeated-measure ANOVA revealed rated arousal, too, to differ significantly among conditions, [$F_{(2,\ 26)} = 112.89$, $p < 0.01$]. Follow-up Bonferroni t-tests showed that disgusting and threatening pictures were higher in arousal ratings than neutral pictures (both $p < 0.01$), whithout a difference between the former ($p > 0.1$).

The mean valence of threatening pictures was significantly lower than that of neutral pictures, in both Experiment 2 [$F_{(1,\ 14)} = 77.79$, $p < 0.01$] and Experiment 3 [$F_{(1,\ 15)} = 116.94$, $p < 0.01$]. Furthermore, repeated-measures ANOVAs revealed the mean arousal to be significantly higher for threatening than for neutral pictures, [$F_{(1,\ 14)} = 86.30$, $p < 0.01$] (Experiment 2) and [$F_{(1,\ 15)} = 125.88$, $p < 0.01$] (Experiment 3).

Thus, the results of the subjective ratings were consistent with the rating of valence and arousal from the IAPS.

TEMPORAL BISECTION

The proportions of "long" responses were calculated for the five probe durations and fitted by a logistic function, for each condition and each subject. The temporal bisection point (TBP) was then calculated based on the 50% point of a given estimated logistic function (Treutwein and Strasburger, 1999). To measure the sensitivity of the temporal bisection task, we estimated the just noticeable difference (JND) of the temporal bisection using the half difference in duration between the 25% and 75% point

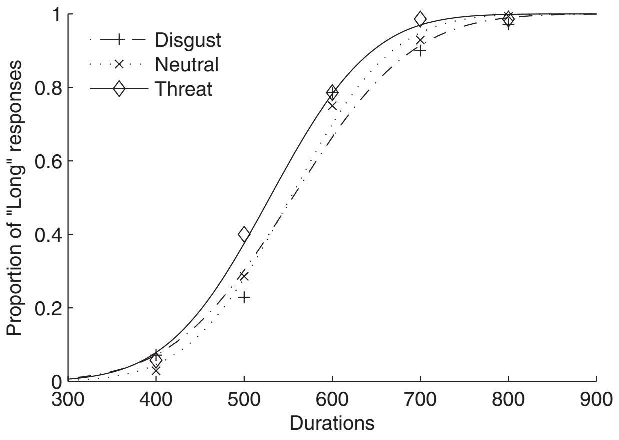

FIGURE 1 | Mean proportions of "Long" responses plotted against probe durations and fitted psychometric functions for three emotion conditions (neutral, threat, and disgust). The dotted curve and crosses represent the neutral condition, the dash-dotted curve and pluses the disgust condition, and the solid curve and diamonds the threat condition.

(Shi et al., 2008; Vroomen and Keetels, 2010). In addition, we measured the Weber fraction with the ratio of JND/TBP.

Figure 1 shows average psychometric curves for the three emotion (i.e., neutral, disgust, and threat) conditions in Experiment 1. The mean TBPs (±SE) for the tactile S/L duration pair 300/900 ms were 552 ± 14, 550 ± 19, and 529 ± 15 ms for the neutral, disgust, and threat conditions, respectively (**Figure 2A**). A repeated-measures ANOVA showed that the type of emotion picture significantly influenced the (subsequently performed) judgment of tactile duration, [$F_{(2,\ 26)} = 4.41$, $p < 0.05$]. Follow-on linear contrast tests revealed tactile TBP to be significantly lower in the threatening condition compared to both the neutral ($p < 0.01$) and disgust ($p = 0.05$) conditions, while there was no difference between the latter ($p > 0.1$). This pattern indicates that the modulatory influence of emotional pictures on tactile duration judgments was due mainly to the threatening condition. The lower TBP in this condition means that participants tended to overestimate the physical tactile duration of a vibratory stimulus preceded by a threatening picture. Interestingly, however, the subjective ratings of arousal (mean 7.41) were as high for disgusting pictures as for threatening pictures (mean 6.86). Given that duration overestimation only occurred in the threatening condition, arousal level alone cannot explain the crossmodal emotional modulation of time judgments.

The mean JNDs (±SE) were 72 ± 8, 73 ± 18, and 59 ± 12 ms for the neutral, disgust and threat conditions (**Figure 2B**). A one-way repeated-measures ANOVA on JNDs failed to reveal any difference among three types of emotion pictures, [$F_{(2,\ 26)} = 0.39$, $p = 0.68$]. The Weber fractions (±SE) were 0.13 ± 0.01, 0.14 ± 0.04, and 0.11 ± 0.02 for the neutral, disgust, and threat conditions, respectively. A repeated-measures ANOVA also indicated no difference among three conditions, [$F_{(2,\ 26)} = 0.32, p = 0.73$]. Both results suggested that emotional pictures did not influence the sensitivity of the subsequent tactile duration judgments.

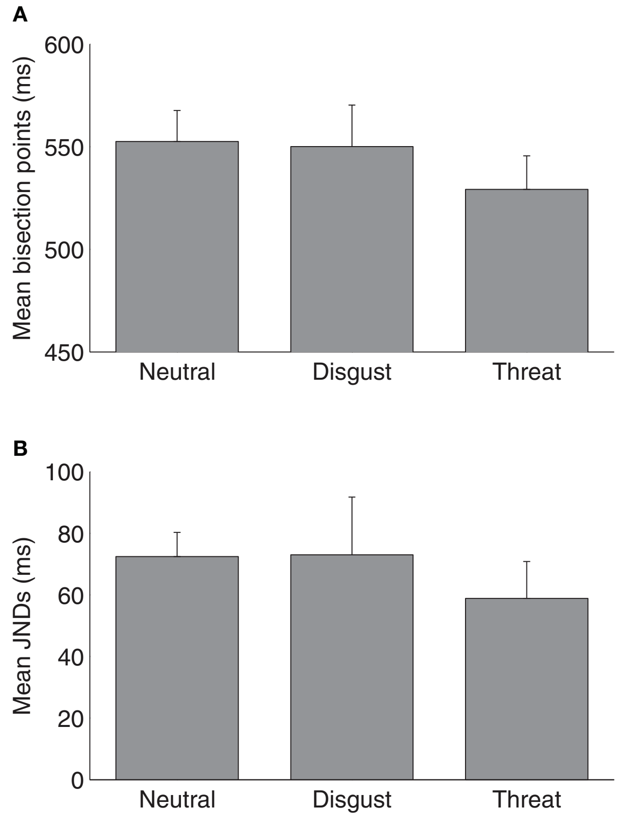

FIGURE 2 | (A) Mean temporal bisection points and **(B)** mean JNDs (and associated standard errors) for three emotional conditions ($n = 14$).

Experiment 2 was designed to examine how threatening pictures influence performance on short-range (300/900 ms) and long-range (1000/1900 ms) tactile temporal bisection tasks. In the short-range task, the mean TBPs (±SE) were 550 ± 12 and 573 ± 12 ms for the threat and neutral conditions, respectively, and in the long-range task, the points were 1399 ± 16 (threat) and 1385 ± 18 ms (neutral), respectively (**Figure 3A**). A two-way repeated-measures ANOVA with the factors temporal bisection range (300/900 vs. 1000/1900 ms) and emotional picture type (threat vs. neutral) revealed the main effect of temporal bisection range, [$F_{(1,\ 14)} = 2136.55$, $p < 0.01$], and the interaction, [$F_{(1,\ 14)} = 6.18$, $p < 0.05$], to be significant; the main effect of emotional picture type was non-significant, [$F_{(1,\ 14)} = 0.14$, $p = 0.71$]. Follow-up simple contrast tests showed that the TBP was lower with threatening pictures (indicative of a duration overestimation) in the short-range task, [$F_{(1,\ 14)} = 5.17$, $p < 0.05$], but not in the long-range task, [$F_{(1,\ 14)} = 0.71$, $p = 0.42$]. Thus, while the results from the short-range condition are consistent with those of Experiment 1, there was no evidence of crossmodal duration lengthening in the long-range condition.

The mean JNDs (±SE) were 55 ± 12 and 69 ± 9 ms for the threat and neutral conditions in the short-range task, and 119 ± 21 and 152 ± 12 ms for the threat and neutral conditions, respectively, in the long-range task (**Figure 3B**). A two-way repeated-measures ANOVA revealed that JND was larger in the

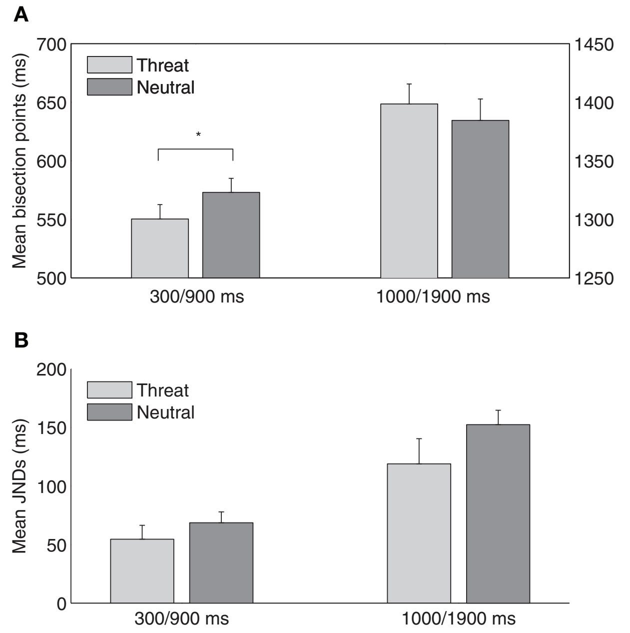

FIGURE 3 | (A) Mean temporal bisection points and **(B)** mean JNDs (and associated standard errors) plotted against threat and neutral picture conditions, for the short-range (300/900 ms) and the long-range (1000/1900 ms) sessions ($n = 15$).

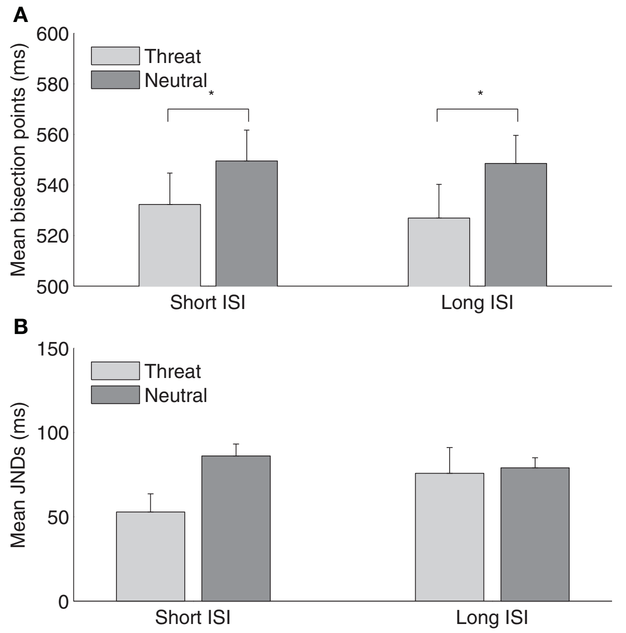

FIGURE 4 | (A) Mean temporal bisection points and **(B)** mean JNDs (and associated standard errors) plotted against threat and neutral picture conditions, for the short-ISI (500 ms) and the long-ISI (1000 ms) session ($n = 16$).

long- than the short-range task, [$F_{(1,\ 14)} = 32.61, p < 0.01$], and was marginally smaller in the threat than the neutral condition, [$F_{(1,\ 14)} = 4.54$, $p = 0.05$]. This indicated that the threatening picture might increase the sensitivity of the temporal bisection for the subsequent tactile duration task. However, the interaction between the duration range and the emotion type was not significant, [$F_{(1,\ 14)} = 0.80$, $p = 0.39$]. To compare task difficulties, we further calculated the Weber fractions. They were 0.10 ± 0.02, 0.12 ± 0.02, 0.09 ± 0.01, and 0.11 ± 0.01 for the threat and neutral conditions in the short- and long-range tasks, respectively. A repeated-measures ANOVA revealed non-significant main effects and interaction (duration range: [$F_{(1,\ 14)} = 0.58$, $p = 0.46$]; emotion: [$F_{(1,\ 14)} = 3.62$, $p = 0.08$]; interaction: [$F_{(1,\ 14)} = 0.01, p = 0.97$]), which suggested task difficulties were relative similar among different conditions (e.g., the short- vs. long-range task).

However, it remains unclear from Experiment 2 whether the absence of a crossmodal duration overestimation following threatening pictures in the long-range temporal bisection task (1000/1900 ms) is due to the modulatory effect of emotion passively dissipating over time. Experiment 3 was designed to examine this question by comparing the effects of short (500 ms) and long (1500 ms) ISIs between the emotional picture and the tactile stimulus using the short-range temporal bisection task (300/900 ms). The intervals from the onset of the emotional picture to the offset of the tactile stimulus in the long ISI condition were then similar to that in the long-range condition (Experiment 2). **Figure 4A** depicts the mean tactile TBPs for the neutral and threat picture conditions for short and long visual-tactile ISIs, respectively. The average TBPs (±SE) were 532 ± 12 and 549 ± 11 for threatening and neutral pictures in the short-ISI condition, and 527 ± 12 (threatening) and 549 ± 10 ms (neutral) in the long-ISI condition. A two-way repeated-measures ANOVA with main terms of ISI and emotional picture type revealed the bisection points to be significantly lower in the threatening compared to the neutral condition, for both short and long visual-tactile ISIs. There were no effects involving ISI (main effect, [$F_{(1,\ 15)} = 0.26, p = 0.62$]; interaction, [$F_{(1,\ 15)} = 0.11$, $p = 0.74$]). This indicates that the modulatory effect of threatening picture in the short-range condition did not simply lessen over time, i.e., as a function of merely lengthening the ISI between the emotional picture and the tactile stimulus.

Figure 4B depicts the mean JNDs (±SE) for the neutral and threat conditions in the short and long visual-tactile ISIs. A two-way repeated-measures ANOVA revealed that JNDs were not influenced by the visual-tactile ISI, [$F_{(1,\ 15)} = 0.58$, $p = 0.46$], but modulated by the type of pictures, [$F_{(1,\ 15)} = 4.91, p < 0.05$]. However, there was no interaction between the visual-tactile ISI and the emotion picture, [$F_{(1,\ 15)} = 3.07, p = 0.1$]. The significant smaller JNDs in the threat than the neutral condition confirmed the finding in Experiment 2. Both results suggest that threating pictures might increase the sensitivity of subsequent tactile temporal bisection task. Weber fractions were 0.10 ± 0.02, 0.16 ± 0.01 for the threat and neutral conditions in the short ISI and 0.15 ± 0.03, 0.15 ± 0.01 for the correspondent conditions in the long ISI. A repeated-measures ANOVA, however, showed no effects of the visual-tactile ISI, [$F_{(1,\ 15)} = 0.61, p = 0.45$], the type of pictures, [$F_{(1,\ 15)} = 3.19, p = 0.10$], and their interaction, [$F_{(1,\ 15)} = 2.48, p = 0.14$].

DISCUSSION

The present study was designed to investigate the effect of viewing visual emotional stimuli on the subsequent estimation of the duration of non-emotional tactile events. We compared the effects of viewing three types of emotional pictures (neutral, threat, and disgust) in a short-range (300/900 ms) tactile temporal bisection task in Experiment 1. The results revealed the processing of threatening pictures to lengthen, relative to the neutral baseline, the subsequent judgments of tactile duration, as evidenced by a lowered mean TBP in the threat compared to the neutral condition. Interestingly, the lengthening effect was not simply due to the high-arousal induced by the threatening pictures: both threat and disgust pictures were rated as high in arousal negative in valence in the subjective ratings (using SAM sheets) of the participants in the present study as well as in the IAPS norms. Yet, no lengthening effect was evident in the disgust condition. This is clearly inconsistent with the predictions deriving from the assumption of a general arousal effect.

Previous studies of judged durations of emotional events themselves have shown that arousal and valences are two main factors for duration distortions (Angrilli et al., 1997; Droit-Volet et al., 2004; Noulhiane et al., 2007; Grommet et al., 2011). Using IAPS pictures, Angrilli and colleagues observed that the durations of high-arousal negative-valence pictures were overestimated (Angrilli et al., 1997). A similar effect has been reported for the auditory modality, with high-arousal negative sounds being judged as longer in duration than positive ones (Noulhiane et al., 2007). Moreover, a recent study suggests that negative high-arousal activation, such as produced by a frightening movie, can also influence the subsequent time judgment of a neutral visual event (Droit-Volet et al., 2011). However, it is not clear from those studies whether arousal activation from one modality can influence time perception in another modality. In contrast to these earlier studies on the temporal perception of emotional events themselves, in the present study, we focused on duration distortions induced by crossmodal emotional linkages. We found that viewing a rather threatening (e.g., a snake attacking), but not a disgusting (e.g., a mutilated body), picture expanded the subsequent tactile duration, although both threat and disgust emotions induced high-arousal. Our findings suggest that the crossmodal modulatory effect of emotion depends on the type of emotional stimuli. This is consistent with the "discrete emotion" theory (Izard and Ackerman, 2000; Mikels et al., 2005), which posits that different core emotions (such as disgust, fear, anger, etc.) link different behavioral functions. Studies of the affective modulation of the startle blink reflex (Balaban and Taussig, 1994; Stanley and Knight, 2004) and duration estimation of emotional faces (Droit-Volet et al., 2007; Droit-Volet and Gil, 2009) suggest that the emotion of disgust has less salience than that of threat. A threatening picture often portrays an attack signal, which invokes the anticipation (or fear) of potential damage to perceiver's body. Thus, the perceiver is put in a state in which she/he needs to react as quickly as possible to the threatening signal (e.g., fight or flight). Indeed, it has been found that automatic defense systems come into operation within an "eye blink" for biologically relevant threat events (e.g., snakes, spiders), with their activation being based mainly on preattentive coding mechanisms (Öhman, 1997; Öhman and Mineka, 2001). The threatening event also establishes a strong association between the visual and tactile modalities, as suggested by several neuro-imaging studies (Dong et al., 1994; Gray and Tan, 2002; Keysers et al., 2004; Lloyd et al., 2006). For example, posterior parietal cortex has been shown to play an important role in the early integration of visual information with somatosensory, proprioceptive signals. Lloyd and colleagues found an increase in posterior parietal cortex activity in response to observing a sharp (painful) stimulus, vs. a non-painful stimulus, touching a rubber hand in peripheral space, in the absence of any direct tactile stimulation (Lloyd et al., 2006). Consistent with reports such as these, our findings provide further behavioral evidence of visual-tactile associations elicited by threat-type emotional pictures.

The asymmetrical crossmodal modulation of duration judgments by pictures of threat versus those of disgust would also argue in favor of multiple clock models (Ivry and Richardson, 2002; Buhusi and Meck, 2005; Bueti, 2011). On this notion, time processing is "distributed" to different sensory-specific brain regions, with each of the multiple clocks operating separately. Within this framework, our results complement, rather than being in conflict with, previous, unimodal studies of emotional modulations of duration judgments. These studies have shown that the durations of emotional pictures themselves are overestimated, likely due to the "visual" clock being modulated by the pictures' arousal and valence signals. Our results go beyond this by showing that emotions induced via the visual modality may influence the "tactile" clock, depending on the strength of the emotional association induced between the visual and tactile modalities.

How does visual threat influence the tactile clock? Does exposure to threatening pictures subsequently speed up the tactile pacemaker or/and shorten the switch latency? Using a short- and a long-range temporal bisection task in Experiment 2, we observed a crossmodal duration lengthening by the threatening pictures in the short-range temporal bisection task (300/900 ms), replicating the finding of Experiment 1; by contrast, no such lengthening was observed in the long-range task (1000/1900 ms). The lacking crossmodal modulation in the long-range condition suggests that the tactile pacemaker is unlikely to be speeded up by preceding high-arousal visual stimuli. Otherwise, one would have expected to see a general slope effect, i.e., a larger duration expansion in the long-range condition. A recent study (Grommet et al., 2011) of the time estimation of visual fear cues using two different duration ranges (250/1000 ms, 400/1600 ms) concluded that the fear effects were mediated mainly by the switch latency, rather than the speeding up of the internal pacemaker. In the study of Grommet et al., the duration expansion of the fear cue itself was of a similar magnitude in both the short- and the long-range condition.

If the tactile switch latency is shortened by the presentation of threatening images in the present study, then why did we fail to observe a duration lengthening in the long-range condition? No difference on Weber fractions between the short- and long-range conditions suggests that the task difficulty cannot be the reason for the non-effect in the long-range condition. Furthermore, the mean standard errors of the TBPs were not significant different between the short and long duration conditions (12 vs 17 ms, $p > 0.1$). This could rule out the potential cause by large variations for long duration estimations. We suggest that the absence of such an effect is due to a dynamic shifting of attention from emotional activation to emotional regulation mechanisms (Zakay, 1989; Macar et al., 1994; Casini and Macar, 1997; Fortin, 2003). Emotional activation is often followed by emotional regulation, in line with the existence of two emotional pathways, one subcortical and one cortical (LeDoux, 1995). The former is rapidly activated by potentially dangerous or survival-relevant stimuli—even though the stimuli are not fully processed, facilitating the preparation of (physiologically autonomous) response programs for avoidance (flight) or fight. The cortical pathway, by contrast, processes information more precisely, though this takes more time. Precise cortical stimulus analysis in turn can help to inhibit or correct "erroneous" early responses elicited by the subcortical pathway, thus readjusting the subsequent behavior. When participants in the present study are exposed to threatening pictures, attentional resources may first be rapidly directed to the defensive system, including the somatosensory system, for preparing a reaction. Possibly, the strong visual-tactile linkage reduces the latency of the tactile switch at the beginning. Consistent with this, tactile duration was overestimated in the short-range temporal bisection tasks of the present Experiments 1 and 2. While the same would apply to the long-range condition, participants (in this condition) would eventually realize that the tactile vibration is not a threat event. Accordingly, attentional resources would be increasingly redirected to processes of emotional regulation. As a consequence, some pulses may be lost in the time accumulation, leading to an underestimation of the tactile duration. The absence of an (overt) emotional modulation in the long-range condition may then arise from the overestimation brought about by the shortened switch latency being nulled by an underestimation owing to the emotional regulation.

It is interesting to note, however, in both short- and long-range conditions the sensitivity of temporal bisection task increased in the threat condition compared to the neutral condition. The higher sensitivity (smaller JND) in the threat condition is further confirmed in Experiment 3 and shown a trend in Experiment 1. These results may well reflect the general alerting effect induced by threatening pictures. However, the alerting could not account for the differential effects in the short- and long-range conditions.

One alternative explanation: general emotional attenuation, might account for the absence of duration lengthening in the long-range condition. As reported in previous unimodal studies (Angrilli et al., 1997; Noulhiane et al., 2007), the duration lengthening induced by emotional stimuli disappeared for the judgment of long durations (usually above 4 s). The absence of an emotion effect in these studies has been attributed to dynamic pacemaker changes by emotional attenuation: the pacemaker rate would be increased by the onset of the emotion event and would then gradually return to baseline when emotion attenuates over time. Note, however, that the emotional attenuation could also be the result of emotional regulation—which are the two faces of one and the same coin.

One interesting question, though, is at what point in time emotional regulation takes over. The results of the present Experiment 3 suggest that emotional regulation is unlikely to occur prior to the subsequent (tactile) event. Recall that in the long-ISI condition of Experiment 3, the time interval from the onset of the emotional picture to the offset of the tactile vibration was the same as that in the long duration condition of Experiment 2. If emotional regulation (or emotional attenuation) took place immediately after the onset of the emotional event, one would predict both conditions to yield the same crossmodal emotional modulation of duration judgments. However, on the opposite (and unlike the nulling effect in the long duration condition), the tactile duration lengthening effect evoked by threatening pictures was almost as large in the long-ISI as in the short-ISI condition. This suggests that the crossmodal linkage activated by threatening events was not attenuated before the subsequent event, at least within the time rage of our study (3 s). The defensive system appears to be still highly activated and dominant for reacting to the external world after the threatening events. Only when the subsequent event is identified to be non-threatening (as under the long duration condition of Experiment 2) does emotional regulation become dominant and the emotion-induced defensive bias dissipates gradually.

In summary, the present results indicate that the crossmodal subjective-duration lengthening effect is emotion-specific: tactile duration is overestimated following exposure to pictures of threat, but not to pictures of disgust of the same high-arousal potential. However, the duration lengthening disappears for long-range durations. This pattern may be best explained by the latency of the tactile (clock's) switch being shortened by crossmodal emotional activation, while emotional regulation takes over after the subsequent (tactile) event is identified as a non-threatening signal.

REFERENCES

Angrilli, A., Cherubini, P., Pavese, A., and Mantredini, S. (1997). The influence of affective factors on time perception. *Percept. Psychophys.* 59, 972–982.

Balaban, M. T., and Taussig, H. N. (1994). Salience of fear/threat in the affective modulation of the human startle blink. *Biol. Psychol.* 38, 117–131.

Bradley, M. M., Codispoti, M., Cuthbert, B. N., and Lang, P. J. (2001). Emotion and motivation I: defensive and appetitive reactions in picture processing. *Emotion* 1, 276–298.

Bradley, M. M., and Lang, P. J. (1994). Measuring emotion: the self-assessment manikin nd the semantic differential. *J. Behav. Ther. Exp. Psychiatry* 25, 49–59.

Brainard, D. H. (1997). The psychophysics toolbox. *Spat. Vis.* 10, 433–436.

Bueti, D. (2011). The sensory representation of time. *Front. Integr. Neurosci.* 5, 1–3.

Bueti, D., Bahrami, B., and Walsh, V. (2008). Sensory and association cortex in time perception. *J. Cogn. Neurosci.* 20, 1054–1062.

Buhusi, C. V., and Meck, W. H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. *Nat. Rev. Neurosci.* 6, 755–765.

Casini, L., and Macar, F. (1997). Effects of attention manipulation on judgments of duration and of intensity in the visual modality. *Mem. Cognit.* 25, 812–818.

Chen, K. M., and Yeh, S. L. (2009). Asymmetric cross-modal effects in time perception. *Acta Psychol. (Amst.)* 130, 225–234.

Chen, L., Shi, Z., and Müller, H. J. (2010). Influences of intra- and crossmodal grouping on visual and tactile ternus apparent motion. *Brain Res.* 1354, 152–162.

Chen, L., Shi, Z., and Müller, H. J. (2011). Interaction of perceptual grouping and crossmodal temporal capture in tactile apparent-motion.

PLoS ONE 6:e17130. doi: 10.1371/journal.pone.0017130

Dong, W. K., Chudler, E. H., Sugiyama, K., Roberts, V. J., and Hayashi, T. (1994). Somatosensory, multisensory, and task-related neurons in cortical area 7b (PF) of unanesthetized monkeys. *J. Neurophysiol.* 72, 542–564.

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

Droit-Volet, S., Fayolle, S. L., and Gil, S. (2011). Emotion and time perception: effects of film-induced mood. *Front. Integr. Neurosci.* 5, 1–9.

Droit-Volet, S., and Gil, S. (2009). The time - emotion paradox. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 364, 1943–1953.

Droit-Volet, S., and Meck, W. H. (2007). How emotions colour our perception of time. *Trends Cogn. Sci.* 11, 504–513.

Droit-Volet, S., Meck, W. H., and Penney, T. B. (2007). Sensory modality and time perception in children and adults. *Behav. Processes* 74, 244–250.

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

Fortin, C. (2003). "Attentional time-sharing in interval timing," in *Functional and Neural Mechanisms of Interval Timing*, ed W. H. Meck (London, UK: CRC Press), 235–260.

Ghose, G. M., and Maunsell, J. H. (2002). Attentional modulation in visual cortex depends on task timing. *Nature* 419, 616–620.

Gibbon, J., Church, R. M., and Meck, W. H. (1984). Scalar timing in memory. *Ann. N.Y. Acad. Sci.* 423, 52–77.

Gray, R., and Tan, H. Z. (2002). Dynamic and predictive links between touch and vision. *Exp. Brain Res.* 145, 50–55.

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

Hare, R. D. (1963). The estimation of short temporal intervals terminated by shock. *J. Clin. Psychol.* 19, 378–380.

Ivry, R. B., and Richardson, T. C. (2002). Temporal control and coordination: the multiple timer model. *Brain Cogn.* 48, 117–132.

Izard, C. E., and Ackerman, B. P. (2000). "Motivational, organizational, and regulatory functions of discrete emotions," in *Handbook of Emotions,* Vol. 2, eds M. Lewis and J. M. Haviland-Jones (New York, NY: The Guilford Press), 253–264.

Keysers, C., Wicker, B., Gazzola, V., Anton, J. L., Fogassi, L., and Gallese, V. (2004). A touching sight: SII/PV activation during the observation and experience of touch. *Neuron* 42, 335–346.

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (2005). *International Affective Picture System (IAPS): Affective Ratings of Pictures and Instruction Manual. Emotion*. Gainesville, FL: NIMH, Center for the Study of Emotion and Attention.

Lang, P. J., Wapner, S., and Werner, H. (1961). The effect of danger upon the experience of time. *Am. J. Psychol.* 74, 94–97.

LeDoux, J. E. (1995). Emotion: clues from the brain. *Annu. Rev. Psychol.* 46, 209–235.

Lloyd, D., Morrison, I., and Roberts, N. (2006). Role for human posterior parietal cortex in visual processing of aversive objects in peripersonal space. *J. Neurophysiol.* 95, 205–214.

Macar, F., Grondin, S., and Casini, L. (1994). Controlled attention sharing influences time estimation. *Mem. Cognit.* 22, 673–686.

Matell, M., and Meck, W. H. (2004). Cortico-striatal circuits and interval timing: coincidence detection of oscillatory processes. *Cogn. Brain Res.* 21, 139–170.

Mikels, J. A., Fredrickson, B. L., Larkin, G. R., Lindberg, C. M., Maglio, S. J., and Reuter-Lorenz, P. A. (2005). Emotional category data on images from the international affective picture system. *Behav. Res. Methods* 37, 626–630.

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

Öhman, A. (1997). "As fast as the blink of an eye: evolutionary preparedness for preattentive processing of threat," in *Attention and Orienting: Sensory and Motivational Processes,* eds P. J. Lang, R. F. Simons, and M. T. Balaban (Mahwah, NJ: Lawrence Erlbaum Associates), 165–184.

Öhman, A., and Mineka, S. (2001). Fears, phobias, and preparedness: toward an evolved module of fear and fear learning. *Psychol. Rev.* 108, 483–522.

Penney, T. B., Gibbon, J., and Meck, W. H. (2000). Differential effects of auditory and visual signals on clock speed and temporal memory. *J. Exp. Psychol. Hum. Percept. Perform.* 26, 1770.

Phelps, E. A., and LeDoux, J. E. (2005). Contributions of the amygdala to emotion processing: from animal models to human behavior. *Neuron* 48, 175–187.

Poliakoff, E., Miles, E., Li, X., and Blanchette, I. (2007). The effect of visual threat on spatial attention to touch. *Cognition* 102, 405–414.

Rozin, P., and Fallon, A. E. (1987). A perspective on disgust. *Psychol. Rev.* 94, 23–41.

Shi, Z., Chen, L., and Müller, H. J. (2010). Auditory temporal modulation of the visual ternus effect: the influence of time interval. *Exp. Brain Res.* 203, 723–735.

Shi, Z., Hirche, S., Schneider, W. X., and Müller, H. J. (2008). *Influence of visuomotor action on visual-haptic simultaneous perception: a psychophysical study. 2008 Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems.* IEEE, 65–70.

Stanley, J., and Knight, R. G. (2004). Emotional specificity of startle potentiation during the early stages of picture viewing. *Psychophysiology* 41, 935–940.

Treisman, M. (1963). Temporal discrimination and the indifference interval: implications for a model of the "internal clock." *Psychol. Monogr.* 77, 1–31.

Treutwein, B., and Strasburger, H. (1999). Fitting the psychometric function. *Percept. Psychophys.* 61, 87–106.

van Wassenhove, V., Buonomano, D. V., Shimojo, S., and Shams, L. (2008). Distortions of subjective time perception within and across senses. *PLoS ONE* 3:e1437. doi: 10.1371/journal.pone.0001437

Vroomen, J., and Keetels, M. (2010). Perception of intersensory synchrony: a tutorial review. *Atten. Percept. Psychophys.* 72, 871–884.

Walker, J. T., and Scott, K. J. (1981). Auditory-visual conflicts in the perceived duration of lights, tones and gaps. *J. Exp. Psychol. Hum. Percept. Perform.* 7, 1327–1339.

Wearden, J. H. (1992). Temporal generalization in humans. *J. Exp. Psychol. Anim. Behav. Process.* 18, 134–144.

Wearden, J. H. (2006). When do auditory visual differences in duration judgments occur? *Q. J. Exp. Psychol.* 59, 1709–1724.

Wearden, J. H., Edwards, H., Fakhri, M., and Percival, A. (1998). Why "sounds are judged longer than lights": application of a model of the internal clock in humans. *Q. J. Exp. Psychol. B* 51, 97–120.

Zakay, D. (1989). "Subjective time and attentional resource allocation: an integrated model of time estimation," *Time and Human Cognition: A Life-Span Perspective,* Vol. 59, eds I. Levin and D. Zakay. (Amsterdam: Elsevier), 365–397.

Zakay, D., and Block, R. A. (1996). The role of attention in time estimation processes. *Adv. Psychol.* 115, 143–164.

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APPENDIX

Table A1 | IAPS stimuli used in the current study.

Category of pictures	IAPS number	Picture description
Mutilation pictures	3030	Mutilation
	3053	Burn victim
	3060	Mutilation
	3071	Mutilation
	3120	Dead body
Animal or human attacking pictures	1052	Snake
	1120	Snake
	1201	Spider
	1300	Pit bull
	1321	Bear
	1930	Shark
	6250	Aimed gun
	6260	Aimed gun
	6300	Knife
	6510	Attack
Neutral pictures	2840	Chess
	5500	Mush room
	7000	Rolling pin
	7009	Mug
	7035	Mug
	7041	Baskets
	7050	Hair driver
	7059	Key ring
	7090	Book
	7140	Bus
	7150	Umbrella
	7161	Pole
	7185	Abstract art
	7224	File cabinets
	7233	Plate
	7235	Chair
	7490	Window
	7700	Office
	7705	Cabinet